# ECCM22

22ND EUROPEAN CONFERENCE ON COMPOSITE MATERIALS

# Book of Abstracts

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Organised by NTNU · under the patronage of ESCM

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# Foreword

On behalf of the Organising Committee, it is my great pleasure to welcome you to ECCM22, the 22nd European Conference on Composite Materials, held in Oslo on 21–25 June 2026 under the patronage of the European Society for Composite Materials and organised by NTNU.

This Book of Abstracts collects the contributions accepted for presentation at the conference — spanning the full breadth of composite materials science and engineering, from constituents, manufacturing and characterisation to modelling, durability, sustainability and emerging applications. Together they reflect the vitality and diversity of our community.

Abstracts are listed in ascending paper-number order; the same number identifies each contribution in the conference programme. An author index at the end of this volume allows you to locate any author's contributions. We are grateful to the Scientific Committee for their careful review, and to our partners and sponsors for making the conference possible. We wish you a stimulating and enjoyable conference.

**Sotirios Grammatikos**

Conference Chair, ECCM22 · NTNU

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# How to Use This Book

Abstracts appear in ascending paper-number order. The paper number is the unique identifier used throughout ECCM22 — the same number appears next to each talk and poster in the conference programme, so you can move between the two easily.

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#5

# Synthesizing Functional Nanocomposites through “Green” Plasma Chemistry

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The synthesis of functional nanocomposites has become a rapidly advancing frontier in materials science, driven by the need for high-performance, sustainable materials in sectors such as healthcare, sensing, and energy. Traditional synthesis methods often rely on toxic reagents, harsh reaction conditions, or energy-intensive processes, which limit scalability and sustainability. In contrast, Atmospheric Pressure Plasma Induced Liquid Chemistry (PiLC) is emerging as a transformative “green” synthesis route. This platform harnesses plasma–liquid interactions to generate a unique cocktail of reactive species in situ, enabling nanocomposite formation under mild conditions without hazardous precursors. As such, PiLC represents a powerful and environmentally responsible tool for engineering nanomaterials with tailored functionalities.

This talk present the recent advances at Queen's University Belfast on advancing PiLC for the design and development of bio-based functional nanocomposites, where renewable biopolymers—such as nanocellulose, proteins, and polysaccharides—are integrated with inorganic nanofillers. This approach not only exploit the potential of abundant natural resources but also facilitates the creation of hybrid materials with tunable structures, interfaces, and properties. By carefully controlling plasma parameters and solution chemistry, PiLC enables modulation of surface chemistry, microstructure, and particle–matrix interactions, leading to nanocomposites that exhibit unique and application-specific functionalities.

Demonstrated outcomes illustrate the versatility of this approach. For example, nanocellulose–gold hybrids synthesized through PiLC have shown strong potential for biosensing, while biopolymer-based nanocomposites embedded with metal nanoparticles have exhibited interesting photothermal conversion and antimicrobial activity and promising use in biomedical coatings.

This talk will highlight both the scientific foundations and the technological potential of PiLC-based nanocomposites, emphasizing how plasma-enabled chemistry can accelerate the transition toward next-generation, sustainable materials that address pressing societal challenges.

#33

# ATR-FTIR enables discrimination of sawdust and pulp in wood-plastic composites

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Recycling of wood-plastic composites (WPCs) requires identification and sorting of these materials. Previous literature has not shown discrimination between WPCs containing different wood materials using optical methods, which is what our research focused on. We used attenuated total reflectance Fourier-transform infrared (ATR-FTIR) spectroscopy to measure WPCs with different concentration of wood and bleached softwood kraft pulp (BSKP) in two different polymer bases, bio-based low-density polyethylene (LDPE) and recycled polypropylene (PP). According to our results, accurate identification of wood and BSKP is possible based on the spectral features of lignin, a material which is present in wood but is removed in the BSKP pulping process. However, this identification was possible only when measuring samples from a cut surface due to aggregation of wood material away from sample surface during manufacturing. Interestingly, when measuring from the non-cut surface, we found a correlation between the ATR-FTIR spectral peak associated with polyolefin (LDPE and PP) molecular absorbance and the Young's modulus of the samples – this is explained by ATR-FTIR requiring contact between sample and probe, and thus signal strength depends on the degree of contact. To the best of our knowledge, these two findings have not been reported in previous literature.

#34

# Meta-Structures of Conductive Biopolymer Blends: Towards Multifunctional and Sustainable Nanocomposites

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The rapid expansion of plastic production has led to increasing environmental concerns despite existing regulations. In order to address this problem, bioplastics (i.e. bio-based and/or biodegradable plastics) could be excellent candidates for providing environmentally friendly alternatives to conventional plastics. Building on the PhD work of N. Masarra (Masarra, 2023), the present study focuses on the development of conductive biopolymer nanocomposites, where immiscible polymer blends are enriched with conductive fillers forming structured networks. A binary PLA/PBAT blend was combined with graphene and/or carbon black and processed by fused filament fabrication (FFF) in order to explore synergistic effects on electrical conductivity and mechanical performance. Original morphologies were observed for these formulations, with the main objective of achieving electrical percolation at minimal filler loadings. This requires the formation of co-continuous morphologies during the solidification while ensuring controlled filler dispersion during processing. By tuning the polymer blend morphology, the percolation threshold — i.e., the minimum filler content required to shift from insulating to conductive behavior (Otero Navas et al., 2021)— can be significantly reduced. Selective localization of conductive fillers within one phase or at the polymer–polymer interface further promotes the creation of percolating networks, leading to the so-called double electrical percolation phenomenon (Khan et al., 2021; Sumita et al., 1991). In addition to structural and functional characterization, a prototype electrode will be manufactured by additive processing and assessed through a life cycle analysis (LCA) to evaluate the environmental impact of such materials. In comparison with extant approaches, the proposed work aims to integrate multifunctionality, sustainability, and eco-design in the domain of polymer nanocomposites.

Keywords: biopolymer blends, conductive nanocomposites, double percolation solidification, meta-structures, life cycle analysis

#38

# Microwave absorbing properties of three-dimensional reduced graphene oxide composites

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This study investigates the synthesis of three-dimensional reduced graphene oxide (3D RGO) nano composites via the hydrothermal method and their microwave absorption properties in the 2–18 GHz range. Graphene oxide (GO) was first synthesized using a modified Hummers' method, followed by hydrothermal treatment at different temperatures (HTT: 130°C, 180°C, and 230°C) and durations (t: 10, 12, and 14 h) to form 3D GO hydrogels. These were dried at 50°C, 70°C, and 90°C (D) to obtain 3D RGO, which was then combined with epoxy resin (66.7 wt%) to fabricate composites. The electromagnetic parameters of the composites were measured with a coaxial waveguide, and reflection loss (RL) and bandwidth were simulated using CST software. Processing parameters significantly influenced dielectric properties: the 3D RGO-HTT180-t10-D70 sample showed the highest real permittivity (ε' = 25.7), while 3D RGO-HTT230-t10-D50 exhibited the highest imaginary permittivity (ε" = 77.1).

Salisbury absorbing structures were designed using the composites with a thickness of 0.5 mm and varying air spacer thicknesses. Increasing hydrothermal temperature enhanced absorption for most samples. The optimal sample, 3D RGO-HTT230-t14-D90, achieved a minimum RL of –68.2 dB at 9.17 GHz with a 5.1 GHz absorption bandwidth when paired with a 3 mm air spacer. At lower hydrothermal temperatures (130°C and 180°C), extending duration improved RL value and bandwidth. For all durations, higher drying temperatures increased RL value. Microscopic analysis revealed that higher hydrothermal temperatures reduced pore density and size (~0.15 μm) while introducing more wrinkles. These micro structural features enhanced electromagnetic wave scattering. Combined with destructive interference in the optimized Salisbury structure, they contributed to superior microwave absorption performance.

#39

# CFRP-Integrated Multilayer Piezoelectric Sensor for Vibration Energy Harvesting and Impact Damage Detection

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Composite structures made of carbon-fiber-reinforced polymers (CFRPs) are widely deployed in lightweight transportation and infrastructure, yet they remain vulnerable to barely visible impact damage that can degrade stiffness, trigger delamination, and shorten service life. In this study, we report a self-powered multilayer impact sensor that laminates CFRP with two lead-free potassium sodium niobate (KNN)–epoxy piezoelectric layers of deliberately contrasted electromechanical properties: a “hard” layer engineered for high stability and harvesting efficiency, and a “soft” layer tailored for large strain compliance and high sensitivity. The proposed multilayer CFRP-piezoelectric sensor demonstrates enhanced durability, mechanical robustness, and sensing sensitivity.

Material compositions were optimized around 35 vol% KNN for the hard layer and 40 vol% KNN for the soft layer, balancing modulus, loss, and poling response. In vibration harvesting, the hybrid device exhibits a clear resonance near ~304 Hz, where load matching yields a peak volumetric power density of ~7.4 μW·cm-3, consistent with finite-element predictions that capture the coupled piezoelectric and structural dynamics. In gentle impact detection (~0.01 J), the device produces reproducible peak voltages on the order of 0.6 V and a sensitivity of ~1.5 mV/g, enabling reliable event recognition under frequent ambient vibrations without external power. Under severe impacts up to ~30 J, the multilayer architecture sustains peak forces around 1.3 kN while maintaining interpretable time–frequency signatures that differentiate high-frequency, sharp responses dominated by the hard layer from low-frequency, smooth responses governed by the soft layer.

Overall, the proposed CFRP/Piezoelectric multilayer device demonstrates a practical pathway to embed self-powered impact sensing and energy-aware structural health monitoring into lightweight structures. The use of lead-free KNN, simple laminate processing, and compatibility with standard CFRP layups support scalability with existing components in aerospace, automotive, sports equipment, and civil infrastructure.

#42

# Multifunctional CNT-Based Composite fibers

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Individual carbon nanotubes (CNTs) offer exceptional mechanical, thermal, and electrical properties, yet translating these merits into macroscopic fibers remains limited by alignment, dispersion, and interfacial challenges. Building on our recent progress and review of the field [1], this talk presents a scalable wet-spinning strategy that exploits liquid-crystalline CNT dopes to produce highly aligned fibers with dense packing and minimal voids. We further engineer polyimide (PI) precursors—featuring molecular motifs that promote strong π–π interactions with CNTs—to control PI crystallinity and morphology, achieving high carbonization yields and excellent thermal resistance. The resulting CNT/PI composite fibers deliver simultaneous gains in thermal conductivity and mechanical strength suitable for aerospace and high-temperature applications [2,3].

The processing route—spinning well-dispersed CNT/PI solutions followed by carbonization and high-temperature graphitization (>1700 °C)—drives the evolution of turbostratic and graphitic domains. Multiscale structural analyses (TEM, X-ray microscopy) elucidate the structure–property relationships and establish a unified framework for polymer-scaffold-guided graphitization in CNT-derived carbon fibers [3]. As an application case, we also introduce CNT–polyaniline (PANI) composite fibers that realize ultrahigh energy and power density for supercapacitors, highlighting pathways to truly multifunctional structural-energy materials [4].

[1] B.-C. Ku et al., A review of high-performance carbon nanotube-based carbon fibers, Funct. Compos. Struct., 5, 045007 (2023)

[2] B.-C. Ku et al., Ultrahigh strength and modulus of polyimide-carbon nanotube based carbon and graphitic fibers with superior electrical and thermal conductivities for advanced composite applications, Compos Part B: Eng., 247, 110342 (2022) [3] B.-C. Ku et al., Polymer-Scaffold-Guided Graphitization for High Thermal Conductivity in SWCNT-Derived Carbon Fibers, manuscript (under review)
[4] B.-C Ku et al., Nanocell-structured carbon nanotube composite fibers for ultrahigh energy and power density supercapacitors, Compos Part B: Eng., 295, 112179 (2025)

#44

# APPLICATION OF EUCALYPTUS CELLULOSE FIBERS MODIFIED WITH SILICA ($SiO_2$) NANOPARTICLES IN ACRYLONITRILE-BUTADIENE-STYRENE (ABS) COMPOSITES

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The combination of organic and inorganic components can generate new classes of materials, known as hybrid materials, whose properties result from the synergistic interaction between their organic and inorganic phases. The inorganic component provides mechanical and thermal stability, while lignocellulosic fibers contribute stiffness and reduce weight. In this context, the aim of this study was to evaluate the effect of incorporating eucalyptus cellulose pulp fibers modified with silica nanoparticles ($SiO_2$) into acrylonitrile–butadiene–styrene (ABS) composites. The composites were prepared using ABS as the matrix and eucalyptus cellulose pulp fibers, either unmodified or modified with silica nanoparticles. Fiber modification was achieved by depositing silica nanoparticles ($SiO_2$) via the sol–gel process, using tetraethyl orthosilicate (TEOS) as the precursor. Two TEOS concentrations and two reaction times were employed to obtain two types of modified fibers (T1: 1.9 g/g, 2 h; T2: 4.2 g/g, 18 h). In addition, two fiber loadings (10% and 20% w/w) were investigated. The composites were produced by extrusion followed by injection molding and evaluated in terms of density, water absorption, tensile and flexural properties, Shore D hardness, heat deflection temperature (HDT), and Vicat softening temperature. Increasing the fiber content from 10% to 20% significantly improved the tensile modulus, flexural strength, flexural modulus, HDT, and Vicat temperature. However, higher fiber content also led to increased water absorption and density compared with neat ABS. The incorporation of modified fibers enhanced the stiffness of the composites under both tensile and flexural loading but reduced strength. Notably, fibers subjected to the longer modification process (T2) produced composites with higher strength and superior thermal stability. In conclusion, the composites produced with eucalyptus cellulose fibers modified with silica nanoparticles exhibited suitable properties, which varied according to the fiber concentration and duration of the modification process.

#45

# Investigation of scaling effects in the impact response of CFPR woven composites

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Woven composites, known for their delamination resistance in impact applications, exhibit size-dependent mechanical behavior due to their inherent heterogeneity and anisotropy. Understanding these scaling effects is critical for optimizing their structural designs. This study investigates scaling effects in the impact behaviour of plain-woven composites through combined experimentation and numerical modeling. Experimental tests using drop-weight (low-velocity) and gas-gun (high-velocity) systems revealed distinct scaling trends: peak load decreased inversely with specimen size, while energy absorption and crack length increased proportionally. To overcome experimental limitations in tracking damage progression, a multiscale framework was developed integrating mesoscale unit cell homogenization with macroscale finite element analysis. The model implemented generalized Hashin criteria for yarn failure and Goldberg's constitutive law for matrix nonlinearity/strain-rate effects through an ABAQUS/VUMAT subroutine. Validated simulations demonstrated faster crack propagation in larger specimens, attributed to delayed fiber failure initiation and stress redistribution mechanisms. The framework elucidates how increased specimen dimensions enhance matrix-dominated energy dissipation while mitigating localized stress concentrations. These findings emphasize geometric scaling's critical role in optimizing impact-resistant woven composites for aerospace and automotive applications. The validated multiscale approach establishes linkages between mesoscale architecture and macroscale mechanical behaviour, enabling predictive design of composite systems under dynamic loading conditions.

#46

# A full-field coupled multiscale modelling framework for predicting the impact behaviour of interleaved composites considering material variability

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Thanks to their improved damage tolerance compared to conventional laminates, interleaved composites are increasingly favoured for critical load-bearing applications like turbine engine fan blades and casings. However, their pseudo-woven internal architecture often leads to the formation of large unit cells (LUCs), with the typical characteristic length reaching hundreds of millimetres. As a result, interleaved composites are macroscopic heterogeneous, posing significant challenges in both characterising their properties and modelling their structural response, thus limiting their engineering applications and potential. This research was aimed at developing a combined experimental and numerical methodology to evaluate the mechanical performance of interleaved composites and thus address the aforementioned challenges. The experimental part included a series of characterisation tests conducted to obtain the material properties of the internal constituents of interleaved composites at various strain rates. Several macroscale tests were also performed to provide model validation data for the numerical work. In the numerical part, a modelling strategy was proposed to automatically and consistently map the mesoscale architecture onto the macroscopic finite element (FE) model, allowing the homogenisation of the behaviour of each macroscopic element uniquely based on the material constituents within the element. At the constituent level, both the nonlinearity and rate dependent of tapes were considered according to the results obtained from the characterisation tests. Also, the Puck and Pinho criteria were employed to describe the failure of tapes. The proposed modelling methodology was implemented into the commercial FE software LS-DYNA. Simulations of the validation experiment were performed, and the results suggest that the proposed model was effective in predicting the mechanical performance of interleaved composites. In sum, this research offers a practical approach for experimentally characterizing the behaviour of interleaved composites and numerically predicting their performance, thereby facilitating their engineering application.

#48

# Investigate the laser-induced surface treatment in the interfacial shear strength of carbon fiber/epoxy composites

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This study investigates the effect of laser-induced surface treatment on the interfacial shear strength (IFSS) of carbon fiber/epoxy composites. A femtosecond pulsed laser operating at a central wavelength of 520 nm with a pulse duration of 323 fs and a repetition rate (f) of 100 kHz was employed to modify the carbon fiber surface. The fluence of the laser was selected as 0.34 J/cm2, 0.68 J/cm2 and 0.85J/cm2, respectively, aiming to improve fiber-matrix bonding without dramatically sacrificing the tensile strength of the carbon fiber. The surface morphology and chemical composition of the laser-treated fibers were analyzed using scanning electron microscopy (SEM) and X-ray photoelectron spectroscopy (XPS), respectively. IFSS was evaluated through the micro-droplet tests. In the micro-droplet tests, a single carbon fiber with an epoxy microdroplet adhered to its surface was mounted on a testing fixture equipped with a precision microvice jaw. The test was performed by pulling the fiber vertically upward at a displacement rate of 1 mm/min. The droplet remained stationary against the microvice until debonding occurred at the fiber–matrix interface. The peak force measured from the load cell of the fixture was employed to calculate the IFSS. SEM results demonstrated that laser-treated carbon fibers apparently exhibited surface roughness as compared the pristine one which has smooth surface. In addition, laser-treated samples showed an improvement of IFSS of up to 35% with respective to the untreated fibers. These results demonstrate the potential of laser-based surface treatment for improving interfacial properties in carbon fiber composites, with implications for advancing high-performance and sustainable composite applications.

#53

# Effect of Combustible Gas Stream Interaction on the Static Strength of Fiber-Reinforced Composites

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The aim of the research was to determine the effect of short-term flame exposure on the mechanical properties of a hybrid composite reinforced with carbon and aramid fibres. Composite panels were produced using the vacuum bagging technique and then cut into samples for mechanical testing: puncture resistance, static tensile, and three-point bending tests. Samples were exposed to flame for 5, 10, 15, 30, and 60 seconds. Exposure for 30 and 60 seconds caused complete structural degradation, preventing further testing. Shorter exposure times (5–15 s) allowed temperature distribution recording and strength measurements. The composite exhibited relatively good thermal insulation, particularly when heated from the aramid layer side. Mechanical properties significantly decreased with increasing exposure time. Impact tests showed that samples heated from the aramid fibre side retained higher puncture resistance than those exposed from the carbon fibre side. Aramid fibres exhibited less deformation: 1% after 5 s (≈20 N drop) and 4% after 10 s (≈88 N drop), indicating greater thermal stability. Tensile tests revealed higher elasticity and tensile strength in samples heated from the aramid side, though the ultimate strength still decreased by about 18% after 5–10 seconds. Bending tests showed the most pronounced reduction: after 5 seconds, strength dropped by 38% (carbon side) and 51% (aramid side); after 10 seconds, by 40% and 54%, respectively. The greatest losses occurred after 15 seconds, reaching 90% and 89%. Thus, short-term flame exposure leads to progressive mechanical degradation, with the aramid layer slightly more susceptible to damage. Microscopic analyses (SEM, optical, profilometer) confirmed matrix degradation, delamination, and microcrack formation.

#55

# Bone-inspired dynamically self-adaptive composites

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Adaptability is one of the hallmarks of living systems, providing resilience in a dynamically changing environment. I will present our efforts to study mechanically adaptive composites for dynamically changing loading environments by coupling stress with material synthesis. Nature produces outstanding materials for structural applications, such as bone and wood, that can adapt to their surrounding environment. For instance, bone regulates the quantity of minerals in proportion to the amount of stress. It becomes stronger in locations subjected to higher mechanical loads. This capability enables the formation of mechanically efficient structures, resulting in optimal biomechanical and energy-efficient performance. However, it has been challenging for synthetic materials to change and adapt their structures and properties to address the changing loading conditions.

To address the challenge, we are inspired by the findings that bones are formed by mineralizing ions from blood onto collagen matrices. I will present a material system that triggers proportional mineral deposition from electrolytes on piezoelectric matrices upon mechanical loadings so that it can self-adapt to mechanical loadings. For example, the mineralization rate could be modulated by controlling the loading condition, and a 30-180% increase in the modulus of the material was observed upon cyclic loadings. To expand the environment where the material can be utilized, we have investigated the synthesis of liquid-infused porous piezoelectric composites inspired by bone and pitcher plants. The material showed over 36 times increase in modulus and 30 times increase in dissipation after 12 million loading cycles, demonstrating self-adaptive behavior in air. Furthermore, the material can be reprogrammed to generate various shapes by self-folding based on spatial distribution of mechanical loading.

We envision that our findings can contribute to new strategies for making resilient materials for dynamically changing mechanical environments, with potential applications including healthcare, robotics, vehicles, and infrastructure.

#59

# CFRP-reinforced hollow aluminum struts for lightweight load-bearing pressure vessels

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The reinforcement of hollow 3D-printed aluminum alloy structures with carbon fiber-reinforced polymer (CFRP) is investigated as a novel approach for conformable and load-bearing lightweight pressure vessels. Combining additively manufactured aluminum with fiber-reinforced composites offers high geometric flexibility and the potential to reduce structural mass while maintaining mechanical performance. However, the differing coefficients of thermal expansion between aluminum and CFRP present significant challenges, particularly for cryogenic applications such as hydrogen storage, where adhesive bonding can lead to high interfacial stresses during temperature cycling.

To overcome these limitations, mechanically interlocked (positive-locking) load transfer concepts are developed and experimentally investigated. Three distinct CFRP anchoring configurations are designed to reinforce a hollow 3D-printed aluminum strut, representing a typical tensile reinforcement element within a pressure vessel structure. The concepts differ in their geometry and anchoring mechanisms, aiming to optimize load introduction and minimize stress concentrations at the aluminum–composite interface.

Each configuration is first assessed through conceptual analysis, followed by the fabrication and testing of representative specimens. Mechanical performance is evaluated under static and cyclic loading to determine strength, stiffness retention, and fatigue behavior. The experimental results demonstrate that positive-locking interfaces can effectively transfer loads while mitigating thermal mismatch effects, offering a promising alternative to conventional adhesive bonding for hybrid metal–composite joints in cryogenic environments.

The study concludes with recommendations for further design optimization and integration of such CFRP-reinforced 3D-printed aluminum components into conformable lightweight pressure vessel systems for hydrogen storage and similar applications.

#61

# Repeated Low-Velocity Impact and Quasi-Static Indentation at Various Temperatures

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De-icing system on the leading edge of turbofan engine nacelles can cause large fragments of shed ice to detach from the nacelle surface and be ingested into the engine, producing high-energy impacts on the composite fan blades of modern turbofan engines. These blades are subjected to tens of thousands of such impact events throughout their lifetime. While the failure mechanisms associated with a single impact event have been widely investigated, the progressive damage behaviour of composite laminates under repeated impacts has received only limited attention in the literature. Nevertheless, understanding how damage accumulates under repeated ice impacts, and determining the life of composite fan blades, is important for both operational safety and the extension of maintenance intervals.

The present study investigates the repeated impact response of carbon fiber–reinforced polymer (CFRP) panels through repeated low velocity impact (LVI) and quasi static indentation (QSI) tests, aiming to determine whether the similarity in failure modes observed in single LVI and QSI tests persists under repeated loading. Additionally, since the aircraft engines operate in-low temperature environments where material response can differ significantly from the room-temperature conditions, the influence of environmental temperature on the damage initiation and accumulation on repeated LVI and QSI require investigations. Therefore, the test fixture used in this study was specifically designed to fit inside the environmental chamber and to be compatible with both the servo-hydraulic testing machine and the drop weight tower.

Damage progression is evaluated using non-destructive techniques including ultrasonic C-scan and X-ray computed tomography (CT-scan). The results provide a detailed characterization of how matrix cracking and delamination develop and accumulate under repeated LVI and QSI tests. Furthermore, the findings also demonstrate the effect of temperature on the damage progression and life of the composite parts.

#62

# Composites without compromise: bio-based epoxy systems for a sustainable future

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The transition toward sustainable materials in composite manufacturing is accelerating, driven by regulatory pressure, customer demand, and environmental responsibility. ELANTAS has developed a comprehensive portfolio of bio-based epoxy resins and hardeners designed for use in structural and non-structural composite applications, including adhesives, laminating systems, and infusion resins. These products are formulated using renewable raw materials and engineered to match or exceed the performance of conventional petroleum-based systems.

A key aspect of this development has been the extensive scouting and testing of bio-based raw materials, carried out over several years. ELANTAS invested significant resources into identifying renewable feedstocks with the right chemical functionality and purity, followed by rigorous validation through lab-scale and industrial-scale trials. This effort enabled the formulation of epoxy systems that deliver high mechanical strength, thermal stability, chemical resistance, and processability — while maintaining compatibility with existing manufacturing processes.

This presentation will showcase the technical capabilities of ELANTAS' bio-based epoxy range, with particular attention to drop-in compatibility, enabling seamless integration into composite workflows without compromising performance. The materials are designed to meet the demanding requirements of sectors such as automotive, marine, and industrial composites.

The development of these resins reflects ELANTAS' strategic commitment to sustainability without sacrificing quality or reliability. By leveraging advanced formulation techniques and thorough testing protocols, ELANTAS ensures that bio-based alternatives are not only environmentally responsible but also commercially viable. This work positions ELANTAS as a key player in the transition toward greener composite technologies and supports the industry's shift toward circularity, resource efficiency, and long-term innovation and competitiveness.

#63

# Improved Interface Strength for Overprinting with CF-LMPAEK

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As the aerospace industry strives towards high rate and low cost manufacturing of structural parts, thermoplastic additive manufacturing has been repeatedly identified as a promising new technology to be combined with existing manufacturing methods in producing new lightweight aircraft structures. Overprinting of laminar continuous fibre structures by means of Fused Granulate Fabrication (FGF) can produce stiffened panels, similar to overmoulding, without additional fasteners or adhesives. Moreover, overprinting offers greater flexibility and removes the need for part-specific toolings. Of the most popular contemporary polymer materials for aircraft structures, LM-PAEK has shown a particular affinity for additive manufacturing, with the lower melting temperature and slower crystallization kinetics promoting in-situ bonding of the plies or layers during deposition.

This paper characterises the tensile bond strength of CF-LMPAEK overprinted structures on TC1225 substrates. Single-walled blade stringers are printed using a Weber DXR25 extruder mounted on a 6-axis industrial robot. TC1225 substrates are consolidated in an out-of-autoclave vacuum process with a [0, 90]2s layup. The matrix content on the substrate surface is varied by consolidating a neat LMPAEK polymer film on certain substrates and the substrate temperature is varied using a heated print bed.

The preliminary results show a dramatic increase in bond strength for the combination of high surface matrix content and high surface temperatures, with ultimate stresses in the range of structural adhesives. This is a very promising result, indicating that homogenous material joints, i.e. those without foreign material and adhesives, are indeed achievable. The fast estimation method used in this work allows for the optimization of process parameters and substrate surface design, with further investigation including temperature profiles in the interface, layer time, and additional surface modifications.

#64

# Towards Automating Hand-Layup: A Preliminary Study on Robotic Draping of Woven Glass Fiber Fabric

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Woven fabrics are widely used as reinforcement textiles in fiber-reinforced plastics (FRP) due to their balanced mechanical properties, good availability, and favorable handling and draping behavior. In the hand-layup process, the textiles are manually draped over a mold and impregnated with thermoset resin using a brush or roller. The manual labor is cost-intensive, has limited repeatability, and a high demand for health and safety measures due to the toxicity of resins. Moreover, draping woven fabrics over doubly-curved molds remains a challenge with a high risk of defects such as wrinkles and fiber misalignments. Most current automation approaches propose complex multi-robot solutions, which require high effort in programming and control.

Thus, this study investigates the potential of using just a single 6-DOF UR10e collaborative robot with a simple brush end-effector for the automated draping and resin impregnation. Twill-weave glass fiber fabrics were draped onto 3D-printed molds of conical shape and impregnated with epoxy resin. A software pipeline was used to generate toolpaths according to a predefined, universal draping strategy accounting for the expected shear angles in the fabric, with the shear distribution being approximated with a kinematic draping simulation. Tool movements follow the fiber orientations from a defined starting point in an order of ascending shear angle. Resin recharging was automated based on travel distance. Parameters such as end-effector speed, brush pressure, path repetitions, and resin amount were varied in the experiments. Process evaluation targeted common macroscopic defects such as wrinkles, incomplete mold conformation, dry spots, and resin-rich zones.

The trials demonstrated that a robotic draping process using a single manipulator following a targeted draping strategy could be feasible for simple doubly-curved geometries. An optimization of brush pressure and the inclusion of preparatory dry runs proved decisive in achieving wrinkle-free results. Slower trajectory execution enhanced resin transfer, ensuring uniform wet-out.

#65

# Assessing pyrolysis techniques for End of Life composite waste

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Composite material recycling is challenging: separating reinforcement fibers from polymer to repurpose them is expensive, leading to most composites being landfilled instead of being reused. The cumulative waste from aeronautical and wind turbine industries could be between 500,000 and 1,000,000 tons by 2050 [1][2].

Currently, the most ecological way to deal with composite waste has been repurpose it in other applications. Co-incinerating composites to harvest thermal energy to replace petrol coke in industrial processes. Glass fiber reinforced polymer can be incinerated in concrete mills to form cement clinker from the glass [3].

Radio wave technology-based pyrolysis [4] can release much less CO2 and only requires electricity. New turbine blades could power the recycling of old ones in a truly circular economy. ARKEMA has developed a resin (Elium) that has already been used to build windmill blades. The Methyl Methacrylate-based Elium resin is polar and susceptible to radio wave heating, unlike nonpolar polymers or Epoxy: no radio wave absorbers need to be added and filtered out of its pyrolysis oil. This reduces energy required to melt Elium composites, processing time and operating costs.

The present work aims to refine the pyrolysis process for Elium composites to recover the maximum amount of monomers for reuse. The kinetics of Elium degradation will be examined to find the optimal pyrolysis yield conditions. The monomers will be recast as test pieces to compare to new pieces (impact, tension, flexion…).

Replacing conventional pyrolizer heating elements with radio wave heaters will reduce energy costs. We anticipate that material testing of reclaimed fibers will show lower degradation and material properties close enough to virgin material to be re-used in industry.

ARKEMA has already produced results showing they can reclaim Elium monomers through pyrolysis [5]. This could enable material self-sufficiency for extended space missions and reduce crude oil dependency.

#66

# INVESTIGATION OF LOW-TEMPERATURE THERMOELECTRIC PERFORMANCE OF Ni-INCORPORATED Cu2SnSe3 SYSTEM

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Cu2SnSe3 based thermoelectric materials have attracted considerable interest due to their unique thermal and electrical characteristics. We investigated the influence of Ni incorporation in Cu2SnSe3 system. Conventional solid-state reaction techniques and sintering were utilized to synthesized polycrystalline Cu2SnSe3/x% Ni (where x = 0, 1, 2, and 3 wt%) composites. Crystal structure was investigated using XRD and the results reveal diamond cubic structure of the samples with the space group of $F\bar{4}3m$. Scanning electron microscopy images show pores with homogeneous surfaces. We present thermoelectric properties in the temperature range 10 - 300 K. The positive sign of Seebeck coefficient reveals that the synthesized samples have holes as the majority charge carriers throughout the temperature range. The resistivity of all samples gradually decreases with the increase in the Ni concentration clearly showing non-degenerate semi-conducting behaviour. The introduction of Ni leads to a reduction in Seebeck coefficient and a notable increment in electrical conductivity which is attributed to the improved carrier concentration. A decrement in thermal conductivity is also observed with increasing Ni composition mainly due to the enhanced phonon scattering and point defects in the Cu2SnSe3 system. We could not get higher ZT with Ni doping, however, we could reduce thermal conductivity.

#67

# Progressive Reinforcement Effects of Continuous Carbon Fibre Layers in PETG-Based 3D-Printed Composites

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Additive manufacturing of fibre-reinforced composites through Fused Filament Fabrication (FFF) enables the design of lightweight, tailored structures with complex geometries. However, the influence of continuous fibre content on the mechanical response of thermoplastic matrices remains insufficiently characterised, particularly considering process-induced defects.

This study investigates the mechanical performance of PETG-based composites reinforced with an increasing number of continuous carbon fibre layers, fabricated using the Anisoprint 3D printer. Specimens containing 0, 3, 6, and 9 fibre layers were produced while maintaining a constant total thickness and suitable printing parameters. The samples were tested under longitudinal and transverse tension, flexural, interlaminar shear, and in-plane shear loading to evaluate both fibre- and matrix-dominated behaviours.

Results reveal a non-linear improvement in mechanical properties with additional fibre layers, attributed to the evolution of void morphology and fibre–matrix interfacial quality. Complementary □□X-ray Computed Tomography (□-XCT) provided a detailed assessment of internal features explaining the observed performance trends. The findings contribute to a better understanding of structure–property relationships in continuous fibre-reinforced thermoplastic composites produced by FFF.

#68

# Proposal of the Modified Block Shear Method for Adhesively Bonded Composite Joints and Strength Evaluation

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The most reliable mechanical fastening for composite joints increase structural weight and processing costs, including drilling. Although resin adhesive bonding is expected to replace these joints, ensuring its reliability requires extensive data on adhesive strength. While numerous strength tests for adhesive bonding have been presented to date, selecting the appropriate method remains a tough challenge for engineers. The single-lap shear test is often used to evaluate composite adhesive strength. However, this method has two significant drawbacks. Firstly, it represents a mixed-mode state in which peel stress dominates. This makes the test highly susceptible to edge conditions and means that the obtained strength values are difficult to use for design purposes. Secondly, the test specimen includes a composite arm and is larger than the evaluated section, resulting in high manufacturing costs.

The aim of this study was to expand the applicability of evaluating composite adhesive strength. Specifically, I modified the block shear method described in ASTM D4501 — intended for evaluating the bond strength of materials such as wood — for use with composites. This modification enables not only specimens prepared specifically for strength evaluation, but also small pieces cut from actual products or structures containing the bonded joint.

The results were compared with those from single-lap shear test. During testing, detailed strain changes in the adhesive and substrates were captured using digital image correlation (DIC) technique. The modified block shear specimens would be less expensive to manufacture than other test specimens used for evaluating adhesive bonding strength, including single-lap shear test. Both experimental and numerical analyses confirmed that equivalent strength evaluations can be achieved using the modified block shear method.

#69

# Converting wood particles into monolithic cellulose reinforced lignin composites

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There is currently a timely need to design and manufacture renewable materials for high volume structural applications and decouple our economy from fossil-derived non-renewable resources. Natural wood is a renewable composite material perfected by nature. The cell walls of wood are layered composite made of cellulose microfibril-reinforced lignin matrix compatibilized with hemicellulose. Over the last decade, significant advancement has been made in the development of ionic liquids (ILs) for biorefining, especially in the direct dissolution of cellulose to produce synthetic cellulose fibres and advancement on dissolving hemicellulose and lignin selectively without dissolving cellulose. Whilst the focus has been on the pre-treatment of natural wood, these ILs do provide us with an exciting opportunity to manufacture the next generation renewable materials with intrinsic scalability that are truly high performance for high volume structural applications.

In this work, a method to convert wood particles into composites is reported. Wood particles were treated with IL and time temperature conditions were tailored to complete the lignin precipitation. This lignin was then used to fabricate monolithic cellulose reinforced lignin composite by introducing PVOH with epichlorohydrin as crosslinker. The extended treatment time was founded to increase the potential of crosslinking to achieve better mechanical performance. The tensile properties of the composite are as high as E= 6GPa and σ=25MPa. Rheological, thermal analysis, Ftir and XRD further characterised treated lignin and monolithic cellulose reinforced lignin composite. The result will be further discussed in the presentation.

#71

# Process-Structure-Property Relationships in Flax Fiber-Reinforced Composites Using PLA and PA11 Film Stacks for Lightweight Applications

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This study investigates the fabrication of fully bio-based thermoplastic flax fiber twill fabric-reinforced composites (FFRCs) using film stacking and hot compression molding. Film extrusion and injection molding grades of PA11 and PLA were processed with varying film thicknesses, temperatures and pressures. Optimization led to exceptional mechanical properties (E = 14.9 GPa; σ > 160 MPa), not previously reported to the authors' knowledge.

These properties are attributed to a high flax fiber volume fraction (Vf > 50 vol%) combined with excellent lamination quality. The use of thin polymer films (t = 200 µm), high pressure (p = 3 MPa) and low-viscosity matrices (compression molding grades) resulted in significant improvements in tensile and flexural performance. These process parameters enable high fiber volume fractions while ensuring complete fiber impregnation without deformation of the flax fiber fabric from excessive pressure.

The flexural moduli of PLA-based composites were increased compared to PA11-based equivalents due to the higher matrix stiffness, while the specific Young's moduli showed slight advantages for PA11 owing to its lower density. Processing at low temperatures and with high cooling rates minimized thermal degradation of flax fibers. Drastically reduced flax fiber discoloration occurred at higher processing temperatures (T = 200 °C) when using a film extrusion grade, presumably because the higher-viscosity polymer films provided a protective barrier against the hot press plates.

Overall, this study establishes a best-practice route for producing bio-based, high-performance composites and provides valuable insights to enhance the attractiveness of bio-based materials for lightweight applications in mobility, construction, medical technology and equipment for sports and recreation.

#72

# Material investigations for stitch and glue boats

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## Introduction

Smaller muscle powered boats are often made of plastics or fiber-reinforced plastics in a hard-shell construction. Another construction method is the so-called stitch and glue method, in which plywood panels are pre-cut to specific shapes, then connected at the joints with wire loops and resin. Fabric impregnated with synthetic resin is applied to the outside. Tropical plywood, fiberglass mats and resins are usually used for these hulls, where alternative materials are focus of this paper.

## Material

Tropical plywood as Sapelli or Okume in marine grade is often used. Glass fiber fabric in twill weave is usually processed on the hulls using epoxy resins. To substitute these materials, a material study and comparison of material properties is necessary. Birch and poplar were selected as alternative plywood. Basalt and linen fabrics were considered as alternatives to glass fiber mats, due to better ecological balance. Synthetic resins with linseed oil base were under investigation. Common testing standards were used for qualification.

## Investigations / results

A condensed sun exposure test of different resins revealed changes in color but not in the mechanical properties during tensile testing. Tensile tests of unmodified plywood (birch, poplar, sapelli, okume) showed about 60% higher tensile strength in fibre direction (outer layers) then perpendicular to it. Best results were found with birch plywood. In tensile tests of different linen fabrics compared with basalt and glass fabrics were the highest values received for standard glass fabric. Bending tests of plywood in both fibre directions and partly with a single glass fabric layer (160g/mm2) on one side, showed also best values for birch plywood. Improvement level to bending strength by fibre reinforcement was depending on plywoods fibre orientation.

Birch plywood is an alternative for stitch and glue boats, epoxy resins with “green” content provide good results; natural fabrics have other advantages.

#74

# Highly selective trimethylamine gas sensor fabricated using conducting polyaniline/metal oxide composites

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The high-sensitivity trimethylamine (TMA) gas sensor at room temperature is prepared using nitrogen doped graphene quantum dot (N-GQD) coated electrospun yttrium doped tin oxide (Y:SnO2) fiber and conducting polyaniline (PANI). The XPS spectrum shows that 0.8 wt% Y:SnO2 contains higher content of oxygen vacancies which might provide more reaction sites for the further interaction with the electron. The response value of TMA gas in the concentration ranging between 10~60 ppm at room temperature for fabricated PANI/N-GQD/Y:SnO2 sensors is significantly larger than those of PANI and PANI/Y:SnO2 sensors. The response difference of PANI/N-GQD/Y:SnO2 sensor is about two times larger than pure PANI sensors. This fabricated TMA gas sensor also displays exceptional long-time stability, repeatability and selectivity. Based on above results, the prepared PANI/N-GQD/Y:SnO2 sensor can be applied to detect the TMA concentration for the freshness of seafood.

#76

# Production of hybrid composites with recycled PET by pultrusion

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This article aims to contribute to the increase of use of thermoplastic matrix composites as an alternative to more traditional thermoset-based composites. Thermoplastic matrix prepregs were produced in tape form by immersion of continuous carbon and glass fibres into a molten polymer bath, combining them with virgin and recycled polymers. The use of prepregs is particularly attractive from an industrial perspective, since the process of combining the raw materials is carried out prior to their application in a consolidation process, ensuring improved quality and reproducibility.

The prepregs were subsequently processed by pultrusion, a continuous and automated manufacturing process that enables the production of constant cross-section profiles suitable for lightweight structural applications. This work focuses on the feasibility of producing hybrid materials that combine carbon fibres and glass fibres with recycled polymers. The objective of combining the different types of fibres is to study mechanical properties and assessing the possible reduction of cost of pultruded products by a more flexible approach.

Since pultrusion of thermoplastic composites remains relatively novel, the process still presents significant scientific and technological challenges. Therefore, this study also includes the determination of the optimal combination of operating parameters to achieve high quality consolidation. Finally, the hybrid pultruded profiles were subjected to mechanical testing to evaluate their performance and compared typical composites, reinforced by one kind of reinforcement. The experimental properties are further compared with predictions obtained from micromechanical analysis, contributing to a better understanding of the processing, structure and property relationships in thermoplastic hybrid composites.

#77

# Design Of Advanced SelfHealing Mechanism In Fiber Reinforced Composite

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The development of self-healing fiber-reinforced composites represents a promising strategy to enhance the durability and safety of structural materials exposed to long-term service conditions. Traditional extrinsic self-healing systems rely on the incorporation of microcapsules or vascular networks containing liquid healing agents; however, their effectiveness is limited to a single healing event and is often incompatible with high-performance thermosetting matrices. In contrast, intrinsic self-healing mechanisms, based on the reversible mobility of thermoplastic phases, offer the potential for multiple healing cycles through external activation, providing a more sustainable and durable approach.

In this work, we present an intrinsic self-healing composite system in which a thermoplastic polyurethane (TPU) healing agent is directly deposited onto carbon fiber fabrics via Fused Filament Fabrication (FFF) prior to resin infusion. The resulting hybrid laminates are produced through Vacuum-Assisted Resin Transfer Molding (VARTM) using a high glass transition temperature aerospace-grade epoxy resin, ensuring both structural integrity and compatibility with the thermal activation required for healing.

Following mechanical damage representative of interlaminar delamination, the healing process is thermally activated to induce controlled flow of the thermoplastic phase, enabling crack closure and partial restoration of the interlaminar interface. The mechanical characterization of the healed composites demonstrated a measurable recovery of interlaminar fracture toughness and improved damage tolerance, confirming the potential of this approach for cyclic loading applications.

This study highlights the feasibility of integrating 3D-printed thermoplastic patterns within fiber-reinforced composites to achieve stimulus-activated, repeatable self-healing without the need for encapsulated agents or complex architectures. The proposed manufacturing strategy provides a versatile route toward next-generation smart composite materials, capable of autonomously mitigating interlaminar damage and extending structural lifetime in demanding engineering environments.

#78

# Additive manufacturing of spinodoid materials for optimized structural components

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Porous architected materials feature high specific strength, damage resistance, and tolerance to off-axis loading. In nature, such materials often exhibit local variations in porosity and orientation, producing gradual changes in mechanical properties across the structure. This allows components such as the human femur to conform optimally to complex stresses at both the macroscopic and microscopic levels. This hierarchical design is highly efficient.

Although advances in additive manufacturing are driving the adoption of porous architected materials, hierarchical designs with gradients in density and anisotropy remain underexplored. They might offer an exciting addition to traditional fiber-reinforced composites, which are largely constrained to in-plane anisotropy due to the reliance on layering or winding plies.

The recently developed spinodoid is a porous, bicontinuous, stochastic structure resembling trabecular bone. Design tools now enable the generation of anisotropic microstructures and gradients in spinodoids, opening the way to graded, bone-like structures. This tunability makes them a promising candidate for structural applications.

However, their manufacturability constraints and the real-world tuneability envelope of their mechanical properties remain uncharacterized, and the efficiency gains from multiscale design have yet to be experimentally verified.

We present an experimental study on the manufacturability and mechanical tunability of spinodoid structures produced via SLA additive manufacturing. We demonstrate compressive moduli of porous materials spanning over two orders of magnitude (3 ~ 300 MPa) and a minimal manufacturable feature size below 1 mm. We further investigate the influence of gradients in density and anisotropy. Finally, we present an aerospace component composed of spinodoid material with optimized anisotropy, comparing its performance against a hinge without microstructural optimization.

#80

# Experimental characterization of bearing mechanisms in a carbon/epoxy composite laminate for the modelling of damage in hole-to-hole assembly

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The hole-to-hole assembly process offers the potential to accelerate production by pre-drilling parts before the final assembly line. However, this method inherently results in hole oversize (holes being larger than the fastener diameter to facilitate assembly) and hole-to-fastener misalignment. This study investigates the bearing response of quasi-isotropic composite laminates as a function of hole oversize through a combination of physical testing and numerical analyses. Two simple geometries have been tested under compression: a quarter hole configuration, which allows in-situ observation of damage, and a half hole configuration, more representative of an assembled plate. This test campaign revealed that damage is governed by fiber failure in compression. The presence of ±45° plies seems to increase the strength of the laminate by recovering the load after the kinking of the 0° plies. These mechanisms will be analyzed further by X-ray tomography. Three different hole diameters were tested to evaluate the influence of clearance. Increasing clearance reduces the strength and overall stiffness of the joint and favors damage by concentrating the compressive stress at the center of the contact area. Based on the experimental results, the capability of the progressive damage model OPFM to capture the observed damage scenario and global behavior in bearing is assessed. The influence of shear stress on fiber failure under compression was integrated into the model. The compressive behavior of the damaged material was adjusted such that the swelling of the laminate with the accumulation of damage is taken into account. This is required to correctly simulate the out-of-plane compressive stresses around the joints caused by the containment of the material by the bolt, which is expected to increase the joint bearing strength.

#82

# Process-Relevant Relaxation and Reptation Times in Thermoplastics for Large-Scale Additive Material Extrusion: A Thermorheological Characterization

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Large-Scale Additive Material Extrusion (LSA-MEX) is gaining traction in research and industry because it enables the manufacture of parts at new spatial and temporal dimensions. The resulting part properties arise from the interplay between process parameters and material-specific effects across structural levels from the micro to the macro scale. At the microstructural level, pore formation, crystallization behavior, and autohesion govern the properties of neat thermoplastics. In short-fiber-reinforced thermoplastic composites, fiber orientation and distribution add further controlling factors. Process-induced molecular orientation caused by shear and extensional flows affects these microstructural phenomena and the resulting mechanical properties. For nozzle diameters above 2 mm, the thermal energy introduced into the extrudate, together with the thermophysical properties of the thermoplastics, leads to extended thermal residence times. The increased segmental mobility of macromolecules promotes relaxation of process-induced orientation and at the same time widens the time window for chain interdiffusion and entanglement at the interface between adjacent strands. As a result, the cohesive bonding between extrudate and substrate, that is autohesion, improves.

This study aims to thermorheologically characterize a neat and a short-fiber-reinforced semicrystalline thermoplastic in order to determine the characteristic times of molecular relaxation and reptation. On this basis, predictions are derived for the decay of process-induced orientation states and for the time spans required to complete the interlaminar autohesion process. The results show that relaxation in neat semicrystalline polymers proceeds markedly faster than in fiber-reinforced composites. Orientations in neat thermoplastics decay more rapidly at a given thermal residence time. In composites, reptation and the associated interdiffusion across the interface are slowed, which lengthens the times needed to establish a load-bearing percolated entanglement network and to achieve full interlaminar bonding. The material-specific insights deepen understanding of process-induced structure and property evolution and support the targeted design of function-optimized components for large-scale additive manufacturing.

#83

# Discrete-Event Simulation for System-Level Optimisation in Aerospace Composite Manufacturing

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Aerospace composite manufacturing involves complex, interdependent processes constrained by limited resources and sequential dependencies. Efficient management of such systems requires advanced production planning and realistic representations of dynamic resource interactions; challenges that traditional static planning methods fail to address.

This study explores how discrete-event simulation (DES) can support improved production planning and resource utilisation in aerospace composite manufacturing. The work integrates a literature review, industrial case study, and simulation-based analysis to identify and address key operational bottlenecks within a high-mix, low-volume production environment. The case study, conducted in an aerospace composites facility, revealed major challenges related to tool availability, process synchronisation, and operator allocation. These factors strongly influence throughput and work-in-progress levels.

A DES model was developed to represent the main process chain, including shared resources, sequential dependencies, and inter-process buffers. The model enables systematic evaluation of production policies and resource configurations. Simulation results indicate that perceived bottlenecks, such as labour constraints, often differ from the true system limitations governed by tool utilisation and scheduling logic. Scenario experiments demonstrate that targeted improvements, such as adaptive batching, flexible resource assignment, and synchronised process control, can substantially enhance overall flow efficiency without additional equipment investment.

The findings underscore the importance of system-level modelling and simulation in identifying leverage points for performance improvement in composite manufacturing. By coupling DES with real-world production data, the approach provides a foundation for data-driven, sustainable, and scalable production planning, supporting future integration with digital twin and AI-assisted decision tools in composite manufacturing systems.

#84

# Design and experimental validation of a composite structure for deep-sea application

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Due to their high performance and lightweight properties, composite structures are increasingly used in marine applications, particularly for deep-sea exploration. Although the entire structure cannot be fully manufactured in composites, the central cylindrical section can be designed using these materials. For this application, a unidirectional (UD) carbon/epoxy composite is used and manufactured by filament winding. There are numerous specifications for the design of these structures. It is necessary to ensure strength (both material and structural), durability (including creep under constant hydrostatic stress, cyclic loading during ascents and descents, and resistance to water uptake), as well as sufficient capability to dissipate the heat generated by onboard instruments.

The aim of this study is to investigate the mechanical behavior of a composite structure under hydrostatic pressure. Resistance, bulking and variable compressibility are studied. In this context, compressibility refers to the ability of the structure to adapt its volume depending on the depth, ensuring equilibrium at a given position. While such compressibility is usually achieved through mechanical systems, the objective here is to rely on the structural response itself, in order to reduce the energy required. To avoid disturbing the internal components, compressibility is considered mainly along the length of the tube.

The material resistance is evaluated using Classical Laminated Theory (CLT) combined with the Hashin failure criterion. The buckling behavior and structural compressibility are investigated through FEA. All three criteria are studied to determine, for a given fiber orientation, the minimum thickness required to withstand failure. The combination of these three criteria permits to determine which is the most influential design parameter and to propose an optimized solution. Based on this optimization process, tubes were tested in a hyperbaric chamber to validate the model predictions. The results of this study will be presented at the conference.

#85

# Novel Recyclable Hierarchical Carbon Fibre/Epoxy Composites: Preserving Fibre Length and Orientation Using Elium®

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Recycling of polymer matrix composites (PMCs) typically yields short, misaligned carbon fibres, restricting their reuse to applications of moderate mechanical performance. To enable a circular economy for carbon fibre composites, it is essential to develop recycling strategies that retain the original fibre length, orientation, and microstructural integrity. This study introduces a hierarchical composite architecture designed to preserve these critical features through repeated recycling. Continuous carbon fibres are first embedded in an insoluble epoxy matrix, forming tape-like primary structural units. The epoxy acts as a chemically resistant primary matrix, shielding the fibres from degradation and maintaining their alignment. These primary tapes are subsequently incorporated into a secondary matrix of Elium®, a recyclable thermoplastic resin with mechanical properties comparable to conventional epoxies and solubility in acetone. Recycling is achieved by selectively dissolving the Elium phase, allowing recovery of intact primary tapes containing aligned fibres for reuse in new laminates.

Hierarchical laminates were recycled up to three times, and their tensile and flexural properties were evaluated after each cycle. The composites retained 60–90% of the mechanical performance of fully epoxy-based systems, with negligible variation in fibre length, orientation, or fibre volume fraction. Push-out tests confirmed that the epoxy-encased fibres were effectively protected during chemical recycling. These findings demonstrate the feasibility of a hierarchical, partially thermoplastic composite that combines recyclability with high mechanical integrity, providing a viable pathway toward closed-loop manufacturing of structural carbon fibre composites.

#86

# Synthesis of a nanocomposite based on recycled epoxidized vegetable oils containing Ag-ZnO nanoparticles for antimicrobial surface protection

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Microbial contamination of surfaces remains a major concern for public health and infrastructure. This study presents a method for synthesizing nanocomposite coatings based on durable epoxy resin loaded with silver-zinc oxide (Ag-ZnO) nanoparticles. These nanoparticles were developed using a green method employing cajeput essential oil. The epoxy matrix is also bio-based, derived from recycled epoxidized vegetable oils crosslinked with 2,2'-dithiodibenzoic acid (DTBA) and catalyzed by imidazole, ensuring both mechanical performance and environmental compatibility. Three formulations containing different AgZnO loadings (10, 20, and 30 wt%) were prepared and deposited as thin films via spin coating. Various characterization tests of the nanocomposites were conducted, including FTIR, UV-Vis, XRD, SEM/EDX, AFM, adhesion tests, TGA/DSC, water contact angle measurements, and antimicrobial assays against Escherichia coli and Staphylococcus epidermidis. The results showed that increasing the AgZnO content improves thermal stability, light absorption, surface roughness, and adhesion, while gradually reducing the water contact angle, thereby enhancing surface wettability. Regarding the primary purpose of the coating—antimicrobial surface protection—the film loaded with 30% nanoparticles achieved 100% antimicrobial activity. These films exhibit the best adhesion to metallic substrates and enhanced photocatalytic activity under UV-visible light. This work paves the way for the development of multifunctional, eco-friendly, and efficient nanocomposite coatings for applications in medical fields and protective surfaces.

#89

# Modeling of Dissipative Mechanisms Related to Fatigue of 3D Woven Composites

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Three-dimensional (3D) woven polymer matrix composites are used in applications requiring high fatigue resistance over more than $10^7$ cycles. However, characterizing fatigue behavior over such long periods is costly and time-consuming. The self-heating method can greatly accelerate this process, but its effective use demands a deep understanding of the dissipative mechanisms and their correlation with fatigue. This is particularly challenging for 3D woven composites due to their complex mesostructure and intrinsic thermomechanical behavior. This work aims to elucidate the dissipative thermomechanical behavior of 3D woven carbon/epoxy composites through multiscale modeling and experimental comparison.

First, an experimental campaign was conducted to characterize the thermomechanical response and fatigue performance of the 3D woven composite and its individual constituents. Temperature measurements were taken during these tests using infrared cameras to analyze changes in heat sources, including dissipation. In addition, damage in the composite was examined based on X-ray tomography observations.

Second, a two-scale modeling approach was developed to capture the thermomechanical and dissipative behavior of the composite. Full-field simulations at the mesoscopic scale were performed on realistic 3D mesostructures reconstructed from X-ray tomography, representing the homogenized yarns and the surrounding matrix. Carbon fibers were modeled as transversely isotropic linear elastic. The epoxy matrix followed an isotropic nonlinear viscoelastic spectral model written within a thermodynamic framework to account for dissipation. The homogenized thermomechanical response of the yarns was then described by a transversely isotropic nonlinear viscoelastic model identified from unit cell simulations.

The model was used to assess the contributions of matrix viscoelasticity, crack formation, friction, and heat exchange to the temperature evolution under cyclic loading. The results offer new insights into dissipative mechanisms and their relation to fatigue. Based on these findings, a protocol is proposed to use self-heating measurements as an accelerated method for estimating the fatigue performance of 3D woven composites.

#91

# Multi-objective optimisation of imperfection-sensitive variable-stiffness composite cylinders

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This study presents a multi-objective optimisation framework for variable-stiffness (VS) composite cylinders accounting for geometric imperfections. Imperfection fields obtained from digital image correlation (DIC) measurements are reduced using principal component analysis (PCA) and expanded via Latin hypercube sampling (LHS) to generate statistically representative synthetic imperfections. These are mapped onto nonlinear finite element (FE) models to evaluate collapse behaviour under axial compression. Gaussian process regression (GPR) surrogates are trained using an adaptively refined Kriging dataset to predict structural mass and collapse load, while the knockdown factor (KDF) is used to quantify imperfection sensitivity. Conservative lower confidence bounds are incorporated during optimisation to promote robust design selection under prediction uncertainty. Multi-objective optimisation is performed using Bayesian optimisation (BO) and the Non-dominated Sorting Genetic Algorithm II (NSGA-II), independently, to simultaneously minimise mass and maximise collapse load and KDF. Normalised Pareto fronts reveal clear trade-offs between lightweight efficiency, structural strength, and robustness. Results show that VS designs with smooth fibre-angle variation improve buckling performance and imperfection tolerance without significant mass penalty, while BO achieves faster convergence than NSGA-II. The proposed framework provides a computationally efficient pathway for reliability-driven design of composite shells.

#93

# The Use of Manufacturing Process Simulation for the Industrialization of Composite Structures

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Airbus Helicopters (AH) manufactures complex, high-quality helicopter components primarily using autoclave processing of composite materials. Since relying solely on experience often results in costly tooling rework and delays, AH increasingly uses manufacturing process simulation (MPS).

The risk of potential defects drives the simulation capability portfolio. AH primarily focuses on three types of simulations:

Heat-up simulation to identify thermal behavior: This is crucial because tooling heats more slowly than the autoclave air, and component temperature curves must be known to ensure complete curing. The simulation allows for optimal design and correct thermocouple positioning to detect hot and cold spots before manufacturing the tooling, adhering to the "first-time-right" principle. The Finite Element Method (FEM) is used for small tooling and Computational Fluid Dynamics (CFD) is used for large, complex tooling to derive realistic heat-up behavior.

Cool-down simulation to identify distortion: Differences in anisotropic expansion, resin shrinkage, and tooling material expansion cause geometric distortion, such as spring-in at composite angles, during cool-down. FEM simulation of the cooling process calculates this warpage, enabling the tooling surface to be compensated in advance.

Mechanical autoclave process simulation to identify defects: This is crucial for sandwich components with honeycomb cores. Defects such as core crush or prepreg wrinkles can occur due to autoclave pressure and low lateral stiffness, particularly when there is too little friction between layers. Realistic simulation requires knowledge of material and friction properties, which AH determines using a dedicated test device. This enables defects to be detected and solutions to be developed during the design phase.

The presentation will demonstrate how MPS has made its way from method development and validation to integration into our industrial processes at AH. Continuously applying MPS increases production efficiency, for example, by reducing cycle times, accelerating assembly steps, and ensuring the first-time-right design of manufacturing equipment.

#95

# Functionalization of PEKK through integration of iron microparticles

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Particle-filled thermoplastics, especially for the improvement of specific properties, were a prominent research focus in the early 80s. Renewed interest in this field has been driven by modern functionalization in automotive and aerospace applications as well as electronic equipment. The advent of thermoplastic 3D printing has similarly broadened the scope of potential implementation, allowing for localized additions and complex geometries.

This work focusses on a high-temperature thermoplastic, PEKK 6003 (Arkema), filled with iron microparticles to modify its electromagnetic properties. Initial trials of iron impregnation of PEKK in a twin-screw extruder resulted in a maximum porosity of 3 % in the pellet output. The application of a vacuum to the extruder setup proved ineffective at reducing pellet porosity due to clogging of the vacuum connection and so the material was characterized with a focus on the melt viscosity and degradation. Rheological measurements showed that the melt viscosity increase of the iron-impregnated PEKK over a 1h period is more than 10 times higher than that of unaltered PEKK. This effect was observed to be independent of the operating atmosphere (air or protective gas) and is therefore attributed to the filler particles. Further investigations (rheometer, TGA and XRD) will be conducted to identify the mechanisms which lead to the increase in viscosity. Of particular interest is whether exposure to air at elevated temperatures leads to a change of the chemical composition or a loss of mass. The mechanisms for melt-state degradation of PEKK have already been shown in literature but the influence of the filler particles is still unknown. Countermeasures will then be evaluated to enable a continuous extrusion of material, with additions to the extruder setup, i.e. vacuum pump, without voids.

#96

# Repairability and residual strength of impacted carbon/PPS laminates in a marine environment

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Thermoplastic composites are increasingly being used for lightweight and high-performance applications due to their superior toughness compared to thermoset composites. This increased toughness allows for better energy absorption during impact and higher resistance to crack propagation, making them ideal for demanding environments. Another important advantage of thermoplastic composites is their capacity to be reheated and repaired after damage, including matrix cracking and delamination. In this context, this study focuses on the repairability of carbon/PPS laminates subjected to impact damage in a marine environment is investigated. Quasi-isotropic laminates, designed following the ASTM D7136 standard, were impacted at energy levels of 5 J, 15 J, 25 J, 35 J, and 45 J using a drop-weight test setup. To evaluate the effect of seawater ageing on the residual strength and repair potential of the material, impacted specimens were immersed in seawater at 60 °C for 100 days. The residual compressive strength of both unaged and aged specimens was then assessed according to ASTM D7137, with pristine compression specimens (ASTM D3410) used as references. The influence of ageing on the residual mechanical performance is discussed based on these results.

In a second phase, the damaged laminates were repaired using a thermo-compression press, following a similar curing cycle as during initial fabrication. The residual strength was re-evaluated to quantify the improvement provided by the repair process. Damage extent and morphology before and after repair were characterized using C-scan, micro-computed tomography, and optical microscopy on cross-sections. These analyses enabled a discussion of the material's repairability under both dry and aged (wet) conditions, as well as the nature of damage within the composite. Digital image correlation (DIC) was employed during residual strength testing to monitor surface strain fields and provide further insight into the material behavior.

#98

# Investigation of Hygrothermal Effects on the Structural Integrity of Flax/PA11 Composites

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Flax fibres are well known for their pronounced moisture uptake, which causes swelling of the fibres. When incorporated into a polymer matrix, this swelling can lead to a reduction in mechanical properties due to deterioration of the fibre–matrix interface. Polyamide 11 (PA11) is a bio-based thermoplastic with low inherent moisture sensitivity and a processing temperature close to the degradation threshold of flax fibres. This makes PA11 a promising candidate for close-to-100 %-biobased composite materials.

The present study investigates the influence of environmental conditioning on the mechanical performance and potential ageing processes of flax/PA11 composites. The conditioning protocol was designed to replicate environments relevant to the aerospace industry, involving controlled humidity and temperature levels corresponding to application and maximum operating environments. Furthermore, specimens were immersed in water for five days in order to simulate a worst-case exposure scenario.

Following environmental conditioning, distinct changes in mass and dimensions were observed. Analysis demonstrated a moisture uptake of approximately 10 wt%, resulting in specimen swelling of up to 20 % in thickness. The absorbed moisture had a substantial impact on the mechanical behaviour, with tensile strength decreasing by up to 15–20 % and stiffness by as much as 75 %. The findings of this study demonstrate that the mechanical performance of flax/PA11 composites is significantly influenced by the quantity of absorbed moisture.

Differential Scanning Calorimetry analyses revealed no observable changes in melting temperature, glass transition temperature, or crystallisation point, indicating the absence of matrix ageing under the applied conditions. Microscopic examination is challenging due to the low contrast between the fibres and the matrix, which prevents microcracks from being detected. However, the swelling of the flax fibres indicates progressive degradation of the fibre–matrix interfacial adhesion.

#100

# Study on Defect Detection Methods of Composite Blades for Large Wind Turbine

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In this study, the design and analysis of large wind turbine blades were performed. After analyzing aerodynamic loads, the aerodynamic design was performed. The aerodynamic characteristics and performance through aerodynamic analysis was carried out. The structural design load was calculated and the structural safety was evaluated after the structural design. Structural analysis was performed using ANSYS, a commercial finite element analysis program. A study on the defects of composite blades was conducted during the structural design process. The types of defects were defined and the various factors that cause blade damage were analyzed. Finally, a study was conducted on a technique for detecting defects by analyzing the sensitivity according to blade defects.

#102

# Processing and impact response of stitched 3D preform carbon/carbon composites based spread tow fabrics

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This study aims to rapidly develop three-dimensional (3D) woven carbon/carbon (C/C) composites. Carbon fiber fabrics were first stacked to a thickness of 2 cm and then stitched using a double-thread sewing technique to form 3D textile preforms. Two types of carbon fiber reinforcements were employed: unidirectional prepregs and spread-tow plain weave fabrics. The stitching parameters were set with both stitch pitch and row spacing of 2 cm, and two configurations were designed—aligned and staggered stitching, with a displacement of 1 cm for the staggered case. After stitching, the 3D preforms were impregnated with phenolic resin and subsequently carbonized process. In the fabrication of carbon/carbon (C/C) composites, the phenolic resin impregnation process was employed. During the heat treatment, the resin released phenol and water between 100°C and 300°C, leading to the formation of long-chain polymer structures. When the temperature exceeded 400°C, methane, water, carbon dioxide, and hydrogen were evolved as the resin underwent polycondensation reactions. As the temperature was further increased to 500°C, aliphatic ether groups were replaced by benzene rings, followed by aromatic dehydrogenation at around 700°C. Finally, carbonization was completed at 1300°C, resulting in the formation of the carbon/carbon composite structure. The impregnation–carbonization cycle was repeated three times to increase the carbon density. The resulting C/C composites were subjected to impact and post-impact compression tests to evaluate their mechanical performance. The results show that the 3D C/C composites fabricated from spread-tow fabrics exhibited 40% higher impact energy and approximately 38% higher post-impact compressive strength compared to those made from unidirectional prepregs. Moreover, the staggered stitching configuration provided superior impact resistance compared to the aligned one.

#104

# The effect of fibre length tensile strength and impact performance of Tow-Based Discontinuous Composites manufactured from dry fibre preforms.

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Short-Fibre Reinforced Composites (SFRCs) have gained interest within the composite industry as recycling dry reinforcement can reduce costs and improve sustainability. Fibre length and distribution can lead to variability in in-plane strength, and reduced strength compacted to continuous reinforced composites [1]. Chopped strand based SFRCs are the most common SFRCs, providing a low cost however low quality and low Fibre Volume Fraction (Vf) [2]. SFRCs utilising chopped prepreg achieve higher Vfs and strength, largely due to the tow based mesostructure is maintained in the resultant SFRC. This study aimed to assess the effect of a tow based precursor within a dry fibre preform based discontinuous composite.

Dry fibre preforms were made from standard modulus carbon fibre tow chopped to 6, 12, 24, and 48mm. Ten plies of each were stacked and infused with a 2-part aerospace epoxy at 3 Bar, averaging 53% Vf and 4.1mm thickness. Five 175x20mm tensile specimens were cut at 0, 90, and 45 degrees per fibre length. Five 63mm diameter disks were cut for static indentation and to assess volume fraction variation using X-CT.

Tensile specimen damage initiation and propagation were analysed using Digital Image Correlation (DIC) and thermography. Gradual stiffness reduction occurred in all fibre lengths as strain was applied, whilst isolated damage events were observed under thermography. 48mm tow specimens showed higher strength than other fibre lengths, with a marked increase in fibre breakage observed, and stiffnesses across all fibre lengths were comparable. Under static indentation, SFRCs isolated damage to smaller area compared to continuous fibre material.

Future work will focus on supressing surface damage initiation to enhance damage tolerance mechanisms found in discontinuous composites.

1. Visweswaraiah, Swaroop B. et al., J. Reinforced Plastics and Composites, 37, 2018, 548–80.

2. Kulhan, T. et al., Functional Composites and Structures, 4, 2022, 022001.

#106

# Deviation from the ideal shear strain state of a FRP under biaxial tension-compression test and standard methods

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The aim of this study is to support decision-making in selecting the most suitable methodology for characterizing the complete non-linear in-plane shear behaviour of fibre-reinforced polymer laminates composed of unidirectional plies. The performance of biaxial tension-compression and uniaxial tensile tests on symmetric ±45º laminates is compared with that of Iosipescu and V-notched rail tests conducted on cross-ply laminates.

The analysis is based on strain fields measured using digital image correlation technique, which reveals distinct non-linear mechanical responses that lead to varying estimations of ultimate shear strain and strength across the different methodologies. This investigation seeks to deepen the understanding of factors influencing shear response by adopting an alternative perspective, by analyzing angular changes within the region of interest and examining how fibre reorientation contributes to deviations from an ideal shear strain state.

No statistically significant variation is observed in the determination of $G_{12}$, defined as the in-plane shear modulus along the principal material directions, across the different tests. Regarding angular changes, the results indicate that the geometrical variations in the region of interest for the Iosipescu and V-notched rail specimens align with a simple shear strain state, while those observed in the uniaxial tensile and biaxial tension-compression specimens correspond to a pure shear strain state. Slight deviations from these ideal states are found even at the non-linear stage, substantiative of the standard calculation of the in-plane shear strain in principal material directions. However, longitudinal strains along the reoriented fibre directions should also be considered in the analysis. Due to the high elastic modulus in the fibre direction relative to the matrix stiffness, non-negligible normal stress components may arise. This could lead to noticeable variations in the measured shear strength across different testing methods.

#107

# Comparison of moisture absorption in thermoset and thermoplastic matrix glass fibre polymer composites for accelerated ageing tests

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There has been extensive use of polymer composite materials in the offshore and marine industries, but understanding their durability remains a significant challenge. The use of thermoplastic matrix composites is attracting growing interest due to their potential for being recycled. However, their long-term ageing behaviour in marine environments is unknown. As a first step, it is necessary to understand the effect of water absorption.

In this work, we investigated two composite materials, a glass fibre reinforced thermoset (Epikote epoxy resin) and a glass fibre reinforced thermoplastic (Elium). Flat panels were fabricated using the wet hand lay-up method, and coupons were extracted for the two composite materials. Elevated water temperatures were used to accelerate the ageing of the two composites, and their diffusivity was evaluated, as well as their glass transition temperature (Tg) at several intervals. To truly understand the behaviour of these materials, it is important to observe changes in the rate of moisture absorption over a range of temperatures and the contrast in Tg between the two different types of resin.

The results show that exposure to various water temperatures produces changes in material properties (i.e., glass transition temperature) which are complex in nature. We measured an initial drop in Tg (16% for GF/Epikote and 9% for GF/Elium) followed by an increase, and we investigated the mechanics of that change. Another key finding was that the GF/Epikote composite showed a higher diffusivity than the GF/Elium composite. At 60°C, we found that the rate was nearly double: $21.9\times10^{-13}$ $m^2$ $s^{-1}$ for the GF/Epikote compared to $11.4\times10^{-13}$ $m^2$ $s^{-1}$ for the GF/Elium.

The findings from this research will have direct implications for applications within the renewable energy sector, aiming to replace the current epoxy-based fibre composite used in wind turbine blades with a more durable and recyclable thermoplastic glass fibre-reinforced composite.

#109

# Data-driven-based roughness descriptors discovery for tapes surface characterization and optimal consolidation modelling

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Tapes surface roughness determines the time evolution of the degree of intimate contact required for ensuring the molecular diffusion and the associated tapes consolidation. However, usual characterization of rough surfaces usually relies in statistical descriptors that even if they could represent the roughness, they are disconnected from the physics occurring at the interface where consolidation occurs.

Thus, the key question could be formulated as follows:

What are the descriptors related to the roughness enabling both, tapes classification (of crucial interest in processing control) and the consolidation modeling (from the inference of the time-evolution of the degree of intimate contact that at its turns depends on the process parameters)?

For providing a valuable response we propose a novel procedure based on the use of a powerful autoencoder with a linear vector latent space, enforced by applying a PCA at the latent space level during the encoder-decoder training. The resulting PCA modes are enforced to represent any existing “a priori” knowledge, for instance valuable statistical descriptors, complemented with the ones needed for inference purposes (classification or modelling), and finally for those needed to ensure the profiles representation after decoding.

To prove the potential of the proposed technology, hundreds of roughness profiles were measured from 12 composites tapes from different providers. The technology described in the previous paragraph was able to proceed with a single mode when the macro-micro roughness was provided, and with three modes when only the micro-roughness was used (by removing the macro-roughness to the different measured profiles). This technology represents an unprecedented characterization and modelling tool, of critical interest in composites forming processes.

#111

# The Contribution of Acoustic Emission Modeling to the Optimization of Damage Source Identification in Composite Materials

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Acoustic emission (AE) monitoring is a useful method to deal with detection and identification of damage in composite materials during mechanical tests. From an experimental point of view, it is not straightforward to establish a quantitative link between the damage sources and AE signals. Modelling and numerical simulations appear as a promising way to reach this objective. In this study, Finite Elements Modelling (FEM) was used to simulate AE signals due to fiber break, fiber/matrix debonding in a model carbon fiber composite. The influence of the type of sensor, specimen geometry and AE source location were also studied. Moreover, AE signals induced by transverse matrix cracking are also simulated numerically using finite elements (FE) for composite laminates exhibiting different number of plies and stacking sequences. The results show that outer ply cracking rather exhibits signals with a low frequency content, not depending much on the ply thickness, contrary to inner ply cracking, for which the frequency content is higher and more dependent on the ply thickness. The same damage mechanism may thus lead to signals exhibiting different features depending on their location in the composite and on the composite meso-structure. The proposed model was extended to identify the main parameters that influence the acoustic emission signatures. Furthermore, a specific procedure has been defined to merge experimental and simulated data. These results pave the way for combining experimental and simulated data to generate a library for identifying real-time damage mechanisms. This outcome has significant implications for the generalisation of acoustic emission signature libraries. This aspect is key for developing a machine learning database with good generalisation ability.

#112

# Measurement and prediction of the development of mechanical properties of a flax-epoxy composite during the curing process

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The variability of microstructure, mechanical properties and geometry of biocomposite parts after the manufacturing process remains a critical gap preventing their full application. This limitation partially stems from an incomplete understanding of the formation of internal and residual stresses during the cure. These stresses are closely linked to the development of the mechanical properties of the part. These properties depend on the degree of cure of the matrix, the temperature, the loading time and moisture content due to the hydrophilic nature of vegetal fibre. This study aims at characterizing and understanding the development of mechanical properties in a flax-epoxy composite as a function of hygric, thermal, chemical (degree of cure) and time parameters.

To achieve this goal, composite plates were manufactured using a Vacuum-Assisted-Resin-Transfer-Moulding (VARTM) process at different degrees of cure. These plates were cut into samples using a milling machine and then conditioned at 20 °C under controlled relative humidity to regulate their moisture content at equilibrium. The samples were then tested in three-point bending using a Dynamical Mechanical Analyser (DMA) under various frequencies and temperatures. The resulting data were analysed using the Time-Temperature Superposition Principle (TTSP) to link time and temperature parameters, based on the faster relaxation observed at higher temperatures.

For the first time, this approach was successfully extended to account for both hygric and chemical effects. Both the absolute modulus and relaxation behaviour are enhanced by a higher degree of cure, lower temperatures, and drier samples. Based on these results, a numerical model was developed to predict the time-dependent evolution of mechanical and relaxation properties as a function of degree of cure, temperature and moisture content. Combined with the polymerization kinetic model of the resin, this approach enables an accurate prediction of the evolution of mechanical properties of a flax-epoxy plate throughout the curing process.

#113

# Quantifying cure conditions of very thick glass fibre composites

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The manufacturing of composite structures poses issues in process control and monitoring when the composite is very thick. Casting thick composite laminates requires control of the cure conditions to avoid a severe temperature rise due to uncontrolled exothermic evolution in the central part of the component. Something that can lead to high built-in residual stresses, leading to low fatigue performance, demolding distortion, or curing cracks.

In the presented work, an experimental setup is developed and applied in laboratory facilities that reflect the setup used on an industrial scale. A model is built and validated based on experimental validation, where a thick 75 mm composite block is cured using a simple temperature profile that closely resembles industrial conditions. The cure kinetics of the resin system are captured using a cure kinetics model including diffusion-controlled reactants. Ultimately, a cure profile tailored to the conditions of the thick composite is proposed, based on modelling predictions that yield a similar cure time and overall reduce residual stresses.

#114

# Integrating BRDF Imaging and Robotics for Automated Inspection of Specular Composite Materials

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This study presents a system enabling the automatic visual inspection of optically challenging composite surfaces. Both the binder and the weave material are mirror-like (specular), making the conventional automated inspection methods fail. Hence, visual inspection in the production of high-quality products with these surfaces is performed manually today. Our method—linear lighting combined with off-axis imaging—provides precise characterization of surface anomalies and forms a robust foundation for AI-driven defect detection. The method provides detection of minute (< 0.1 mm) defects by determining disturbances in the bidirectional reflectance distribution function (BRDF). The underlying physics of both the imaging system and subsequent analysis algorithms makes the system understandable and results explainable. As the imaging method imposes strict constraints on the relative angle between the imaging system and the surface normal, we have integrated it with robotic handling and CAD-based path planning to enable scalable automation. The path planner is subject to constraints given by the imaging system and evaluation of process time, areas with high change in surface normal will require more time to evaluate. Furthermore, this digital integration enables defect localization and cross process root cause analysis for process improvement. The solution has been successfully validated in a relevant environment and currently awaits on-site testing. In total, the system demonstrates how composite materials with optically highly challenging surfaces can be effectively digitized and inspected, paving the way for reduced operator workload and improved consistency. This approach supports digitalization in composite manufacturing, offering enhanced quality assurance, traceability, and productivity while being a step towards fully integrated inspection systems with advanced analytics.

#115

# Calibration of a multiaxial stress criterion for efficient strength prediction of fusion-bonded thermoplastic composite repairs

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Fusion welding of thermoplastic composites is a promising process for structural repairs. However, a specific methodology for predicting the strength of fusion-bonded/welded thermoplastic composite repairs is needed, particularly for efficient prediction of load-bearing capacity based on a stress/strain criterion. In this work, the development of a rapid, reliable, and robust methodology for predicting the strength of thermoplastic fusion welded composite repairs subjected to multiaxial loads is investigated. To achieve this objective, specific coupon samples are designed and produced using an industrial fusion welding process in order to induce different stress states on the fusion welded interface. Thick adherend shear test (TAST) specimens were manufactured with 5, 10, 15 mm bonding length in order to test the interface meanly under shear stress. In addition, stringer foot specimens subjected to four-point bending were manufactured in order to study the failure scenario mainly due to peel stress at the interface. The TAST samples demonstrated superior performance compared to an epoxy-bonded system. The same conclusion can be drawn for the stringer foot samples, which exhibited higher strength.

These results were used to calibrate a predictive criterion for the strength of the fusion bonded interface. Cognard-Spaggiari multi-axial criterion is applied on an elastic linear FEM model, in conjunction with the critical distance theory to elevate mesh dependency. A methodology for determining the integration limits of the critical domain is proposed. For the initial validation of the proposed methodology, TAST tests with a bond length of 10 mm and 15 mm, combined with stringer foot tests, were used to calibrate the selected interface criterion. This calibrated criterion was then used to predict the strength of TAST samples with 5 mm bond length. Future work will focus on predicting the strength of larger-scale repaired specimens.

#116

# Additively Manufactured Polymeric TPMS Façade

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This paper presents an innovation in a polymeric façade system that merges structural performance, material efficiency, and biophilic functionality. The proposed concept is based on additively manufactured triply periodic minimal surface (TPMS) geometries, designed to optimize the stiffness-to-weight ratio and thermal performance while enabling the integration of vegetation and water storage. The polymeric TPMS structure, 3D-printed from PETG, forms a self-supporting double-skin façade connected to a transparent glass layer in between. Unlike conventional glass façades that rely on separate structural and thermal components, this system unifies load-bearing capacity, passive heat regulation, and evaporative cooling within a single lightweight element.

A parametric workflow was developed to couple geometric design with mechanical optimization under wind and self-weight loading. The study suggests that the polymeric TPMS façade can serve as a building component for net-zero architecture, offering structural adaptability, reduced material use, and enhanced energy performance. Prototyping and experimental validation of large-scale panels are ongoing, aiming to link advanced manufacturing with sustainable architectural engineering.

#117

# Data-centric Lagrange based multiple objective optimizations of biaxial loaded rectangular columns using nonlinear programming

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Structural optimization, as an alternative to manual design, is an active research area in which a wide range of computational paradigms are employed to obtain optimal designs under prescribed conditions and performance criteria. Early approaches relied on explicitly analytical derivations that, while capable of high fidelity, are generally impractical for complex systems because of the algebraic complexity involved. Subsequent studies explored nature-inspired metaheuristics, such as swarm intelligence and evolutionary strategies. Although flexible, these stochastic procedures rely heavily on randomness, complicating reproducibility, the development of systematic, and standards-oriented tools. More recently, artificial neural network (ANN)–based techniques have shown promise for automated structural synthesis; nevertheless, their efficacy is often constrained by the high cost of dataset generation and network training.

The present study proposes the application of a nonlinear programming formulation to optimize the configuration of biaxially loaded rectangular reinforced-concrete columns under multiple loads. Sequential quadratic programming (SQP) is employed to minimize cost, self-weight, and $CO_2$ emissions while enforcing the design provisions of ACI 318. Given inputs including material properties and factored load combinations, the procedure returns optimized cross-sectional dimensions and reinforcement schedules within practitioner-specified bounds. SQP targets smooth, differentiable constrained problems ranging from a few to several hundred decision variables. SQP is a fundamentally gradient-based procedure: each iteration determines a search direction by solving a quadratic subproblem, yielding a robust, systematic pathway to convergence. A weighted-sum scalarization adjusts the relative importance of the three objectives and produces Pareto-efficient solutions, enabling engineers to select designs consistent with project-specific preferences and trade-offs.

#119

# Influence of dwell times on structure development and mechanical performance of press-consolidated C/PEKK laminates

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Widespread adoption of welded thermoplastic composites in aircraft manufacturing depends on establishing clear relationships between processing conditions, structural evolution, and mechanical performance. Developing reliable, high-volume production routes remains challenging because of the limited capability welding outcomes. In addition, bond performance does not depend solely on the welding process. The interlaminar strength is governed by microstructural development at different length scales, requiring consideration of the structure's complete process history, including manufacturing of the initial parts.

This study investigates the influence of thermal history on unidirectional AS4D/PEKK-FC press-consolidated laminates, used as the base material for conduction welding. Varying dwell times of 10, 30, and 60 min. were used, with the intermediate value representing standard manufacturing practice. Temperature, applied pressure, and cooling rate were kept constant at 375 °C, 20 bar, and 5 °C/min, respectively. Samples were characterized via differential scanning calorimetry, confocal and digital microscopy, three-point bending for transverse strength, and double cantilever beam for mode-I fracture toughness. Repeatability was verified through four consolidation cycles using two prepreg batches.

Transverse strength decreased by 18% and 38% as dwell times progressed from 10 to 30 and 60 min., reaching 104.5 MPa at the longest condition. Conversely, fracture toughness declined by 24% and 37% at 30 and 60 min. from its maximum of 2.1 kJ/m² at 10 min. Progressive reduction of ply waviness on the consolidated cross-section was observed as a function of dwell time, suggesting fiber-matrix redistribution. All conditions showed crystallinity between 29-31% and crystallization peak temperatures around 289 °C, indicating no signs of thermal degradation. The findings indicate that extended dwell times primarily influence morphology at the ply scale rather than the polymer level.

#120

# Non-destructive moisture detection for damage control in stitch-and-glue composite materials

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## Introduction

Due to their lightweight construction potential and adaptable properties, composite materials are used in numerous applications, ranging from vehicle construction and wind turbines to the maritime sector. Innovative developments in wood-based composite materials using the stitch-and-glue construction method are becoming increasingly attractive for structural boat applications. This method combines plywood, fibre fabric and resins to create lightweight structures, dimensionally stable and water-resistant. With a focus on sustainability, combining renewable wood-based materials with bio-based resins can offer further ecological benefits. Previous studies analysed alternative material combinations such as birch and poplar plywood, basalt and linen fabric, and epoxy resins with natural components regarding their mechanical and physical properties. Building on these investigations, this paper focuses on typical damages of the composite material. The aim is to develop a non-destructive testing (NDT) solution, especially for moisture detection as part of ecological quality control.

## Materials / Manufacturing

The examined stitch-and-glue composite materials consist of plywood panels pre-cut to specific shapes. These are connected at the joints using copper wire loops and then sealed. Fabric impregnated with synthetic resin is applied to the outside to make the surface waterproof and robust. Boat hulls usually consist of tropical plywood, fibreglass mats and resins. Typical damage is caused by impacts on the outer skin or by fractures resulting from other mechanical stress. Besides the accompanying loss in materials resistance, possible moisture ingress poses a high risk of further softening the composite material.

## Investigations / Results

Starting with fundamental considerations regarding typical damage and moisture ingress as result of water exposure, non-destructive testing techniques are used to determine the degree of damage. Investigations are carried out using thermography. Recent results of the NDT development highlight opportunities and limitations of the method. An outlook on its potential as an economical solution for quality control is provided.

#121

# Novel Approach for Non-Propagation Threshold Evaluation under Fatigue in Ceramic Matrix Composites

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During their manufacturing process (notably machining) or throughout their service life (such as overload or impact events), turbofan engine components can experience damage in the form of localized “macro-cracking”. Assessing the robustness of materials with respect to fatigue resistance under such damage is therefore of significant interest. Traditionally, strain-controlled tests using SEN (Single Edge Notch) specimens are performed to calculate non-propagation thresholds, known as K-threshold values. It leads to the determination of design criteria to prevent the growth of such potential “macro-cracks”. However, for ceramic matrix composite (CMC) materials, these conventional approaches are particularly challenging to implement. The mechanical strains of interest are low, and the signal-to-noise ratio of strain sensors does not allow for precise test control. Building on exploratory work conducted on titanium and inspired by Janssen specimen geometry, a stable crack propagation testing methodology has been proposed to characterize CMCs. By loading a notched elliptical holed specimen in compression, controlled propagation of damage can be ensured. The precise dimensions of the specimen geometry were determined through parametric studies, with the objective of closely matching the stress intensity factor drop-off rate recommended by the ASTM standard (ASTM E647, 2015). This method enables fatigue testing under imposed load, which is easier to control. Subsequently, following mechanical fatigue testing, the resulting crack length can be measured via SEM or optical microscopy, and the K-threshold value can finally be determined computationally. This approach was initially validated through tests at ambient temperature and was subsequently extended to high-temperature testing. Conducting compression fatigue tests in the presence of a high-temperature furnace required exceptional rigor in implementing the test protocol, particularly concerning the specimen clamping and the definition of stopping thresholds.

#122

# Fire resistant polymer electrolyte for structural energy storage composites

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Structural energy storage composites offer an effective route toward lightweight and multifunctional materials that can simultaneously bear mechanical loads and store electrical energy. Despite their promise, the practical use of such systems has been constrained by the flammability and limited thermal stability of conventional epoxy-based polymer electrolytes. In this study, a new fire-resistant polymer electrolyte was developed using phenolic resin, an ionic liquid (EMIM TFSI), and lithium salt (LiTFSI). The strong interaction between the ionic liquid and lithium salt initiates emulsion polymerisation of the phenolic resin, creating a three-dimensional cocontinuous network that enables rapid ion transport through hydroxyl-ion coordination. By carefully optimising the composition ratio, the electrolyte achieved a high ionic conductivity of 2.87 mS/cm, which is comparable to the conductivity of the pure ionic liquid (approximately 5.2 mS/cm), while maintaining good mechanical integrity. The phenolic-based electrolyte exhibits outstanding flame retardancy, achieving a UL-94 V-0 rating and significantly outperforming epoxy-based solid electrolytes in fire resistance. When integrated into carbon fibre laminates, the resulting structural supercapacitors demonstrate excellent electrochemical performance and superior safety under thermal or mechanical stress. This work establishes a new generation of fire-resistant polymer electrolytes that provide a practical and scalable pathway for the development of safer, lighter, and more efficient structural energy storage composites, with strong potential for implementation in aerospace, defence, and other advanced engineering applications.

#123

# Thermal simulation of thermoplastic resistance welding for complex-geometry interfaces

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Despite the increasing number of composite components in modern aircraft, the joining techniques used to attach these components to one another has seen minimal changes. Rivets are still the dominant joining method, applying metal-based principles and point-loading to composites. This approach undermines the individual components and prevents the overall composite aircraft structure from achieving its full potential. Composite welding technology, specifically thermoplastic welding, offers a modern alternative to the rivet approach. Through welding, load distribution throughout the aerostructure can be improved, as can the design freedom of individual parts by removing the need to subtract material for subsequent rivetted joining. While thermoplastic welding has made significant advances in the past decade, much of the work has focused on the fundamental principles of joining planar components, with the joining of complex geometries (double curvature surfaces or variable angle paths) being minimally addressed. Researchers at DLR have made advances to extend flat-panel thermoplastic welding to complex geometries, developing new welding elements which may be tailored to non-linear joint interfaces. In this work, the thermal simulation of complex-geometry interface welding is presented. An electrically conductive roving (made from a 3K carbon fiber) and a supporting polymer film (made from LM-PAEK) are both individually characterized with respect to their thermal and electrical properties, providing otherwise missing data on these properties at the high temperatures necessary for welding 500°C. Combining these materials in a multiphysics model, the temperature profile is simulated on the basis of an individual roving, welding element and the full welding process. Simulated temperatures are observed of experimental values obtained experimentally using thermocouples and infrared cameras, providing a good estimate and meeting EASE standards for accuracy. The temperature distribution of the welding element is almost perfectly recreated. Enabling simulations of double-curved surface welding to be performed for difference geometries and process parameters.

#124

# Lifetime extension certification approaches of wind turbine blades based on testing

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Wind turbine blades are designed using statistically derived lower-bound design values, and hence it would be expected that many blades should have a significant useful lifetime beyond the design life. The inherent complexity that characterizes composite structures and the fact that the understanding of composite materials has not reached the same level of maturity as for metallic materials add to the challenge of accurately predicting what is the lifetime and response of wind turbine blades. Existing guidelines on the lifetime extensions rely on calculations of consumed life, and information from inspections. There is uncertainty associated with both aspects considering the current state of the art. In this paper, two different approaches to the structural assessment of wind turbine blades beyond their design lifetime are presented. The first approach makes use of the design factors in full blade tests in which only minor damage is allowed. These partial factors account for uncertainties in the loads and strength of materials and depend on the applicable standard. The second approach consists of identifying the critical failure modes that will initiate in the structure and potentially develop further, and subsequently perform a damage tolerance analysis according to DNV-ST-0376 ed.2024. As part of the testing activities described in this paper, eight 17m blades manufactured by LM using glass fibers encased in polyester resin were subjected to accelerated fatigue tests. These blades were decommissioned in 2017 from the Vindeby Wind farm which was the first offshore wind farm in the world commissioned in 1991, and hence had already completed their operational lifetime. Despite some limitations, the approaches represent a way to address the lifetime extension of wind turbine blades and bridge the gap between the design considerations, their operational performance, and the uncertainty relating the useful lifetime beyond the design life.

#125

# The effect of curing pressure on consolidation of aligned discontinuous fibre-reinforced composites (ADFRCs)

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ADFRCs are attracting increasing attention as a more sustainable class of composite materials, due to their potential for the effective re-use of reclaimed carbon fibres, which, when combined with unique formability, allows for high-rate manufacturing. However, the manufacturing quality of ADFRCs can be highly dependent on processing conditions such as curing temperature and pressure, particularly when the matrix is a snap curing resin system. This study investigates the effect of snap curing pressure on the consolidation characteristics of an ADFRC prepreg material, such as void content and fibre volume fraction. The material investigated consisted of aligned 4 mm carbon fibres partially impregnated using a B-staged snap-curing epoxy resin film. A series of unidirectional composite preform samples were first prepared under a vacuum debulking temperature of 20 °C and cured under pressures ranging from 1 bar to 50 bar, using a bespoke compression test rig with heating plates simulating press moulding conditions. The cured samples were sectioned and examined using optical microscopy to determine void content and fibre volume fraction. The results showed a strong correlation between increased curing pressure and reduced void content, with fibre volume fraction rising to approximately 39 % before reaching a plateau at 50 bar due to the effects of direct fibre-to-fibre contacts, which limits further compaction. It was observed that at lower compaction pressures, complete consolidation and resin infiltration were hindered by limited fibre movement, attributed to a small proportion of misaligned fibres. As a result, higher pressures were required to promote compaction, reduce void content, and improve resin distribution. This behaviour contrasts with that of conventional continuous-fibre prepregs. The results suggest that optimisation of compaction and curing parameters, potentially supported by improved impregnation or debulking processes, is critical to achieve higher fibre volume fractions with low void contents, enhancing the overall performance of ADFRCs.

#126

# Design of Lightweight Hollow Structures using Natural Filler-Reinforced PLA Composites for Engineering Applications

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Lightweight structural designs have become a critical priority in sectors such as aerospace/automotive/ biomedical engineering, where reducing component weight directly contributes to energy efficiency and performance. Hence, this study proposes a novel design concept that integrates natural filler-reinforced polylactic-acid (PLA) composites with hollow structures, represented by two internal cavity geometries at 30% cavity volume, which replace solid cores with patterned voids to reduce weight without compromising strength. Three wood-based PLA composites were designed and evaluated, including sandalwood/PLA, elmwood/PLA, and a commercial wood-filler PLA filament, alongside neat PLA as the reference. Across the wood-filled systems, the tensile/flexural modulus increased relative to neat PLA, where the flexural modulus improvements were of up to 25% at higher loadings (15-20 wt.%), consistent with the reinforcing effect of lignocellulosic fibres. These filaments are lightweight, biodegradable, and aesthetically appealing, making them a versatile and sustainable option that combines mechanical reinforcement with design flexibility for a wide range of 3D-printing applications. This improvement in stiffness provides a solid foundation for applying these bio-based composites in load-bearing lightweight structures. Hollow internal architectures were designed using topology optimisation to reduce weight while retaining structural integrity. The resulting digital models were evaluated using finite-element simulations to predict stress distributions, deformation behaviour and vibration characteristics, thereby guiding the design towards optimal performance. Then, specimens were produced via additive manufacturing and mechanical tests were performed. Potential applications of this approach include lightweight aircraft components such as wing panels, fuselage ribs, automotive interior skeletons, personalised biomedical braces/splints, and lightweight sports equipment frames and so on. Overall, this work demonstrates the feasibility of achieving stiffness enhancements of 20–30% over neat PLA while simultaneously enabling weight reduction through hollow structures. By combining renewable bio-based composites with advanced lightweight-design strategies, this work aims to pave the way for sustainable, high-performance engineering structures manufactured through additive techniques.

#127

# Enhancing the Electrochemical Performance of Alkali-Activated Electrolytes for Supercapacitor Applications

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Alkali-activated materials (AAMs) are increasingly being adopted in the construction industry as sustainable alternatives to ordinary Portland cement, offering significant reductions in carbon emissions. However, their potential to function as structural energy-storage media remains largely untapped due to limited ionic conductivity and charge-transport efficiency. This study advances the design of AAM electrolytes by introducing functional additives to improve continuous ionic pathways and conductive networks within the matrix. The fly ash-slag AAM was synthesised via NaOH-$Na_2SiO_3$ activation and integrated with embedded stainless steel, mixed-metal oxide titanium (MMO Ti), and carbon fibre (CF) mesh electrodes to form structural supercapacitor specimens. To improve ion mobility and interfacial charge transfer, cross-linked hydrogel and biochar were introduced as functional additives. The hydrogel improved ionic conduction by retaining internal moisture and forming continuous ionic migration channels, while biochar introduced conductive and porous pathways that facilitated charge accumulation. Electrochemical characterisation, including electrochemical impedance spectroscopy (EIS), cyclic voltammetry (CV), and galvanostatic charge and discharge (GCD), was conducted at 1, 7, and 28 days. X-ray diffraction (XRD), scanning electron microscopy (SEM), and Fourier transform infrared spectroscopy (FTIR) analyses were performed to examine phase formation and the microstructure of mixes with different additives. Compressive testing of each mix was conducted at 28 days to ensure their structural performance. The results indicate that the use of hydrogel and biochar effectively enhanced ionic conductivity and specific capacitance without compromising mechanical performance. In comparison of the electrode meshes, CF exhibited greater potential for future surface modification owing to their lower cost, lighter weight, and superior structural compatibility within alkali-activated matrices. These findings present a new pathway for developing multifunctional, self-sustaining infrastructure materials that integrate structural integrity with embedded energy-storage capability.

#128

# Static and fatigue tensile properties of epoxy-vitrimer-based CFRP

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Carbon fiber reinforced polymer (CFRP) composites are widely used in various applications because they have outstanding mechanical properties and are lightweight. Epoxy-based thermosetting CFRPs are widely preferred. However, due to their permanently cross-linked networks and thermosetting nature, epoxies and their composites cannot be reprocessed, degraded, or recycled after full curing. As the consumption of thermosetting CFRPs increases, so does the amount of waste generated from off-cuts during manufacturing and retired components. This has raised an urgent need to recycle CFRP waste for environmental and economic reasons. Advances in dynamic chemistry make it possible to recycle thermosetting composites. Epoxy-vitrimers with disulfide crosslinks are advantageous because they are catalyst-free and have a rigid polymer structure. Teijin Ltd. has developed a novel, disulfide-crosslinked, epoxy-vitrimer-based CFRP. However, the mechanical properties of epoxy-vitrimer-based CFRPs are not well understood.

In the present work, static and fatigue tensile tests of high-strength polyacrylonitrile (PAN)-based carbon (IMS65) fiber-reinforced a bisphenol A diglycidyl ether/4-aminophenyl disulfide-based epoxy-vitrimer CFRPs with [+45/0/-45/90]2s and [0/90]3s were performed to evaluate their potential. The static and fatigue tensile characteristics of the conventional epoxy CFRPs (IMS65/Q-11NB) with [+45/0/-45/90]2s and [0/90]3s were also investigated for comparison. Fatigue damage, such as matrix cracking and delamination, often results in a significant reduction in the modulus of composite laminates. Hence, it is crucial to develop an analytical model to describe the cumulative damage of composites due to fatigue based on apparent stiffness reduction. The stiffness reduction during fatigue loading of both CFRPs were also evaluated. Under static loading, the tensile strength of the epoxy-vitrimer CFRPs were 6~10% higher than those of the conventional epoxy CFRPs. Under fatigue loading, the fatigue responses of the epoxy-vitrimer CFRPs were 7~12% higher than those of the conventional epoxy CFRPs.

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# Experimental Study on S–N Characteristics and Failure Mechanisms of CFRP and GFRP in Cryogenic Environments

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The global pursuit of carbon neutrality and climate change mitigation has intensified research on hydrogen-based energy systems. Hydrogen is widely utilized for power generation through fuel cells. The deployment of fuel cell heavy-duty vehicles (HDVs), including long-haul trucks and construction machinery, has been accelerating in recent years. Increasing the hydrogen storage density contributes to reducing operating costs and improving overall profitability, thereby enhancing operational efficiency through an extended driving range and prolonged continuous operation.

Liquid hydrogen has the significant advantage of reducing its volume, which provides an efficient means of large-scale storage and transportation. Nevertheless, the practical utilization of liquid hydrogen involves substantial technical challenges, particularly concerning storage safety and thermal management. Among various hydrogen storage technologies, lightweight and thermally efficient composite tanks are indispensable for achieving reliable and efficient liquid hydrogen storage. Fiber-reinforced plastics (FRPs), particularly carbon fiber-reinforced plastic (CFRP) and glass fiber-reinforced plastic (GFRP), are promising structural materials due to their high specific strength, stiffness, and design flexibility. However, their mechanical performance under cryogenic conditions, especially in terms of fatigue behavior, remains insufficiently understood, hindering their application in long-term service environments.

This study experimentally investigates the S–N characteristics and failure mechanisms of CFRP and GFRP under cryogenic temperatures. Tensile and fatigue tests were conducted to evaluate the effects of low-temperature environments on static and cyclic strength, and detailed fracture surface observations were carried out using optical and scanning electron microscopy. The results demonstrate that cryogenic exposure influences fatigue strength due to changes in matrix deformation behavior and fiber–matrix interfacial bonding. Furthermore, distinct temperature-dependent variations in fracture morphology were observed, providing insights into damage evolution and failure processes. These findings establish a foundation for designing and evaluating the structural reliability of lightweight, composite tanks for liquid hydrogen storage, contributing to the advancement of hydrogen-based energy infrastructure.

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# An Analytical Parametric Study on the Mechanics of Hydrogen Pressure Vessels

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Type IV pressure vessels storing hydrogen at 700 bar are pushing the limits of high-pressure storage, yielding unusually large composite thicknesses. At high thickness-to-radius ratios, their mechanical behaviour is substantially different from more conventional thin-walled vessels, with a non-negligible contribution from out-of-plane normal and shear stresses. Additionally, these vessels feature a complex design, consisting of a high number of plies in the cylinder region, which transform in the dome area into layers with varying fibre angles and thicknesses, and which undergo ply drops. This composition is a direct consequence of the filament-winding manufacturing process, which is very efficient, but induces several complexities and uncertainties. These include variations in fibre volume fraction, fibre angle, material properties and thickness build-up, which are known to noticeably affect the mechanical behaviour and burst pressure.

To obtain a better understanding of both the general mechanical behaviour of these vessels, as well as the influence of manufacturing variations, an efficient and accurate analytical framework was developed in our work. Our analytical framework improves existing models on several aspects: (1) it uses 3D elasticity theory to capture out-of-plane stresses instead of a traditional 2D plane stress assumption, (2) it includes any type of stacking and fibre angle variations in the dome region, (3) it accounts for ply drops and thickness variations in the dome region, (4) it captures fibre volume fraction variations. Dedicated governing equations were developed for both the dome and cylinder region, considering all these aspects, and a numerical solution method was elaborated based on the finite difference method. When implemented in Python, our model generates the entire 3D stress state in seconds, allowing a detailed investigation of the mechanical behaviour of Type IV pressure vessels. Moreover, our analytical model is equipped with the required ingredients to study the influence of the listed manufacturing variations.

#131

# Various Innovative Thermoforming Processes Using Rods Manufactured by Thermo-compression Pultrusion of Carbon Fiber Reinforced Thermoplastic Prepreg/Semipreg Sheets

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Carbon fiber reinforced thermoplastics (CFRTP) have unique characteristics of melt upon heating and solidify upon cooling, which enables them to be manufactured with excellent productivity, impact resistance, secondary processability and reusability. However, thermoplastics generally exhibit high melt-viscosity after polymerization, making it extremely difficult to impregnate the polymer into the fiber bundles during the manufacturing of CFRTP. Therefore, high-performance prepreg sheets, in which the fiber bundles are fully impregnated with thermoplastic polymers in advance, are generally used, however they are unsuitable for complex shapes because they are very rigid and inflexible, any preforming of the sheets is required before molding. This presentation will introduce a laboratory-scale thermal pultrusion machine equipped with a compression insert mold that has been developed originally for continuous manufacture of high-quality CFRTP rods with various cross-sectional profiles using commercial-available prepreg and semipreg sheets, such as CF/PEEK, CF/PPS, CF/PA and CF/PP. The behavior of this thermos-compression pultrusion process will be clarified, and a method for exploring the optimal conditions for obtaining high-quality rods will be explained. Furthermore, as examples of secondary processing applications of thermo-pultruded rods, a CF/PEEK rivet fastening process developed for joining dissimilar multi-materials such as CF/PEEK laminates and metals, and a manufacturing method for lattice structural components by thermal compression molding using a near-infrared heater and a compact servo-press unit will be introduced, and the results of evaluating their usefulness will be discussed. Moreover, a battery cover trail product manufactured by the thermo-pultruded rod insert-injection molding will be demonstrated as innovation manufacturing method using CFRTP pultrusion molding. From the development and experimental results of various innovative thermoforming processes using such carbon fiber reinforced thermoplastic prepreg/semipreg sheet hot compression pultrusion rods, it can be concluded that this will be useful as a manufacturing method for next-generation thermoplastic CFRP.

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# Data-Driven Prediction of Polymer Composite Durability Using QSPR with SMILES (BigSMILES) Representations

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This study presents a data-driven framework for predicting the durability of polymer composites by integrating Quantitative Structure Property Relationships (QSPR) with advanced machine learning methods. The objective is to review and systematize current modeling approaches that link polymer structure, processing conditions, and environmental degradation mechanisms toward reliable lifetime prediction of polymer-based composites.

The work emphasizes recent progress in molecular representations SMILES and its polymer-specific extension, BigSMILES, which enable the encoding of the stochastic nature of macromolecular chains in a form suitable for computational learning. These representations serve as the foundation for graph-based and transformer-based models that extract structural and chemical features directly from polymer sequences. Such models enable scalable prediction of long-term mechanical retention, oxidation resistance, and environmental stability.

A particular focus is placed on multimodal architectures that combine polymer chemistry with physical and processing parameters, such as filler type, interphase properties, and exposure conditions. This integration supports the evaluation of degradation pathways, including hydrolysis, UV aging, and oxidation. The models are trained and validated using open-access polymer databases and composite datasets available online, ensuring transparency, reproducibility, and adaptability to new material classes.

The study also outlines emerging strategies for coupling QSPR predictions with spectroscopic and environmental data to enable rapid, non-destructive evaluation of degradation and recyclability. By consolidating advances in polymer informatics and open data-driven modeling, this work defines the current state and future directions of digital durability assessment in polymer composites. It provides a unified conceptual and computational framework aimed at reducing experimental cost and accelerating the sustainable design of long-lived composite materials.

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# Ascorbic Acid-Assisted Dispersion Strategy for Si Nanoparticles Embedded in Si@SiOC Composites for High-Performance Li-Ion Batteries

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Silicon oxycarbide (SiOC) has emerged as a promising buffering matrix for silicon (Si)-based anodes owing to its excellent electro-chemo-mechanical stability, high chemical tunability, and cost-effectiveness. However, conventional Si@SiOC composites still suffer from severe aggregation of Si nanoparticles (NPs) within the matrix, which reduces the active material utilization, induces internal stress, and accelerates structural degradation during prolonged cycling. To overcome this issue, we developed an ascorbic acid (AA)-assisted dispersion strategy to achieve uniform distribution of Si NPs in the SiOC matrix. The strong adsorption of AA molecules on the Si surface enhances the colloidal stability of Si precursors and suppresses agglomeration during the sol–gel synthesis. Moreover, the introduction of AA facilitates the formation of abundant free carbon domains (FCDs) during pyrolysis, which improves both electrical conductivity and mechanical resilience of the composite. The optimized sample (S05AA50V6) exhibits outstanding electrochemical properties compared with the undispersed counterpart. Electrochemical impedance spectroscopy (EIS) and galvanostatic intermittent titration technique (GITT) analyses reveal that the AA-treated composite possesses significantly lower charge-transfer resistance and higher lithium-ion diffusion coefficients. In addition, ex-situ cross-sectional scanning electron microscopy (SEM) clearly demonstrates that the uniform dispersion effectively suppresses aggregation-induced cracking and excessive solid–electrolyte interphase (SEI) growth during repeated cycling. These improvements collectively contribute to enhanced cycling stability, high reversible capacity, and excellent rate capability. Overall, the incorporation of ascorbic acid as a green and effective dispersant offers a simple, scalable, and environmentally friendly approach to optimizing the dispersion and conductivity of Si@SiOC composites. This strategy provides new insights into the rational design of durable, high-performance Si-based anodes for next-generation lithium-ion batteries.

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# Elucidating the mechanism behind enhanced flax fibre composite mechanical performance after cyclic moisture conditioning

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Flax-reinforced natural fibre composites are increasingly explored as sustainable alternatives to synthetic materials due to their renewable origin, low density, and high specific mechanical performance. However, their hydrophilic nature limits their application as moisture uptake can degrade the fibre–matrix interface and reduce mechanical properties.

This study investigates the enhancement of moisture durability in flax fibres through the hornification effect and elucidates the underlying mechanisms. FlaxTape™ 200 fibres underwent cyclic humidity conditioning comprising 20 alternating cycles between high (85%) and low (23%) relative humidity, with each cycle lasting four days. Mechanical properties were assessed for technical and elementary fibres using the impregnated fibre bundle test (IFBT) and single fibre testing (SFT) coupled with Digital Image Correlation (DIC).

IFBT results revealed a notable “fibre repair” effect, with tensile strength and modulus increasing by approximately 23% after ten cycles (C10). In contrast, elementary fibres exhibited minimal changes suggesting that the middle lamella predominantly governs the hornification response. This behaviour is hypothesised to be due to pectin mobility and redistribution within the fibre bundles, which may fill surface flaws and inter-fibrillar voids, improving cohesion and structural integrity.

Extended humidity cycling up to 100 cycles confirmed this trend with maximum enhancement observed after 50 cycles (C50): tensile strength and modulus increased by 23% and 26%, respectively. Even after 100 cycles (C100), fibres maintained a 12% improvement relative to uncycled samples. These findings provide insight into the hornification mechanism in flax fibres and demonstrate that controlled or natural environmental cycles can improve mechanical stability, supporting the long-term performance of flax fibre-reinforced composites in sustainable structural applications.

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# Probabilistic Simulation of Low-Velocity Impact in Non-Crimp Carbon Fibre Composites Using Finite Element Analysis and Uncertainty Quantification

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The mechanical response of fibre reinforced polymer materials is inherently affected by manufacturing imperfections such as fibre misalignment, voids, and resin-rich pockets. These uncertainties can significantly influence the structural performance and must be accounted for in predictive simulations. To capture these effects, finite element analysis (FEA) input parameters were treated as random variables, with their distributions calibrated from experimental variations observed in progressive fracture tests under tensile and compressive loading.

Simulations were performed using the continuum-based material model MAT219 in the commercial FEA software LS-DYNA to account for intralaminar damage evolution. Markov Chain Monte Carlo (MCMC) methods were employed to infer probabilistic distributions of the FEA input parameters from experimental data obtained from compact tension and compression tests. These calibrated distributions were subsequently applied to simulate low-velocity impact tests on quasi-isotropic non-crimp carbon fibre fabric composites.

The resulting probabilistic simulations show strong agreement with experimental force–time responses, with measured data falling well within the upper and lower bounds predicted by the uncertainty-informed FEA models. This validates the approach and highlights the importance of incorporating experimentally derived uncertainties into simulation workflows.

In addition, a global sensitivity analysis was conducted to evaluate the influence of individual FEA input parameters on the impact response. The analysis identified the most critical parameters and revealed potential correlations that affect simulation outcomes, offering valuable insights for model refinement and experimental design.

This study demonstrates how uncertainty quantification can be effectively integrated with FEA to produce probabilistic predictions of composites subjected to complex loading scenarios, such as low-velocity impact. The approach enhances the reliability of simulation-based assessments and provides a robust framework for understanding the role of material and modelling uncertainties in structural analyses.

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# Twin-screw extrusion of highly filled polymer compounds used in conductive plate production for energy applications.

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The increasing demand for efficient, durable, and cost-effective components in electrochemical energy systems such as fuel cells, electrolyzers, redox-flow batteries, and heat exchangers drives the development of foils made from electrically and thermally conductive polymer composites. Highly filled polymers containing conductive agents like graphite and carbon black offer a promising balance between processability, performance, and cost. These materials are especially attractive as bipolar foils for compact and high-performance fuel cells and electrolyzers, where high electrical and thermal conductivity, low hydrogen permeability, and mechanical strength under pressure are required.

Compounding such highly filled systems remains challenging. Filler contents exceeding 50 vol.% cause complex rheological behavior that impedes homogeneous dispersion and promotes polymer degradation. The mechanical energy input can further break down filler agglomerates and damage polymer chains, directly impacting the previously mentioned key factors of the composite. To address these issues, extrusion strategies using a corotating twin-screw extruder (TSE) are investigated. A modified clamshell-barrel TSE, openable along its screw length, enables local sampling to analyze filler dispersion and degradation mechanisms within individual process zones.

Although TSEs provide intensive dispersive mixing, excessive shear forces and temperature gradients can deteriorate the polymer matrix and disrupt the conductive network. Process optimization therefore focuses on screw configuration, temperature control, and the balance between mixing efficiency and mechanical stress.

This contribution presents a systematic study on the compounding and process optimization of highly filled polymer composites by variation of screw design and temperature. The analysis highlights the narrow process window between sufficient mixing and the onset of thermal or mechanical degradation. The derived process-structure relationships provide guidelines for optimized extrusion of conductive foils and form the basis for developing efficient, sustainable, and scalable composites for next-generation electrochemical energy application components, bridging the gap between high requirements and scalable manufacturing.

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# Design and Fabrication of a Racing Car Seat with Recycled Continuous and Chopped Carbon Fibre Composites

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The automotive industry is increasingly adopting circular strategies to reduce its environmental footprint without compromising structural performance. This work presents a recycling and (re)manufacturing approach for end-of-life composite automotive components, aiming to reintroduce reclaimed fibres into high-performance applications. Continuous carbon fibres were recovered from filament-wound automotive drive shafts through supercritical solvolysis, enabling complete resin removal while preserving fibre continuity and mechanical integrity. The reclaimed fibres underwent surface properties restoration by resizing, improving interfacial adhesion and compatibility with thermoset matrices. The re-sized fibres were then converted into prepreg materials using a drum prepreg machine for laminate fabrication. In parallel, end-of-life shredded composite parts, such as hoods, were recycled via supercritical solvolysis to reclaim chopped carbon fibres. These were subsequently sized in a pilot-scale line and compounded with thermoplastic matrices to produce reinforced inserts. Both material streams were integrated into the manufacturing of a racing car seat, combining continuous recycled carbon fibre prepregs for the main shell with thermoplastic inserts reinforced with chopped recycled fibres in critical zones. The final geometry and insert placement were determined through finite element stress modelling, allowing optimization of the load paths and structural reinforcement. The resulting design ensured that the component successfully met FIA safety requirements. Mechanical characterization guided laminate stacking, insert positioning, and joining strategy, ensuring optimal stiffness-to-weight ratio and crash performance.

Beyond validating individual processes, the study creates a framework linking fibre reclamation, surface restoration, and structural redesign into a robust route for sustainable remanufacturing. The successful fabrication of a racing seat from recycled carbon fibres confirms that environmental responsibility can be aligned with high-performance standards.The component both meets FIA safety requirements and reduces the reliance on virgin carbon fibres. The results indicate a viable solution for integrating recycled composites into mainstream mobility applications, ensuring alignment between sustainability targets and engineering performance.

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# Manufacturing and Characterisation of 3D Woven Composites Developed Using Next-Gen Jacquard-less Loom

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3D weaving has emerged as a transformative technology owing to its capability to engineer near-net-shape, joint-free architectures with superior resistance to delamination. However, current implementations on Jacquard and Dobby looms remain constrained by intrinsic process inefficiencies, and most critically, severe fibre degradation induced by high-friction yarn manipulation. This fibre damage is especially detrimental when processing brittle reinforcements, and has thus far hindered the exploitation of ceramic-based 3D woven composites in thermally demanding applications where their performance advantages would be most pronounced.

To address these challenges, University of Manchester has developed a novel technology, Next-Gen 3D weaving loom which eliminates Jacquard harness, promising a faster, cost-effective process with minimised fibre damage. This research aims to investigate the potential of Next-Gen loom by manufacturing 3D woven composites with carbon and brittle fibres and benchmarking its performance against traditional Jacquard loom.

Three different iterations of 3D woven preforms were manufactured: Iteration 1and Iteration 2 were 100% carbon fibre preforms manufactured using traditional Jacquard loom and Next-Gen loom respectively; Iteration 3 was carbon fibre (warp and weft) / alumina fibre (binder) preforms manufactured using Next-Gen loom.

The preforms were analysed to quantify the physical properties and then infused to produce composite panels. Specimens were extracted from the panels for mechanical testing and X-ray Computed Tomography (XCT) inspection.

The results demonstrate that Next-Gen loom delivers substantial performance advantages over conventional Jacquard technology. Ceramic fibres were successfully incorporated with minimal damage. In addition, the setup time was reduced to approximately one-third of that for a Jacquard system, highlighting its potential for more efficient industrial deployment. These findings confirm the benefits of the Next-Gen loom and provide a strong foundation for advancing its technology readiness level in support of a competitive UK 3D weaving supply chain.

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# Recycling of High-Performance FRP Composites Towards a Circular Material Economy

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Carbon fiber-reinforced polymers (CFRPs) and glass fiber-reinforced polymers (GFRPs) are essential materials in modern industries due to their exceptional strength-to-weight ratio and long-term durability. They are widely used in aerospace, wind energy, ship-building, civil structures' strengthening and gas storage applications. However, their production is highly energy-intensive, costly for CFRP and current recycling technologies fail to recover intact/integral carbon and glass fibers or epoxy resin components efficiently. Developing sustainable recycling methods is therefore crucial to reducing waste and for enabling a circular FRP composites economy.

This work presents a mild catalytic-solvolysis approach for the efficient depolymerization of the epoxy-matrix of CFRPs and GFRPs. The process operates without harsh chemicals at mild temperatures (up to 55°C): The main depolymerization is achieved in a peroxide-based solution, leading to a controlled degradation of the epoxy matrix while fully preserving the integrity and alignment of the reinforcing fibers/fiber fabrics. The recovered carbon fibers retain their original morphology and tensile strength, as confirmed by SEM and mechanical testing.

Mass spectrometry of the depolymerized solution revealed a major presence of 'Bisphenol-A' which is a primary monomer of epoxy, demonstrating the recovery of high-purity monomeric and oligomeric components suitable for re-polymerization. This recovery enables re-synthesis of the epoxy and supports a closed-loop recycling, where both fibers and polymeric units are reintegrated into new FRP composites.

This mild recycling process is scalable, cost-effective, and environmentally sustainable, offering ≈ 95% reduction in greenhouse gas emissions compared to virgin fibers production. By delivering clean, undamaged and reusable carbon and glass fibers alongside recoverable epoxy resin components, the approach establishes a viable pathway toward a sustainable recycling of FRP composites based on epoxy matrix. In a recent demonstration, we successfully recycled carbon fibers, fabrics and epoxy monomers from an autoclaved 6 mm-thick multiply CFRP panel used in a commercial aircraft.

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# Fabrication and characterization of TaxHfyCz coatings on C/C composites by vacuum plasma spray

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Carbon/carbon (C/C) composites are widely applied in various fields such as aerospace, defense, and high-temperature industrial applications due to their excellent properties, characterized by low density, light weight, high strength, and superior thermal conductivity. The C/C composites retain outstanding mechanical strength at ultra-high temperatures above 2,000 °C and exhibit superior thermal stability beyond 1,000 °C. However, the limited oxidation resistance of C/C composites in air above approximately 500 °C poses a major challenge to their high-temperature applications.

To overcome this limitation, coating technologies using ultra-high temperature ceramics (UHTCs), such as ZrC, HfB2, HfC, and TaC, have been developed. Among UHTC materials, the ternary carbide Ta0.8Hf0.2C, known to possess the highest melting point (around 4,200 °C) among carbide systems along with HfC, has attracted significant attention, and active research has been conducted on its powder synthesis and coating processes. Nevertheless, studies on Ta–Hf–C-based coatings remain limited.

In this study, Ta0.8Hf0.2C coatings were fabricated using the vacuum plasma spray process, and the effects of discharge power, one of the key process parameters, on coating characteristics were investigated. The coating process was carried out under plasma input power conditions of 34, 40, 43, and 49 kW. The surface and cross-sectional properties of coating specimens were analyzed. As the plasma input power increased, the thickness of the TaxHfyCz coating layer increased to 86, 126, 133 and 175 μm, respectively. In addition, changes in the crystal structure of α-Ta separated on the coating surface were observed.

The microstructure and phase composition of the coatings were analyzed using scanning electron microscopy (SEM) and X-ray diffraction. Furthermore, the porosity of the cross-sectional coating layers was quantitatively evaluated based on the SEM micrographs, and the mechanical properties were characterized by Vickers hardness testing.

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# Method for Inspecting the Inner Surface of Large Carbon Fibre Composite Structures

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For safety critical applications the inner surface of large, duct-like carbon fibre composite structures needs to be inspected for various types of defects such as scratches, lack of resin or matrix distortion. However, there are several challenges related to the curved shapes of the inner walls, the change of the cross section along the part and the difficulty to access the interior of parts, which can be several meters in length. To address this problem, an integrated inspection system is proposed, which moves into the duct, scans the surface and acquires images of the complete inner surface. The inspection system consists of several cameras and light sources mounted on a mobile unit that is inserted into the duct. A set of 2D images with different illumination is acquired, which enables the computation of several image channels representing fibre orientation, polarization and diffuse reflectivity. This creates a sufficiently informative representation of the reflection properties of the surface to allow defect-detection and analysis. To address the varying geometry along the part, laser triangulation is used to measure the 3D shape. This 3D information is used in real-time to calculate a correct 3D mapping of the acquired 2D images. The resulting images are then stitched and can be visualized as a distortion-free representation of the inner surface. Such images are usable initially for inspection by human experts and later through automated image analysis. Results are presented from the scanning of a 4m long structure with cross-sections varying from 15 to 50cm in width and 20 to 60cm in height. Image quality is assessed in terms of stitching quality, dimensional correctness and image sharpness and shows good results without artifacts.

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# Design Optimization of Thick-Walled Type IV Hydrogen COPVs using an Analytical Framework

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Type IV composite overwrapped pressure vessels (COPVs) for hydrogen storage employ thick laminate walls to sustain working internal pressure of 700 bar. Under these conditions, thin-shell and plane-stress assumptions are no longer valid and out-of-plane stress components play a significant role in the vessel stress state. Accurate optimization therefore hinges on models that resolve the full three-dimensional stress field while remaining fast enough to explore thousands of design variants.

We present a process-aware analytical framework for Type IV tanks that predicts the three-dimensional stress and displacement state of thick composite–liner systems. The framework's computational efficiency enables multi-parameter sweeps that support design studies aimed at reducing carbon mass, increasing volumetric energy density or reducing CO2 footprint, while tracking safety constraints. Dome geometry, multiple-material layups and stacking sequence are among the most important parameters to construct trade-off maps and converge on efficient, manufacturable designs.

We present two cost-oriented optimization case studies executed under common performance and manufacturability constraints to demonstrate the model's capabilities.

Material optimization. We reduce cost by substituting lower-cost reinforcements where local demand allows while reserving high-performance carbon fibres for highly stressed layers. The model quantifies the resulting load redistribution across the laminate and the associated reduction in carbon usage, while checking safety and manufacturability limits.

Layup optimization. By changing hoop/helical angle ratios, layer sequences and thickness distribution to better match the vessel's loads, required thickness is reduced, directly trimming carbon usage and mass. The improved layup also allows an increase in usable storage volume, enabling gains in volumetric energy performance without enlarging the external envelope or compromising safety factors.

Together, these studies show how fast, process-aware three-dimensional models can lower COPV cost and improve volumetric energy density of hydrogen storage, complementing simple design rules and full finite-element analysis.

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# Thermomechanical characterization of polyethylene terephthalate cords for rubber matrix composites

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Thermoplastic polymeric cords, such as PET (polyethylene terephthalate) cords, are nowadays largely employed as uniaxial reinforcements of rubber-based composites in tyres structural components, in particular in body plies. During the tyre construction and vulcanization polymeric cords undergo complex histories of load and temperature which strongly affect the final behavior of the reinforced rubber composite and hence of the tyre. As a first step towards a reliable prediction of the in-service thermomechanical behavior, we performed an extensive experimental campaign on PET yarns and cords. As the stiffness and strength of the final cords depend both on the material of the filaments and on the twist and number of the plies composing the cord, we first tested bundles of parallel fibers (untwisted yarns), then twisted yarns and finally cords. To properly characterize the behavior, we performed isothermal tension tests with temperature ranging from 20°C to 170°C, free shrinkage tests and force shrinkage tests with different temperature histories. The tests showed the quantitative and qualitative difference in the mechanical response below and above the glass transition temperature. Finally, we investigate the effect of thermal and pre-load treatments on the tensile behavior of greige and dipped cords. A model to interpret the main experimental findings is proposed.

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# Microstructure analysis of micro-X-ray computed tomography scans of staple fiber yarns

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Staple fiber yarns (SFY) based on carbon fiber-reinforced plastics enable efficient recycling of continuous fiber-reinforced plastics. However, in order to evaluate the manufacturing of the semi-finished product and the component production itself, new and improved methods for analysis of its microstructure are required. This article therefore presents a new processing pipeline for high resolution and large field of view X-ray computed tomography (CT) data, using Non-New-U-Net (nnUNet), a convolutional neural network (CNN) and a fiber tracking algorithm for instance segmentation. For this purpose, two overlapping CT scans of three SFY samples with a yarn elongation of 20%, 35%, and 50% were made, using a Zeiss 520 Versa 3D X-ray microscope and stitched together in a post-processing step. Using a specially trained nnUNet, these image stacks were segmented into fiber, matrix, and pore areas. This made it possible to determine areas with high and low local fiber volume content, which in turn served as training and test data for the CNN. Using the Python module “fibretracker” from Technical University of Denmark, the fiber trajectories were determined from the fiber areas. To estimate the accuracy of these operations, this procedure was also applied to synthetically generated data and the results were compared. The accuracy of the segmentation of the image stacks with the nnUNet could thus be quantified at 97–99%. While the semantic segmentation has only a small error, the results of the instance segmentation with the CNN and the fiber tracking algorithm are less accurate.

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# Design and Finite Element (FE) Analysis of Helicoidal and Double-Double (DD) Carbon Fibre-Reinforced Polymer (CFRP) Laminates for Improved Low-Velocity-Impact (LVI) Damage Tolerance

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Modern aircraft design has an increasing demand for lightweight, high-strength, high damage-resistant structural materials, with carbon fibre-reinforced polymers (CFRPs) among the most promising candidates. However, complex in-flight loading conditions and harsh environments necessitate enhanced damage tolerance in CFRP structures, and improving the laminate microstructure remains one of the key pathways. Of many existing microstructural designs, bio-inspired helicoidal and double-double (DD) laminates have demonstrated enhanced performance compared with conventional QUAD laminates [1, 2].

This work presents a framework that combines the buckling-matched laminate design with robust low-velocity-impact (LVI) simulation to assess the damage tolerance of helicoidal and DD laminates against a QUAD baseline. Specifically, we design the buckling-matched laminates via D-matrix equivalence, isolating the effect of microstructure on damage tolerance; and we predict the LVI response by implementing a finite-element (FE) model with the advanced LaRC05 damage model [3] via a VUMAT subroutine in Abaqus/Explicit. To improve the numerical fidelity, we explore other FEA techniques such as the sub-stacking for improved computational efficiency, hourglass control algorithms for reduced-integration elements, and geometric-imperfection perturbation for triggering realistic post-buckling behaviour. Eventually the FE prediction correlates with the experimental results in terms of impact load history (force-time) and damage patterns in the specimen.

The buckling-matched design ensures a fair comparison across microstructures, and the developed FEA workflow enables systematic exploration of helicoidal and DD layups with potential damage-tolerance gains relative to the baseline. Initial FEA and experimental observations indicate that the helicoidal architecture delays fibre-failure initiation compared with its DD and QUAD counterparts. The full scope of laminate designs, modelling choices, and LVI prediction results will be reported at the conference.

References

[1] Kazemi ME et al., 2023, Compos Part B 264:110930.

[2] Hawkins A et al., 2026, Compos Part B 309:113115.

[3] Pinho ST et al., 2012, J Composite Materials 46(19–20):2313–2341.

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# Application of Broussonetia papyrifera Bark in Green Materials

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This study uses paper mulberry (Broussonetia papyrifera) bark and vegetable-tanned leather as core materials, integrating environmental protection concepts with modern design to develop an environmentally friendly material that combines cultural heritage and durability. Paper mulberry bark fiber possesses properties such as strength, breathability, and antibacterial properties, allowing it to be woven into fabric and develop a unique "bark fabric culture." This study attempts to expand its application in green materials through innovative processing techniques.

In terms of processing technology, traditional paper mulberry bark processing relies on prolonged soaking and manual beating, which easily generates significant noise, is time-consuming and labor-intensive, and makes it difficult to control the stability of stretching. Therefore, this study attempts to conduct a "bark rolling stretching experiment," systematically comparing the stretching effect of paper mulberry bark fiber using different soaking water temperatures (30°C and 65°C), soaking times (1 minute and 5 minutes), sample conditions (with or without peeling), pre-soaking treatment, and the number of rolling passes (1 and 3 times) and rolling spacing (1, 0.5, and 0.2 mm) as variables. The results showed that after soaking the peeled samples in 65°C water for 5 minutes, under single rolling conditions with a 0.2 mm spacing, the maximum elongation width reached 24.5 cm, significantly higher than the approximately 13.5–17.7 cm elongation of traditional unsoaked samples. This demonstrates that hot water and mechanical treatment significantly optimize processing efficiency and quality stability. In product design applications, this study combined the optimized paper mulberry bark material with vegetable-tanned leather to design composite products emphasizing natural texture and environmental friendliness.

Through the innovative processing technology and product practice of this study, paper mulberry bark, as a renewable plant resource, demonstrates its important value as a green material when applied to composite materials.

Keywords: paper mulberry (Broussonetia papyrifera) bark, vegetable-tanned leather, rolling, soaking

#157

# A numerical model to predict compressive strength with fibre defect and structural contributions

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The compressive strength of carbon fibre reinforced polymers has been a major challenge for both the scientific community and industry since the 1960s. It is widely accepted that fibres micro-buckling is responsible in most cases for compressive failure involving stiff

carbon fibres. This phenomenon describes the buckling of fibres, loading in shear the surrounding matrix leading ultimately to the laminate failure. The presence of an initial cure induced fibres misalignment angle accelerates the micro-buckling process by increasing the shear loading development rate.

It is believed that this this phenomenon can be delayed by reducing the unidirectional ply thickness or by adding off-axis neighbour plies to prevent fibres buckling, making the micro-buckling problem inherently multi-scale. Those parameters are known as structural effects and only affect the micro-buckling onset as part of the laminate modal response. A numerical multi-scale 3D model is therefore proposed to take into account both the influence of the UD ply response as well as its surrounding. This numerical model is based on the stacking of fully modelized hexagonal RVEs in which a fibre misalignment was introduced surrounded by deformable and oriented homogenized plies. This numerical model is compared to experimental four points bending tests results carried with both High and Intermediate Modulus carbon fibres.

As a perspective for this presentation, the numerical model should be optimized to limit its computation time and outputs weight. Moreover, some precise material strength definitions should be added to account for different compressive failure modes such as fibre crushing that could occur before the micro-buckling instability and therefore before the positive action of structural effects.

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# Synthesis of Double-Double Hybrid Laminates Exhibiting Unconventional Thermal Expansion Behaviour

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Most composite materials exhibit positive thermal expansion (CTE), expanding when heated. However, specific fibre orientations and constituent combinations can be engineered to achieve zero or even negative thermal expansion. This study examines the design of hybrid laminates capable of achieving zero (ZCTE) or negative (NCTE) in-plane thermal expansion, exploiting Tsai's Double-Double (DD) design theory for bi-angle laminates with [±Φ/±Ψ] stacking sequences.

The DD approach provides additional tailoring capability beyond conventional quasi-isotropic or cross-ply configurations by coupling in-plane and bending stiffness through two independent fiber angles to achieve homogenisation.

Analytical models based on classical laminate theory (CLT) were used to predict the effective CTE under thermal loading by integrating material anisotropy and orientation-dependent stiffness–thermal coupling. Non-dimensional parameters and homogenised laminate properties were introduced to generalise the results across different material systems.

To validate and expand the design space, the study considered both natural fibres (e.g., flax, hemp, and jute) and synthetic fibres (e.g., carbon, glass), enabling tunable thermal responses while maintaining mechanical integrity and sustainability. The study discusses how hybridisation, via judicious selection of constituent fibres, stacking order, and orientation pair (Φ, Ψ), can cancel or reverse the thermal expansion of the laminate.

The results outline practical guidelines for designing lightweight structures with tailored thermal behaviour relevant to the fields of aerospace, precision mechanics, and energy devices. By combining experimental data, analytical modelling, and dimensionless design maps, this study establishes a framework for developing adaptive composite materials that preserve dimensional stability under thermal fluctuation.

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# Unsupervised–Supervised Classification and Regression Machine Learning (USS-ML) Framework for Predicting Mechanical Properties of Reconstructed Poplar, a High-Performance Fiber-Reinforced Biocomposite

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Machine learning algorithms can be used for extracting meaningful patterns from complex and diverse datasets, enabling the development of effective predictive models. These approaches can be used to accelerate the development of high-performance wood-based composites (HPWCs) and reduce extensive mechanical testing. In this work, a data-driven 'unsupervised, supervised classification, supervised regression machine learning' (USS-ML) framework is applied to a specific kind of HPWC, namely reconstructed poplar [1], to predict the target mechanical properties (elastic modulus and tensile strength) using material–fabrication parameters including room-temperature delignification, hot delignification, relignification, drying duration, nominal thickness reduction, hot press temperature, and fiber direction.

In this approach, the target mechanical properties are clustered using k-means, identifying groups of similar samples via the elbow method. Then, a fully connected neural network (FCNN) classifier mapped material-fabrication parameters to these clusters, forming a self-supervised learning step. Finally, an FCNN regressor combined process parameters and predicted clusters to estimate continuous mechanical properties.

The complex relationships between fabrication parameters and mechanical properties, along with a relatively limited number of experiments, make USS-ML a suitable choice for accurate predictions. To assess the model robustness for generalization, a 5-fold cross-validation was performed. Feature importance analysis helped identifying the key parameters controlling performance, by providing insights into influential fabrication settings. The predicted results using the USS-ML model were also compared with those obtained by using a simple End-to-End FCNN. These results help to show the potential of predictive modeling for the estimation of material properties based on fabrication parameters, accelerating sustainable material development while minimizing experimental efforts.

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# Improving the delamination bridging performance of Z-pins through novel glass fibre Z-pinning

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Laminated composite stiffened panels are used in aerospace structures thanks to their exceptional specific properties. They are sensitive to impact-induced interlaminar damage which can drastically diminish their strength.

Through-thickness reinforcement, like Z-pinning, may help overcoming this issue by preventing delamination propagation, especially at stiffener-skin interfaces. Impact induces local mode II driven fracture, for which industry standard carbon fibre (CF) Z-pins perform poorly.

This work exploits the high failure strain of S2-glass (GF) to create Z-pins effective across all mode mixities. 0.3mm diameter GF/epoxy pins are manufactured via in-house micro-pultrusion. The effect of individual fibre diameter is investigated through the consideration of two configurations composed of either 9µm or 14µm diameter fibres. These are compared to standard carbon fibre T300/BMI pins. T300/epoxy pins, manufactured via the same process, are used to rigorously separate the influence of the fibre and resin.

The bridging behaviours of the pins are obtained using the “single pin” test configuration where a low number of pins is embedded into a laminate. Samples are loaded across the whole range of mode mixities using a miniature Arcan setup.

S2-glass’ superior compliance and failure strain delay the transition from Mode I pullout to mode II fibre rupture for GF pins compared to CF pins (happening respectively at around 70% and 40% mode II). Furthermore, in the event of GF pins rupture under mode II loading, a less brittle failure profile than the T300 pins is observed.

GF/epoxy pins exhibit around a 4-fold increase in dissipated energy in mode II and 2-fold around 40% mode II compared to CF/BMI, with similar performance in mode I. Energy dissipation slightly decreases with fibre diameter, while the resin has a negligible influence.

S2-glass/epoxy Z-pinning is a promising configuration, demonstrating a substantial increase in dissipated energy compared to the T300/BMI Z-pins across all mode-mixities.

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# Damage behavior of all carbon fiber composite honeycomb sandwich structure under low-velocity impact load

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The honeycomb sandwich structure, owing to its exceptional particular strength and specific stiffness, is extensively utilized in essential components including aircraft doors, satellite supports, and the frame of new energy vehicles. The rapid advancement of novel materials has enabled the integration of high-performance composite materials with honeycombs, hence expanding the design possibilities for lightweight sandwich structures. This work examines the sandwich structure consisting of carbon fiber composite panels and honeycomb cores, comprehensively analyzing its dynamic response and failure mechanism under low-velocity impact load. Experimental impact tests were conducted at various energy levels, and the damage states, ranging from negligible damage to total perforation, were described using industrial tomography technology. A detailed honeycomb finite element model was developed based on the damage evolution criterion of plain weave composite materials to analyze the energy absorption characteristics of each structural component throughout the impact process. The results revealed that the experiments and simulations exhibit a significant degree of consistency regarding peak loads and failure modes. Upon complete penetration of the sandwich structure, the principal role of energy absorption shifted from the upper face sheet to the bottom face sheet. The increase in impact energy did not significantly affect the peak contact force; however, it did lead to a greater extent and variety of damage sustained by the core. By analyzing the critical geometric parameters (wall thickness, cell side length, and core height) of the honeycomb core using the validated simulation model, it was determined that decreasing the cell side length is a superior design strategy for achieving structural lightweighting and impact resistance.

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# Accelerated fatigue assessment of adhesively bonded joints using energy-based criteria and non-linear constitutive behavior

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The integration of composite and metallic components through adhesive bonding enables the development of lightweight structures with high mechanical efficiency, leading to an expansion of their industrial applications. In such multimaterial assemblies, one key issue is the complex stress distribution within bonded joints, which limits the applicability of conventional fatigue assessment methods. The fatigue life of bonded joints is particularly difficult to predict due to the viscoelastic behaviour of adhesives, the multiaxiality of applied stresses, and edge effects arising from joint geometry [1].

This research aims to develop a methodology for the accelerated investigation of fatigue in adhesively bonded joints. The approach relies on a fatigue criterion defined by the energy dissipated per loading cycle and a constitutive law used to evaluate this criterion within the adhesive layer. The methodology follows four successive stages. First, the intrinsic behaviour of the adhesive is characterised through mechanical tests on bulk specimens. Fatigue tests and infrared thermography are then employed to identify and validate the dissipative energy–based fatigue criterion, the latter providing a rapid indicator of self-heating and damage evolution [3]. The constitutive law and fatigue criterion are subsequently assessed using bonded joints tested with a modified Arcan specimen, enabling controlled proportional multiaxial loading and reduced edge effects [2]. Finally, the methodology is adapted to bonded configurations to account for stress redistribution and free-edge influences.

The results obtained on bulk specimens and the application of the methodology to bonded joints tested with the modified Arcan device will be presented during the conference. Comparisons between predictions and fatigue tests performed on bonded specimens under different multiaxial loadings and fatigue stress ratios will also be presented.

References

[1] C. Bernolin. 2022.

[2] J.-Y. Cognard, R. Cr´eac'hcadec, L. Sohier, P. Davies. 2008.

[3] V. Le Saux, Y. Marco, S. Calloch, C. Doudard, P. Charrier. 2010.

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# Effect of seawater on performance of composite structures

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Fiber-reinforced plastic sandwich structures (FRPSSs) are increasingly used in marine applications thanks to their high strength-to-weight ratio, good corrosion resistance and buoyancy. Assessment of the effects of moisture uptake on their out-of-plane mechanical performance, structural integrity and safety after exposure to seawater is vital for design and its optimisation.

The paper investigates these effects for FRPSSs with various core configurations loaded with indenters with different geometries, emulating various types of external loading. A new in situ acoustic emission (AE) methodology is applied to monitor the moisture evolution process, while X-ray micro-computed tomography validates its influence on out-of-plane failure modes observed in quasi-static indentation experiments. The obtained results indicate that the AE velocity can be effectively used to monitor the moisture uptake, serving as an in situ structural health monitoring approach. It was revealed that the core configuration had a limited effect on moisture ingress. Samples exposed to sharp indentation exhibited the greatest decrease in their load-bearing capacity of FRPSSs while that for blunt indentation was the lowest. This can be explained by reduced penetration forces resulting from matrix plasticization and degraded matrix/fibre interface, exacerbated by a smaller contact area. Also, early damage initiation and intensified damage progression were observed for sharp indenters after the seawater exposure. The core of FRPSSs significantly influenced localized damage in samples indented with conical and flat indenters, unlike those subjected to hemispherical ones. The seawater exposure adversely affected the energy absorption and penetration performance, enhancing macroscale damage mechanisms.

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# A Numerical Investigation of the Consolidation Behaviour of Composite Helmet Shells

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This study examines material deformation in a composite helmet hard shell, produced through a bladder assisted moulding process using a male mould. The helmet geometry is convex and features sharp corners and edges, which present manufacturing challenges related to material flow and compaction. The shell employs a multi material composite layup composed of woven and non woven epoxy prepregs with multiple ply drops, designed to meet safety and performance standards. Because of the geometrical, material, and process complexity, discrepancies exist between the manufactured helmet and the intended target geometry defined by the ply book. Significant discrepancies are observed between experimentally measured thickness of the helmet and the idealised geometry using cured ply thicknesses provided from the material supplier. This deviation affects numerical analyses, as the idealised geometry is not representative of what is observed in practice. The purpose of this work is therefore to simulate the manufacturing process and the behaviour of the prepreg materials using a consolidation model, in order to adjust the inputs to mechanical simulations. The study focuses on capturing the influence of geometric complexity and multi material interactions on the overall consolidation behaviour of the helmet shell. Experimental compaction tests were conducted on the constituent materials, comprising two woven and one non woven composite, to characterise their consolidation response. The materials contained different fibre types, including nylon, glass, and carbon. The results were used to calibrate the user defined material model (UMAT), the consolidation model, implemented within a finite element framework. The process model replicates industrial manufacturing conditions, including layup schedules, bladder pressures, mould temperatures, and dwell times, to predict the final geometry and identify regions prone to defects. Comparison with experimental measurements shows good agreement and provides insights into optimising consolidation and improving the structural integrity of complex composite components.

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# Experimental and numerical study on thermal deformation and mechanical properties of 3D printed continuous carbon fiber reinforced composites

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The additive manufacturing (AM) of continuous carbon fiber reinforced thermoplastic composites (CFRTP) enables more flexible design and manufacturing of lightweight, high-strength structures. However, a major challenge for industrial application is the occurrence of warpage defects caused by thermal deformation, which compromise dimensional accuracy. These defects arise from the complex interplay of heat transfer, thermal contraction, and crystallization-induced shrinkage, especially for semi-crystalline polymers, during the printing process. This study proposes an analytical model to quantitatively predict warpage, based on classical laminate theory and analytical model, incorporating both thermal contraction and crystallization-induced shrinkage. To develop this model, fundamental thermomechanical experiments were conducted to acquire the necessary properties of 3D printed parts. Through in-situ temperature measurements, we identified an extremely high cooling rate of approximately 33°C/s during printing. Subsequent differential scanning calorimetry (DSC) analysis revealed that this rapid cooling suppresses crystallization, resulting in a low as-printed crystallinity of about 3%. Furthermore, by correlating data from thermomechanical analysis (TMA) and DSC, the shrinkage associated with cold crystallization was quantified. These experimental findings were integrated into the analytical model to improve the accuracy of warpage prediction. The prediction results of the analytical model are compared with 3D-scanned data of thermal warping.

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# Effect of moisture on stiffness of polyester resin with high biobased fraction

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Biobased polyester resins can be seen as a sustainable alternative to reduce consumption of fossil-based polyester. As these resins are intended to be used in green composites, they are likely to be combined with natural (e.g. cellulosic) fibers, which have to be protected from moisture. However, polymers with bio-based constituents are often found to be susceptible to humidity, which impacts their mechanical performance and makes them less attractive for commercialization. The newly developed polyester resins included in the study are made of fully biobased 5,5'-sulfanediyldi (furan-2-carboxylic acid) (SFA) as a replacement monomer for e.g., fossil-based phthalic acid, and fumaric acid (FA) in combination with different proportions of diols and curing agents at different concentrations. According to literature, some diols used such as 1,3-propanediol or glycols can play a different role in moisture absorption. When developing new materials, small quantities are available for assessment. For this reason, Vickers hardness indentation has been used as a quick characterization technique not only because it requires small samples but also, due to its relationship to stiffness of the material. The aim of this study is to investigate the influence of moisture on stiffness of different partially biobased polyester resin formulations by measuring hardness. The reversibility of the effect of moisture on polymer properties was also considered. The results show that Vickers hardness is reduced depending on the moisture content of each polyester formulation, as well as an indication of the reversible change once the material is dried after saturation. To conclude, the formulations with glycols showed higher reduction in hardness at saturation than formulations with propanediol. Even though all the formulations showed a decrease in hardness upon saturation, the highest moisture absorption was below 2 w/w%.

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# Towards High-Value Recycling of Composites Using High Voltage Fragmentation

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The recycling and reuse of glass and carbon fiber composites are of utmost importance for advancing sustainable technologies and reducing the environmental burden associated with end-of-life products. Despite their widespread use in multiple industrial sectors, the majority of composite waste is still incinerated or landfilled, resulting in significant loss of valuable materials and contributing to environmental impacts. A major barrier to the implementation of industrial-scale recycling lies in the difficulty of obtaining secondary raw materials with properties suitable for reuse in high-value applications.

High Voltage Fragmentation (HVF) represents an innovative recycling technology with the potential to overcome these challenges. The process relies on high-voltage electrical pulses to fragment composite materials, generating shockwaves that preferentially propagate along the fiber–matrix interface. In contrast to conventional mechanical recycling, HVF has been shown to produce particles with a narrower size distribution and to preserve longer fiber lengths, both of which are key to improving the performance of recycled composites.

In this study, different HVF operating parameters will be applied to various glass fiber waste streams. Recycled samples will be produced from the recovered fractions and subsequently subjected to mechanical testing to evaluate their properties. By systematically comparing the results, it will be possible to identify the most effective HVF process settings for maximizing material quality and performance.

This preliminary analysis is a crucial step towards validating HVF as a viable recycling route for composites. The development and characterization of recycled samples not only enable a deeper understanding of the material's potential but also lay the groundwork for integrating HVF into future industrial recycling processes, ultimately supporting the creation of high-value secondary raw materials.

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# Material heterogeneities in Frontal Polymerization

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Frontal Polymerization (FP) offers an energy-efficient alternative to conventional curing of fiber-reinforced composites. The process relies on a self-sustaining exothermic reaction that drives a localized curing front, enabling rapid polymerization at several centimeters per minute. FP has been successfully applied to thermoset resins such as epoxies, widely used in aerospace applications for their mechanical and thermal performance. Among FP approaches, Radical Induced Cationic Frontal Polymerization (RICFP) is particularly promising, achieving fiber volume fractions above 60% [1], comparable to aerospace-grade materials.

In RICFP, an externally triggered reaction sustains a thermal front exceeding 200 °C and traveling through the resin at speeds up to 70 cm/min [2]. While this enables fast and efficient curing, it also introduces challenges related to front stability and material uniformity. Steep thermal gradients and uneven conversion can lead to heterogeneous network structures, whose effects on mechanical properties remain poorly understood. Prior studies suggest that these gradients may induce internal stresses [3-4], while front instabilities have even been exploited to create patterned structures [5]. A deeper understanding of these mechanisms is key to improving control and reproducibility in FP.

To investigate these effects, samples were produced under various conditions to examine the influence of initiator concentration, initiation temperature, pressure, viscosity, and gaseous environment on front behavior. Dynamic Mechanical Analysis was used to correlate processing parameters with mechanical performances, complemented by micro-FTIR, Raman spectroscopy, and nanoindentation to characterize the cured network. Results indicate that when front propagation is obstructed by high resin viscosity or by mechanisms that dissipate part of the front's energy, the front slows and stabilizes, leading to better control over the resulting mechanical properties, particularly the glass transition temperature.

[1] Staal et al., https://doi.org/10.1016/j.compscitech.2024.110584

[2] Tran et al., https://doi.org/10.1016/j.compositesa.2020.105855

[3] Li et al., https://doi.org/10.48550/arXiv.2310.01559

[4] Chen et al., https://doi.org/10.1021/acsaenm.4c00526

[5] Lloyd et al., https://doi.org/10.1021/acscentsci.1c00110

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# Experimental and Numerical Analysis of the Effects of Sand Particle Erosion on 2D Carbon-Epoxy composite

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Today aerostructures can be used in harsh environments where the parts are submitted to severe conditions of use [1]. Solid particle erosion is caused by multiple impacts of particles on a surface. Erosion wear is the type of damage that modify the surface of the composite parts. In this study, the aim is to qualify the surface modification of carbon epoxy composite specimens after sand particle erosion. To do so, an experimental and a numerical study are conducted in parallel. The experimental tests are performed with varying erosion parameters: impact angle and exposure time. Then, the surface integrity of the specimens is analysed as a function of the erosion test parameters: geometric parameter (profile, roughness), micro-morphologic parameter (delamination, fibre crack, resin ploughing...). The analysis of the surface integrity indicates that the 60° and 90° impact tests cause the most damage to specimens. This is due to the brittle behaviour of the carbon fibres [2]. The numerical side of the study aims to validate an implemented damage composite material law by correlating the results. Tje particles are reproduced in the model thank to 3D reconstruction of their form and size by microscopic pictures of the particles.

[1] O. Gohardini, Impact of erosion testing aspects on current and future flight conditions, Progress in Aerospace Sciences 47 (2011).

[2] V. Boggarapu, R. Gujjala, S. Ojha, A critical review on erosion wear characteristics of polymer matrix composites, Material Research Express 7 (2020).

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# Segmented Rim Design for High Performance Flywheel Energy Storage System

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The use of flywheel energy storage systems (FESS) is well established in short-duration operations such as grid stabilization, frequency regulation, and uninterruptible power supply. This is due to their high-power density, rapid dynamic response, and long service life. To extend their use to broader applications and achieve competitive energy capacity-to-cost ratios, it demands a fundamental redesign of the rotor because conventional single-material flywheels, metallic and composite, are limited by stress constraints and inefficient material utilization. An advanced press-fitted multi-rim composite design has been proposed to overcome this problem by reducing radial stress, thereby improving energy density and capacity. However, it is prone to circumferential stress accumulation at rim interfaces, rim detachment under high angular velocity operation, and manufacturing complexity.

To overcome these limitations, a novel rotor architecture termed the Segmented Rim Flywheel (SRF) is introduced. Unlike press-fitted designs, the SRF employs multiple thin composite rims separated by strategic air gaps rather than interference fits. According to analytical and numerical models, the SRF can achieve nearly twice the energy capacity of a conventional single-rim flywheel with an identical outer dimension. The improvement results due to the configuration's ability to significantly reduce both radial and axial tensile stresses and enabling the rotor to approach its circumferential strength limit. Therefore, the flywheel can operate at higher rotational speeds. Subsequent analysis reveals that inner rims can be replaced with lower-strength composites in order to reduce material cost while maintaining overall performance. Additionally, the design eliminates interfacial stress concentration. Overall, the SRF concept represents a promising next-generation flywheel system capable of delivering high energy storage capacity and adaptable power output across a range of applications.

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# Modelling and experimental study of hydrogen permeation in polymer composites

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This work summarises our research into hydrogen permeability in polymer composites for future hydrogen pipeline infrastructure. Particularly, it provides a new insight into the effects of microstructural features on the overall hydrogen permeability of those systems through a combined 3D modelling approach and full-scale permeation experiments on a thermoplastic composite pipe (TCP) composed of E-glass fibre-reinforced high-density polyethylene (EGF/HDPE). Model predictions at different temperatures showed that local fibre clustering can significantly reduce permeability by increasing the tortuosity of diffusion pathways. The effect of fibre orientation on hydrogen permeability was found to depend on the level of fibre agglomeration — while for plies with fibre-rich domains the orientation had an insignificant effect on permeability, the latter was noticeably reduced with increasing ply misalignment when plies contained uniform fibre distribution. This research presents the first hydrogen permeability assessment of EGF/HDPE composites, highlighting the potential of this material system for the transportation of green hydrogen.

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# Delamination characterization and tensile damage evolution in unidirectional all-carbon hybrid laminates

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The lack of ductility of unidirectional long fibre reinforced polymers under tensile loading can be overcome by interlayer hybridization where low elongation (LE) material is sandwiched between high elongation (HE) material. This results in pseudo-ductile tensile behaviour due to the interaction of damage modes, such as LE ply fragmentation and delamination [1]. In this context, the present study aims to investigate the effect of stacking sequence on the tensile pseudo-ductile behaviour of thick ply unidirectional all-carbon hybrid laminates, as well as their Mode I and II fracture toughness. High elongation Toho® Tenax® IMS60 (ply I) and low elongation DIALEAD® K13916 (ply K) carbon fibres were used to reinforce a Huntsman XB 3515 epoxy matrix. The layup sequences of the manufactured all-carbon hybrid laminates were: [I/KI], [I/KI]2 and [I/KI]4. Other laminates were produced to measure the fracture toughness of the I/K, I/I, and K/K interfaces.

Quasi-static tensile tests were performed using embedded distributed fibre optic sensors (DFOS) to measure the strain evolution within the laminate along the specimen's length. The fibre optic sensors were placed at an I/K interface and an I/I interface in each specimen.

The laminate sequence revealed a slight increase in the stress level at the initial fragmentation of the K plies in the thicker laminate. Meanwhile, the thinner laminate exhibited a slightly larger strain range on the pseudo-ductile plateau. This was a consequence of the slower propagation of delamination in the [I/KI] laminate, after the initial fragmentation of the K ply.

As for the fracture toughness, the measurements revealed lower GIc and GIIc values for the hybrid I/K interface compared to the homogeneous I/I counterpart, as also detected in [2].

Keywords: All-carbon hybrid laminates; Delamination; Tensile pseudo-ductility; Tensile damage.

References

[1] Swolfs, Gorbatikh, Verpoest, 2014, https://doi:10.1016/j.compositesa.2014.08.027

[2] Sapozhnikov, Swolfs, Lomov, 2020, https://doi.org/10.1016/j.compstruct.2020.111886

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# Adaption of the multi-axial warp knitting process for processing of rCF-Tapes

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The importance of lightweighting materials to reduce environmental impact whilst pushing the limits on weight reduction and mechanical performance is increasing. Consequently, demand for Carbon Fibre Reinforced Parts (CFRP) has been increasing for more than 10 years [NN25]. Simultaneously the demand to recover and reprocess the used fibres from composites for a more sustainable supply chain has also increased.

Depending on the method of recovery, length, quality, and surface properties of the fibres differ. Short fibres in different length distributions, can be processed into different textile products, such as nonwovens, tapes or yarns. In the industry however they are primarily used in nonwovens with low degrees of orientation and yarns with high percentages of non-carbon content. These preforms are mostly used in non-structural applications, even though the available properties of the individual fibres can reach up to 90 % of the virgin material properties of the single filaments [KKG+21]. Alongside single fibre properties, fibre orientation is an important factor, among others.

Lineat Composites Ltd. has developed a highly oriented recycled carbon fibre tape – the alignment enables much of virgin carbon fibre properties to be maintained, unlike traditional randomly oriented non-wovens. These tapes can be processed into non-crimp fabrics to increase composite production speed. However the use of 100 mm wide short-fibre tapes is not standard process on an industrial multi-axial warp knitting machine. On warp-knitting machines tapes are spread in- or offline and fed into the system. The rovings traditionally used can bear a high tensile load when being placed onto the machine, but Lineats development tapes require lower loads. Therefore, the insertion process was adapted and improved. Tensile samples were produced from the resulting textile and tested according to DIN EN 574-5.

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# Innovative approach for converting untreated bast fibres into engineered UD tapes tailored for multi-axial non-crimp composite manufacturing.

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This study presents an innovative method for developing aligned tape reinforcements from chemically untreated bast fibres for sustainable composite applications. Bast fibres such as banana and bamboo are utilized in their raw, technical form—without chemical pretreatment—preserving their natural integrity while minimizing environmental impact and processing complexity. A major advancement of this approach lies in its ability to bypass traditional spinning, yarn conversion, and tape production processes typically required in fibre reinforcement manufacturing. Instead, fibres are directly aligned and bonded using binder systems to form unidirectional (UD) tapes with a 90-degree orientation.

These UD tapes are subsequently processed into composite laminates through vacuum infusion using a bio-based epoxy resin, contributing to a fully bio-derived and low-emission materials system. Flax fibre tapes, prepared under the same conditions, are used as a benchmark for comparative analysis. Mechanical characterization of the resulting laminates is conducted in accordance with DIN EN ISO 527-4, focusing on tensile strength, stiffness, and fibre-matrix interaction.

The findings indicate that untreated bast fibres, when effectively aligned, can deliver competitive mechanical performance without the need for chemical surface treatments. Additionally, the tape production process accommodates a degree of fibre length variability, enhancing reproducibility and promoting improved property homogeneity—both of which address persistent challenges in natural fibre composite development.

While the present work focuses on unidirectional reinforcement, the tape format offers future potential for incorporation into multi-axial non-crimp textile architectures. This research thus establishes a scalable and resource-efficient foundation for the development of next-generation natural fibre composites. Applications are envisioned across industries such as automotive, building materials, and consumer products, where sustainability, lightweight design, and mechanical integrity are critical performance drivers.

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# Cradle-to-Gate Life Cycle Assessment of Imported Banana and European Flax Fibers for Biocomposite Production

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The demand for sustainable raw materials in composite manufacturing has led to increased interest in natural fibers as reinforcements in bio-based composites. This study presents a cradle-to-gate life cycle assessment (LCA) comparing the environmental performance of two fiber types used in natural fiber-reinforced composites: banana fibers sourced from India and flax fibers cultivated and processed in Europe.

Banana fibers, extracted from banana pseudo-stems—a post-harvest agricultural residue—offer a potentially lower-impact alternative to flax, which requires dedicated land use and agricultural inputs. The assessment includes fiber production, processing into a composite-compatible form, and transport to a European manufacturing facility. Two banana fiber scenarios are modeled: (1) raw banana fibers exported from India and processed in Europe, and (2) banana fibers fully processed into textiles in India before export. These are compared against European flax fibers cultivated, processed, and transported within Europe.

The LCA follows ISO 14040/44 standards with cradle-to-gate boundaries and harmonized functional units. Environmental impacts are evaluated across multiple categories including global warming potential, cumulative energy demand, water use, and land occupation. Inventory data are drawn from Ecoinvent and literature sources.

Initial results show that Indian banana fibers processed in Europe perform favorably in several categories, largely due to avoided agricultural burdens and access to lower-emission electricity grids. However, when processed in India, the environmental performance declines significantly due to the carbon-intensive energy mix. In comparison, European flax fibers exhibit higher land and energy demands but benefit from shorter supply chains and consistent production standards.

This comparative study highlights how supply chain configurations and regional energy contexts critically influence the sustainability of natural fibers for biocomposite applications. Banana fibers show promise as a low-impact alternative, particularly when processing is aligned with renewable energy infrastructure.

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# Flexural failure of pseudo-ductile carbon / glass hybrid laminates and the interaction between tensile and compressive response

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Previous work has shown that hybrid laminates of thin-ply carbon / glass exhibit pseudo-ductile response in tension, with a knee point followed by a plateau region where fragmentation occurs. Similar behaviour is seen with standard and high modulus carbon. Pseudo-ductility also occurs in compression in thin-ply carbon / glass hybrids with high modulus carbon fibres. However, with standard modulus fibres there is no pseudo-ductility in compression because failure of the hybrid laminate is triggered by shear instability well before the carbon fibre failure strain is approached.

Monolithic composites of both glass and carbon loaded in bending may fail in either tension or compression. The strain for shear instability in compression depends on the strain gradient, with thin laminates failing at higher strains than thick ones. This can lead to a switch in failure mode, with thin specimens failing initially in tension, but thick ones failing first in compression. With pseudo-ductile hybrids, the behaviour is further complicated by fragmentation, and the different pseudo-ductile responses in tension and compression.

This paper reports experimental studies on the flexural behaviour of both high modulus and standard modulus thin-ply carbon / standard thickness S-glass hybrids to investigate how the responses in tension and compression interact. Both composites show highly non-linear response with pseudo-ductility, finally failing in compression.

With high modulus carbon, fragmentation occurs first on the compression side and then later on the tension side. Standard modulus carbon hybrids only fragment in tension but reach very high compressive strains as the strain gradient inhibits the shear instability. The failure strains in this case are higher when the carbon layer is thinner due to the greater support from the adjacent glass plies.

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# Evaluation of the Suitability of Carbon Fibre Reinforced Non-Metallic Pipelines for Oil and Gas Industry

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Pipelines are vital assets in the present global energy supply chain, enabling the large-scale and efficient transportation of hydrocarbons. While metallic pipelines remain widely used, they are highly vulnerable to corrosion, often resulting in leaks and costly failures. Nonmetallic pipelines, particularly fiber-reinforced composites, offer a promising alternative by mitigating corrosion risks while reducing weight and improving mechanical performance. However, their adoption in real-world applications is hindered by several challenges, mainly related to optimum pipe materials, as well as the inspection and maintenance standardization. Therefore, this study investigates the performance of carbon fibre reinforced polymer (CFRP) pipelines fabricated using a braiding technique with an epoxy matrix. It involved conducting experimental evaluations on CFRP pipes with diameters of 2 inches and 4 inches, constructed using 4, 5, and 6 layers of carbon fibres. The findings revealed that the 6-layer configuration consistently demonstrated enhanced structural integrity, achieving and surpassing the required performance standards. This verifies that the 6-layer configuration is the most optimal design, providing an effective balance of mechanical strength, durability, and operational safety. Particularly, the computed maximum allowable operating pressure (MAOP) was almost 17% above the industry threshold. In addition, the resulting transverse compressive strength reached 147% improvement over values reported in previous studies. The findings of this study underscore the effectiveness of the braiding technique in manufacturing high-performance composite pipelines, establishing it as a reliable approach for achieving an optimal balance of strength, durability, and operational safety within hydrocarbon pipeline networks.

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# A conductive polymer composites (CPCs)-based micron-thick embeddable strain sensor via fused deposition modeling (FDM).

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Flexible strain sensors fabricated from conductive polymer composites (CPCs) have recently attracted growing research interest due to their customizability, stretchability, and high sensitivity [1]. Moreover, nanocarbon-filled CPCs filaments are well suited for used in flexible strain sensors, as their enhanced electrical properties come from the formation of nanoscale conductive networks [2]. In addition, fused deposition modeling (FDM) has been widely applied in the fabrication of smart structures from its high versatility, ease of use, high resolution, and cost-effectiveness. Hence, this study aims to investigate the mechanical influences and electrical responses of CPCs-based flexible strain sensors integrated within 3D-printed structure via dual-nozzle FDM process.

Three distinct sensors' configurations were integrated within a rectangular polylactic acid (PLA) structure in two orientations : along (0°) and perpendicular (90°) to the length of the structure. Two types of nano carbon black composites : CB/PLA (CP) and CB/TPU (CT) were employed for the fabrication of strain sensors. Coupled electro-mechanical tensile tests were conducted to examine the mechanical influence of the thin-film strain sensors and their electrical responses under progressive loading. Overall, introducing a thin-film CPCs strain sensors into polymer structure does not significantly alter the mechanical properties within the elastic and plastic domains. Regarding sensor sensitivity, expressed by the gauge factor, the CPCs strain sensors exhibited a nonlinear evolution of resistance, resulting in a positive gauge factor (GF1) in the elastic range and a negative gauge factor (GF2) at higher strains. CP sensors show superior GF1 values, whereas the CT sensors exhibited higher GF2 values. Post-mortem analyses including SEM and micro-CT provided insight into the sensor and substrate interfaces. These observations revealed that CP sensors maintained adhesion and captured deformations until failures, while CT sensors were partially debonded under large deformations.

[1] H. Liu et al., https://doi.org/10.1002/adma.202004782.

[2] M.R.H. Mazumder et al., https://doi.org/10.1016/j.compositesa.2024.108578.

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# Feasibility of Reusing CFRP Wind Turbine Elements as Load-Bearing Secondary Structures

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The growing demand for sustainable End-of-Life (EoL) solutions in the composite industry highlights the urgent need to develop circular strategies for carbon fiber reinforced polymers (CFRP). While most research and industrial activities currently focus on repurposing glass fiber reinforced polymers (GFRP), the potential of CFRP components for second-life structural applications remains largely unexplored. This paper investigates the feasibility of repurposing CFRP elements from the wind energy sector as a complementary strategy to conventional recycling methods. To support this objective, structural investigations are conducted to identify the damage state of extracted components. Subsequent mechanical tests of EoL CFRP spar cap substructures taken from an Enercon E-103 wind turbine blade (WTB) demonstrate that these components retain high stiffness and strength properties. The tested unidirectional CFRP beams exhibit substantially higher stiffness than comparable GFRP beams, indicating that such components are promising candidates for reuse in load-bearing structural applications and thereby extending the service life of the material. A catalogue of potential repurposing applications is presented, demonstrating that the reuse of CFRP beams is particularly promising for secondary engineering functions. By showing that CFRP components can be reused without chemical, mechanical, or thermal recycling steps, this study provides an alternative pathway to processes such as solvolysis, which are often energy-intensive and may lead to material degradation. The results highlight the technical feasibility and environmental benefits of repurposing as an R9 strategy for CFRP, contributing to resource conservation, emission reduction, and improved circularity. This work establishes a basis for future research on design guidelines, standardization approaches, and scalable implementation concepts for integrating repurposed CFRP structures into diverse secondary applications.

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# Deconsolidation of semi-cured carbon-epoxy laminates at forming temperatures

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This study investigates the deconsolidation behaviour of semi-cured composite laminates with varying degrees of cure when subjected to temperatures representative of hot forming processes. The aim is to quantify the extent of deconsolidation and develop a mechanistic understanding of the underlying phenomena.

In the semi-cure process [1], dry non-crimp fabric is stacked, infused with resin while being compacted, and then partially cured. This creates an impregnated laminate that is rigid at room temperature but retains sufficient polymer network reactivity to allow for some resin re-flow and cross-linking upon secondary heating. However, when reheated without compaction, the resin viscosity may drop to a level where the surface tension or elasticity required to maintain fibre consolidation is insufficient. This can lead to deconsolidation, increasing the risk of void growth, interlaminar separation, and other defects—highlighting the need to identify processing windows that minimise defect formation.

To investigate these effects, laminates with varying degrees of cure were manufactured using vacuum assisted resin infusion and characterised post-infusion using X-ray computed tomography, microscopy, and laser-scan metrology. The samples were then reheated at varying temperatures and heating rates, with subsequent analyses used to track and compare defect progression across different conditions.

The outcomes of this work contributes to defining a viable processing window for semi-cured materials outside of vacuum pressure consolidation, by linking resin viscosity (as a function of degree of cure and temperature) to the onset and progression of defects. This understanding will support the development of forming techniques that minimise defect formation or development, advancing the semi-cure process towards reliable, high-quality manufacturing of integrated structures.

References:

[1]: M. O'Leary, R. Hartley, A. Radhakrishnan, M. Mavrogordato, T. McMahon, and J. Kratz, "Interlaminar properties of carbon fibre/epoxy laminates produced through a semi-curing process" Composites Part A: Applied Science and Manufacturing, vol. 187, no 108488, Dec. 2024.

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# Experimental Characterization of Out-of-Autoclave Composite Adhesive Joints for Aeronautical Applications

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Considering the increasing demand and production rates in the aerospace sector, it has become essential to investigate out-of-autoclave (OoA) composite manufacturing technologies that enable lower costs, shorter cycle times, and improved environmental sustainability. In the past, OoA composites were often disregarded due to their inferior quality compared to their autoclave-cured counterparts. However, recent advancements in OoA processing have made it possible to achieve composite materials with properties comparable to those produced in autoclaves.

This study focuses on the experimental investigation of the adhesive joints between OoA-manufactured carbon-fibre composites. Three manufacturing routes were explored: heated vacuum-assisted resin transfer moulding (Heated-VARTM) and two stamping-based processes—thermoset hot press and thermoplastic hot stamping. The experimental campaign aimed to the mechanical behaviour of these materials for use in the numerical simulation of bonded structures. To this end, four tests were conducted: (i) bulk tensile test (BTT), (ii) thick adherend shear test (TAST), (iii) double-cantilever beam (DCB), and (iv) end-notched flexure (ENF).

In addition, single-lap shear tests were performed to characterise the adhesive bonding performance of the composite-to-composite joints. In each test, the adherends were identical and manufactured using one of the three methods described above. All joints were bonded using 3M™ Scotch-Weld™ EC-9323 epoxy adhesive. This experimental work precedes the numerical study, which will be published in a later phase.

The results highlight the strong influence of the manufacturing route, system, and surface preparation on fracture behaviour. Different failure modes were observed in the DCB and ENF tests, with variations in the fracture toughness between the thermoset and thermoplastic specimens. Distinct joint combinations exhibited different failure mechanisms and load-bearing capacities: thermoset hot-press joints showed cohesive failure and the highest strength, while thermoplastic and Heated-VARTM joints exhibited adhesive or fibre-tear failures with lower loads, underlining the role of surface treatment and processing parameters in joint performance.

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# Environmental impact of tyres and possible reduction strategies

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Tyres are highly engineered products essential in modern society because they allow mobility and transportation of goods. In 2022 the global tyre production accounted for around 2 billion units but it is expected to grow. The effective recycling rate of ELT, intended as the use of the material for the same original purpose is very low (around 2 %) and it is necessary to find ways to prolong their lifes and to reduce their environmental impact. Among the different possibilities of improving the circularity of tyres, retreading is an interesting and ready technology having the potential to save substantial fraction of energy required for processing the raw materials and manufacturing of tyres. On the other hand, the reclaiming process of end-of-life rubber allows to recover material and to save virgin resources reducing the amount of material to be disposed.

Despite the possible environmental advantages arising from the use of retreaded tyres the studies present in the open literature are still very limited and focused only on few aspects of the environmental impact (CO2 emissions) or based on non-primary data. This study investigates the environmental impact of retreaded truck tyres and of the use of reclaimed rubber starting from primary data. A comparison with respect to a corresponding new tyre is also proposed.

The results show that retreaded tyres allows to significantly reduce the environmental impacts according to all the considered impact categories: the climate change is reduced of 37.9 %, the consumption of fossil fuels of 39.4 %, the consumption of natural resources of 37.1 %, the water consumption of 41.2 % and the emission of particulate emissions of 7.6 % (PM2.5) and 27.4 %(PM10). The use of reclaimed rubber to substitute virgin material in the manufacturing process allows a further reduction in the environmental impact.

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# Feasibility-Aware Bayesian Modelling and Optimization of Composite Structures with Failure Constraints

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Machine learning has emerged as a powerful tool for predicting and designing composite structures, where geometric parameters and layup configurations serve as inputs, and mechanical properties as outputs. However, modelling composite layups presents a fundamental challenge due to their high dimensionality, variable length, and discrete nature. Typical carbon fiber reinforced polymer (CFRP) components can contain dozens to hundreds of plies, making it impractical to generate sufficiently large datasets that fully explore the input space and capture the complex mapping between layups and structural responses.

This study introduces a Bayesian framework for fast, probabilistic prediction of composite failure behaviour, addressing the curse of dimensionality inherent in layup modelling. Instead of explicitly exploring the large layup space, the model directly predicts the failure probability distribution of structures, enabling estimation of the upper and lower bounds of failure indices without the need for layup optimization.

To further enhance data efficiency, we propose a novel output space sampling method that systematically generates representative layups based on diverse failure responses. By sampling in the output space rather than the input space, the method effectively captures all possible failure behaviours and improves the accuracy of Bayesian learning.

The framework is validated through open-hole compression tests, with failure indices evaluated using the LaRC05 criteria. A comprehensive dataset of geometries and layups is constructed for training, and a heteroscedastic variational Bayesian last-layer model is developed for uncertainty quantification. Results demonstrate that the proposed approach achieves accurate and efficient probabilistic predictions of composite failure indices across different geometries and loading conditions, offering a promising pathway toward data-efficient and uncertainty-aware design of advanced composite structures.

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# Fatigue of Laminated Composites under Compressive Loading: Comprehensive Investigation of Dissipative and Failure Mechanisms

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The use of laminated composite materials in aeronautics has increased significantly over the past decade. The selection of materials largely relies on experimental testing, which can be both time-consuming and costly, especially for fatigue testing. To reduce these costs, the self-heating method, increasingly used in the literature, offers an attractive alternative. However, to be reliable, this approach must be based on a clear understanding of the mechanisms responsible for temperature rise and those driving fatigue failure, as well as the link between them. This has been rarely addressed in the literature for laminated composites subjected to compression loading.

To address this issue, the present study combines mechanical testing, infrared thermography, X-ray tomography, and multiscale modeling. Cyclic compression tests were conducted at a stress ratio of 10 on a quasi-isotropic carbon/epoxy laminate. Infrared thermography was employed to quantify energy dissipation during a series of cyclic loadings with increasing stress amplitudes. The energy dissipated per cycle was estimated from the temperature evolution using the heat equation. X-ray tomography was utilized to characterize the damage mechanisms leading to fatigue failure. Fatigue tests were stopped just before complete failure to determine the failure scenario. Results show that macroscopic cracks initiate in the 45° plies and then propagate into the neighboring 0° plies, ultimately causing final failure. Multiscale modeling was used to identify the physical mechanisms responsible for the observed temperature increase. The mesoscopic behavior of the ply was modeled on the basis of simulations on a unit cell considering the mechanical behavior of the fibers and the matrix. The results show that the temperature increase is mainly due to the ±45° plies, which are also responsible for fatigue failure. Therefore, energy dissipation can be used as an indicator of the fatigue limit and as a driving parameter to predict the S–N curve.

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# Numerical study of the effect of through-thickness and transverse compressive stresses on out-of-plane shear damage in composite laminates

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Among the many out-of-plane characterization tests, inter-laminar shear ones are often the first choice. While it may initially appear that damage is due to pure shear stresses, the reality is more complex. In fact, bending will induce out-of-plane and transverse compressive stresses which will have a significant influence on damage and thus overestimate the shear failure value. This is sometimes not considered numerically. However, this study tends to show how reliability on models can be affected if this phenomenon is not taken into account.

In this article, three-point bending and punch-shear tests on a quasi-isotropic laminate are first conducted. Results show a higher dispersion for three-point bending tests, partly due to strong free-edge effects. A dialogue with an advanced numerical model is then carried out, showing at first a poor correlation with experimental results despite inherent dispersion, therefore calling into question the failure criterion used in the model. A numerical analysis between the two tests highlights the influence of out-of-plane and transverse compressive stresses on shear damage, while also pointing out on three-point bending tests the influence of free-edge effects on stress distribution through the laminate and damage scenario. On the other hand, a higher compressive behaviour is observed for the punch-shear test, showing the particularity of this experiment. Based on these results, a new failure criterion considering these compressive stresses as a reinforcement in out-of-plane shear stresses is proposed and integrated into the model on interface elements modelling delamination and matrix cracking, for both tests. A validation is eventually made, showing better correlation with the experimental results.

Perspectives for that study are, based on inter-laminar shear tests like those presented, the identification of a single reinforcement coefficient value that would depend on the lay-up and the test considered then aim at giving better reliability on a numerical model.

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# High-Fidelity Finite Element (FE) Modelling for Type-IV Composite Pressure Vessels: Predicting Damage Behaviour and Assessing the Influence of Local Defects

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Type-IV composite overwrapped pressure vessels (COPVs) have gained significant attention for hydrogen storage due to their lightweight design, high strength-to-weight ratio, and excellent corrosion resistance. These vessels are required to withstand an exceptionally high nominal working pressure (NWP) of 70 MPa (700 bar), making structural integrity a critical factor in ensuring both safety and long-term reliability. To address these design challenges, finite element analysis (FEA) provides a reliable and effective means to simulate realistic loading scenarios, assess stress distributions, and predict potential failure mechanisms. In this study, the mechanical response and damage progression in a 55-litre Type-IV COPV are investigated through a detailed finite-element simulation campaign. A segment of the cylindrical section was modelled to represent the mid-section of the Type-IV pressure vessel. The composite lay-up was explicitly modelled layer-by-layer using three-dimensional solid elements, rather than conventional or continuum shell elements. The composite lay-up configuration was obtained from ComposicaD software, ensuring that the modelled lay-up stacking sequence closely reflected practical design. A novel set of boundary conditions was applied to replicate the realistic mechanical loads, i.e., the loads a cylindrical section would experience within the COPV, and the results were validated against those from a reference model of the full COPV. To predict damage progression, a user subroutine for the three-dimensional (3D) Hashin damage model was implemented to assess the through-thickness mechanical behaviour of the composite overwrap accurately. Finally, the effects of voids and wrinkling were assessed by explicitly modelling these local defects within the cylindrical section. This modelling strategy provides a robust framework for evaluating the mechanical damage behaviour of composite-overwrap in Type-IV pressure vessels. It accounts for local defects while utilising a realistic set of boundary conditions, an approach not previously combined. Thereby, a validated foundation for the rational design of composite pressure vessels is established.

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# Fatigue in Composites: Mean-level correction and transformation of load-controlled fatigue test data into strain-based SN-curves

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In this study fatigue performance of composite materials is experimentally investigated, and methods to analyze test data are suggested. The examined material system is a fiber-reinforced polymer composite consisting of a non-crimp unidirectional glass-fiber fabric and epoxy resin. The experimental program included fatigue tests and static tests. Tension-tension fatigue tests were conducted under load-control at constant stress-based R-ratio of $R\sigma=0.10$, where the R-ratio is the ratio between the minimum and the maximum stress. Quasi-static displacement-controlled tensile tests were conducted to determine static strength in terms of ultimate tensile stress and corresponding strain.

During load-controlled fatigue test, the applied maximum stress and the stress-based R-ratio, $R\sigma$, remain constant by definition. However, for composites that experience stiffness degradation, the maximum strain increases during load-controlled fatigue tests, and creep-effects leads to a non-constant strain-based R-ratio, $R\varepsilon$. Conventionally, load-controlled fatigue data are transformed into strain-based SN-curves using Hooke's law, by assuming a constant (initial) modulus. The SN-curve describes the relation between the loading and the number of cycles to failure. This conventional approach neglects stiffness degradation and mean strain shifts caused by creep, and may lead to an underestimation of fatigue performance in the strain-based SN-curve.

This paper suggests an alternative method to transform load-controlled fatigue test data into a strain-based SN-curve. The strain-based SN-curve is established from the concept of fatigue equivalent strain, which incorporates the effects of non-constant strain in load-controlled tests. A mean-level correction based on a constant life-diagram is applied to adjust the strain-based R-ratio to $R\varepsilon=0.10$. SN-curves are presented in terms of both maximum strain and strain range, and static strength is included as a limitation for low cycle fatigue. The SN-curves established based on the suggested methods show an increased expected fatigue lifetime when compared to SN-curves based on conventional methods.

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# Eigenfrequency control of composite beams via collaborative topology and fiber orientation optimization

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Fiber-reinforced composites have become a central focus in modern engineering and materials science owing to their exceptional stiffness-to-weight ratio and broad applicability across a wide range of industries. Recently, combined topology and fiber path optimization of composite structures has been receiving significant attention, driven by advances in additive manufacturing techniques that have enabled fabrication of variable stiffness designs involving curved fibers. However, joint optimization of geometry and anisotropy fields is prone to local optimality issues, which occur due to the solution dependency on initial fiber orientations and the large number of design variables involved. Addressing this challenge, we proposed a novel collaborative optimization scheme, in which topology and fiber directions are optimized independently through iterations. In addition, the fiber volume fraction is gradually increased from an isotropic state to alleviate the influence of the initial fiber angle distribution on the final design. Moreover, problem dimensionality is reduced using scarce anisotropy variables contained on the nodes of coarse auxiliary meshes that are dynamically created over the solid domain. The developed methodology has been shown to generate structurally efficient designs that outperform the ones obtained with the conventional concurrent optimization approach. In this paper, we extend the proposed strategy to design composite structures with enhanced dynamic characteristics. The method is used to maximize the fundamental eigenfrequency and eigenfrequency gaps of a fully clamped beam under a volume fraction constraint. The results demonstrate the effectiveness and robustness of the presented technique in composite optimization problems that require simultaneous vibration-response improvement and weight reduction.

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# Polymeric thin film-based triboelectric nanogenerators for self-powered platforms

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Triboelectric nanogenerators (TENGs) have recently garnered significant attention for their potential to power wearable electronics and small-scale energy harvesting devices. However, rigid materials limit the application of TENGs, particularly in flexible electronics, leading to growing interest in flexible materials as alternatives to conventional rigid ones. This presentation introduces polymer nanocomposite films for various types of TENGs via a simple, straightforward, low-cost, reproducible, and eco-friendly layer-by-layer (LbL) method. Our research has yielded the following results: (1) A body-attachable, antibacterial, and encodable TENG featuring an ultrathin, freestanding, semi-transparent chitosan/alginate/silver nanocomposite multilayer structure. Its potential for use as an encodable skin contact sensor has been successfully demonstrated. Consequently, this environmentally friendly chitosan/alginate-based TENG can be used as next-generation implantable, wearable, patchable, and encodable portable electronic devices. (2) Functional polymer nanocomposites designed as electron-blocking layers for high-strain power-amplifying TENGs. Applying LbL-assembled electron-blocking polymer nanocomposites between the cathode friction material layer and graphene-based LbL electrodes significantly enhanced TENG output performance. (3) Self-powered gelatin-based LbL TENG for microbial inactivation and particle removal in water. The gelatin TENG-driven electrophoresis device for removing harmful nanoparticles and E. coli demonstrated effective operation without external power, making it applicable for water disinfection systems. For harmful particle removal, this eco-friendly gelatin-based TENG can be utilized as a sterilizer, an in-body adhesive patch, or an implantable electronic device. (4) Development of antimicrobial films and cell stimulation platforms. A reproducible single-electrode TENG-based composite film using chitosan/silver nitrate as the anode triboelectric layer was introduced. This device can eliminate approximately 100% of four bacterial species in the first cycle.

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# Evaluating single-fibre fragmentation and transverse single-fibre tests for interfacial characterisation in composites: advantages and limitations

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Single-fibre tests are widely used to investigate the fibre-matrix interface in composite materials. Typically, tensile loading along the fibre axis probes mode II interfacial behaviour [1], while transverse loading reveals mixed-mode I-II responses [2]. Despite limitations, most notably their reduced mechanistic representativeness compared to multi-fibre composites due to the absence of neighbouring fibres, single-fibre tests remain the most robust approach for quantifying interfacial response and extracting relevant properties.

This study combines advanced experimental methods to assess the strengths and limitations of single-fibre testing. First, in situ single-fibre fragmentation and transverse single-fibre tests were conducted on glass- and carbon-epoxy interfaces, with synchrotron holo-tomography, a high-resolution 3D nanoimaging technique. These experiments enabled direct observation of microscale damage events under mode II [3] and mixed-mode I-II [4] loading. Results were further enhanced with 3D strain fields obtained via finite-element-based digital volume correlation, and subsequently compared with multi-fibre and bundled composite configurations to evaluate representativeness. Second, the same test protocols were coupled with polarised light microscopy to capture complementary through-thickness 2D information. This approach provided a broader field-of-view than synchrotron imaging, enabling correlation between early-stage damage evolution and ultimate failure, an insight otherwise inaccessible with tomography alone.

Together, these combined techniques establish a more complete picture of fibre-matrix interfacial behaviour across different length scales. By linking microscale damage initiation with macroscale failure, the study highlights both the possibilities and inherent constraints of single-fibre tests. These findings support the development of more robust experimental frameworks for characterising interfacial mechanics and provide a benchmark for future studies bridging single- and multi-fibre composite behaviour.

[1] Sugimoto et al., Carbon 61, (2020), 83-88.

[2] Martyniuk et al., Compos Part A Appl Sci Manuf 55, (2013), 63-73.

[3] Chatziathanasiou et al., Small 20, (2024), 2406168.

[4] Chatziathanasiou et al.,. Compos Part A Appl Sci Manuf 197, (2025), 109024.

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# Development of recyclable vitrimer matrix systems for infusion processes in large-volume applications

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Vitrimers are a new class of polymers that belong to the Covalent Adaptable Networks (CANs) and were discovered in 2011 by Leibler and his coworkers. Vitrimers combine the reprocessability of thermoplastics and the mechanical performance of thermosets as a result of their ability to dynamically exchange the covalent bonds of their polymer network under a thermal stimulus. In the last decade, many vitrimer formulations have been developed with the potential to be applied in composite manufacturing.

In the present work, a newly developed, siloxane-based vitrimer matrix with a fast stress-relaxation was used to manufacture continuous Glass Fibre-Reinforced Vitrimers (GFRVs) by Vacuum Assisted Resin Infusion (VARI). The advanced GFRV specimens were tested to investigate the mechanical performance of the vitrimer composite before and after reprocessing. This vitrimer matrix was selected because it exhibited a comparable performance to the epoxy-thermoset system RIM 135 / RIMH 137 by HEXION™ that is commonly used in wind turbine blade industry, and because it had a very low viscosity, which is crucial for infusion processes. The mechanical properties of in-plane shear and Mode II Fracture toughness of the GFRV were evaluated before and after two reprocessing scenarios, that were thermoforming and healing of the vitrimer composite, respectively. Additionally, the Mode II fracture toughness of the produced GFRV specimens was measured according to test standards ASTM D7905. The above specimens were repaired under different repairability cycles of varying temperature and pressure, and their fracture toughness was re-evaluated.

In a second step, β-Aminoester-based vitrimers were developed that can meet multiple stringent requirements at the same time, being very long pot life (> 3h), sufficiently large Tg (> 80°C), very low viscosity, high stiffness after curing, low toxicity and repairability. Also those vitrimers were demonstrated for use in large-scale infusion processes for wind turbine blade applications.

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# A Multiscale Optimisation Framework for Early-Stage Design of Composite High-Aspect-Ratio Wings

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Early and detailed understanding of a design reduces the risk of costly and time-consuming revisions, particularly for high-aspect-ratio wings with novel structural layouts. This work builds on a previously established methodology for predicting composite failure and focuses on its extension to multiscale optimisation of composite wing structures, which is the main novelty presented here. By enabling the consideration of both global aerodynamic and local material behaviour, this approach addresses one of the key challenges in advanced composite wing design: integrating complex laminate responses into overall structural performance predictions.

The approach combines a rapid nonlinear aeroelastic solver, based on Hodges' intrinsic beam theory, with a physics-guided machine learning surrogate model trained to predict ply-level composite failure from global FEM data. The integration through bespoke superelements allows computationally efficient simulations while retaining high-fidelity representation of the wing's structural response. This capability makes the methodology particularly suitable for exploring novel, complex composite wing designs at the early stages of the design process, where multiple configurations and load cases must be evaluated quickly.

In this study, the methodology is extended to define a multiscale optimisation problem for bend–twist-coupled composite high-aspect-ratio wings. Avoiding ply-level composite failure is enforced as a constraint, ensuring that local material limits are respected while optimising global wing performance. This demonstrates the feasibility of formulating optimisation problems in which detailed ply-level constraints are fully incorporated in the overall structural response of advanced composite wing designs.

By combining high-fidelity simulation, surrogate modelling, and ply-level failure constraints, this framework provides a powerful tool for exploring innovative composite wing concepts while maintaining structural integrity. This work illustrates the potential of physics-informed machine learning and multiscale optimisation to support the design of safe, lightweight, and performance-driven next-generation high-aspect-ratio composite wings.

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# Study of post-treatment techniques for recycled carbon fibers to improve fiber-matrix bonding with epoxy resin by transverse fiber bundle tensile tests

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The loss of carbon fiber sizing during thermal or chemical recycling of carbon fiber reinforced plastic (CFRP) impairs the fiber-matrix bonding of the recycled fibers with new epoxy resin. For this reason, various approaches to fiber post-treatment are being studied to improve the impaired adhesion properties. Characterizing fiber-matrix bonding is also challenging, particularly when single-fiber testing equipment and semi-finished fiber products are not available.

In the present work, carbon fiber rovings are subjected to a recycling process with subcritical water (45 min @ 275 °C) to simulate hydrolytic CFRP recycling with corresponding sizing loss. Subsequently, a chemical post-treatment in 5 % nitric acid (30 min @ 95 °C) or a thermal post-treatment in air (90 min @ 450 °C) are carried out. Scanning electron microscope images do not indicate any damage to the fibers – neither resulting from the recycling process nor from the two post-treatments.

Transverse fiber bundle (TFB) tensile specimens are prepared with the original rovings, the desized rovings and the two desized rovings after post-treatment using epoxy resin. TFB tensile tests are performed on the four series to evaluate fiber-matrix bonding. Comparing original and desized rovings, the results show a drastic decrease in transverse tensile strength by more than 30 % as result of the recycling process underlining the importance of the sizing. The two post-treatments, however, lead to an increase in transverse tensile strength of the respective series by about 25 and 35 % compared to the series with the desized roving. They seem therefore suitable to improve fiber-matrix bonding of recycled carbon fibers with epoxy resin.

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# Development of Overcoated Prepreg Filaments for Sustainable Composites

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This work presents the development of sustainable composites in the form of natural fiber–reinforced and self-reinforced thermoplastic filaments produced via an extrusion overcoating process. The method continuously coats fibers with a compatible thermoplastic matrix to produce pre-impregnated (prepreg) filaments. Various core–sheath combinations were developed: flax fibers were combined with polyethylene (PE) and polylactic acid (PLA) matrices, while self-reinforced composites (SRC) were prepared by coating high-performance polymer fibers (monofilaments or yarns) with lower-melting sheaths: polyamide 6/co-polyamide (PA6/CoPA), polyamide 66/co-polyamide (PA66/CoPA), and polyethylene terephthalate/co-polyester (PET/CoPES). Composite properties were assessed through mechanical testing, microscopy, and polarized Raman spectroscopy.

The natural fiber composite prepreg filaments were further processed into unidirectional bars by hot-press molding to evaluate the composite's maximum mechanical performance. The flax/PE composite bars, achieving up to 57 vol% fiber content, exhibited a tensile strength of ~210 MPa and an elastic modulus of ~27 GPa, demonstrating potential for civil engineering reinforcement applications. In addition, biodegradable flax/PLA composites with 54 vol% fiber content, including their chemically modified variants, reached flexural strength and modulus values of ~260 MPa and ~27 GPa, respectively.

SRC filaments reached 40 vol% fiber content and were used in 3D printing trials. The PA6/CoPA filament showed tensile strength of ~200 MPa and high ductility (~25% strain at break). Printed parts retained ~55% of filament strength while maintaining ductility despite partial thermal degradation. The developed SRC filaments combine strength, toughness, and flexibility, enabling lightweight, impact-resistant structures and expanding the range of 3D printing feedstocks for large-scale robotic fabrication of custom furniture and functional components.

#210

# Experimental and Numerical Study of Mantis Shrimp Inspired Thin-Ply Bouligand Composites

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Carbon fibre reinforced polymer (CFRP) laminates are widely used in lightweight structural applications but are prone to interlaminar delamination under impact or out-of-plane loading, which significantly reduces residual strength. To mitigate this limitation, bio-inspired lamination sequences, such as Bouligand structures, have been explored. A notable example is the dactyl clubs of the mantis shrimp, which feature a helicoidal Bouligand arrangement with pitch angles ranging from 1.6° to 18°, providing enhanced resistance to high-energy impacts. Such designs have shown that lower pitch angles can improve residual strength, even with fewer 0° fibers, offering significant improvements in damage tolerance and impact resistance.

In this work, the influence of different pitch angles in helical laminates on the performance of thin-ply CFRP structures is investigated. Four Bouligand structures with varying pitch angles were fabricated with 40 gsm Thin-Ply material to explore the effect of angle variation on mechanical properties, including interlaminar shear strength and damage tolerance. ILSS tests were conducted to assess the interlaminar properties, while compressive after-impact (CAI) tests evaluated damage tolerance and residual strength under different loading conditions. The results indicate that structural performance is strongly influenced by pitch angle, with lower pitch angles contributing to a change in failure modes from interlaminar delamination to helical matrix cracking.

Additionally, numerical simulations were performed in Abaqus using a user-defined material to model damage and failure behaviour in composites. These simulations enabled a systematic evaluation of the combined effects of pitch angle and ply thickness on mechanical performance. Overall, the experimental and numerical findings demonstrate the potential of Bouligand thin-ply laminates to bridge the gap between strength and damage tolerance in advanced composite structures, providing a foundation for optimizing pitch angle and ply thickness combinations.

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# Repairable, reusable and recyclable-by-design glass-fiber-reinforced vitrimer composites from biobased sources

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Epoxy-based fiber-reinforced composites are intensively employed due to their outstanding thermo-mechanical properties and chemical stability. However, conventional recycling methods are not suitable for the management of their end-of-life, as current industrial processes are costly and time-consuming. Additionally, oil-based monomer precursors of known toxicity (e.g., epichlorohydrin, bisphenol A) are employed for matrix synthesis, making the overall fabrication process non-renewable and unsafe. Within this framework, vitrimers have emerged as an alternative solution to conventional thermoset polymers due to their ability to undergo topological rearrangement of their covalently crosslinked network above a threshold temperature, hence being reprocessable and recyclable, while maintaining thermosetting features at lower temperatures. Given the need to reduce environmental impact and replace fossil-derived feedstocks, current research is focused on fabricating biobased vitrimeric composites. In the work presented, an epoxy oligomer derived from brown algae was crosslinked with a biobased anhydride to produce a self-catalytic, vitrimeric glass-fiber reinforced composite. The matrix was demonstrated to undergo fast stress relaxation via temperature-activated transesterification reactions. Accordingly, the derived GF-reinforced composite featured suitable thermomechanical response (Tg ≈ 90 °C, E ≈ 40 GPa) and facile reprocessability due to the vitrimeric properties of its continuous phase. In particular, this material could undergo self-healing, welding (54 MPa adhesive strength), and shape reconfiguration through thermomechanical cycles (200 °C, 10 MPa) in narrow time windows thanks to fast topological rearrangement. Finally, the chemical recyclability of the material was demonstrated through catalyzed glycolysis in mild conditions (150 °C, ambient pressure). The thermomechanical properties of the reclaimed fibers were compared to those of the virgin reinforcement, demonstrating similar features and lack of degradation suitable for second-generation composites. To evaluate the environmental impact of the vitrimeric composite with respect to a standard thermoset counterpart, their Material Circularity Indicator was computed, yielding an improvement as high as 75%.

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# Nano and nanoengineered composites reinforced with carbon nanotubes

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Composites comprised of carbon nanotubes (CNTs) are reviewed after more than 30 years of development following the identification of these hollow crystalline tubes of carbon in 1991. CNTs were identified early on as potential advanced fibres for mechanical reinforcement in composites, particularly given their carbon microfibre analogue and the then mature (carbon) fibre reinforced polymer (FRP) composite industry. Early CNT research focused on characterizing the various forms of CNTs, notably single and multi-wall CNTs (SWCNTs and MCWNTs) and their interaction with matrices, mostly polymers. Mixing approaches dominated early work, resulting in low volume fraction (vol%) and randomly-oriented CNTs, with a key contribution being that CNTs, as hard nanostructures, can influence the host polymer matrix in a classic process-structure relation. As understanding grew in the first two decades, more synthesis methods emerged and as the field evolved, composites comprised of CNTs focused more on processes to increase vol% towards those achieved in structural composites (~50 vol% of fibres) which proved difficult with mixing approaches, controlling the alignment of the CNTs by macroscopically structuring them into yarns or sheets, and hierarchical or hybrid composites that combine existing micron-diameter continuous fibres (microfibres) and nanoscale reinforcements. Accordingly, we focus our attention here on composites comprised of CNT ‘fibres’ in polymer matrices, the dominant composite system to date. Such CNT-comprised composites are either nanocomposites with CNTs as the filler or reinforcement, or nanoengineered composites where CNTs complement microfibres, such as a hybrid carbon microfibre FRP (CFRP). We present a high-level history of CNT-comprised composites and give a brief view of current and future developments.

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# Fused filament fabrication and recycling of bio-based polyamide 11 reinforced with recycled short carbon fibers

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Additive manufacturing (AM), and in particular fused filament fabrication (FFF), has rapidly evolved into a key technology for producing complex polymer components with reduced waste and high design flexibility. Despite its widespread adoption, the sustainability of FFF is still limited by the reliance on petroleum-based materials and by the degradation that polymers undergo during repeated thermal cycles. In this context, bio-based polyamide 11 (PA11), derived from castor oil and known for its good mechanical properties and high impact strength, represents a promising alternative, especially when combined with recycled reinforcements.

This study investigates the processing, performance, and recyclability of PA11 composites reinforced with 10 wt% and 20 wt% recycled short carbon fibers (rCFs). The materials were produced via melt compounding and subsequently processed through both hot pressing (HP) and fused filament fabrication(FFF). Their rheological, thermal, and mechanical properties were evaluated across multiple recycling cycles to assess their suitability for circular manufacturing.

Results show that rCF addition substantially improves tensile stiffness and strength, confirming the effectiveness of recycled carbon fibers as reinforcement. However, this enhancement is accompanied by reductions in ductility and impact strength, which intensify at higher fiber contents. Recycling leads to progressive material degradation, more pronounced in FFF samples due to combined thermal and shear stresses, which causes polymer chain scission and fiber breakage. Despite this, composites retain up to 95% of their elastic modulus and 80% of their ultimate tensile strength after several recycling steps.

Thermal analyses reveal that rCFs significantly reduce PA11 shrinkage during cooling, improving dimensional stability and printability without requiring heated chambers. Overall, PA11/rCF composites exhibit strong potential for sustainable additive manufacturing, although further optimization is needed to minimize degradation during repeated processing.

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# Laser Cutting Behavior and Process Optimization of (Ti-Zr-Hf-Nb-Ta)C–SiC High-Entropy Ceramics

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High-entropy ceramics (HECs) represent a novel class of ultra-high-temperature materials combining outstanding hardness, thermal stability, and chemical resistance with significant brittleness, which makes conventional machining nearly impossible. In this study, the influence of fiber laser cutting parameters on the machinability and surface integrity of the (Ti-Zr-Hf-Nb-Ta)C ceramic system reinforced with silicon carbide (SiC) was investigated. The material, developed by the Institute of Materials Research of the Slovak Academy of Sciences, was processed using a Fiber Laser MSF Compact 3001.15L operating in both pulsed and continuous modes. The experimental matrix included variations in laser power, cutting speed, number of beam passes, and assist gas type (nitrogen and argon). The quality of the cuts was assessed in terms of kerf width, surface roughness, heat-affected zone (HAZ), and remelted layer thickness and morphology using optical microscopy and 3D surface analysis. Statistical evaluation of the measured data was performed in Minitab software to determine the most significant parameters affecting cut quality. The findings highlight the importance of coupling thermal–mechanical effects with precise parameter control to ensure reproducible cut quality. These insights provide a deeper understanding of laser–material interactions in HEC systems and offer valuable guidance for future optimization and industrial scalability. The obtained results demonstrated a strong correlation between laser power, cutting speed, and the extent of the heat-affected zone. The optimal combination of parameters minimized surface defects and ensured a stable kerf geometry. The study expanded the current understanding of laser processing of high-entropy ceramics and provided a solid experimental foundation for further optimization and industrial application of these advanced materials.

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# Multiscale experimental analysis and AI-assisted optimisation of bio-based UDCF/ PA11 composite laminates via VBO processing

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Composite overwrapped pressure vessels (COPVs) incorporating thermoplastics enable weldable, high strength, and recyclable structures. Maximizing the strength to weight ratio and minimizing fabrication defects (voids, porosity, poor consolidation) are critical, because even small defects in the structure can significantly degrade mechanical properties, shorten fatigue life, and lower burst pressure, directly compromising the safety margins of hydrogen pressure vessels.

This study presents a comprehensive approach to optimize composite key process parameters using the Vacuum-Bag-Only (VBO) hand lay-up method. The focus is on unidirectional carbon fiber tapes impregnated with a bio-based and recyclable thermoplastic resin (UDCF/PA11), designed for novel lightweight hydrogen pressure vessels. The influence of processing parameters: consolidation temperature, dwell time, and cooling rate on mechanical behavior was systematically investigated through experimental multiscale analysis (quasi-static testing coupled with microscopic analysis). Cross-sectional micrographs show that consolidation at 220–230 °C produces a dense, homogeneous structure with minimal void content, while large, irregular voids persist at 200 °C and are only partially mitigated at 210 °C. Consequently, structural defects are significantly reduced at 220 °C and 230 °C (void content <0.02 %), supporting the superior tensile strength and modulus obtained from quasi-static tests within this temperature range.

Additionally, machine learning models were employed to predict optimal manufacturing conditions. The combined experimental and AI-assisted analysis identified 226 °C, 45 minutes, and slow cooling rate as the optimal processing parameters for the material studied, resulting in high mechanical performance and excellent microstructural integrity.

These results also demonstrate the potential for AI-integrated composite design and manufacturing optimization in sustainable hydrogen storage industry.

Key words: Carbon fiber/thermoplastic composites; Vacuum-bag-only (VBO); Process optimization; Multiscale analysis; Machine learning in composites; Microstructural integrity; Sustainable hydrogen storage.

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# Influence of relative fibre geometry on crack initiation and growth in unidirectional composites under transverse and shear loads

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This work analyses the mechanical response of unidirectional composite materials through a microscale modelling approach, focusing on the initiation and evolution of cracks under transverse and shear loading conditions. Representative Volume Elements (RVEs) with different geometric configurations are developed, varying both the relative orientation and spacing between fibres. Numerical simulations are carried out in ABAQUS/Standard, applying Periodic Boundary Conditions (PBCs) to accurately capture the microstructural response, and incorporating cohesive surfaces at the fibre–matrix interfaces to model degradation and failure mechanisms. Additionally, the Extended Finite Element Method (XFEM) is employed to describe in detail the onset and propagation of matrix cracks.

The micromechanical model is used to reproduce generic plane-stress states under combined transverse and shear loading, from which homogenized stress–strain curves and failure envelopes are obtained. A parametric study is performed for different fibre arrangements, systematically varying the relative fibre angle and volume fraction, as well as the aspect ratio of the RVE. The numerical framework is complemented with an automatic MATLAB post-processing tool that tracks crack nucleation and growth from ABAQUS contour images, quantifying crack length and decohesion angle around each fibre.

The study enhances the understanding of how microstructural morphology affects damage mechanisms and effective properties, providing useful guidelines for the design and optimization of composites with improved fracture resistance under multiaxial loading conditions. Results reveal that variations in fibre orientation and spacing significantly influence the sequence and mode of failure at the ply level, with intermediate relative angles, particularly 45°, promoting higher apparent shear strength and delayed damage initiation compared with other configurations.

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# Multidisciplinary Design Optimisation Framework for Composite Structures with Manufacturing Constraints

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This paper presents a modern Multidisciplinary Design Optimization (MDO) framework tailored for composite structures, with a focus on the structural design of a planar stiffened-skin composite panel under manufacturing constraints. Steadily increasing needs of lightweight and more efficient aerostructures demands fiber-reinforced composites and structural design optimization. In response, this work emphasizes the importance of incorporating structural design optimization early in the conceptual and preliminary phases of the design process—phases where design freedom is highest, but information availability is limited. This reflects the well-known design process paradox: early decisions have significant long-term impact yet must be made with limited data, whereas later decisions occur when design flexibility is greatly reduced.

Despite the critical importance of early-stage optimization, current composite structural design practices often overlook manufacturability, resulting in increased effort to adapt optimized designs for production and added weight leading to suboptimal designs, and longer development cycles. Figure 1(a) illustrates the extended Design Structure Matrix (xDSM) of a conventional structural optimization process [1]. To address these challenges, we propose an enhanced MDO framework (Figure 1(b)) that integrates not only structural performance criteria but also non-functional requirements such as manufacturability and sustainability.

The proposed framework is applied to the design and manufacturing of a stiffened-skin composite panel subjected to combined in-plane compression, shear, and external pressure. A multilevel optimization approach is adopted, enabling the concurrent design of skin and stiffeners. Design variables include the number, geometry, and spacing of stiffeners, as well as laminate design for both skin and stiffeners. This work builds upon our previously established bi-level optimization framework [2–4]. To ensure manufacturability, constraints derived from AFP limitations—such as tool-part collisions and consolidation quality—are incorporated into the optimization. The results highlight the trade-offs between minimizing structural weight and ensuring manufacturability, underscoring the necessity of integrating production feasibility into early-stage structural optimization.

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# Control of Cathode/Electrolyte Parasitic Interfacial Reactions in Composite Utilizing Sulfurized Carbon

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All-solid-state lithium batteries (ASSBs) are gaining prominence as next-generation energy-storage systems because they replace flammable liquid electrolytes with solid electrolytes that offer superior thermal stability. This shift directly addresses the critical safety risks associated with thermal runaway in conventional lithium-ion batteries, while also enabling consistent operation across a wide range of temperatures. Among solid electrolyte families, sulfide-based electrolytes—particularly lithium thiophosphates—are especially attractive due to their high lithium-ion conductivity, mechanical deformability, and suitability for room-temperature processing. Despite these strong advantages, the practical performance of sulfide-based ASSBs continues to be limited by interfacial degradation at the cathode/electrolyte interface, where steep chemical-potential differences trigger parasitic reactions and promote interdiffusion of cathode and electrolyte species. While protective coatings on cathodes have been widely explored to mitigate these issues, the equally important interface between sulfide electrolytes and conductive carbon additives has received comparatively little attention. Carbon, which is essential for maintaining electronic percolation within composite cathodes, can inadvertently accelerate electrolyte decomposition through parasitic electron transfer, generating resistive by-products and destabilizing the composite structure. To address this overlooked challenge, we introduce a simple vapor-phase sulfur treatment of carbon nanotubes (CNTs) that forms a sulfur-rich passivation layer on their surfaces. In this process, CNTs are physically mixed with elemental sulfur powder and heated to 300 °C, where sublimated sulfur vapor reacts with the carbon surface. This low-cost, scalable approach avoids the complexity of chemical vapor deposition while producing CNTs that suppress electron-driven electrolyte degradation and maintain adequate conductivity. The sulfur-containing surface layer also exhibits strong chemical compatibility with sulfide electrolytes, acting as a self-passivating barrier that minimizes interfacial reactions. XPS, EELS, and TOF-SIMS analyses validate the effectiveness of this strategy, demonstrating its promise for enhancing stability and durability in sulfide-based ASSBs.

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# Modeling Strategies of Thick Ply Stack Draping Simulations for Large Carbon Composite Components

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The continuously increasing demand for aircraft has augmented the need for advanced automation technologies in the aviation industry. Established automated processes are currently restricted to simple or moderately complex geometries with small stacks. The goal of this research is to enable the development of an automated manufacturing process that allows such automated manufacturing for thick ply stacks (~ 10 mm). Therefore, stacks of dry fabric are preformed utilizing the diaphragm process and subsequently impregnated with resin transfer molding. A key component of this effort is a detailed investigation of the draping behavior of thick laminates using finite element analysis. While draping simulation is already a well-explored field, most studies focus on thin, small and simple components [1, 2]. Computational effort depends strongly on the number of elements (part dimension, thickness, number of plies) and the required resolution for manufacturing effects, limiting the transferability to larger parts. The presented study aims to simulate the forming behavior of thick ply stacks and the localization of binder fixation points. We conduct: 1) tests on two small-scale components with high complexity (involving tapering, joggles and curvatures); followed by 2) the upscaling to large demonstrators. We use the non-crimp fabrics (NCFs) NCAMP DRNF 710092 (V/90°/V/0°/PB) and NCAMP DRNF 710089 (PB/+45°/V°/-45°/V) as well as unidirectional (UD) layers DRWF 720001 (V/0°/PB) from Teijin. The materials are tested using standard methods to calibrate the test-data based *FABRIC model in Abaqus/CAE. We analyze different modeling strategies (element size, NCF and binder point connection behavior, homogenization strategies for ply bundles), process approaches (step chronology and single vs. double diaphragm forming) and strategies to reduce computation time (mass scaling and summarizing multiple layer packages). The aim is to predict the draping quality accurately, allowing for a virtual process optimization.

[1] Osterberger, et al. (2022) https://doi.org/10.3389/fmats.2022.865477

[2] Bardl, et al. (2018) https://doi.org/10.1016/j.compositesb.2017.08.007

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# Multifunctional bio-composites as topsoil covers for forestry and agriculture applications

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Topsoil covers (TSCs) are bio-based mulching films designed to support reforestation and agriculture in arid conditions by inhibiting weed growth and reducing soil moisture loss after transplantation. This study was focused on developing bio-based composites as TSCs by coupling xanthan gum (XG) and wood fibers. The aim was to find a viable, high-performance alternative to commercial plastic mulching films, which pose a serious threat to the environment by releasing microplastics into the soil. TSCs were produced by first mixing XG and wood fibres in aqueous solution, and then cross-linking the resulting hydrogel composites with citric acid (CA) at various concentrations and under specific heat treatment conditions. These TSCs exhibited exceptional water absorption capability (up to 1500 % increase over the original weight), retaining their shape even after multiple absorption and drying cycles. The water vapour permeance (9.5·10^-6 g/(Pa·s·m²)) was comparable to that of a commercially available woven fabric polypropylene (PP) mulching film. The average penetration resistance of the composites, which simulates the resistance of TSCs to weed perforation, was statistically higher than that of the commercial PP material. Single flame source tests demonstrated the non-flammable behaviour of the produced topsoil covers, despite the presence of wood fibers in their composition. Moreover, the wood fibers provided dimensional stability and minimal shrinkage (15.4%) after exposure to outdoor conditions for two months. Furthermore, after 7 months of exposure, more than 60% of the sample mass was biodegraded. Field trials conducted to assess the effect of TSCs on tree growth demonstrated that the produced TSCs maintained excellent plant health. This research showed the potential of xanthan-based composites as TSCs when cross-linked with citric acid, offering a simple, cost-effective, and scalable technology for forestry and agriculture applications with superior water-regulating properties.

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# Influence of Continuous-Wave and Pulsed Mode Fiber Laser Parameters on Machining Quality of CFRP Composites

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This study provides an in-depth evaluation of how critical fiber laser cutting parameters affect the machining quality of carbon fiber reinforced polymer (CFRP) composites when using both continuous-wave (CW) and pulsed-mode (PM) laser regimes. As CFRP materials continue to gain widespread adoption in lightweight structural and high-performance engineering applications, there is an increasing demand for machining technologies that can deliver high precision while minimizing thermal and mechanical damage. Fiber laser cutting represents a promising non-contact alternative to traditional methods, offering flexibility, reduced tool wear, and the potential for high processing speeds. Nevertheless, excessive heat input remains a major challenge, often leading to matrix degradation, delamination, or fiber pull-out, which negatively influence the structural integrity of the final component. The experimental part of the work focuses on the effects of laser power, scanning speed, and the number of laser passes on key quality indicators, including kerf width, heat-affected zone (HAZ), heat-affected zone from bottom (HAZ_B), and overall cutting performance. CFRP laminates were processed under controlled laboratory conditions using both CW and pulsed fiber laser modes. The results demonstrate clear differences in the cutting mechanisms observed for each regime. Laser power was identified as the primary factor influencing kerf width, with higher power consistently leading to wider kerfs. Scanning speed exhibited the strongest effect on thermal damage; increasing the speed significantly reduced both HAZ and HAZ_B dimensions. Overall, the findings contribute to a better understanding of the trade-offs associated with CW and pulsed fiber laser cutting and offer valuable guidance for the optimization of process parameters in industrial CFRP machining.

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# Novel multifunctional sandwich composites for thermal management and mechanical performance

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In this work, multifunctional composites were developed for dual applications: thermal energy storage and structural performance. The innovative core consisted of epoxy (EP) foam embedded with microencapsulated phase change materials (PCMs), designed to optimize latent heat storage. The integration of PCMs enabled the storage and release of thermal energy, making these materials suitable for applications where temperature regulation is crucial. The EP foam cores were combined with external skins made of epoxy/carbon fibre laminates, resulting in lightweight and mechanically efficient sandwich structures. The use of carbon fibre skins provides stiffness and strength-to-weight ratio, while the foam-PCM core contributes to the thermal functionality. This synergy between mechanical and thermal performance makes the composite panels suitable for advanced engineering applications, especially in fields where both weight reduction and thermal management are essential. Comprehensive microstructural analysis confirmed a strong and uniform interfacial bonding between the foam core and the laminate skins. This was critical for maintaining the structural integrity of the panels under mechanical loading conditions. Mechanical testing showed that the sandwich composites exhibit flexural and compressive properties comparable to those of conventional EP sandwich panels without PCMs, indicating that the addition of PCMs did not significantly compromise the structural performance. Furthermore, thermal analysis demonstrated enhanced energy storage capacity and improved insulation behaviour. The PCM-filled foams exhibited a notable phase transition enthalpy, effectively absorbing and releasing heat within a targeted temperature range.These advanced multifunctional composites represent a promising solution for sectors such as aerospace, automotive, and refrigerated transport, where thermal regulation, weight efficiency, and structural reliability are critical.

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# Toward rheological characterisation of thermoplastic pre-impregnated UD tape, for its recycling and reuse.

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Thermoplastic composite winding enables the manufacturing of lightweight tanks particularly suited for the transportation sector. Those composite-based tanks are made of valuable tapes constituted by continuous fibers embedded in a polymeric matrix. Nevertheless, a classical recycling without downcycling of these structures is a major technical and economical challenge.

In order to retain the value of the composite, the end-of-usage processing should preserve the continuity of the fibers to maximize the mechanical properties and maintain the fibers embedded in the matrix to simplify reuse.

The global aim of the project is to enable material circularity of thermoplastic composite wound structures through innovative material design, peeling-based disassembly and tape reprocessing using a holistic design for reuse approach. A multiphysics and multiscale simulation tool is developed to model the mechanisms involved during the different processes.

The work presented here will combine experimental campaigns, modeling and simulation towards a rheological characterization of thermoplastic pre-impregnated UD tape, for its recycling and reuse.

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# Experimental Evaluation of Fiber Laser Cutting Parameters and Quality Characteristics in GFRP Machining

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This study presents a detailed investigation into the influence of key fiber laser cutting parameters on the machining behaviour and cut quality of glass fiber reinforced polymer (GFRP) composites. With GFRP materials increasingly used in transportation, aerospace, and structural applications, achieving efficient and damage-minimised machining has become essential. Laser cutting represents an attractive alternative to conventional mechanical methods, offering high precision and the absence of tool wear; however, the heterogeneous structure of GFRP leads to challenges such as kerf taper, heat-affected zone (HAZ) formation, and surface roughness degradation. In this research, GFRP laminates were processed under controlled fiber laser cutting conditions, where the effects of laser power, scanning speed, assist gas pressure, and focus position were systematically evaluated. Results showed that laser power and cutting speed were the dominant factors governing kerf formation. Higher power increased kerf width due to intensified thermal penetration, while increasing cutting speed effectively reduced heat accumulation, leading to smaller HAZ and improved kerf taper. Assist gas pressure contributed to debris evacuation, reducing surface roughness, although excessive pressure introduced minor kerf widening effects. These trends align with reported parameter sensitivities in GFRP processing, where cutting speed notably influences thermal damage, and power strongly affects kerf geometry. Furthermore, the observed correlations between specific point energy ESP, kerf width, and material removal behaviour confirm that energy concentration plays a crucial role in process stability and efficiency. Overall, the findings provide a practical basis for parameter optimization in GFRP laser cutting, offering insights for achieving narrow kerfs, reduced thermal damage, and improved machining quality in industrial applications.

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# Historical Perspective on Modeling of Processing of Polymer Composites

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History of modelling of Composites Manufacturing processes can be traced back to modelling of polymer processes. Extrusion to process thermoplastics was first used in Germany in 1935 and it was not until 1962 that McKelvey in his book on Polymer Processing formalized modelling of polymer processes such as extrusion and injection moulding in a text book. Traditionally, composite manufacturing followed a trial-and-error approach, and it was not until the mid 1980s that process modelling and simulation gained attention as a tool to improve yield in manufacturing and play a role in process design.

However, there were many challenges associated with process modelling due to multiple coupled phenomena that exchanged mass, momentum, and energy at multiple scales of these heterogeneous materials. Moreover, characterisation methods needed to be developed to create a database of material properties such as viscosity and permeability for process modelling to address the phenomena that occur more realistically during manufacturing. These challenges and their timeline are addressed.

The history of process modelling is discussed to reveal the synergy between raw materials, process parameters, and the microstructure of composites. The impact of process modelling will be outlined, and the future of this field is discussed.

The adoption of FEA in the 1980s and their development for more complex simulations, allowing detailed predictions of flow and thermal behaviour, allowed for optimisation of composite manufacturing processes. Homogenisation techniques, multiscale modelling, and the integration of process structure and property models emergence along the way to couple process parameters with material performance is presented for well-known composite manufacturing processes. The question of how this can potentially lead to the integration of machine learning and AI into composite process models to optimise manufacturing in real time is discussed.

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# Dynamic characterisation using laser impact loading of damage properties of UHMWPE-fibres based composites used in ballistic protection

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Composites based on Ultra-High Molecular Weight Polyethylene (UHMWPE) fibres are currently among the most widely used materials in personal ballistic protection solutions due to its specific performance. In order to improve and optimise the efficiency of such protection against ballistic impact, the material properties requires dynamic characterisation of the properties due to their strain rate sensitivity. However, this dynamic characterisation is as crucial as difficult to realise for UHMWPE-fibres based composites and innovative characterisation techniques must be investigated to determine the interlaminar damage and fracture properties.

Among these techniques, LASer Adhesion Test (LASAT) is a recent dynamic testing method for composites that can reach ballistic strain rates. In this work, LASAT experimental campaign is realised on the Hephaïstos platform at PIMM laboratory under various loadings conditions. Different laser parameters and sample preparation are considered. For instance, laser intensity and focus size of the laser source were varied. Samples were coated with various techniques so as to promote the heat dissipation and different containments to improve wave propagation through the sample, were investigated. Velocity measurements is achieved using Photonic Doppler Velocimetry and post-mortem analyses using X-Ray micro-computed tomography are performed. The collected data is correlated to establish a link between typical damage and back-face velocity profiles, and to identify the associated mechanical phenomena and real internal interlaminar damage. Finally, the influence of the different loading conditions on the interlaminar damage occurrence is evaluated. This work provides valuable insights about the relevance of the LASAT test as a dynamic testing method for the UHMWPE-fibres based composites and for characterisation of materials used in ballistic applications. The main advantage of this experimental technique comparatively to dynamic conventional mechanical testing methods is that loadings induced reach the strain rate involved in ballistic impact while remaining perfectly controlled.

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# Recyclable Building Block Structures based on local use of cleavable resin: manufacturing and separation studies

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Thermoset-based fiber-reinforced polymers (FRP) benefit from high thermomechanical properties, excellent fiber-matrix adhesion and long service life. However, due to their crosslinked network structure, recycling of thermoset-based FRP remains an unresolved issue. Cleavable resin systems represent a versatile and efficient solution to solve this challenge. Their network structure contains bonds that can be degraded by applying mild solvents and moderate temperatures. According to the approach suggested here, targeted local use of cleavable resins allows realization of Building Block Structures (BBS). This means that Building Blocks (BB) of limited geometrical complexity made of FRP with conventional epoxy matrix are combined to more complex Building Block Structures (BBS). The resulting multi-matrix composites (MuMC) combine the excellent properties of epoxy resins and the high value of reinforcing fibers with the possibility to efficiently separate and flexibly reuse or repurpose the BBs.

To analyze the feasibility of such an approach, pultruded bars are selected as BBs and Recyclamine resin is used as cleavable resin. In a first step, a liquid composite molding (LCM) process is set up that allows reproducible manufacturing of a generic BBS with variable geometrical features and defined resin-rich cleavable areas. The mechanical performance of this MuMC-BBS is evaluated by bending tests. In a next step, cleaving trials in acetic acid are performed. These give first insights into the required diffusion time and practicable diffusion paths within the BBS. Finally, the surface and mechanical properties of the reclaimed BBs (pultruded bars) are analyzed in order to evaluate their suitability for potential repurposing.

The contribution presents new solutions to the pressing problem of thermoset-based FRP recycling and identifies innovative applications for cleavable resin systems as part of MuMC designed to meet both loadability and sustainability requirements.

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# Thermoplastic Pultrusion of Bio-PA6 Hybrid Carbon Fiber Laminates with Enhanced Multidirectional Performance

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This work carried out within the framework of the EU funded FOREST project, reports on the development and characterization of thermoplastic pultruded laminates manufactured from bio-based polyamide 6 (bio-PA6) matrix reinforced with hybrid carbon fibre architectures. The laminate design combines unidirectional (UD) continuous carbon fibre plies with randomly oriented recycled carbon fibre (rCF) nonwoven mats, aiming to couple high longitudinal stiffness and strength with improved multidirectional performance and interlaminar toughness. The bio-PA6 matrix was tailored via synthesis parameters and additives to ensure low viscosities and efficient fibre wetting during pultrusion.

Multilayer laminates with a specific UD/rCF stacking sequence were produced and evaluated in terms of processability, dimensional stability, and impregnation quality. Mechanical performance was assessed by tensile, flexural, and impact tests, while microstructural investigations using electron microscopy provided insights into resin distribution and fibre/matrix interfacial bonding. The results indicate that the introduction of rCF mats enhances transverse properties, impact energy absorption, and out-of-plane stiffness, without compromising the high axial properties characteristic of UD composites.

The study validates a novel thermoplastic pultrusion manufacturing process and confirms the feasibility of manufacturing sustainable laminates by combining bio-PA6 with hybrid reinforcements of pristine and recycled carbon fibres The resulting materials exhibit a favourable balance of mechanical performance, lightweight, and sustainability, offering strong potential for structural applications in the transportation sector where both high performance and recyclability are required.

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# Experimental Validation of a Lamb Wave–Based Damage Detection Methodology for CFRP Laminates Used in Aircraft Structures

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As the application of carbon fiber reinforced plastic (CFRP) composites in aircraft structures continues to expand, the demand for reliable and efficient damage detection technologies has become increasingly critical. In this study, a Lamb wave–based damage detection technique utilizing piezoelectric (PZT) sensors was proposed for CFRP composite specimens fabricated with the same specifications as those actually used in aircraft structures. The methodology converts PZT sensor signals obtained from both undamaged and damaged specimens into periodic waveforms using a sinusoidal Gaussian function, extracts scattered signals, and determines the group velocity through the Hilbert transform. The damage location is estimated using a mapping function, and the damage size is visualized through a circular function.

Experiments were conducted using 700 mm × 700 mm CFRP laminated plates that are actually employed in aircraft structures. These plates were fabricated with 30, 40, and 50 plies, and were tested under sensor spacing conditions of 90 mm, 200 mm, and 285 mm, respectively. A total of 27 damage detection tests were performed to evaluate the accuracy and consistency of the proposed methodology under various laminate thicknesses and sensor arrangements. The damage detection errors ranged from 1.8 to 16.9 mm for the 90 mm spacing, 1.1 to 18.1 mm for the 200 mm spacing, and 1.5 to 13.8 mm for the 285 mm spacing. Despite variations in sensor spacing and laminate thickness, the proposed methodology maintained high detection accuracy and consistent signal response.

The proposed Lamb wave–based damage detection methodology was experimentally validated using CFRP laminates that replicate the actual structural configuration of aircraft composites, demonstrating stable and reproducible performance across different sensor spacing conditions. This technique is expected to be effectively applied to structural health monitoring (SHM) and maintenance strategies for next-generation aircraft, including eVTOL and UAM platforms.

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# Finding the right lenghtscales for microstructural description in unidirectional composites

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Unidirectional thermoplastic composite tapes are essential materials for high-performance applications. They combine excellent mechanical properties with compatibility for automated, large-scale manufacturing. However, the fabrication of unidirectional composites is technologically challenging, leading to microstructural variability. Local variations in fibre architecture and porosity can significantly affect the macroscale mechanical behaviour, including damage initiation and propagation.

The work of Gomarasca et al. (2025) has demonstrated that porosity locations can correlate with local fibre architectural characteristics in unidirectional composite tapes. Microstructural heterogeneities such as pore clustering and fibres meandering with high transversal tortuosity and misalignment through the tape were shown to propagate across multiple lengthscales, from micro to mm scale. Knowledge of feature propagation constitutes a key opportunity for statistical representation, process control, and predictive modelling. Capturing these correlations and propagation distances is essential for defining representative or statistically relevant volume elements (RVEs/SVEs) and for realistic microstructural generation.

Building on the recent work described above, we extend the methodology for three-dimensional characterisation and analysis of pore–fibre interactions in unidirectional thermoplastic prepregs to larger length scales. Using X-ray micro-computed tomography at single fibre resolution, we quantify pore morphology and microstructural descriptors such as fibre tortuosity and meandering effects, and we evaluate their spatial correlations along the fibre direction. The resulting statistical distributions and correlation lengths reveal that characteristic features in fibre architecture and pore networks extend over millimetre-scale distances.

The determination of these characteristic lengthscales allows for the quantification of spatial correlations and variability, informing the selection of representative or statistically relevant volume elements. This statistical insight lays the groundwork for generating synthetic microstructures that preserve the key heterogeneity features observed experimentally.

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# Hot/Wet Interlaminar Fracture Characterisation of A Newly Developed Phenolic-Triazine Ester Composite System

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There is a drive to develop high-temperature organic matrix composites to reduce weight and costs within the aerospace and energy sectors. Cyanate ester resins (particularly phenolic-triazine, or PT, resins) are a class of thermosetting polymers that possess top-of-the-range high-temperature properties for use in extreme environment applications. PT resin blends exhibit excellent thermal stability and possess attractive processability attributes, enabling manufacturing methods that are not feasible with their inorganic counterparts. Although carbon fibre reinforced polymers (CFRPs) that incorporate PT resins are capable of operating in temperatures well over 200°C in their as-manufactured dry state, the effect of moisture-rich, elevated temperature environments, or hot/wet environments, on material performance is less explored. To expand the possible applications of PT resin composites, it is essential to understand material behaviour through characterisation at varying moisture saturations and elevated temperatures. As delamination is a leading failure mechanism within laminated composites, it is imperative to measure the resistance to delamination, known as fracture toughness, of advanced composite materials to inform their design considerations and subsequent applications.

Within this work, a newly developed PT resin blend was integrated into an intermediate modulus CFRP system, and extensive hot/wet experimental characterisation was conducted. Long-term moisture cycling, including drying stages and conditioning at 40%, 60%, and 85% relative humidity, was carried out. Dynamical mechanical analysis of each subset was conducted to obtain loss and storage moduli and glass transition temperatures. Mode I and Mode II interlaminar fracture properties were determined using double cantilevered beam specimens and end-loaded split specimens, respectively. Interlaminar shear strengths were determined using short-beam shear specimens. Scanning electron microscopy and computed tomography imaging techniques were used to conduct fractographic studies, allowing the identification of notable features between moisture contents and test temperatures. Through substantial testing, relationships between moisture, glass transition temperature, test temperature and mechanical properties were derived.

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# Modelling degradation and healing effect on inductive welding of carbon fiber reinforced composite

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Electromagnetic Induction Welding (EMIW) is a promising technology for carbon fiber reinforced polymer (CFRP) composite welding without adding material, with high rates and low energy consumption. However, the welded interface performance is critical to the whole assembly performance, hence the need to properly account for the healing prediction during process development.

During the manufacturing process of the parts, before their use in welding, they undergo multiple heating cycles, such as stamping forming and autoclave consolidation. These processes expose them to high temperatures, often exceeding the degradation threshold of the thermoplastic matrix, sometimes for extended periods. This thermal history causes the thermal degradation, an irreversible change, which affects healing kinetics, and thus the welding time required to achieve the desired weld performance. Besides, cooling rate affects crystallization kinetics; a slower rate will be required for greater crystallization.

These constraints led to design a dynamic EMIW process guaranteeing good healing and crystallization of these materials by integrating all the constraints from the design phase of the tooling, the inductor, as well as the process parameters.

In this paper, healing and crystallization models will be presented along with the methodology for identifying parameters. Furthermore, these models will be coupled to a magneto-thermal model in order to simulate and obtain the degree of healing and crystallization of welded parts.

This information will allow a better knowledge of the thermal cycles necessary for good welding. They will also allow the design and parameters of the welding system to be adapted according to the thermal history of the materials to be welded.

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# A Pathway to Circularity in Composite Manufacturing:

# Targeting High-Impact Consumables

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The production of composites depends on consumable materials to achieve high-quality. These consumables, including breather, vacuum bags etc, play critical roles in curing and ensuring the quality of composite components. Despite their role in achieving necessary quality standards, the market for consumables offers limited options for sustainable alternatives, leaving few choices that align with environmental goals. This provides an opportunity for innovation to improve circularity and reduce waste volume and carbon footprint.

This project addresses one aspect of this by assessing the types, quantities, and environmental impacts of consumables used across a research facility. The study takes a systematic approach, analysing all purchased consumables over a 3-year period. To quantify the impact of consumables and inform decision making on priority consumables, a cradle-grave life cycle assessment (LCA) was conducted across several consumable categories.

Key findings indicate that breather, tape, and bagging film are the primary drivers, particularly in terms of Global Warming Potential (GWP 100). These alone account for 62.1% of the total GWP, with breather fabric being the most significant. Additional sensitive work highlights the differences between manufacturing process. The results indicate that within pre-preg autoclave processing, high impact consumables are encompassed by those discussed above, however for large scale infusions, these high impact consumables are overtaken by tubing and other specific infusion products, like flow mesh and infusion channels.

Alternative materials and waste reduction methods are assessed both for their environmental benefits and their feasibility within the high-precision demands of composite manufacturing. Solutions were assessed within two main categories: substitution with new products, and recycling of existing consumables.

These findings have important implications for the broader composites industry, providing critical insights to drive innovation. By addressing the environmental impacts of consumables and fostering the development of sustainable alternatives, this research supports the transition toward more responsible manufacturing practices.

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# A multi-drop filling process of multi-matrix on multi-fabric for deployable composites fabrication

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Fiber-reinforced polymers (FRPs) as lightweight structural materials are increasingly in demand for applications in advanced industries such as soft robotics and deployable aerospace structures. In such advanced structures, both the superior mechanical properties of existing composites and exceptional flexibility in specific areas are simultaneously required. The processing technology for manufacturing monolithic composites that simultaneously possess the trade-off characteristics of rigidity and flexibility without requiring separate structures such as dissimilar material joints or hinges can satisfy these requirements.

This study proposes a multi-drop filling process of multi-matrix on multi-fabric preform for fabricating monolithic FRP structures tailored for deployable composite applications. Combining rigid and flexible epoxy resins enables precise resin patterning, overcoming the limitations of traditional single-resin systems. In addition, A layered structure utilizing multiple fibers with different materials and weaving structures was employed, enabling flexible bending without compromising structural strength. This approach allows the selective imparting of mechanical properties within monolithic structures, facilitating deployment mechanisms and ensuring stability under repetitive cycles without hysteresis.

The resulting FRP structures exhibit a flexural modulus of 6.95 GPa for rigid sections and 0.66 GPa for foldable sections, allowing selective folding with a radius of curvature less than 0.5 mm. The successful fabrication of a monolithic composite with a triangulated cylindrical origami (TCO) structure highlights the potential for mass production of advanced FRP structures, suitable for next-generation rigid–soft robotics and deployable aerospace structure applications. Unlike existing soft materials, the TCO FRP demonstrates durability under repeated deployments at high strains of up to 80%, producing a significant deployment force of 2.75 kgf, enabling repetitive motion. It is expected that this work significantly advances the development of adaptable, scalable materials for next-generation robotics, aerospace systems, and deployable structures.

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# Reinforcement Effects of Plasma-treated Carbon Nanotubes on Polyimide Nanocomposites

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In this study, significant enhancements in the mechanical properties and thermal resistance of polyimide (PI) nanocomposites were achieved through the incorporation of a very small amount of plasma-treated carbon nanotubes (CNTs). PI is a super engineering plastic widely used in electronics, aerospace, and other high-performance applications. Recently, the development of lightweight PI materials with improved strength and thermal resistance has attracted considerable attention. In this context, nanocarbon materials have emerged as promising nanofillers for designing lightweight, high-performance polymer nanocomposites. Among various nanocarbons, CNTs are particularly attractive because of their high aspect ratio and large specific surface area in addition to their excellent mechanical, thermal, and electrical properties. However, the chemically inert surfaces of pristine CNTs often result in poor compatibility with polymer matrices and severe aggregation that limit their reinforcement ability in polymer nanocomposites. To address these limitations, we conducted plasma treatment to activate the CNTs surfaces and successfully introduced isocyanate groups. As a result, the PI/CNTs nanocomposites with plasma-treated CNTs exhibited markedly higher tensile properties and improved thermal resistance compared to PI/CNTs nanocomposites with untreated CNTs, even at extremely low filler contents. For example, the Young's modulus and tensile strength increased by 83% and 51%, respectively, with the addition of only 0.001 wt% of plasma-treated CNTs. Furthermore, the elongation at break was maintained at the level of neat PI, leading to an overall 41% improvement in toughness. In terms of thermal properties, the nanocomposites with 0.002 wt% of plasma-treated CNTs exhibited the highest thermal decomposition temperature, which was 15 ºC higher than that of PI. These results demonstrate that effective interfacial modification through plasma treatment enables significant reinforcement of PI even at ultra-low CNT loadings.

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# Time-resolved Study of CF/PPS and CF/Epoxy Aging Under Hygrothermal and Irradiative Conditions

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The growing interest in unidirectional (UD) fiber-reinforced thermoplastic composites and [±α]-laminates for high-pressure hydrogen applications has raised concerns about their performance and resilience after prolonged exposure to UV radiation and moisture. Such exposure can cause significant damage to the thermoplastic polymer matrix, leading to material strength degradation.

To quantify the effects of these factors on thermoplastic composites, a comparative aging study was conducted between UD polyphenylene sulfide (PPS)-carbon fiber composites and thermoset UD epoxy-carbon fiber composites. Specimens were subjected to four environmental degradation conditions relevant to industrial applications: hygrothermal exposure, immersion in water, simulated daylight cycles in a UV climatic chamber, and high-pressure hydrogen. The resulting effects on mechanical and chemical properties were analyzed using quasi-static tensile tests, fatigue tests, ultrasonic time-of-flight measurements, FT-IR spectroscopy, and scanning electron microscopy.

Tensile tests revealed that, unlike the temperature-dependent increase in matrix crystallinity and stiffness observed for the [90°]-UD-PPS material, the [±75°]-PPS laminates showed no initial increase in stiffness under hygrothermal conditions, only a gradual decrease in stiffness and ultimate tensile strength (UTS) over time. UV weathering led to an initial stiffness increase for the UD-PPS, with no similar effect for the laminate. UV irradiation resulted in a decrease in IR bands associated with crystallinity, and additional hydroxy and carboxyl groups were detected on the surface, indicating oxidation. Compared to the similar increase in UTS and stiffness for pure UV and weathering, a significantly larger decrease in fatigue resistance was observed for weathered samples. The correlation between relative stiffness from tensile tests and ultrasonic measurements validates a new non-destructive method for detecting aging in CFRP composite specimens.

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# A framework for designing a 2D Woven Carbon/Carbon Composite model, validated with a structural scale demonstrator

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Carbon/Carbon-like Matrix Composites provide high stiffness-to-weight ratio and excellent high-temperature resistance, making them ideal candidates for functional components in aerospace and defense. In this context, an original 2D woven composite with carbon fibers and a weak ceramic matrix infiltrated by the PIP process has been developed, available in two grades differing in density and thus mechanical properties. One revels a quasi-linear and low-damage behavior with high mechanical performances, and the other one exhibits more pronounced damage accumulation. Based on experimental results, we first assume that our material behaves like a C/C composite.

While 3D and 4D C/C composites have been extensively studied, regarding fatigue, oxidation, and high-temperature testing, 2D woven C/C composites remain poorly documented in the literature. Macroscopic damage models developed for CMCs – such as ODM at ONERA – or for 3D C/C composites are not directly transferable. Furthermore, academic studies usually focus on the coupon scale, and remain to be validated at structural scale. Therefore, the objective of this study is to develop a constitutive law specifically tailored to the provide 2D woven composite, and validated with respect to a structural demonstrator.

The methodology relies on close experimental–numerical interaction. An initial experimental database served to preselect relevant constitutive model candidates. Complementary tests will be conducted to complete the models selection and calibrate their parameters. Ultimately, a constitutive model will be chosen as a trade-off between representativity and applicability to large structure.

In this work, a demonstrator test campaign will be designated at sub-component level to challenge our numerical approach. The demonstrators will be subjected to various loadings: tension–compression, bending, torsion, and multi-axial combinations. The campaign will assess the relevance of the proposed modelling framework by confronting numerical predictions and detailed multi-instrumented experimental data.

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# Influence of Fibre Misalignment and Temperature on the Compressive failure of GFRP

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Fibre-reinforced polymers (FRPs) are key structural materials and have become indispensable in many technical fields such as wind energy and aviation. The design of industrial components typically begins at the coupon level. Standard tests are usually performed on nominally defect-free specimens at room temperature. In contrast, real structures exhibit manufacturing deviations and operate under demanding environmental conditions, including elevated temperatures [1,2]. To obtain realistic mechanical properties these conditions must be reproduced as closely as possible [3].

This work investigates the influence of defined fibre misalignments and elevated ambient temperatures on the compressive behaviour of FRPs. Including the reference sample, the compressive properties of four test specimen configurations were tested at four ambient temperatures (20, 50, 70, 90 °C).

Regardless of the test specimen configuration, increasing test temperature results in reduced strength, and this reduction becomes more pronounced at higher ambient temperatures.

Furthermore, it can be observed that at low/moderate temperatures (22, 50 °C), the fibre misalignment has a significant influence on the strength, but surprisingly, at elevated temperatures (70, 90 °C), the fibre misalignment suddenly plays no or only a minor role.

A possible explanation for this behaviour can be found in the representative damage patterns (Figure 2). The microscope images clearly show that the damage behaviour changes from fibre breakage to buckling. This change does not occur abruptly, but can be observed gradually as the temperature rises. Initially, local areas buckle and finally global buckling occurs.

These results indicate a transition region between 50 and 70 °C in which the failure behaviour changes from fibre to matrix dominated. This characteristic temperature T° seems to occur well below the glass transition temperature (110 °C), but is critical for the design of FRP structures.

References

[1] Kulkarni, Pritam, et al.

[2] Boyer, R., et al.

[3] Alves, M. P., et al.

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# Extensional Viscosity of Polyaryletherketones and its Composites in Material Extrusion Additive Manufacturing

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Material extrusion (MEX) is an additive manufacturing (AM) technique in which molten polymeric feedstock is extruded through a heated nozzle and deposited in successive layers onto a platform in order to build a three-dimensional part. During the extrusion and deposition stages in MEX, the feedstock material is subjected to complex mixed flows containing both shear and extensional components. Each flow component influences the feedstock's behaviour in fundamentally different ways: with polymers typically exhibiting strain hardening under extensional (stretching) deformations, in contrast to the shear-thinning response commonly observed during shear flow. As a result, an inappropriate balance of an MEX feedstock polymer's shear and extensional rheology can negatively affect its extrudability, layer to layer adhesion, and the mechanical performance of the final printed part. Despite this, the extensional component to flow in MEX is often neglected, with shear flow assumed to dominate at all parts of the extrusion process. It is crucial to understand both components in order to gain a greater understanding on their impact in MEX. Extensional flow is dependent on the intrinsic properties of the feedstock, the printing settings and the extrusion hardware and can be further impacted by the addition of composite fillers. In this paper, an extensional viscosity fixture (EVF) mounted on a rotational rheometer, is used to experimentally compare the extensional viscosity of a low melt Polyaryletherketone (PAEK) and PAEK composites at melt temperatures. Such that the impact of filler morphology and concentration on the extensional viscosity can be determined, and its influence in the MEX setting.

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# Thermal fatigue and hygrothermal aging behaviour of CNT/GFRP/CFRP composites

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Anti-icing/de-icing (AI/DI) is vital for flight safety, which is conventionally achieved by hot air bleed systems, while facing new challenges for the latest generation aircraft with composite wings. Electro-thermal systems are promising alternatives, owing to their high energy efficiency, low maintenance requirements and the absence of bleed exhaust holes. In particular, carbon fibre reinforced plastics (CFRPs) integrated with heating elements, e.g., carbon nanotubes (CNTs)/glass fibre reinforced plastics (GFRPs), was thought as one promising candidate for aerostructures with AI/DI functions. However, the difference of thermal expansion and moisture absorption between different components, will ignite the internal stress between interfaces under the cyclic thermal and hygrothermal loading, and affect the strength of composites. Regarding the thermal load of the aircraft, the external static air during the flight ranging from -55℃ to 20 ℃. On the other hand, -20℃ to 10 ℃ possess the highest risk of ice accretion, with the AI/DI system switched on, the temperature will range from -20℃ to 80 ℃. In combination, the temperature range for the thermal cycling is set from -55℃ to 80 ℃ in this work.

During 10,000 thermal cycles, the interlaminar shear strength (ILSS) of the composites were evaluated periodically using double beam shear tests, which decreased continuously and stabilized at ~88% after 2,000 cycles with appropriate thermal stability. While for the hygrothermal aging, the synergy effect of thermal and moisture significantly accelerated the degradation of the composites, and resulted with a reduction of ILSS by more than 50% after 64 days at 80 ℃. Microstructures reveal that the debonding and voids caused by the internal stress and matrix plasticization, are the primary factors in weakening the interfacial properties. Furthermore, after either thermal cycling or hygrothermal aging, no visible damage was observed around CNTs, indicating its excellent compatibility with FRP composites.

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# Predicting longitudinal strength of unidirectional composites using a discrete damage model within full-field FFT-based simulations.

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The tensile strength of unidirectional fiber-reinforced composites is affected by stochastic fiber breakage, typically following a Weibull distribution, and the subsequent redistribution of loads. Various strength models exist, but they have limitations in predicting fiber break density, clustering, and failure. This study introduces a strength framework that employs full-field FFT-based computations coupled with a discrete fiber damage model. The equilibrium is computed for a voxelized 3D microstructure of the composite, in which fibers are organized into blocks susceptible to breakage. Monotonic stress-based loading is imposed, and macroscopic failure is declared when equilibrium cannot be maintained. Compared with existing models, this approach reduces reliance on assumptions about load transfer, matrix contributions, and clustering definitions while enabling large-scale simulations. Moreover, alternative fiber strength distributions and matrix behaviors can be readily implemented, since they are not part of the modeling assumptions. The simulation framework is evaluated within the context of the latest comprehensive benchmark established by the community, ensuring consistent inputs and comparability with experimental results. After establishing consistent numerical parameters and domain sizes, the model is compared with existing models and experimental data. The findings indicate that this method provides stress-strain predictions that align more closely with experiments than those of other models, particularly noting a lower strength alongside low-modulus softening. However, similar to most models, the fiber break density is overestimated and follows a similar trend. Sensitivity analyses are conducted on the fiber debonding length and failure criteria; however, these do not fully resolve the discrepancies in fiber break density observed in experimental data. Ultimately, an alternative set of Weibull parameters is identified that satisfies both the stress-strain curve and the fiber break density but does not align with single-fiber tests, suggesting that extrapolating the Weibull law from single-fiber tests to shorter lengths may be incorrect.

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# Towards a better understanding of the fibre/matrix adhesion in flax/epoxy composites

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Environmental concerns are driving research into sustainable composite materials to minimize the ecological footprint of industries such as construction and transportation. In this context, plant fibres offer promising alternatives to synthetic fibres like glass. Those fibres are valued for their favourable mechanical properties and low density.

The fibre/matrix interface is a key parameter that contributes to the mechanical properties of the composite, as this is where the load transfers and damage initiation occur. At the nanoscale, this boundary may evolve into an interphase, a narrow region with a gradient of mechanical properties. However, there has been very few works that characterise the thickness and the properties of the interphase region for bio-based composites. Previous studies applied Atomic Force Microscopy in PeakForce Quantitative Nanomechanical Mapping Mode (AFM – PF-QNM) on a flax/epoxy system, and have evidenced the existence of an ultra-thin interphase layer with a thickness ranging from 40 to 120 nm, characterized by a gradient in elastic properties. However, as the interfacial shear strength is generally high between flax fibres and the aliphatic amine/epoxy-based matrix, it is important to understand the adhesion mechanisms between the fibres and the matrix at that level.

Novel infrared spectroscopy techniques, namely Optical Photothermal InfraRed Spectroscopy (OPTIR) allow high-resolution (400 nm) mapping of the intrinsic chemical bonds within a system. By providing detailed insights into the chemical interactions at the interface, the obtained results can help clarify the mechanisms that define the adhesion between the fibre and the matrix.

Combined OPTIR and AFM – PF-QNM mappings can provide a multiphysical approach to the nature of the interface in flax/epoxy composites, leading to a more comprehensive understanding of its behaviour and properties, through correlative spectro-mechanical microscopy. Such understanding is crucial for optimising the design and performance of fibre-reinforced composites in various applications.

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# Fatigue Analysis and Residual Strength Evolution of High-Performance Unidirectional Carbon-Fibre Composites for Hydrogen Storage Applications: Characterisation Using Split-Disk Ring Tests

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In the context of climate change and pollution challenges, the shift towards cleaner energy sources has become imperative. Recently, hydrogen has been emerging as a key focus in the fields of scientific and technological research due to its clean, versatile nature. The advancement of the hydrogen storage sector necessitates the development and testing of new high performance materials to ensure their viability and durability in various hydrogen-related applications. The work presented in this paper takes place in the frame of the CAVENDISH project of the European Union and focuses on the mechanical assessment of a latest-generation high-performance carbon-fiber composite material for its application in hydrogen storage in the aviation industry. The adopted study approach consists in the evaluation of the residual strength of the material after a fatigue history. First, the material in ring form is loaded in tension-tension fatigue using the split disk method until a defined number of cycles. Following the fatigue, a quasi-static tensile test is carried out on the ring specimen until failure. This method allows the comparison of the material strength before and after its fatigue life. Contrary to expectations, the material showcases an 11% improvement of the residual quasi-static strength after its fatigue life compared to the quasi-static strength of the unsollicited material. No statistically significant difference is found between the rings tested up to different numbers of fatigue cycles. Regarding the rigidity, even though the data collected from the tensile testing machine points towards a stiffening of the tested material after fatigue, non-destructive vibration tests show a 5% loss in the elastic modulus of the tested rings after fatigue. This phenomenon of apparent stiffening is likely linked to the geometry of the test structure. Further mechanical testing and data analysis is underway to form a full view of the material’s behaviour.

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# A Polyurethane Foam/Hydrogel Composite with Extreme Vibration Damping

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Damping systems are used to control the loads induced by vibrations in mechanical machinery and structures. Materials commonly used in this context include mineral oils, elastomers and rubbers, which are fossil-based and offer limited end-of-life options. Conversely, viscoelastic biobased materials have seen a rise in popularity thanks to suitable performance combined with improved sustainability credentials.

We present a composite system composed of a soybean-based flexible polyurethane foam (PUF) infused with a poloxamer-based hydrogel (Pluronic F-127). The composite is obtained by in-situ gelation within the PUF at room temperature in 5-10 minutes, depending on the poloxamer concentration, providing a facile fabrication route and potential for upscaling. Additionally, the system is non-toxic and biodegradable.

The load-bearing capacity of the composite was evaluated through quasi-static compression tests, which revealed remarkable stiffness up to 250 kPa and an energy dissipation of nearly 12% during cyclic tests.

Notably, during vibration transmissibility testing performed using a bespoke rig, the composite exhibited a loss factor of 30-45% in the frequency range of 30-60 Hz. These frequencies correspond to low-frequency vibrations commonly encountered in machinery and transportation systems, which are often challenging to dampen using conventional materials which are limited to loss factors of 10-30%.

These results provide a preliminary assessment of the viability of this composite system as a damping solution, with a notable improvement in both performance and eco-friendliness compared to industry standards. In the future, we will investigate the effect of environmental conditions (such as varying temperatures and relative humidity) on the stability and mechanical behaviour of the composite.

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# Solvent-Based Manufacturing of Flax/Recycled PET Thermoplastic Tapes: A Feasibility Study on Thermal Stability and Microstructure

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Thermoplastic composites based on renewable and recycled resources are attracting considerable interest in the context of sustainable development and the circular economy. In this context, flax fibres are a promising alternative to synthetic reinforcements thanks to their low density, bio-based nature, balanced stiffness and strength properties. In addition, recycled polyethylene terephthalate, recovered from household bottles, is an interesting matrix for low-impact applications. The combination of these two components makes it possible to develop environmentally friendly, circular, high-performance unidirectional (UD) tapes, as long as the fibres are properly impregnated.

The present work focuses on the feasibility of manufacturing UD tapes from flax fibres with recycled PET as the matrix, using an innovative manufacturing process. The method consists in dissolving the PET in a suitable solvent, then precipitating the polymer within the fibres at a controlled speed thanks to a non-solvent. This approach, which has already been validated for carbon fibres, is being applied here for the first time to flax fibres. It provides uniform impregnation at room temperature without the need for energy-intensive melting treatment techniques.

In addition to microstructural characterization by optical microscopy and image analysis, the impregnation behaviour of PET solutions on flax fibres will be evaluated through capillary rise experiments. It will provide insight into the wetting dynamics of different PET solutions, allowing the selection of the most suitable solution for optimal impregnation. The mechanical properties are characterized by tensile and three-point bending tests to establish the relationship between microstructure and overall composite performance.

The results demonstrate, for the first time, the feasibility of manufacturing circular thermoplastic tapes from flax fibres and recycled PET, confirming the potential of this approach for sustainable, high-performance, and recyclable natural fibre composites. This study opens new opportunities for sustainable materials that combine mechanical efficiency, recyclability and a reduced environmental footprint.

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# Structural battery composites from multifunctional carbon fibre reinforced high performance polymer prepregs

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Structural battery composites (SBC) having energy storage capacity and mechanical strength in one integrity has drawn great interests in multifunctional composite community. Since the structural battery composites offers a light weight, loading bearing energy storage device for vehicle and building applications, they are selected as one of the Top 10 Emerging Technologies of 2025. At a material lever, SBC are designed to resemble a fibre reinforced polymer composite configuration, in which coated carbon fibers are used as reinforcement and electrodes and polymer electrolyte provides ion conductivity and load transfer between carbon fibres. However, the multifunctionality of such SBC were not satisfying – this was especially noticed in terms of low energy density (e.g. up to 30 Wh/kg) as compared to conventional Li ion batteries (300 Wh/kg). This could be due to the low active material loading and low fibre volume fraction. The latter one could cause the poor contact between active materials and carbon fibre current collectors and excessive electrolyte in the SBC.

We coated lithium iron phosphate and lithium titanate on carbon fibres with an aerial loading of 20 mg / cm2, exceeding the reported loading of 5 mg / cm2. To guarantee promising mechanical properties of the SBC as well as high ionic conductivity, bicontinuous electrolyte containing a macroporous high performance polymer was produced. The carbon fibre reinforced anode and cathode with highly loaded active materials were impregnated with a liquid precursor of the bicontinuous electrolyte followed by the lay-up of battery prepregs and the subsequent consolidation. The resultant SBC had a specific capacity of 75mAh/g at a dis/charge rate of 0.5C, superior to those of current structural batteries. The SBC had a Young's modulus of 30 GPa and tensile strength of 200 MPa.

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# Numerical and experimental investigation of temperature and polymerization evolution during filament winding of Elium resin composites

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Filament winding has been widely applied in the fabrication of composite structures. The quality of the wound products is strongly influenced by the thermal history during processing. A high temperature gradient can induce the development of residual stresses. Therefore, understanding the temperature distribution and its evolution within the composite during the manufacturing process is essential for process optimization.

In this study, a numerical model was developed to predict the temperature and degree of polymerization evolution during the in-situ polymerization filament winding process. The model incorporates temperature-dependent thermal properties, the influence of winding speed, and the polymerization behaviour of Elium resin. The numerical model was implemented in ABAQUS, where a user subroutine (UMATHT) was developed to couple the general heat transfer equation with the polymerization kinetic model, while considering temperature-dependent material properties. The kinetic model, based on the Arrhenius-type empirical formulation, was used to describe the exothermic nature of the free-radical bulk polymerization. The parameters of this model were determined from Differential Scanning Calorimetry (DSC) experiments. The winding process was simulated using a model-change technique, in which the successive activation of composite layers represents the deposition of new windings.

The model results were compared with temperature measurements during the winding process by placing thermocouples between the wound layers. The good agreement between simulation and experiment shows the reliability of the proposed thermal model. Furthermore, the numerical framework establishes a quantitative link between the process parameters and the resulting temperature and polymerization distributions, enabling the achievement of complete and uniform polymerization, reduction of residual stress, and overall improvement of product performance. The validated model thus provides a useful tool for optimizing process parameters and improving product quality in filament winding with Elium resin.

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# Finite Element (FE) Investigation of Process-Induced Residual Stresses in Type-IV Composite Pressure Vessels: Implications for Enhanced Design Reliability

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Type-IV composite pressure vessels (CPVs) are extensively used for the storage and transportation of pressurized hydrogen gas. These vessels are typically manufactured using the filament winding process, which can be classified as dry or wet, depending on whether the fibre bundles are impregnated prior to or during the winding. Throughout the winding process, the polymeric liner is internally pressurised, and the fibre-rovings are placed under tension to ensure proper winding. Liner pressure induces stresses in the composite-overwrap, while fibre pre-tension influences the fibre volume fraction (FVF) across the laminate thickness, thereby altering the magnitude of the stress buildup. This study investigates the coupled effects of mechanical and thermal processes on the development of residual stresses in a 55-litre composite pressure vessel, fabricated using the wet filament winding technique. High-fidelity finite element modelling is employed to simultaneously simulate the evolution of residual stresses during winding and curing, accounting for liner pressure, fibre pre-tension, and cure kinetics. The cure-kinetics analysis enables the estimation of residual stresses generated by the epoxy's chemical shrinkage during the curing, along with the thermal residual stresses resulting from the mismatch in the coefficients of thermal expansion (CTE) between the fibres and the epoxy. Fibre-direction residual stresses are tensile during the winding stage due to the applied liner pressure. In contrast, during the cool-down phase of the curing process, these stresses can be either tensile or compressive, depending primarily on the composite-overwrap architecture. The study demonstrates that these process induced thermo-mechanical residual stresses substantially alter the overall stress distribution within the plies of fully cured CPVs while subjected to a nominal working pressure of 70 MPa. Proper incorporation of these residual stresses during the detailed design phase can significantly enhance the design reliability, and overall safety of these composite pressure vessels.

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# Enhancing Mechanical Properties Through Reactive In-Situ Plasma-Assisted Extrusion of Glass Fibre-Reinforced Polypropylene/Polyamide-6 Blend Composites

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Short glass fibre-reinforced thermoplastic composites offer a potentially sustainable alternative to thermosets for aerospace, automotive, and packaging applications. The sustainability of these composites can be enhanced by incorporating mixed waste-polymers as the matrix. However, thermoplastic polymers are often immiscible, which can result in low-quality products when used as blends. To address this challenge, a reactive bulk plasma treatment compatibilization approach was developed and employed during melt compounding to improve interfacial adhesion within the blend through functionalization of non-polar polymer chains. In this study, polypropylene and polyamide-6 were blended to form the matrix, and short fibre composites were fabricated using two processing techniques. The first method was pre-impregnation reactive extrusion, in which the polymers were melt-compounded in a twin-screw extruder along with plasma treatment. The resulting blend was impregnated onto the continuous glass fibre tow using a cross-head impregnating die, followed by pelletizing and re-extrusion through a twin-screw extruder. The second method used this reactive extrusion approach with a more integrated setup, where direct continuous fibre addition into the extruder enabled simultaneous plasma treatment of polymers and fibre addition as an in-situ extrusion approach. Plasma treatment in both techniques facilitated compatibilization of the polymer phases, resulting in a more homogeneous matrix and improved fibre-matrix interfacial bonding. SEM micrographs support homogeneous phase distribution and stronger fibre-matrix interfacial bonding in the plasma-treated composites. The pre-impregnation reactive extrusion method showed 33% and 46% increases in chord modulus for the plasma-treated 90PP/10PA6 and 10PP/90PA6 blend composites, respectively, compared to the untreated composites. The in-situ reactive extrusion method demonstrated a 9% improvement in both blend composites after plasma treatment relative to their respective untreated samples, with higher fibre length distributions.

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# Influence of Twisting Angle and Braiding Layers on the Bending of Glass Fibre Reinforced Thermoplastic Profiles

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The increasing demand for automation and functional integration in the processing of continuous fiber-reinforced polymers calls for innovative forming processes that enable efficient manufacturing of complex, three-dimensional geometries. Thermoset composites, though widely used, are inherently non-bendable, necessitating additional joining steps, metal connectors, or complex assembly procedures resulting in higher production costs and longer lead times. In contrast, thermoplastic composites offer the potential for direct forming, enabling simplified production and enhanced design flexibility.

This study presents an innovative process route for manufacturing fiber-reinforced thermoplastic profiles by combining thermoplastic braiding pultrusion with subsequent rotary draw bending, a process originally developed for metal forming. The integrated approach allows for the continuous, tool-guided forming of profiled semi-finished products with various cross-sections, from rods to tubular structures, while maintaining high geometric precision and mechanical integrity. The result is a high degree of automation and significant potential for the series production of complex, curved composite components.

This research focuses on investigating key material and process parameters, including the influence of the braiding layer composition and the effect of fiber twisting angles during bending. Microscopic analysis is used to assess fiber deviation and cross-sectional deformation, while DSC, DMA and density measurements provide insight into fiber volume content, curing behavior, and confirmation of optimal bending temperatures. Furthermore, tensile tests are conducted to evaluate the mechanical performance and applicability of the bent profiles as reinforcement elements in concrete structures.

The findings demonstrate that rotary draw bending of thermoplastic composites can maintain structural integrity while reducing process complexity. This technology opens new pathways for lightweight, high-strength components in the energy, aerospace, and construction industries, offering enhanced production efficiency, improved sustainability, and expanded design possibilities for advanced composite structures.

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# The Story of Pultrusion

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Pultrusion is a one-step, continuous manufacturing process for composite profiles. First, the technology is introduced: its main elements, the materials being used, the shape possibilities and the main features of the resulting products. The 'Story of Pultrusion', then takes you back in time. It covers the pioneering days, the technological developments, the transformation from an art into a science.

The author lists his very personal selection of landmark applications throughout the now more than seventy years of pultrusion history. It starts off with simple shapes for electrical insulators, portable ladders, standard construction profiles. Functions are integrated into more complex geometries for building and especially transportation applications. Top performance is demanded for such products as the structural backbone of windmill blades or elevator ropes.

The chapter ends making the case for standardization and harmonization towards deeper market penetration, especially in the large but conservative construction market. Finally, the circularity of composites is demonstrated. Composites are strong enablers for decarboniation and offer a wide range of solutions for a greener world, based upon their very long lifetime, low weight and tailored features towards the intended applications.

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# Development of alternative testing strategy to obtain in-plane shear failure properties of UD composites under cryogenic environment

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Thermoplastic composites have been demonstrating their interest for cryogenic applications, due to enhanced toughness. They are generally assembled through multi-orientation layered structures, and current developments address e.g. pipes for superconductive cable applications or type V liquid hydrogen (LH2) tanks. Thus, one of the important characteristics to assess is the in-plane shear properties for efficient design of such structures, while taking into account thermal-induced transverse-to-fibre tensile internal stresses. In our previous works, it has been shown experimentally that such stresses could lead to early damaging in cross-ply specimens traditionally used to determine in-plane shear properties through [+/-45°] tensile testing. The present work aims at developing a new approach for this test, through off-axis monoangular specimen tensile tests. A preliminary FEA study allowed to determine a relevant specimen and test configuration : fibre orientation, geometry of specimens, clamping conditions, and prediction of the shear strain and stress fields along the specimen surface. A test fixture allowing for specimen rotation has thus been designed and manufactured, and first room-temperature (RT) DIC-instrumented tests have shown a sufficient, yet not complete, clamp rotation that allowed to limit the stress concentration points related to the off-axis tension. Good correlation has been obtained with RT [+/-45°] tests. The off-axis tensile tests have then been carried out in a cryogenic chamber at -162 °C, with wisely located gage instrumentation and acoustic emission. Though rotation has been partially prevented through formation of ice on the rotating surfaces, thus causing early failure initiated at local stress concentration zones, the tool concept could be adapted to deep-cryogenic environments such as in cryomachines or LH2 immersion, with minor improvements.

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# Coupled Multiphysics Simulation of a Shape Memory Alloy Hybrid Composite Actuator Module with ANSYS LS-DYNA

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Shape memory alloys (SMA) are Smart Materials that enable active shape control in various applications, including hybrid composite actuator structures, due to their stress- and temperature-induced phase transformation. To support the design process of SMA-based components through computer-aided engineering, numerous analytical and finite element (FE) models have been developed in past to predict their thermomechanical behavior. However, many of these models still exhibit limitations, particularly with respect to thermomechanical coupling and comprehensive validation against experimental datasets. This article therefore examines a material model implemented in the ANSYS LS-DYNA FE-software environment, which is based on a micromechanical constitutive formulation by Kelly et al. [1]. This model is based on minimizing the Helmholtz-free energy and accounts for the initiation, saturation and growth of the individual SMA phases. The objective of this study was to develop a FE model of a shape memory alloy hybrid composite actuator (SMAHC) and to conduct fully coupled multipysics simulations by coupling mechanical, thermal and electromagnetic solvers. These simulations include a representation of the SMA wire heating via Joule heating, while also allowing the application of various loads and ambient temperature conditions to the SMAHC. The resulting simulation data were subsequently validated using both experimental measurements and results derived from a fully coupled transient analytical model by Kaiser et al. [2] to assess the suitability of the material model and its applicability for future SMA applications and the design process of SMA actuators. A qualitative comparison of the material behavior demonstrated good agreement and reproduced the characteristic hysteresis behavior of the actuator deflection as a function of temperature. Quantitatively, the simulated deflections were in the correct order of magnitude, although they were partly outside the experimental confidence interval of 95%. Overall, the results still show a generally consistent trend between simulation and experiment.

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# Design Optimization of Metal Leading Edge Cap Joint in a Composite Fan Blade of Aircraft Engine subjected to Static Flexure and Thermal Loading

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The composite fan blades in aircraft engines demand designs that ensure structural integrity under operational loads while resisting foreign object damage and bird strikes. As part of ongoing efforts to improve the existing design, newer materials and newer designs needed to be investigated. This study presents a finite element analysis investigation of a cut section coupon model of composite fan blades with metal leading edge caps, modelled through parametric 3D model and subjected to static flexure loading and thermal loading (because of variations in the thermal expansion coefficients of different materials). The coupon model has three main constituents, metal leading edge cap, composite and the structural adhesive. Three metallic caps materials Ti-6Al-4V, Inconel 718, 15-5 PH stainless steel were considered for metal leading edge cap. IM7/8551 carbon fibre epoxy composites was considered as base material for fan blade. Design optimization (geometrical shapes) was performed using three possible geometric design variations of metal leading edge joint and three possible materials for metal leading edge as mentioned earlier.

The structural integrity of the metal leading edge cap, structural adhesive and the composite is evaluated for flexural loads and thermal loads. Combined thermo-mechanical loading evaluation was also performed. Optimal metal leading edge joint design and material will be the one which shows the lowest inter-laminar shear strain level under representative flexural, thermal and combined thermo-mechanical loading. The results will help the aerospace structure designers in selecting the best material and joint design for the metal leading edge joint of composite fan blade which will provide best performance under critical load cases. The coupon design is based on the test results of a blade cut section coupon. For the shortlisted optimum cases from this work, further full blade models will be developed and will be investigated under bird strike loading.

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# Testing mechanical properties of polyamide cage using component test and Finite Elements modeling

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Polyamide cages are used in multiple applications, including bearings for Electric Vehicles (EV), where this type of polymer cage provides multiple benefits, replacing traditional metal cages. Polymer cages in bearings offer benefits like lighter weight, lower noise and friction, and substantially lower price compared to metallic cages. High rotational speed in EV can lead to bearing heating, meaning that a polyamide cage is subjected to challenging conditions, comprising of high temperature and centrifugal force. Differently from steels, polymers are sensitive to temperature, i.e. the mechanical properties, like elastic modulus, strength and creep rate are strongly dependent on temperature, which is associated with the glass transition phenomenon. An additional complexity, is the anisotropy in mechanical properties, which is caused by fibers reinforcement. The orientation of fibers governs material strength (stiffness and other properties), and since this orientation (microstructure) is closely related to manufacturing process, the mechanical properties of a tested specimen can differ from the properties of a real component. A special test with a EV cage, termed here as the “stretch test” is proposed in the current work to characterize the cage mechanical properties, which despite of material heterogeneity and anisotropy are considered as homogenized and isotropic. This is needed for the sake of simplification, enabling in future the proper engineering cage modeling and design. The stretch test is accompanied by the Finite Elements (FE) modeling, which being combined with reverse engineering allows to recalibrate the stress-strain curve obtained in the uniaxial test. It is also used to calibrate the creep behavior. Recall, that the microstructure of uniaxial test specimen and its mechanical properties may be different from cage, meaning that the currently proposed methodology improves the characterization of the reinforced polyamide. Finally, an additional testing technique enabling to predict the cage behavior under centrifugal loading, is presented.

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# Unlocking the value of recycled composites through advanced metrology

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The test methods for existing fibre reinforced composite materials, developed following decades of research, are well-established and widely used for verification and materials development. The current need for end-of-life waste solutions for composite products has led to a significant effort by the composite materials community to develop suitable methods for the recycling of composite materials. However, following an international survey and national workshop led by NPL, it was found that one of the largest barriers to the full realisation of a circular composite materials economy remains trust in and understanding of the properties of the recycled fibres. At present, it is not well understood whether the existing characterisation techniques developed for virgin composite materials and constituents can be applied to recycled fibres.

There is an urgent demand by the owners of recycling technologies and prospective users of the recycled materials for fast, reliable characterisation techniques. To respond to this call, NPL has applied a number of techniques to measure the thermal and electrical properties, strength, and processing properties such as fabric permeability. These techniques were evaluated for suitability and precision (i.e. repeatability and reproducibility). This work has yielded mixed results which have shown that current characterisation techniques and methodologies require further development, and new measurement standards will likely be necessary to ensure industry confidence.

This work will present the current findings and recommendations covering both the applicability of the measurement techniques trialled, best practices developed for testing of recycled materials, and current knowledge on the properties of recycled materials relative to their virgin counterparts.

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# Long- and short-term creep of 3D-printed polymer structures

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This research aims to develop and validate a methodology for experimental creep testing and predict the long-term deformability of 3D-printed polymer structures. The hypothesis is that the structural mechanics of fibre-reinforced polymer composites can be applied to fused filament-fabricated structures, considering the printing settings and stress states. The methodology includes details on testing equipment, specimen design, grips, strain measurement techniques, and practical recommendations for conducting creep experiments. This approach was validated on 3D-printed anisotropic materials, mainly polylactic acid, as well as some other materials. The work was done on extruded mono fibres, but also flat and tubular specimens produced on UltiMaker 3D printers. By combining various loading modes (tension, compression, and torsion), the comprehensive characterisation of creep compliance in printed materials and structures was performed. The testing was conducted under tensile loads up to 120 kN and torsional loads up to 420 N·m; test durations range from several hours for short-term tests to over 1000 h for long-term creep evaluations.

To describe the performance of materials under creep, Prony series parameters were obtained from short-term creep tests within the linear viscoelastic range on flat specimens (in longitudinal and transverse directions). The creep behaviour of both specimen sets was described using a shared retardation spectrum but different instantaneous moduli, suggesting structural anisotropy in 3D-printed objects. However, the most significant effect was observed on the elastic properties: transverse stiffness was lower than longitudinal stiffness. In general, creep properties of printed specimens depend on the intrinsic viscoelastic properties of the bulk polymer. It was also concluded that under loads within the linear viscoelastic range, the creep performance of 3D-printed specimens did not depend on the microstructure. In terms of environmental conditions, temperature and relative humidity were considered, showing that these factors significantly influence creep behaviour.

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# On thermal oxidation of a vitrimer based on disulfide exchange

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The increasing use of composite materials and the associated waste management challenges have led to efforts to develop alternatives to traditional thermoset matrices. Vitrimers are a promising option, as they offer similar properties to thermosets below their glass transition temperature (Tg) and exhibit thermoplastic-like malleability above Tg. Their covalent adaptive network (CAN) also provides the advantage of extending the lifespan of composites through self-healing, reuse, and recycling. Vitrimer-based composites can be reshaped using processes such as thermo-adhesion or thermoforming. However, these methods involve high temperatures, which may degrade the network through thermo-oxidation and alter its properties. Since vitrimers have only been developed in the last 15 years, limited data are available on their long-term stability. Nonetheless, understanding this specific point is fundamental for the development of these materials for practical applications. This study investigates the thermal oxidation at different temperatures of a vitrimer based on disulfide exchange, formulated with DGEBA based resin (SR1710) and 4-aminophenyl disulfide (4-AFD) hardener. The results are also compared with the epoxy formulation (SR1710 with SD3303 hardener). Chemical changes during the thermal oxidation were monitored by FTIR-ATR (Fourier Transform Infrared spectroscopy – Attenuated Total Reflectance) and the thermo-mechanical behavior was studied by DMA (Dynamic Mechanical Analysis). During oxidation, scission of the crosslinked chains occurs, leading to the formation of oxidized groups such as carbonyls and amides, that can be monitored by FTIR to better understand of the oxidation kinetics. Such changes in the three-dimensional network increase the molecular mobility, resulting in a decrease of the glass transition and modification of the relaxation time.

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# Spinheat-assisted Debonding-on-demand Structural Adhesives for Recyclable Composite Structures

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Disassembling adhesively bonded substrate components is challenging and often hinders the repair of faulty parts and the recycling of end-of-life components. Conventional debonding methods, such as oven heating, mechanical separation, or chemical treatments, may damage the substrates and not so 'clean' approaches. Therefore, developing localized debonding techniques that weaken the adhesive without degrading the adherend is highly desirable for ease of separation at lower load. Spinheat technology (also referred to as induction heating), has emerged as an alternative to conventional debonding techniques, offering contactless and localized debonding of adhesive joints. However, existing studies on induction debonding have mainly employed ferric oxide nanoparticles, which can cause overheating and scorching of adhesives and sometimes damage the substrates. Using curie temperature-controlled modifiers (e.g., Mn-Zn ferrite nanoparticles), also called curie nanoparticles (CNP), can be utilized to develop stimuli-responsive debonding-on-demand (DoD) adhesives that mitigate overheating issues and support circular economy objectives.

The current experimental study investigates selective spin-heating of adhesive using an alternating magnetic field (AMF) to achieve controlled debonding-on-demand. Glass fiber reinforced polymer (GFRP) composite substrates were lap-bonded using an epoxy adhesive modified with CNPs with varying weight percentages. Debonding performance was examined by testing the lap joints while simultaneously applying AMF-induced spin heating to the adhesive. An AMF with magnetic field strength of 200 Oe resulted in localized adhesive heating and lead to significantly reduced the joint failure load by approximately 90% compared to unheated control specimens. Besides exploring the debonding efficiency, we investigated the thermomechanical, mechanical, and microstructural properties of the CNP-modified adhesives. Furthermore, the debonded substrates were successfully rebonded after mechanical abrasion of remanent adhesive layer and acetone cleaning, demonstrating the recyclability of joints for further use. The proposed methodology can be used for efficient disassembly, repair, and recycling of adhesive joints used in aerospace, automotive, and renewable energy applications.

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# Meso-Structure-Based Thermomechanical Modelling of Carbon Fibre Reinforced Thermoplastic Laminates Subjected to Kerosene Flame: Porosity Nucleation, Growth and Mechanical Consequences

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This investigation develops a mesoscale finite element framework for predicting the thermomechanical behaviour of quasi-isotropic carbon-fibre-reinforced polyphenylene sulphide (C/PPS) laminates exposed to a kerosene flame delivering a heat flux of 116 kW/m² and a flame temperature of 1150 °C, in accordance with FAA fire-resistance requirements.

Rapid heating drives successive phase transitions in the thermoplastic matrix (glassy → rubbery → molten → pyrolytic decomposition at approximately 450 °C), which generates gaseous products that nucleate, grow and coalesce into porosities. These voids simultaneously provide thermal insulation that retards through-thickness heat propagation and severely degrade the laminate's load-carrying capacity.

A three-dimensional mesoscopic model explicitly resolves woven fibre bundles and surrounding matrix. The formulation incorporates conductive heat transfer, convective and radiative boundary conditions on the unexposed face, a radiative flux on the exposed face, temperature-dependent pyrolysis kinetics, porosity evolution governed by internal gas pressure.

Numerical predictions accurately capture the pronounced through-thickness thermal gradient, progressive porosity development initiating in the flame-exposed ply, laminate swelling, load redistribution from degraded 0°/90° plies to cooler interior plies, and a 70–74 % reduction in axial stiffness within the initial 60 seconds of exposure. These results exhibit strong agreement with in-situ tensile tests conducted under simultaneous flame attack and with post-exposure X-ray microtomography, although the model currently underpredicts total porosity owing to the omission of matrix/bundle delamination and intra-tow voids.

Despite reliance on simplifying assumptions—notably weak thermomechanical coupling, absence of delamination damage modelling, and linear-elastic constituent behaviour—the approach successfully reproduces the dominant degradation mechanisms during the critical first minute of fire exposure, the period in which the majority of structural capability is lost. The framework therefore offers considerable promise for assessing the residual performance of thermoplastic composite aircraft structures subjected to engine-fire events, while identifying interfacial delamination as the principal phenomenon requiring incorporation in subsequent model refinements.

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# Citius, altius, fortius: the crucial role of composites in sports

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This presentation reviews the multiple applications of composites in sports from a historical perspective, and the crucial role of composite materials in gaining performance, comfort, safety, and freedom of design in many sports applications. The focus is placed on Olympic sports, addressing composites' role in 15 different competition sports, ranging from water sports to cycling, from fencing to athletics and winter sports. Common trends are the benefits of using fibre-reinforced composites to increase specific stiffness or strength, as well as energy restitution, which can be tailored from very elastic materials to high damping according to the required performance. Another key point is the versatility of composite materials combinations, as well as manufacturing techniques adapted to prototypes or tailored designs, and to appealing marketing presentations. Finally, the history of composites in sports is far from complete, as new material combinations, with a strong emphasis on performance combined with sustainability, enter this rich and fast-developing area each day.

#274

# The Role of Fracture Toughness on the Failure Mechanism of High Off-Axis Angle Ply Laminates

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High off-axis angle-ply laminates with fibre orientation larger than 45 ($\theta > 45^o$) are desirable for use in applications demanding high flexibility while providing high specific strength. In this work, the failure mechanism of such laminates made of carbon fibre reinformed polymer (CFRP) layups $[\pm\theta]ns$ subjected to tensile loading is studied in detail, and the effect of fracture toughness of the applied polymer matrix material, such as, epoxy or PEEK, on its ultimate strength and damage modes is identified.

A finite element model (FEM) with cohesive elements has been developed to simulate the matrix related damage initiation and development, including delamination. To predict fibre failure, the compressive and tensile stresses along the fibre direction were exported at each load step. A Weibull modulus approach was used to find the normalized stresses to take account of local stress concentrations and non-uniform meshing. Subsequently, these normalized stresses were used to predict fibre failure based on maximum stress failure criteria.

The results indicate that the final failure mode of high off-axis angle-ply laminates is highly sensitive to the matrix properties, particularly Mode II fracture toughness and strength. Unlike the laminate with lower fracture toughness matrix material, which failed primarily due to delamination, the higher fracture toughness matrix laminates resisted delamination propagation. Instead, the developed matrix cracks instigated a new failure mechanism which has an array of short matrix cracks aligned with the fibre direction on the adjacent plies. With continued loading, the array of short matrix cracks grew to a certain length and ultimately failed due to fibre breakage. This failure mechanism is also observed in a high-resolution CT scan analyses conducted on carbon fibre/PEEK coupons with high off-axis angle plies.

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# Minimally Intrusive Remaining Useful Life Estimation of Composite Pressure Vessels Using Foundation Models

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The global drive to mitigate greenhouse gas emissions is transforming the way industries generate, store and consume energy. Among emerging clean technologies, hydrogen is increasingly recognized as a key enabler of decarbonisation across the transport sectors. However, the safe storage of hydrogen remains a critical challenge. Composite-wound pressure vessels are widely employed to store compressed hydrogen, but their long-term reliability and resistance to cyclic loading in operations remain major safety concerns for the public. Progressive damage accumulation within the composite layers can eventually lead to catastrophic failure, necessitating accurate estimation of the Remaining Useful Life (RUL) of these vessels.

Physics-based RUL estimation approaches rely on complex damage evolution laws and detailed material characterisation, which are often unavailable or impractical for end-users. We seek here to investigate RUL estimation with minimal and low-cost sensing. This paper introduces a fully-data driven methodology based on deep learning Foundation Models for the RUL estimation, which are pre-trained accurate large models. The proposed approach provides a cost-effective alternative to fibre Bragg gratings, a space-efficient substitute for Digital Image Correlation systems, and a non-invasive solution that avoids the introduction of weak spots associated with integrating gauges between composite layers and instead uses surface mounted strain gauges.

In this methodology, large pre-trained Foundation Models are employed as zero-shot encoders to extract latent embeddings from pressure and strain cycle data. These embeddings are subsequently processed by a Recurrent Neural Network (RNN) to estimate the RUL. Experimental validation demonstrates that strain signal shape can predict the RUL of pressure vessels independent of time or load recording.

This work contributes to the advancement of hydrogen safety by introducing a scalable, low-cost and physics-free solution for the life prediction of composite storage vessels.

#277

# Computational Sensitivity Analysis of Fracture metrics in Orthotropic Composites

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Crack propagation in composite materials often follow a fibre-avoidance mode [1]. Several modelling strategies have been proposed to simulate this crack growth behaviour – Fracture mechanics and Damage mechanics based. Owing to its rigorous theoretical basis and ability to better represent the physical crack growth behaviour faithfully, the fracture mechanics approach is generally preferred, especially for cases with an existing crack [2].

Before developing a computational fracture mechanics-based strategy for predicting crack growth in orthotropic composites, the behaviour and sensitivity of commonly used fracture metrics needs to be examined, in order to establish a fracture criterion sensitive to fibre orientation. This study investigates the ability of these fracture metrics to characterize the resistance / support to crack growth (with fibre orientation ranging from parallel to perpendicular to the crack), and thereby provide a means to arrive at a crack growth prediction based on predicted metrics. The computational methodology considers analysis of different specimens with varying levels of orthotropicity and are performed assuming straight ahead crack extension. Fracture metrics in simulations are evaluated using the J-Integral method based on the Virtual Crack Extension and Interaction Integral formulations.

The resulting fracture metrics when evaluated for orthotropic materials were found to exhibit path dependence. This dependence was examined with respect to varying fibre directions, and quantified by constructing the 'Coefficient of variation' parameter. Results indicate that, when the fibres oppose the crack, all fracture metrics are at their lowest. But across specimens and orthotropicity levels, only the Energy Release Rate provides a consistent and physically meaningful measure of fracture resistance. Overall, the findings suggest that, due to its sensitivity to fibre orientation, the ability to quantify resistance to crack growth and comparatively better path-independent nature, an energy-release-rate based fracture criterion will offer a robust foundation for predicting crack direction in orthotropic composite materials.

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# Ultrathin $Ga_2In_2O_3$–Ag Plasmonic Composite Membranes for Dual-Mode Photonic and Spectroscopic Detection of Biomolecules

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We present a proof-of-concept demonstration of an ultra-sensitive molecular detection platform based on a novel plasmonic $Ga_2In_2O_3$ composite membrane integrated with silver nanodomains. This scalable and cost-effective system employs an ultra-thin (~100 nm) solid-state nano-porous film, enabling simultaneous electrical and optical detection of bovine serum albumin (BSA) at the single-molecule level. The $Ga_2In_2O_3$ composite membranes were fabricated through a mechanically assisted rolling–squeezing process of room-temperature liquid Galinstan (Ga–In–Sn alloy), followed by thermal annealing at 400 °C to induce crystallization and form a naturally porous nanoscale network. Subsequent ultrasonic-assisted treatment in a Galinstan/$Ag^+$ medium produced galvanic replacement, yielding uniformly embedded Ag plasmonic nanodomains within the porous matrix. The combined thermal dealloying, cavitation, and galvanic-replacement mechanisms give rise to a unique composite architecture ideally suited for plasmon-enhanced sensing. This ultrathin bio-nanophotonic platform integrates a solid-state nanopore with a field-effect transistor (FET) biosensor, enabling dual-mode monitoring of biomolecular behavior. Electrical measurements reveal that photoinduced charge redistribution near Ag-decorated nanopores produces a pronounced contrast in photo-ionic current, greatly enhancing detection sensitivity. Concurrently, SERS measurements capture distinct BSA vibrational fingerprints facilitated by the localized plasmonic enhancement.

The synergy between FET and SERS detection allows real-time observation of discrete BSA translocation events, supporting both quantitative and qualitative molecular analysis. This work establishes a promising pathway toward atomic-scale biosensing using ultra-low-energy solid-state composite nanopore systems, offering significant potential for the next-generation biomolecular sequencing, plasmonic composite materials, and photochemical energy-harvesting nanogenerators.

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# Effects of Processing and Nanofiller addition on the Mechanical and Thermal properties of Thermoplastic Epoxy Resin

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In recent years, the rapid advancement of electronic devices and information processing speed has led to an increasing demand for thermal interface materials (TIM). Extensive research has focused on heat-dissipating materials, including liquid crystalline polymers and polymer composites with thermally conductive fillers (e.g., graphene, BN, carbon nanotube, alumina particles), as potential substitutes for metal materials. However, challenges remain, such as the poor processability and high cost of liquid crystalline polymers, and the deterioration of mechanical properties caused by excessive filler loading to compensate for the low thermal conductivity of the matrix. To address these issues, this study developed Thermally Conductive Epoxy (TCE) resin. TCE is recyclable and simultaneously exhibits high mechanical properties and thermal conductivity as a neat resin. Tensile tests and thermal conductivity measurements have shown that TCE possesses a tensile strength exceeding 100 [MPa] and a thermal conductivity greater than 1 [W/m*K]. These high mechanical and thermal properties are believed to be related to the appearance of crystallinity enabled by polymer design that imparts thermoplastic-like behavior, in contrast to conventional thermosetting epoxy resins. However, the crystallinity and morphology of TCE varied depending on the processing method. It is noteworthy that injection molding induces the formation of fiber-like crystalline phases. In addition, the effects of compounding with thermally conductive fillers (graphene, BN) remained unclear. Therefore, in this study, the effects of different molding processes and the incorporation of thermally conductive fillers on the morphology and crystallinity of the TCE were systematically investigated, along with the underlying mechanisms. This study provides insights into the design and processing of high-performance thermoplastic epoxy resins for advanced thermal management applications.

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# Advancing sustainable marine materials with graphene-coated natural fiber composites

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Fiber-reinforced plastic (FRP) composites have been widely used in the marine industry for several decades due to their low density and excellent corrosion resistance, enabling reduced emissions during operation. However, the rapid growth of FRP production—primarily glass and carbon fiber composites—has resulted in increasing manufacturing and end-of-life waste, creating significant environmental challenges. Natural fibers offer a more sustainable alternative, yet their relatively low mechanical performance and hydrophilic nature limit their suitability for marine applications. To overcome these limitations, this study investigates the use of graphene—renowned for its exceptional mechanical strength, barrier properties, and water resistance—as a coating for natural fibers. This work presents a novel approach for developing sustainable marine-grade composites by utilizing graphene-coated flax fibers in a bio-epoxy matrix. Flax fibers were coated with varying graphene contents to evaluate the influence of graphene loading on composite performance. Laminates were produced using vacuum infusion, and their mechanical and water-resistance properties were tested according to relevant ASTM standards. The results demonstrate that graphene coatings in the range of 0.75–1.5 wt.% significantly enhance the hydrophobicity and mechanical properties of flax-based composites. This method offers a promising pathway for producing high-performance, sustainable alternatives to traditional FRPs for marine applications.

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# Thresholds for the transition from arc to tunneling debonding in single fibers under uniaxial tension

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A micromechanical framework is established to analyze the development of fiber/matrix debonds propagating either circumferentially or longitudinally. Interface fracture mechanics–based solutions to the plane problem of a circular inclusion embedded in an infinite matrix with a partially debonded interface are employed to formulate a relation between arc and tunnelling debonding. The assumption of steady-state tunnelling debonding provides a simple energetically-based solution to the complex spatial problem of debond tunnelling directly derived from solutions to the equivalent plane problem.

Finite element analyses of the plane problem were performed under plane-strain uniaxial tension to overcome limitations of existing analytical solutions restricted to relatively small debond angles and single crack configurations. Models with one or two symmetric debonds were investigated for representative carbon-fiber/epoxy and glass-fiber/epoxy systems, along with a homogeneous reference case.

Energy release rates and mode-mixity phase angles related to circumferential fracture were determined as functions of the debond arc angle. The results of these analyses were applied to evaluate critical stresses for both arc and steady-state tunnelling debonding through application of typical mixed-mode interface fracture criteria.

The framework predicts that debonds grow either circumferentially for relatively small debond arc angles or by unstable tunnelling beyond a characteristic threshold arc angle. The threshold angle for the transition from arc to tunnelling debonding and the associated critical applied stress are demonstrated to be sensitive to the elastic mismatch, mixed mode fracture criterion, and debond configuration.

The results provide a physically consistent description of steady-state tunnelling derived analytically from plane solutions and align with experimental observations of combined circumferential and tunnelling debonding in fiber-reinforced composites.

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# History of carbon fibres: Origins and evolution

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Polyacrylonitrile-based carbon fibers, now the mainstream, originated in Japan. Extensive research in the U. K., the U.S., and Japan led to the development of pyrolysis technology, establishing a continuous production system, and paving the way for industrialization. Concurrently, competition for precursor fiber development intensified between Courtaulds and Toray. Application development required a sophisticated matching of precursor fibers, pyrolysis technology, and prepreg, an intermediate product. Each company had different strategies, either pursuing independent development or collaboration. This chapter outlines the evolution of carbon fiber from its origins to its current state, highlighting key milestones and technological advancements.

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# Improving flax fibres mechanical properties for sustainable composites: defect microstructural rearrangement during chemical bleaching studied with µ-tomography and multiphoton microscopy

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Extensive research has been devoted to the use of flax fibres in biocomposites, with the aim of developing more sustainable reinforcement materials. Although the composite-like hierarchical architecture of flax fibres provides high mechanical potential, their performance is strongly affected by the presence of kink-band defects. These defects correspond to local buckling zones that induce microfibril misalignment and the formation of pores, ultimately reducing the mechanical properties of the fibres.

In this work, the effect of a chemical bleaching treatment on elementary flax fibres was investigated. Surprisingly, tensile tests showed an improvement in mechanical performance, in particular an increase in tensile strength and Young's modulus. To understand the origin of this enhancement, multimodal characterisation was conducted at both the surface and within the cell walls of the fibres.

First, SEM imaging revealed that bleaching removes external impurities and partially etches the primary cell wall, particularly in areas with defects. To explain the mechanical results and gain access to fibre ultrastructure, X-ray computed microtomography was performed on the Anatomix beamline at Synchrotron SOLEIL, enabling a quantitative analysis of defect-associated porosity. This analysis showed a 3.8-fold reduction in pore volume after treatment. Second-harmonic generation microscopy, which is used to visualise cellulose microfibrils, also demonstrated reduced microfibril misalignment within kink-band regions following bleaching.

These observations explained the improved mechanical response of the fibres. To clarify why defect severity decreased, NMR analysis was performed. The results indicated an increase in cellulose crystallinity, together with the removal of pectins and amorphous domains. This chemical restructuring promoted a reorganization of cellulose microfibrils through a co-crystallization mechanism, particularly within kink-band regions.

Overall, these findings represent a significant step toward developing treatments capable of reducing structural defects and enhancing the mechanical properties of flax fibres, contributing to the broader effort to improve the performance of plant fibre based composites.

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# Acoustic emissions for damage evolution monitoring on 4PB composite recycled samples

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Aim of this work is to present a detailed investigation of the failure modes and damage evolution of patched, short-fiber, recycled CFRP samples, in comparison with their long-fiber counterparts, during a flexural test.

Recycling composite materials is of paramount importance due to the expansion of the sector and the consequent increase in waste. A technique developed by Politecnico di Milano and the University of Bologna makes it possible to recover a large portion of the waste produced by end-of-rolls and nesting processes, by re-assembling valuable material according to a specific architecture. This process leads to the production of a so-called equivalent lamina, which can be used in a traditional lamination process.

The resulting material is therefore a discontinuous, ordered layer of short fibers that has not yet been fully investigated. While its static properties have already been assessed, the initiation and evolution of damage remain an open topic. This work aims to address this issue by monitoring the acoustic emission of samples tested under a 4-point bending loading configuration.

Acoustic emissions, which allow specific failure modes to be detected and tracked during the test, were recorded for both recycled and traditional long-fiber samples, and a comparative analysis is presented. The acoustic fingerprints of the two configurations show some similarities, but also specific features that make it possible to distinguish between the two sets of samples. In particular, the recycled samples exhibit events with much lower energy content, especially when approaching the peak load. Furthermore, patched samples show events in specific regions of the amplitude–duration space, making them easy to spot and identify.

This analysis could pave the way for real-time monitoring of recycled composite samples, improving their reliability and, consequently, their attractiveness in the market.

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# Predictive Model for the Mechanical Shear Resistance in Ultrasonic Spot Welds of Binder-Stabilized Glass Fiber Preforms

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Binder stabilized preforms have proven to be a plausible candidate for manufacturing large, complex glass fibre (GF) components, such as wind turbine blades. Therefore, it is of interest to further investigate the practical applicability of these structures in order to automate lay-up processes.

A relevant challenge in the production of large curved lay-ups is the insufficient friction between GF layers, which causes gravity-driven slippage of the preforms during the fabrics positioning. Ultrasonic spot-welding (USW) has been identified as a promising solution to prevent slippage, ensuring a quick and automatable process. Previous studies on bespoke USW setup have shown that welding temperature directly influences the tensile and peel strength of the weld. Consequently, developing an accurate model for the prediction of weld temperature and mechanical characterization is necessary for maturing and controlling the manufacturing process. However, predicting the behaviour of binder-coated fabrics in USW is difficult: the binder-coating is only 2% of the mass fraction for each layer; moreover, is not distributed uniformly across the surface of the preforms. These aspects introduce complexity in the system, ultimately impacting the accuracy of current models.

In this paper, an improved model is presented, accounting for a greater number of process parameters involved in the USW of glass fibre reinforced polymers (GFRP) as well as the local variability of superficial binder distribution. The resulting model is able to accurately predict the temperature distribution in the region surrounding the weld spot and to correlate the welding temperature with the final mechanical properties (tensile strength and peel resistance) of the samples. The proposed model allows for the identification of optimal process parameters to be implemented in an automatic lay-up setup.

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# Influence of Printing Direction on Thermal Anisotropy in Large-Scale Additively Manufactured Composite Tooling

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Additive manufacturing (AM) is increasingly used in the production of composite tooling due to its design flexibility and cost efficiency for complex geometries. Within the framework of the TORPROPEL project, the Technical University of Munich (TUM) focuses on the composite optimization of a toroidal propeller, including the additive manufacturing of molds for blade fabrication. The molds are produced using polycarbonate reinforced with 20% short carbon fibers, which enhance the stiffness, strength, and thermal conductivity of the printed material. However, fiber reinforcement introduces directiondependent properties. The fibers tend to align along the printing path, resulting in

anisotropy of thermal properties.

This anisotropy can significantly affect the outcome of the curing process of the composite blades. Non-uniform heat distribution may cause local temperature gradients, leading to uneven curing, residual stresses, and potential geometric distortions, such as warpage or spring-in. Furthermore, the relatively high coefficient of thermal expansion (CTE) of the polymer matrix can induce dimensional deviations between the designed and the final cured geometry.

This study investigates the influence of printing direction on the thermal behavior of largescale additively manufactured molds. Specimens were extracted from printed panels fabricated at different raster orientations (0°, 30°, 45°, and 60°), and their thermal conductivity and coefficient of thermal expansion (CTE) were experimentally characterized. The results provide insight into the relationship between printing strategy, fiber orientation, and resulting thermal anisotropy, contributing to improved predictive modeling and process design for AM-based composite tooling.

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# The history of nondestructive testing (NDT) on fibre reinforced polymer composites

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Nondestructive testing (NDT) is a crucial part of quality control as it helps to identify defects, flaws, and other imperfections that may compromise the performance and integrity of material components and structures. For composite materials, NDT faces unique challenges especially because of their anisotropy and heterogeneous structure that can make defect detection after production challenging, while many different production processes exist, each with their own specific problems in guaranteeing high quality products. Moreover, the gradual development of different damage types during use makes the inspection of composites complex.

This chapter presents the NDT techniques or methods for the inspection of composites, enabling the detection of defects, damage, or material degradation that could compromise the performance or safety of the composite structure. It will be shown how different techniques, some known for metals, were used on composites and were further developed to deal with the multitude of damages in composites. At present the continued advancement in computer power, data acquisition, processing techniques and computational models leads to sensors for on-line damage monitoring techniques. The future of NDT on composites is bright, with ongoing research and development promising more accurate, efficient, and comprehensive inspection methods.

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# Jellyfish-Like Self-Floating Photothermal Membranes Featuring Optimized Water–Heat Balance for Broad-Spectrum Solar Evaporation and Desalination

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Green, low-cost, and scalable water purification technologies are needed because environmental degradation and the global energy crises have increased the shortage of pure freshwater. Simple operation, plentiful energy, and economic viability make solar-driven interfacial evaporation a potential method. However, current solar evaporators still struggle to achieve efficient photothermal conversion, thermal insulation, continuous and rapid water transport, stable self-floatation, multifunctional capabilities such as photocatalysis, and large-scale, cost-effective fabrication.

To address these limitations, this study develops a scalable, jellyfish-inspired, self-floatable multilayer photothermal evaporator. The evaporator features a top photothermal layer of B-$TiO_2$-modified carbon fibers, which exhibit superior light absorption and photothermal conversion, a middle hydrophilic rayon layer that enables unidirectional and continuous water transport, and a bottom polyurethane (PU) foam layer that provides thermal insulation and buoyancy. To further enhance water transport, cotton threads were incorporated as vertically aligned water channels through needle stitching, significantly accelerating upward water delivery while preserving thermal confinement and floatability.

Comprehensive evaluations of water transport behavior, photothermal conversion efficiency, evaporation rate, and associated energy consumption were conducted. The multilayer CF/Rayon/PU structure achieved an evaporation rate exceeding 2 kg $m^{-2}$ $h^{-1}$ under one-sun illumination, demonstrating high solar-to-vapor efficiency, excellent desalination performance, and the ability to achieve simultaneous photocatalysis and evaporation. The system also exhibited strong mechanical robustness and recyclability. To overcome the limitations of manual stitching and improve manufacturability, a needle-punching method was further explored to fabricate an equivalent integrated structure suitable for large-scale production.

Outdoor field tests confirmed the system's effectiveness in solar-driven water purification and wastewater treatment, displaying remarkable cycling stability and practical deployment potential. Overall, this work establishes an advanced design and fabrication strategy for multifunctional Janus-type evaporators, offering a scalable pathway toward sustainable freshwater generation and contributing to solutions for global water scarcity and energy challenges.

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# Fatigue-creep interaction in hemp fibre composites

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Hemp fibre-reinforced polymers (HFRPs) are increasingly explored as sustainable alternatives to conventional fibre composites for long-lifespan high-performance structural applications such as wind turbine blades. However, their fatigue durability is strongly influenced by time-dependent deformation mechanisms, and the combined effects of fatigue and creep are scarcely explored. This study investigates the tensile fatigue behaviour, creep response, and fatigue–creep interaction of unidirectionally dominated HFRPs manufactured with two matrix systems: a thermoset epoxy Swancor-2511 and the recyclable thermoplastic Elium®. For benchmarking and comparison to conventional material systems, glass-fibre composites are also evaluated.

To capture the influence of time-dependent damage accumulation, three complementary loading modes are employed: constant-amplitude fatigue loading and constant stress loading at multiple stress levels, combined alternating fatigue-creep protocols with systematically varied hold durations. The latter loading mode introduces controlled periods of sustained stress during cyclic loading, enabling quantification of the additional damage driven by creep when embedded within a fatigue load sequence. Mechanical response and damage evolution are evaluated primarily in terms of lifetime, using cycles to failure and/or time to failure. Dissipated strain-energy analysis is used as a unified metric for estimating accumulated damage across different loading conditions.

The study aims to advance understanding of fatigue-creep interaction in composites where both the fibre and matrix exhibit viscoelastic time-dependent behaviour. By comparing fatigue behaviour in tests with and without dwell periods at the upper stress level, the work isolates the specific influence of creep on the fatigue-life and clarifies the dominant time-dependent damage mechanisms that govern long-term performance, while also representing a more realistic loading scenario for service conditions. The outcomes are expected to improve durability prediction for bio-based composites and to support more reliable assessment and design of recyclable, sustainable structural materials.

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# Mesoscale wetting behaviour of rovings during resin infiltration

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Fiber-matrix wetting interactions during manufacturing of continuous fiber-reinforced polymers (FRPs) can strongly influence the composites final properties and performance. However, the dynamic wetting during resin infiltration is influenced by various factors such as sizing chemistry and surface morphology of the fibers as well as geometry of the fiber bundle, distribution of the sizing along this bundle and rheological properties of the resin. In this project, the dynamic wetting of commercial carbon fiber rovings by a widely used epoxy resin through a combined experimental-numerical approach was investigated on the micro- and mesoscale. Experimental characterization of the fibrous material and the resin was correlated with static and velocity-dependent advancing contact angle measurements. Specific focus was put on the inner flow front inside the fiber bundle during wetting as geometry changes of the bundle could be observed due to capillary forces between the fibers. This experimental part was complemented by a simulative approach using mesoscale-derived capillary pressure and permeability parameters to quantitatively reproduce the time-dependent infiltration dynamics. While the contact angles between fibers and resin were found to be dependent on the infiltration speed inside the bundle, the dynamic contact angles were found to have only little influence on the capillary rise simulations. A more significant impact was found to be the bundles cross-sectional geometry which experiences significant changes during the advance of the flow front. The bundle geometry affects both the capillary pressure function and the relative permeabilities that are calculated for the flow front simulation. The bundle geometry in turn was found to depend on other mesoscale and microscale parameters. In this integrated approach, experiments and simulation could be brought into sufficient agreement. Quantitative comparison of both approaches enabled enhanced insight into fiber-resin interactions, offering a pathway to optimize composite manufacturing processes and improve material quality.

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# Lightweighting, recycled and renewable materials towards sustainable composites for automotive applications

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Lightweighting, recycled and renewable materials towards sustainable composites for automotive applications

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This study focuses on the development of sustainable composites for automotive applications through two distinct approaches. The first approach concerns the lightweighting of glass fiber (GF)/polyester sheet molding compounds (SMCs) by replacing 50% of the calcium carbonate (CaCO3) filler with less than 1% cellulose nanocrystals (CNCs). The composites are made using an SMC pilot line and are hot-pressed after proper conditioning. The effect of the CNC on the mechanical properties, curing behavior of the polyester resin, and viscoelastic properties is investigated. This improvement achieved a promising 21% reduction in density without compromising the composite's tensile, flexural, or impact properties. Moreover, the addition of CNCs led to a 22% increase in tensile modulus, highlighting their potential for lightweight composites. The second approach involves using reclaimed GFs (RGF) and/or natural fibers instead of virgin GF (VGF) and recycled polypropylene (rPP) as sustainable alternatives to GF/PP composites. These composites are produced by melt mixing followed by injection molding, and their mechanical and thermal behaviors are examined. The stiffness of the contaminated rPP was significantly improved by 116% with RGF reinforcement. Furthermore, XRD analysis disclosed the presence of beta-form peaks in the rPP formulations. This finding helped explain the material’s smaller percentage reduction in impact strength compared to vPP.

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# Fracture characterization of hybrid composite / metal joints under dynamic loading conditions

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Carbon-Fiber Reinforced Polymer (CFRP) materials are used to design aeronautical structural components. These composites are gradually replacing some traditional metals parts and can be combined with metal to form hybrid materials achieving the optimal balance between mechanical strength, thermal performance and lightness.

In order to do so, the adhesive bonding technique is often used because of its advantages, such as the absence of drilling (which allows for a more uniform stress distribution) and the ability to use more complex geometries. For instance, the fan blades of the current LEAP (Leading Edge Aviation Propulsion) engine are made of a composite material bonded to a titanium leading edge. In service, the fan blades must be designed to resist various dynamic impacts such as bird ingestion. In such cases, the evolution of the damage propagation kinetics under static conditions is insufficient to demonstrate the durability of the assembly.

The aim of this work is to describe the crack propagation behaviour of the bonded interface between titanium and composite materials submitted to different types of multi-axial dynamic loading in the mixed-mode I+II plane at constant speeds up to 5 m/s. To this end, several experimental setups have been developed to study this phenomenon.

The results showed that the critical energy release rate of the adhesive could be adequately described by the Gong-Benzeggagh failure criterion. On the other hand, the dynamic testsresults showed a significant decrease in the critical energy release rate under mode I, in consistency with M.Lißner publications. In addition, a detailed analysis of the fracture surfaces and associated crack propagation paths using optical microscopy enables a more reliable characterization of the adhesive and/or cohesive failure mechanisms.

KeyWords : Composite, Titanium, Dynamic, Fracture, Bonding.

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# Thermosets in aeronautical composites: understanding their behavior at the heart of their properties

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Aerospace industries have been using high-performance resins as matrices for composite materials for many decades. Aromatic polyimide (PI) materials are used for very specific applications for high-temperature resistant carbon fiber composites due to their superior thermal, mechanical and chemical properties. To obtain thermosetting resins that ensure satisfactory impregnation of the textile reinforcement in prepregs and good processability of the semi-product, the Thermosetting Resin Solution, a mixture of reactive monomers dissolved in a solvent, has been developed. Although this system improves thermostability and processability, the reactivity and reaction drift of the reactive monomer solution are not yet fully understood. In systems where the solvent consists of alcohols, the anhydride, one of the monomers used to form PI, undergoes esterification producing a multitude of compounds of different natures. This diversity of compounds leads to various reactions with diamines, the second monomer to form PI, affecting the final product. For example, the rapid reaction between diamines and dianhydrides necessitates the presence of carboxylic esters, which slows down the amidation reaction and helps controlling volatile release during implementation processes. Esterification therefore plays a crucial role, both in improving material properties and in offering significant industrial advantages. However, because these reactions generate numerous by-products and occurs within the part itself, achieving the reproducibility of the polymer formation remains challenging. Previous studies on resins have shown that these factors can lead to defects, including irreversible porosities and laminations. Given these complexities and the increasingly requirements of aeronautics, the development and deeper understanding of composites are crucial. This study investigate the behavior of these compounds, as a function of the ester nature (ester-acid/diester or ethyl/methyl ester…), the reaction kinetics (via NMR, IRTF, LC-MS, HPLC) and their influence on polycondensation (in particular the effect of by-products on the properties) to achieve a more controlled processing of these materials.

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# Topology-Dependent Damage Mechanisms in Interpenetrating Metal-Polymer Phase Composites

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Interpenetrating phase composites (IPCs) consist of fully interconnected, three-dimensional networks of multiple phases, allowing each phase to retain its intrinsic properties. The co-continuity of the phases promotes more uniform load and damage distribution, enhancing energy-absorption. In metal–polymer IPCs, this structural advantage is complemented by the electromagnetic shielding of the metallic phase together with the vibration damping of the polymer phase. This unique combination of properties makes metal–polymer IPCs a promising candidate for a range of aerospace, automotive, and biomedical applications.

Although previous studies have provided critical insights into the mechanical performance of metal-polymer IPCs, the fundamental mechanisms governing the damage remain relatively unexplored. The present study therefore aims to reveal the dominant damage modes in metal-polymer IPCs, specifically the aluminum-epoxy system. First, we use Selective Laser Melting (SLM) to 3D print aluminum lattice structures and subsequently infiltrate them with epoxy via vacuum-assisted processing, creating architected interpenetrating metal–polymer composites. Two distinct architectures are considered: strut-based body-centered cubic (BCC) and sheet-based gyroid structures.

The composites are tested under quasi-static compressive loads while using a point-tracking method for accurate measurements of macroscopic strain. Pure epoxy and aluminum samples are also tested to calibrate finite element models (FEM) of the composites, which show excellent agreement with experimental results in the elastic regime. Pre-test X-ray CT scans confirm minimal manufacturing porosity (<0.2%), whereas post-test CT enables identification and quantification of key damage mechanisms, including interface decohesion, metal ligament cracking, and polymer fracture. Comparative analysis reveals how these mechanisms vary with architecture, highlighting the influence of topology on damage. These combined experimental and modeling insights can guide the design of metal–polymer composites with enhanced energy-absorption performance.

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# Embedding pulsating heat pipes in carbon composites for advanced thermal management

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Efficient thermal management in carbon fibre reinforced polymers (CFRPs) is crucial for high-performance aerospace and automotive applications. However, conventional integration of thermally conductive foreign materials can introduce thermal expansion mismatches, degrade mechanical performance, and increase mass. This work presents a novel approach to thermal management in CFRP structures that embeds pulsating heat pipes (PHPs) directly within composite laminates. PHPs show promising capabilities as a passive two-phase heat transport mechanism and operate through the self-sustained oscillation of a working fluid driven by the cyclic expansion and contraction of vapour bubbles.

To fabricate CFRP PHPs, a sacrificial material vaporisation technique is employed to form continuous, sealed microchannel networks within the cured composite. This is achieved without introducing foreign materials or compromising structural homogeneity. Sacrificial materials compatible with additive manufacturing are used to fabricate the preform geometries, and a post-cure oven cycle vaporises the sacrificial material, resulting in an embedded pipeless network. The geometrical accuracy of the embedded network was evaluated using both invasive and non-invasive imaging techniques. Charging methods were investigated to accurately fill and seal the CFRP PHP with a prescribed quantity of working fluid. Finally, a bespoke thermal test rig was developed to enable comparative experimental analyses of thermal conductivity.

Operation of the embedded PHPs demonstrated an almost 150% improvement in apparent thermal conductivity compared to solid CFRP, with performance governed by orientation, channel geometry, internal surface roughness, and anisotropic through-thickness thermal conductivity of the material. The utilisation of embedded PHPs could transform a CFRP structure into a multifunctional composite, combining load-bearing capabilities with integrated thermal management.

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# Biomimetic Hierarchical Structures Based on Bone Architecture: Overlap-Controlled Toughening via Additive Manufacturing

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Natural composites such as bone and nacre achieve high toughness through staggered, hierarchical arrangements of stiff platelets in a compliant matrix. Theoretical models of bone-inspired architectures predict that mechanical performance increases non-linearly when platelet overlap exceeds a critical threshold due to enhanced load transfer and cooperative deformation. This study experimentally investigates this mechanism using additively manufactured multi-material composites based on this hierarchical design principle.

Two material systems were explored: ABS/TPU, selected as representative and widely used 3D-printing polymers, and glass-fiber-reinforced polypropylene combined with a polyethylene-based plastomer, where the plastomer matrix that encloses the PPGF platelets was chosen for its biocompatibility, making the system relevant for applications requiring safe material-skin interaction. Platelet-matrix specimens with systematically varied overlap were produced by material-extrusion additive manufacturing. Tensile bar specimens provided baseline elastic and strength data for the constituent materials, while square platelet structures were subjected to instrumented penetration impact testing.

The results reveal a non-linear relationship between overlap and mechanical performance. Stiffness, strength, and impact energy absorption rise sharply once platelet overlap exceeds a critical threshold. These findings demonstrate that biomimetic principles derived from bone hierarchy can be effectively implemented through additive manufacturing. The overlap-controlled architecture enables tunable non-linear toughening, offering a pathway toward lightweight, impact-resistant composites inspired by natural design rules.

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# A novel multi-scale methodology for climate-driven durability assessment, evaluating the environmental footprints of flax fiber reinforced composite structure

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Flax fibre-reinforced composites (FFRC) have attracted interest as sustainable alternatives for traditional composites in semi-structural applications, offering specific mechanical properties with reduced environmental impacts. However, current life cycle assessment (LCA) studies of FFRC applications do not account for their durability during the use phase. Indeed, FFRC have a particular sensitivity to weather factors like temperature, UV irradiance, relative humidity, and precipitation. This behaviour affects their mechanical properties, especially for structural outdoor applications, limiting their lifespan. This study aims at integrating a representative lifespan into the use phase of a complete LCA for a vertical-axis wind turbine (VAWT) rotor blade made of flax fibre reinforced polypropylene. The lifespan of the rotor blades will be determined through ageing of the composite, at both macro and structural scales, by considering the effects of weather factors onto its mechanical properties. FFRC macro-scale specimens are thus subjected to natural ageing at various geographical locations with different climates: oceanic, Mediterranean, desert and tropical. Concurrently, a VAWT with FFRC rotor blades is installed outdoors in France for natural ageing studies. Furthermore, macro-scale composite specimens undergo artificial ageing to simulate the degradation induced by various climatic conditions. To identify the scale effects, structural scale specimens, namely the rotor blades, are subjected to the same testing protocol. Mechanical and physical characterisation tests are then carried out at both scales after natural and artificial ageing to determine the effect of distinct climatic conditions and the corresponding degradation phenomenon on the mechanical strength of FFRCs. By correlating the two types of ageing, an acceleration factor will be determined to estimate the service life of the rotor blades, which will be consequently incorporated into the use phase of the VAWT rotor blade LCA.

Key Words: Flax fibre composites, Polypropylene, Durability, LCA, Mechanical characterisation.

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# Fiber detection in microstructural images of composites: benchmarking and sensitivity analysis of segmentation methods

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Fiber detection in 2D/3D images of advanced composites is of utmost importance for assessing both manufacturing quality and mechanical performance. Herein, we report the results of a recent benchmarking exercise that received contributions from eight research groups, with eleven different image processing approaches. The participants analyzed three distinct micrographs of a unidirectional laminate to identify individual fibers. Micrographs belonged to the same region of interest and differed in imaging protocols. During the talk, we will discuss the results obtained by the participants and the sensitivities of the used image processing techniques to factors such as illumination inhomogeneities, pixel density, polishing-related surface defects, and fiber packing. We will also detail best practices for processing of 2D/3D images such as those used in this benchmark. Finally, we will introduce the libraries that host the dataset, scripts of participants, and the documentation, that we are releasing as part of this benchmarking exercise to promote transparency and to take the first steps towards standardized protocols.

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# Modeling Strategies and Failure Prediction for Fiber-Reinforced Composite Structures Using Code_Aster: Current State and Future Directions

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The growing adoption of fiber-reinforced composite materials in industrial applications, including energy power plants, presents new challenges for structural analysis and failure prediction. Code_Aster, an open-source finite element solver developed by Électricité de France (EDF), provides advanced capabilities for simulating thermal, mechanical, thermo-mechanical, and coupled phenomena, including nonlinear behaviors such as plasticity, viscoplasticity, damage, and large deformations. Although Code_Aster has been extensively applied for metals or polymers in nuclear engineering, its use for composite and multi-material structures remains less documented, particularly regarding failure mechanisms.

This work investigates a range of modeling strategies for composite structures in Code_Aster, including 2D (plane strain/stress), plate, shell, 3D solid, and cohesive element approaches. In addition, it demonstrates how Python-based workflows can streamline the simulation process by automating key tasks. In this context, libraries such as MEDCoupling can be employed for mesh generation or fiber orientation assignment, improving both efficiency and reproducibility. The study further evaluates the applicability of different fracture and damage modeling approaches for classical coupons specimens (notched and unotched)—such as Finite Fracture Mechanics (FFM), Linear Elastic Fracture Mechanics (LEFM), and damage mechanics—while highlighting current capabilities, limitations, and future directions for composite modeling within Code_Aster

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# Experimental and numerical comparative study on the crashworthiness of pristine and recycled 3D-printed fiber-reinforced lattice structures

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In recent years, increasing attention has been given to 3D-printed structures as crash-absorbing components. The variety of materials and structures that can be built with additive manufacturing techniques allows almost endless design possibilities. The energy-absorbing performance of metallic and polymeric lattice structures has been proven to be comparable and even superior to that of conventional engineering solutions. However, significant work needs to be conducted on the crashworthiness evaluation of these structures, with a focus on strain rate dependency and high-strain-rate behavior to assess their real potential. Recycling of plastics has become more important in recent years due to the continuous rise in plastic production and the high pollution due to incorrect disposal. Hence, additive manufacturing can be one of the possible solutions to mitigate this global concern, providing ways to process end-of-life plastic products. In this work, 3D-printed lattice structures built from both pristine and recycled short-fiber-reinforced PA12 are tested under quasi-static and high-strain-rate conditions, investigating their crash-absorbing performance. Three different densities (200 g/l, 300 g/l, and 400 g/l) are built and tested to observe the effect of different structures on the energy-absorbing behavior in different strain rate conditions. A direct impact Hopkinson pressure bar apparatus is employed, with a wave separation technique and high-speed cameras. The effect of the strain rate on the 3D-printed fiber-reinforced structures depends both on the material and the density of the structures. Recycled material proves to suffer from considerable embrittlement due to the increase of strain rate, with relevant decrease of the specific energy absorbed. Pristine material shows instead a positive effect of the increased strain rate, improving energy absorption. Finally, anisotropic finite element models are developed, which are able to simulate the behavior of the structures, reproducing the main aspects of their high-strain-rate behavior with good accuracy.

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# A complete design of ultra-lightweight composite structures using topology optimization and additive manufacturing

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In applications demanding ultra-lightweight yet stiff structures, topology optimization can effectively remove inefficient material from a design. This approach substantially reduces structural weight while causing only minor reductions in stiffness. However, unlike cases involving isotropic materials, integrating continuous fiber placement into the topology optimization framework introduces significant challenges. Furthermore, a post-processing step is often necessary to improve the manufacturability of topology-optimized designs.

Among the various anisotropic topology optimization approaches, the level set-based method is particularly notable for its ability to represent continuous fibers within a topology design. In this framework, fiber orientations are determined from the tangent vectors of the level set iso-contours. To facilitate additive manufacturing, geometric constraints, such as fiber path overlaps and gaps, have been incorporated into the level set-based topology optimization process.

In this study, we propose a level set-based anisotropic topology optimization framework for the design of ultra-lightweight composite structures with tailored continuous carbon fiber (CCF) paths. Numerical and experimental findings demonstrate that composite structures with tailored CCF paths outperform those with fixed fiber orientations.

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# Tailoring Transcrystallinity and Moisture Stability in PA6/PA12 Copolymer CFRTPs Fabricated by T-RTM

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Carbon fiber–reinforced thermoplastics (CFRTPs) based on polyamide 6 (PA6) monomer, ε-caprolactam, enable rapid liquid molding through the reactive thermoplastic resin transfer molding (T-RTM) process. However, PA6 exhibits pronounced moisture sensitivity and weak interfacial adhesion with carbon fibers, which limit its long-term structural reliability.

To overcome these drawbacks, we present a copolymerization-assisted T-RTM strategy that dissolves a small fraction of ω-laurolactam, the precursor of PA12, into ε-caprolactam. Beyond improving molecular compatibility with carbon fibers, ω-laurolactam reduces the density of hydrogen-bonding sites and introduces longer aliphatic segments into the polyamide network. This disrupts the continuous hydrophilic domains typically found in PA6, suppressing water clustering and slowing diffusion along the polymer–fiber interface. As a result, the copolymer matrix exhibits inherently improved moisture resistance while retaining the low-viscosity processability required for high-quality infiltration.

Across ε-caprolactam to ω-laurolactam molar ratios ranging from 100 to 80, the copolymer matrix develops tunable crystallinity and polarity that facilitate the formation of a continuous transcrystalline interphase on carbon fibers without requiring additional thermoplastic sizing. This interface significantly strengthens interfacial load transfer and composite integrity. The mechanical performance demonstrates composition-tuned synergy, as moderate ω-laurolactam incorporation simultaneously reinforces tensile, interlaminar, and impact responses through improved interfacial bonding and fiber–matrix continuity.

To highlight relevance to mobility structures, we identify an application-centered design window in which the optimized transcrystallinity, minimized voids, and improved interfacial strength work cooperatively to enhance impact resistance and fatigue durability. A harsh moisture-exposure test at 60 °C for one month confirmed significantly reduced water uptake in this regime, while characterizations by micro-CT and polarized optical microscopy revealed stable impregnation and epitaxial growth at the fiber surface. Overall, the copolymerization-assisted T-RTM approach preserves the simplicity and speed of reactive molding while yielding moisture-resistant, mechanically robust CFRTPs tailored for next-generation mobility structures.

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# Multiscale enhancements in Z-pin reinforcement performance through curing parameters

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Z-pins, typically fabricated from high-stiffness and high-strength materials, are vertically inserted for interlaminar enhancement of composite laminates. This study established a multiscale analysis framework integrating finite element simulations and experiments to investigate curing effects on the mechanical behavior of Z-pinned composites (Fig. 1).

A fully 3D coupled thermo-chemical-mechanical process model was utilized to simulate the heat transfer, property evoluation, and stress development during the entire cure cycle. At the mesoscale level, Representative Volume Element (RVE) models explicitly represent Z-pin-induced microstructural features, including the Z-pin itself, resin-rich regions, fiber waviness, swelling, and unaffected composite areas. The curing-induced Z-pin/composite interfacial conditions were predicted, and resulting effective Z-pin bridging behaviors were verified by Z-pin pullout tests. The results reveal that curing process induces the interfacial cracks between the Z-pin and surroundings, which subsequently influences Z-pin bridging performance under pullout displacement. Adopting a lower holding temperature over an extended period (e.g., 383 K for 200 min) is shown to mitigate curing-induced interfacial damage, leading to higher Z-pin energy dissipation (Fig. 2).

These cure-dependent Z-pin bridging information were further incorporated into macroscale models to study the cure effects on the delamination resistance of multi-pinned specimens. The predicted failure process of multi-pinned specimens under displacement loading (i.e. delamination initiation, propagation, stick-slip, and catastrophic failure) were verified by Double Cantilever Beam (DCB) test results. Specimens cured at 383 K for 200 min exhibit a 38.82% improvement in steady-state mode I interlaminar fracture toughness compared to those cured at 403 K for 150 min (Fig. 3). Combining the experiments and numerical simulations, this paper presents a viable pathway for optimizing the Z-pinning reinforcement through the curing profile design.

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# Leveraging Processing-Induced Electromechanical Anisotropy of Laser-Induced Graphene for One-Shot Engraving of Highly Sensitive Strain Sensors

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Laser-induced graphene (LIG) is a promising carbon nanomaterial for flexible devices, owing to its straightforward and cost-effective fabrication. However, laser rastering produces highly anisotropic microstructures that influence the macroscopic response. This study systematically investigates the electrical and electromechanical anisotropy of LIG fabricated on polyimide (PI) films using a commercial $CO_2$ laser. We modified the scanning process by virtually rotating the object by a prescribed tilt angle in the design software while keeping the laser scanning direction fixed. This simple yet novel manipulation of the scanning strategy induces fluence gradients across the sample, strongly affecting the microstructure, conductivity, and sensing performance of the resulting LIG. Raman mapping coupled with principal component analysis (PCA) was employed to characterize spatial microstructural variations of LIG at different tilt angles. This analysis, supported by SEM imaging, revealed pronounced differences in graphitization and defect density tied to the scanning strategy. Our findings show a strong dependence of LIG properties on the tilt angle, with the optimal configuration at 0° yielding the highest gauge factor and lowest resistance. Furthermore, the level of anisotropy in the electrical and electromechanical properties can be tuned via laser power. To demonstrate the practical significance of anisotropy, we fabricated a piezoresistive strain sensor using LIG patterned at optimized tilt angles, achieving gauge factors three to ten times higher than with conventional, constant tilt-angle configurations. We further explored the anisotropy of LIG fibers (LIGF), showing that their electromechanical properties also vary with tilt angle. Exploiting LIGF anisotropy, a transmission line-based capacitive strain sensor was developed, demonstrating up to a tenfold improvement in sensitivity. These results establish the scanning strategy as a powerful and accessible lever for optimizing strain sensors and expanding their use in wearable electronics, structural health monitoring, and soft robotics. The approach is fully compatible with scalable, industrial $CO_2$ laser platforms.

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# Microwave-assisted technologies for fibre-reinforced thermosets composites recycling

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Effective recycling techniques are crucial, as evidenced by the growing usage of fiber-reinforced thermoset composites in engineering applications. The crosslinked nature of the resin leads conventional recycling methods to be energy-intensive, chemically harsh, and fiber-damaging. In order to address these constraints, this research investigates microwave-assisted recycling as a more environmentally friendly substitute.

Two recycling routes were tested. First, a bidirectional glass fibre-reinforced unsaturated polyester composite was solvolysed under microwave irradiation under mild conditions to promote resin depolymerisation without damaging fibres. The obtained liquid phase was further treated, in order to evaluate the possibility of establishing a closed-loop chemical recycling process. Then, microwave-assisted pyrolysis was carried out on a carbon fibre-reinforced epoxy composite (amine-cured) as a solvent-free degradation route.

Recovered fibres from both routes were characterised to evaluate processes impact and their reuse possibility. Microstructural, thermal and mechanical analyses were carried out to evaluate fibre quality. To verify the effectiveness of resin removal, residual matrix content was measured by thermogravimetric analysis (TGA). The purity of the fiber surface and possible microstructural deterioration were revealed by scanning electron microscopy (SEM). By evaluating Young's modulus, elongation at break, and ultimate tensile strength and comparing the results to those of virgin fibres, single-fibre tensile testing was used to evaluate the preservation of mechanical properties. The liquid fractions produced during solvolysis and pyrolysis were also characterised using Fourier-transform infrared spectroscopy (FTIR) and elemental analysis to identify degradation products and evaluate their reuse potential.

Overall, this work contributes to the development of more sustainable recycling strategies for thermoset composites by demonstrating the feasibility of fibre recovery while also considering the circular use of process by-products, using microwave-assisted technologies.

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# Enhanced interfacial performance and durability of basalt fibre composites via star-like copolymer and MXene-based surface treatments

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The development of high-performance and environmentally resilient composite materials continues to drive interest in surface-engineered bio-based epoxy systems and advanced fibre modification strategies. This work presents an integrated investigation into the enhancement of a bio-based epoxy resin and basalt fibre-reinforced composites (BFRC) through the use of a star-like n-butyl methacrylate-block-glycidyl methacrylate copolymer additive and MXene-assisted fibre functionalisation. The segregation behaviour of the star-like copolymer within the epoxy matrix was first examined, revealing that even low additive contents (≤0.5 wt%) preferentially migrate towards the resin surface due to the copolymer's high density of chain ends and reduced surface tension. Atomic force microscopy and contact angle measurements confirmed that this near-surface enrichment lowers the epoxy surface tension and improves its wettability towards basalt fibres, thereby promoting more favourable fibre-matrix interactions.

To evaluate long-term performance, the hydrothermal ageing behaviour of BFRC modified with the star-like copolymer was assessed. Before ageing, interlaminar fracture toughness and critical load increased by 49% and 26%, respectively, compared with unmodified BFRC. However, the increased water uptake induced by the additive resulted in more pronounced degradation during ageing, with toughness and critical load decreasing by up to 48% and 33%. Microscopic observations revealed roughened fibre surfaces, debris accumulation and signs of interphase deterioration, indicating moisture-driven damage mechanisms.

In parallel, MXene-enhanced plasma treatment of basalt fibres was investigated as a complementary route to strengthen fibre-matrix adhesion. Interfacial properties were evaluated through microdroplet pull-out testing, while numerical modelling supported the interpretation of the experimental results. The treatment produced homogeneous MXene deposition and increased fibre surface roughness, leading to a marked improvement in interfacial shear strength.

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# Use of bio-based and recycled composites in sports and leisure products

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Sustainability has become a key marketing factor in consumer products. The use of recycled fibers, natural fibers, or bio-based matrix systems is often promoted as environmentally beneficial. However, many claims lack technical substantiation. Natural fiber–reinforced plastics (NFRP) are frequently presented as sustainable alternatives to glass fiber–reinforced composites, without fully considering functional and ecological implications.

This study conducts a Life Cycle Assessment (LCA) according to DIN EN ISO 14040/44 to evaluate the environmental impacts of different fiber and material concepts. Critical factors for developing sustainably optimized products are identified. Predefined application scenarios, a saxophone reed, a chair, and a surfboard, are analyzed to assess load cases and evaluate material substitution.

Results show that natural fibers such as flax, with a tensile strength of 0.8 GPa, reach only about a quarter of the strength of E-glass fibers (3.4 GPa). Substituting NFRP in statically loaded components requires larger cross-sections, increasing material use. Despite a lower production $CO_2$ footprint (0.6 kg $CO_2$-eq/kg versus 1.8 kg $CO_2$-eq/kg for glass fibers), the higher material demand leads to roughly 25% more resin consumption, significantly reducing the ecological advantage. Higher costs (five times that of glass fibers) and limited durability under moisture further restrict applicability.

The study demonstrates that natural fibers are not inherently more sustainable; their ecological performance strongly depends on application and design. Holistic, LCA-based assessments are essential for informed decisions in sustainable product development.

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# MHz X-RAY IMAGING OF HIGH STRAIN-RATE FAILURE OF OPEN-HOLE UNIDIRECTIONAL FLAX FIBRE COMPOSITES

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Natural fibre–reinforced polymer composites (NFRPCs) are gaining increasing attention as sustainable alternatives for lightweight structural components due to their low density, high specific stiffness, and reduced environmental impact. Among them, flax fibre composites exhibit favourable damping and renewability, yet their widespread adoption remains hindered by moisture sensitivity, property variability, and limited fibre–matrix compatibility, which together promote complex, rate-dependent failure mechanisms. This work investigates the high strain-rate compressive behaviour of flax fibre–reinforced polymer composites, focusing on micromechanical damage evolution. Split Hopkinson pressure bar (SHPB) experiments were conducted in conjunction with in-situ synchrotron X-ray imaging at beamline ID19 (ESRF) to visualise the initiation, interaction, and progression of internal damage under dynamic uniaxial compression. Strain rates between 100 and 600 $s^{-1}$ were explored to elucidate the transition of dominant failure modes from quasi-static to impact regimes. The combination of high-speed mechanical testing and time-resolved synchrotron tomography provides unprecedented insight into the rate-dependent deformation and failure of natural fibre composites. The findings not only deepen the mechanistic understanding of dynamic damage processes in flax composites but also deliver microstructure-informed design strategies to enhance impact resistance and enable the reliable use of sustainable composites in crashworthy lightweight structures.

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# In-situ-infrared thermography tensile testing - a new method to distinguish different failure mechanism in thermoplastic and thermoset composites?

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High-performance, lightweight composite materials are becoming increasingly important in numerous industrial applications due to their excellent strength-to-weight ratio. These materials' mechanical properties, particularly stiffness and strength, are typically evaluated through quasi-static tensile tests. In these tests, the specimens are gradually loaded until they fail. In this study, an infrared (IR) camera is used directly during the tensile tests to detect thermal signals or anomalies on the surface of both sides of the test specimens. These signals can indicate local defects, delamination, or other critical material degradation. This enables extended in-situ observation of the failure processes. Infrared thermography (IRT) is a subgroup of non-destructive testing (NDT) methods that enables the rapid, contactless, and large-area evaluation of material conditions. There are numerous post-processing methods for analyzing thermograms, including pulsed phase thermography (PPT). In PPT, the time signal is first converted into a frequency signal using a Fourier transform, and then the amplitude and phase images are evaluated. As part of this work, we adapted these methods, particularly PPT, for tensile tests to efficiently and effectively process IRT data. Additionally, we use and modify a color-coded representation in which phase and amplitude images are combined in the HSV (hue, saturation, value) color space to visually differentiate defect areas from intact areas. Both thermoset and thermoplastic composites were examined. The initial results clearly show differences in failure behavior in the IRT images. For now, they only suggest that the combined mechanical and thermographic analysis could be suitable for distinguishing between different failure mechanisms. Further systematic investigations are necessary to answer this question conclusively and confirm the method's applicability to different composite materials.

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# Influence of low-velocity impact damage on crack propagation in adhesively bonded thermoplastic composites

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High-performance thermoplastic composites are increasingly utilized in lightweight structures due to their excellent mechanical properties and the potential for efficient manufacturing processes such as welding and stamp forming. When combined with structural adhesive bonding, they enable multi-material concepts and high damage tolerance. While the effects of low-velocity impacts (LVI) on composite laminates have been widely studied, the resulting influence on crack propagation in adhesively bonded thermoplastic joints remains insufficiently understood.

The present study investigates the influence of impact-induced damage on crack propagation behavior in both adhesively bonded and unbonded carbon fiber-reinforced thermoplastic (CFRTP) specimens. Controlled low-velocity impacts were applied to introduce localized and complex damage into Double Cantilever Beam (DCB) and End-Notched Flexure (ENF) specimens, representing mode I and mode II loading conditions, respectively. The resulting damage morphology was characterized using ultrasonic testing and X-ray computed tomography. Subsequent quasi-static DCB and 4ENF tests were conducted to evaluate the influence of the pre-damaged regions on crack growth. Furthermore, Crack Lap Shear (CLS) specimens were subjected to cyclic loading to investigate fatigue-driven crack propagation in impacted bonded joints.

Results reveal that the influence of impact-induced damage on crack propagation strongly depends on the applied loading conditions. Under static mode I loading, the presence of impact damage leads to an abrupt and premature failure, indicating a significant reduction in crack resistance. In contrast, during cyclic mixed-mode loading, the influence of impact damage on crack propagation behavior is negligible, suggesting that the adhesive layer and the thermoplastic matrix can effectively accommodate such local defects under these loading conditions.

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# Benchmark Activity for micro-Structure Image-processing for Composites: Voids in 2D

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This study compares 12 segmentations masks and associated porosity metrics from 10 different research groups from around the world. This benchmarking activity aims to improve confidence and consistency in void segmentation, which is critical due to the significant effect voids have on the performance of composite components and the broad scatter in historic datasets.

In order to capture the effects of voids in advanced simulation tools and capture local variations, accurate micro-scale segmentation of void regions is needed. This drives the need for image-based analysis to replace more conventional standardized macro-characterization methods such as acid digestion and burn-off. Within image segmentation methods applied to voids detection two primary categories can be distinguished: thresholding-based and more recent machine-learning-based. Both approaches can be used to take 2D, 2.5D, or 3D datasets and generate masks that identify pixels belonging to voids. While the literature contains many examples of such techniques being used, there is limited cross-validation, resulting in uncertainty when comparing results or translating techniques from one study to another.

To assist the academic community in standardization and improvement of void segmentation efforts, this study tasked different research groups, each with their own in-house segmentations solution, with segmenting 2 high resolution micrograph image. These images were provided as part of a larger database that could be used for tuning/training. No limitations were put on the techniques the participants could use. From the individual masks, the basic metrics of void content and number of voids were extracted for comparison. A combined mask was also generated by summing the individual masks and this was used to identify areas of interest. Exploration of the disagreement highlighted by the combined mask has generated useful insights into the relative biases of specific algorithms or process steps for future researchers.

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# Scalable defect inspection of NCF preforms using polarisation imaging

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The increasing use of carbon fibre reinforced polymers (CFRPs) in aerospace primary structures is driving a shift toward more rapid and scalable manufacturing strategies. To meet net-zero aviation goals and replace legacy fleets, the industry is transitioning from traditional autoclave-based processes to highly automated, out-of-autoclave methods using non-crimp fabrics (NCFs).

A critical challenge in this transition is the large-scale inspection of dry fibre preforms with complex geometric features, which is further complicated by highly reflective material surfaces, and intricate material architectures [1–3]. Methods such as laser profilometry often struggle with reflectivity limiting their ability to accurately capture surface features [4]. While advanced techniques like X-ray CT and thermography offer improved defect characterisation, they are typically expensive, slow, and inapplicable for large-scale or in-situ inspection of non-crimp fabric (NCF) preforms [4,5].

As a result, there is a growing need for inspection technologies that are scalable, non-contact, and capable of delivering reliable data in real time to support modern composite manufacturing workflows.

In this study, a polarisation imaging technique was evaluated against a state-of-the-art photometric stereo imaging technique for defect detection of a bi-axial carbon fibre NCF preform. While the photometric stereo approach achieved high resolution fibre orientation mapping, the reliance on controlled lighting, multiple exposures, and proximal positioning, limited integration and scalability. In contrast, polarisation imaging offered a promising alternative, enabling defect and orientation detection under ambient lighting with minimal system complexity.

However, inconsistencies in pixel level fibre orientation measurements were found to compromise the accuracy of fibre angle detection and, consequently, fibre-angle based defect detection. This paper investigates the process sensitivity and proposes strategies to minimise its impact, with the goal of improving measurement reliability and consistency.

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# Introducing a Double-Welding Approach and Investigating the Effect of Welding Time on the Room- and Low-Temperature Performance of Resistance-Welded CF/PEKK Joints

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Thermoplastic composites are widely used in the aerospace industry owing to their excellent strength, stiffness, and durability. Their ability to be re-melted enables efficient joining processes, making them attractive for advanced engineering applications. This study investigates the resistance welding (RW) of carbon-fibre-reinforced poly-ether-ketone-ketone (CF/PEKK) composites, focusing on the effects of welding time and a double-welding technique, first introduced in this study, on joint quality under room temperature (RT) and low-temperature (−50 °C) conditions. CF/PEKK laminates are incorporated a custom-designed multi-layered heating element composed of a stainless-steel mesh embedded between PEEK-film and glass-fibre layers. A process window ensuring strong bonding is established by optimising welding parameters using differential scanning calorimetry (DSC), thermogravimetric analysis (TGA), and thermomechanical analysis (TMA). Within this process window, welding is performed at 50, 70, and 90s using both single- (SW) and double-welded (DW) approaches. Joint performance is evaluated by single-lap shear (SLS) tests at RT and −50°C, supported by microscopy, Micro-CT, and DSC characterisation.

The results show that increasing welding time markedly enhances joint strength and interface consolidation, with the SW joints welded for the longest duration exhibiting the highest SLS strength. Implementing DW further improves interfacial integrity for shorter weld durations by healing voids, while extended durations cause slight matrix degradation and reduced crystallinity, leading to a decrease in strength at RT. Conversely, at −50°C, the joints display higher load capacity than at RT, and DW joints show superior performance, where the improved interfacial quality allows the increased matrix rigidity and stiffness to be more effectively utilised, resulting in enhanced low-temperature performance.

These findings highlight that precise control of welding time and careful application of the double-welding strategy can significantly improve weld quality and reliability. The approach, validated under both RT and low-temperature conditions, demonstrates strong industrial relevance for high-strength thermoplastic composite joints in aerospace structures.

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# Investigation of the interfacial properties of CF/PEEK composites using molecular dynamics

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As global sustainability goals advance, ensuring the durability of CFRP composites in demanding applications, such as hydrogen storage tanks, has become a major engineering challenge. Durability is strongly tied to the fibre-matrix interface, which is essential for load transfer and resistance to failure. This interface shows a complex multiphase structure influenced by surface tension, chemical bonding, and mechanical adhesion. The thermoplastic PEEK matrix offers exceptional mechanical and thermal stability, making a detailed understanding of its multiscale and thermo-mechanical behaviour crucial for developing cryogenic-ready composites.

This study provides valuable insights into PEEK's thermal behaviour and crystallinity through high-performance molecular dynamics (MD) simulations and density functional theory (DFT) calculations. An atomistic PEEK model comprising over 35,000 atoms was developed using the PCFF force field. The model successfully reproduced key properties, including structural morphology, glass transition temperature (149 °C), melting temperature (352 °C), and density (1.26 g/cm³) and aligned closely with experiments.

The validated PEEK model was then used to construct a carbon fibre/PEEK interface by stacking PEEK molecules across three graphene layers, resulting in more than 140,000 atoms. A novel noise function introduced pseudo-random defects into the graphene to aim for a more representative carbon fibre surface. Interfacial shear strength (IFSS) was determined via simulated fibre pull-out tests with different defect levels, stacking sequences, and temperatures ranging from 300 K to 20 K. The IFSS of 67.7 ± 4 MPa at 300 K (26 °C) agreed well with experimental results (60 ± 10 MPa). At cryogenic temperatures, IFSS increased by 12% at 77 K (-196 °C) and by 17% at 20 K (-253 °C). Internal interaction analysis provides the first atomic-scale insight into the behaviour of the CF/PEEK interface under cryogenic conditions.

Overall, the study demonstrates how high-fidelity MD can complement experiment and clarify nanoscale mechanisms that influence macroscopic composite performance.

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# Comparison between 1D and 3D finite element models used for the prediction of fiber damage in unidirectional composites

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The finite element method is widely used to model the process of fiber damage in unidirectional composites. Each fiber is divided into sections, and each section is assigned a strength according to a specified distribution. Two of the most important modeling approaches are those that use 1D elements (e.g., the spring element model, SEM [1]) and 3D elements (e.g., the full three-dimensional finite element model, full 3DFEM [2]).

In the SEM, each section is represented by a bar element, and the fibers are connected to each other through bar elements that represent the matrix. In contrast, the full 3DFEM uses multiple 3D finite elements to discretize both the fibers and the matrix.

Due to the reduction in the number of degrees of freedom in the SEM, simulations are significantly faster. However, the stress fields in the matrix around a broken fiber are not captured in detail, since only one linear element is used to connect the fibers, which can lead to inadequate stress concentrations. This limitation is not present in the full 3DFEM, where multiple elements are employed to connect the fibers.

The aim of this study is to investigate the differences in the predicted macroscopic behavior of the composite between the two modeling approaches. To this end, representative volume elements (RVEs) with 18 and 50 fibers are developed and analyzed using both models. The results show that the SEM provides a good approximation of the macroscopic stress–strain response of each RVE and can therefore be considered a preferable choice.

References:

[1] R. P. Tavares et. Al., A dynamic spring element model for the prediction of longitudinal failure of polymer composites, Computational Materials Science 160 (2019) 42–52.

[2] E. Polyzos et al., Probabilistic progressive damage modeling of hybrid composites, Mechanics of Materials 197 (2024) 105087.

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# Biaxial tension-compression fixture for cruciform CFRP specimens on uniaxial testing machines

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Accurately determining the shear behaviour along principal material directions is essential for reliable analytical modelling, numerical simulations, and the design of lightweight composite structures. Traditionally, widespread adoption of T–C cruciform testing has been limited by the requirement for advanced biaxial machines equipped with four independent actuators and load cells. To overcome this limitation, the aim of this study is to present a biaxial tension–compression fixture for cruciform specimens that enables the characterization of the complete non-linear in-plane shear response using standard uniaxial testing machines.

Recent approaches have employed ±45° symmetric CFRP cruciform laminates subjected to equal-magnitude tension and compression, together with anti-buckling support, in order to promote a pure shear state oriented at 45° to the loading axes. This configuration allows shear characterization at strain levels far beyond those achievable with standard shear tests, which is particularly relevant for components in aerospace, wind energy, and automotive applications that experience complex multiaxial stress states.

Building on this framework, the present work introduces a dedicated 45° tension–compression fixture capable of reproducing biaxial T–C loading on conventional universal machines. Existing fixtures often alter the loading rate or fail to maintain a constant 1:1 load or displacement ratio when specimens exhibit highly non-linear behaviour, compromising the fidelity of shear characterization. In contrast, finite element simulations of stiffness and buckling demonstrate that the proposed fixture remains rigid and stable under the high loads associated with CFRP specimens. The design ensures that a theoretical 1:1 displacement ratio is preserved while transmitting tensile and compressive loads of equal magnitude. Numerical results show that this ratio is effectively maintained throughout the entire loading sequence, including the nonlinear deformation regime. The next step will be to conduct experimental tests to verify that the predicted force–displacement relationships are accurately reproduced under real testing conditions.

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# Processing charactistics of unidirectional prepregs with bio-derived poly(furfuryl alcohol) matrices

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Furan resins based on bio-sourced polyfurfuryl alcohol (PFA) offer great potential to minimize the ecological impact of high-performance composite parts made from thermoset prepregs and at the same time reduce reliance on petrochemical precursors. While these bio-resins are recognized for their competitive thermo-mechanical performance and excellent fire, smoke and toxicity (FST) properties, processing remains an understudied challenge due to the separation of water from the polycondensation reaction. This study examines crucial processing properties of PFA prepregs from the perspective of manual and automated prepreg lay-up processes. For prepreg preparation, unidirectional carbon fiber non-wovens were impregnated with acid-catalyzed, in-house synthesized PFA resin. The prepregs were B-staged under vacuum to remove volatiles from pre-curing, after which the final prepreg quality was assessed in terms of porosity, fiber volume fraction, and dimensional stability. Tack and drape were characterized in conjunction with key aspects of the physio-chemical prepreg state. The processing-relevant material parameters were found to be highly sensitive to both out-time and processing temperature. A strong interdependency between the investigated influencing factors was identified and discussed in terms of its implication for the adjustment of prepreg lay-up processes.

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# Influencing fibre orientation in fibre-reinforced plastics using shape memory alloys during manufacturing – a feasibility study

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Fibre-reinforced plastics are characterised by their low density, high mechanical properties and functional integration, which facilitates the development of high-performance lightweight structures. Local weak points emerge due to various factors, including non-graded transitions at interfaces between two fibre-reinforced composites because of the lack of fibres. Due to their poor mechanical properties, these weak points require local reinforcement, which consequently leads to oversizing. This approach is at odds with the principles of lightweight engineering and sustainability because more material is needed for production and operation. The creation of graded transitions necessitates the targeted manipulation of fibre orientation. As shown in previous works the functional integration of shape memory alloys enables the deformation of fibre-reinforced plastics to achieve the required geometry. Previous papers focus on temporary shape shifting through the integration of shape memory materials after the manufacturing of the fibre-reinforced plastic. The present study investigates the implementation of a permanent fibre manipulation through shape memory alloy wires as an integral component of the fibre reinforced plastic during the manufacturing process. The goal is to achieve a local fibre reorientation so that fibres are located in the boundary layer for load dedicated structures. In order to accomplish this objective, NiTi-shape memory wires are shape-set as bending actors and are embedded in a two-step manufacturing process in a glass-fibre-reinforced plastic plate. In this case study, a plate is to be given an orthogonal bracing, where fibres are to be positioned vertically from the plate plane. The shape memory wires are first integrated into a flat multi-layer structure outside the neutral axis. Before the matrix is cured the wires are thermally activated and position the fibers out-of-plane by interlocking. The improvement of the mechanical properties out-of-plane of the newly produced composite compared to composites with non-graded transitions is confirmed by tensile tests.

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# Modelling delamination initiation and propagation in composite structures using a combined CZM-VCCT approach.

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Delamination is a critical failure mechanism in composite laminates, arising from interlaminar stress concentrations and leading to extensive damage propagation. Delamination growth can significantly reduce structural integrity, residual strength, and component stiffness, making it particularly dangerous in safety-critical applications. Accurately simulating this behaviour requires modelling both the onset of damage and its subsequent evolution under quasi-static and cyclic loading conditions.

In this work we present a hybrid modelling framework that combines Cohesive Zone Modelling (CZM) for delamination initiation with the Virtual Crack Closure Technique (VCCT) for subsequent propagation. The CZM provides an accurate representation of crack initiation through the traction–separation law, enabling a versatile prediction tool for interlaminar damage nucleation without requiring a predefined crack tip. Once the cohesive interface locally reaches full degradation and a discrete crack has formed, the delamination front is automatically remapped on a new model and the analysis transitions to a VCCT-based formulation. The VCCT is used to evaluate mixed-mode Strain Energy Release Rates (SERR) at the crack tip to determine the delamination growth. The proposed hybrid methodology is implemented in an automated Python workflow that manages all finite element preprocessing, delamination front extraction, damage update, and post-processing steps.

The framework is validated against established experimental benchmarks to assess its ability to predict crack onset location and propagation behaviour across different loading conditions.

This combined approach enabled us to exploit the VCCT's simplicity – only requiring the fracture toughness values to model delamination propagation – while compensating for its shortcomings on nucleation detection through the use of CZM. This resulting framework provides a versatile and accurate tool for analysing delamination in composite laminates.

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# Sustainable Composites for Cabin Monuments – Recycling of Resins with tailored FST Properties

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Interior cabin monuments till date are mostly made out of glass fiber composites with phenolics which are entirely of virgin origin. These are not only difficult to recycle but even when they are mechanically shredded, the recovered components are not planned for re-use. However, in the German Federal Government's LuFo-VI funded project CirKle (ReCycling Werkstoffe für Flugzeug Kabinenbauteile; EN: Recycling materials for aircraft cabin components) this ideology is being re-imagined. This project strives to make interior cabin monuments sustainable by using recycleable resins as well as recycled carbon fiber based preforms instead of virgin and non-recycleable counterparts. The aim is to recover the individual components for reuse thus trying to close the loop for a product which has mostly had a cradle-to-grave life cycle. Given that fire, smoke and toxicity (FST) characteristics is a major requirement for these monuments, DLR has been developing these sustainable composites with additives within CirKle to tailor the FST behaviour. In line with the project's ideal, this work presents one of the first efforts within CirKle to additionally recover the powdered additive (ATH based S-11) by recycling the bulk composites processed with sustainable resin systems. The main challenge addressed here is the process optimization for recovering these additives as cleanly as possible along with the recovered resin component. The purity of these additives, i.e. if there is any resin component still remaining on the surface has been investigated via thermal analysis. The possibility to reuse the solvent remnants for further reprocessing is also looked into.

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# Optimization-Based Material Calibration for Ballistic Impacts on Composite Plates

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The demand for ultra-high molecular weight polyethylene (UHMWPE) composite personal protective equipment continues to grow in the defense sector. By 2035, the polymer matrix composites are projected to account for over 50% of the ballistic composite market [1], driven by their remarkable strength-to-weight ratio . However, the development and performance evaluation of products made of UHMWPE composites currently relies heavily on costly and time-consuming experimental testing campaigns. Numerical simulations offer an efficient alternative to physical testing, reducing labor, time, and material waste while improving predictive capability.

The material properties of UHMWPE composites are highly sensitive to pressure and temperature during the consolidation process, making it difficult to apply standard material data across different manufacturing conditions. To address this issue, this study presents an optimization-based framework using LS-OPT to determine material parameters for unknown consolidation conditions using minimal experimental testing input. Simplified ballistic experimental testing provides physical behaviors that numerical models can replicate through the optimization process, allowing for the iterative adjustment of key material parameters until experimental and numerical behavior converges. The optimized composite material parameters are then compared across multiple experimental configurations to evaluate the precision and accuracy of the calibration approach that would then reduce the need for future experimental testing.

Through reduced experimental evaluation, material parameters implemented in finite element software, including IMPETUS and LS-DYNA, can be efficiently calibrated to reproduce the observed ballistic responses. This process can streamline the development and certification of future UHMWPE composite protective equipment, improving readiness in defense applications.

[1] N. Kaitwade, "Ballistic Composites Market – Size and Share Forecast Outlook 2025 to 2035," Future Market Insights, 2025.

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# Lifetime Prediction of Discontinuous Fiber Reinforced Polymers

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Discontinuous fiber reinforced polymers are of particular interest for producing complex geometries, high volume parts, and cost-efficient components. These materials combine the lightweight and processing advantages of thermoplastics with the enhanced mechanical performance provided by glass or carbon fibers. The key parameters influencing their behavior are fiber orientation, fiber content, and fiber length. Longer fibers improve creep resistance and load transfer efficiency, which are crucial for applications subjected to long term loading and temperature variations. However, the processing of long glass fiber reinforced polymers remains challenging due to higher viscosity, fiber breakage during molding, and increased manufacturing costs.

A comprehensive understanding of material behavior is essential for safe and sustainable component design. In this study, the focus was on the mechanical characterization of polypropylene reinforced with 30 wt.% and 40 wt.% long glass fibers. The material behavior was analyzed under quasi static and cyclic loading, emphasizing fatigue performance and fracture mechanics. Special attention was given to the influence of fiber orientation and fiber content on stiffness, strength, and lifetime.

Experimental data were post processed to evaluate damage evolution and identify indicators for the transition from fatigue analysis to fracture mechanics analysis for life time estimation. This approach enables a more accurate estimation of lifetime and failure mechanisms in structural components.

Additionally, fractographic analyses were carried out to investigate the underlying fracture mechanisms. The results showed that, under cyclic loading, failure is predominantly governed by the matrix behavior and fiber pull out is significantly less compared to short fiber reinforced polymers. These insights contribute to a deeper understanding of long fiber reinforced polypropylene and support the development of reliable, lightweight, and sustainable engineering materials for future applications.

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# Smart luminescent coating for impact damage detection on composite laminates

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Composite materials are extensively employed in aerospace structures for their exceptional strength-to-weight ratio, yet they remain susceptible to impact or indentation induced damage. Traditional Structural Health Monitoring (SHM) approaches, using embedded or surface-mounted sensors such as fiber Bragg gratings or piezoceramics can compromise laminate integrity and introduce challenges related to wiring, connectors, and electromagnetic interference. These drawbacks increase system complexity, weight, and cost while reducing reliability.

Mechanoluminochromic (MLC) materials present a compelling alternative, as they exhibit fluorescence changes in response to mechanical stress. However, their limited mechanical robustness restricts direct application. This work introduces a novel smart coating that integrates a copper-based Hybrid Coordination Polymer (HCP) into a thermoset paint, combining MLC functionality with the mechanical resilience and processability of polymer coatings.

The MLC coating was spray-deposited onto a cross-ply woven carbon fiber reinforced plastic (CFRP) laminate and subjected to quasi static indentation (QSI) at various energy levels using an instrumented drop-weight tower, producing barely visible damage (BVD). Under UV illumination, the impacted regions were imaged with a smartphone, and custom MATLAB algorithms were used to analyze fluorescence intensity via the green-to-blue ratio. This optical signal showed a strong correlation with the peak puncturing force, as confirmed by micrographic examination of the laminate cross-section.

The proposed smart MLC coating enables full-field, non-contact, and nondestructive detection of impact damage without altering the component’s appearance under visible light. Its simplicity, affordability, and compatibility with real-time imaging technologies highlight its potential as a next-generation SHM solution for aerospace and other advanced composite applications.

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# Multiphysics Simulation of Linerless CFRP Tank for LH2 Storage

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The adoption of liquid hydrogen ($LH_2$) as a sustainable energy carrier requires lightweight, high-integrity storage systems. Type-V composite tanks, constructed entirely from carbon fibre-reinforced polymer (CFRP) without a metallic liner, offer significant mass savings but pose unique challenges under cryogenic conditions. This research presents a comprehensive approach that combines multiphysics simulations for a virtual full-scale inner tank and experimental validation and simulations of a small-scale Type V tank demonstrator.

The workflow integrates multiscale composite modelling using DIGIMAT to capture temperature-dependent properties and progressive failure mechanisms. Thermal-structural coupling is performed with MSC Nastran SOL 153/159 for cooldown analysis and SOL 400 (Marc technology) for nonlinear response under combined thermal and pressure loads. Fluid–structure interaction (FSI) is addressed through Cradle CFD (scFLOW) to simulate the influence of transient pressure distributions, which are mapped onto the structural model. Possible damage progression and various failure modes are evaluated under representative operating conditions, and laminate optimisation is conducted using SOL 200.

A small-scale composite tank demonstrator was manufactured using roll-wrapping of thin-ply prepreg weaves for the cylinder and manual layup of prepreg for the dome ends. The tank was then subjected to non-destructive cryogenic pressure testing using LN2. Experimental data from cooldown tests were used to verify and validate the simulation framework. Results demonstrate a strong correlation between predicted and measured strain fields. The workflow significantly reduces reliance on costly physical testing and supports the work towards digital certification of composite cryogenic vessels.

This work advances predictive modelling for complex composite structures and contributes to the development of next-generation hydrogen storage systems for aerospace and space applications, aligning with global sustainability goals.

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# Damage Modelling of Thick Composite by Non-Intrusive Global/Local Approach

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This work deals with the development of a global–local Finite Element Method for pre-sizing large composite structures with local damage. Launcher composite structures may exhibit typical manufacturing-induced defects such as delamination between plies, core/skin separation, or impact damage (BVID). In current design practices, the effect of such defects is generally assessed in the later stages of the sizing process. The long-term aim of this work is to account for them already during preliminary design so that the resulting structure is intrinsically optimized for damage tolerance.

Given the large dimensions of launcher structures, a fully detailed finite element model of the entire component cannot be computed within the 24-hour turnaround time available at the preliminary design stage. A non-intrusive bidirectional global–local method will therefore be implemented, coupling a coarse global plate model with a refined representation of a region where damage is likely to initiate or propagate.

The local model is driven by interpolating the global shell displacements. At the global–local interface, the difference between the nodal reaction forces from the refined local model and the coarse global model is computed. This difference reflects the effect of the defect or local feature as captured by the refined model, and is then applied at the interface as a corrective load in the global model. The iterations continue until this corrective load stabilizes, indicating that the global response has fully integrated the influence of the local behaviour.

As a first application, the method will be tested on a composite plate with a hole or notch under tensile loading. The global and local meshes will coincide at the interface, with local refinement around the discontinuity. This first model will be validated against an experimental campaign on carbon/epoxy specimens to assess how accurately the approach captures stress concentrations and associated damage.

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# Low-cost, high-volume manufacture of oxide based CMCs

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Ceramic Matrix Composites (CMCs) are an enabling technology for high temperature and high performance applications. Oxide matrix and oxide fibre CMCs sit at the lower end of the CMC spectrum, having only around one third of the weight of competing metallics, while maintaining excellent fracture toughness performance in addition to reliable operation up to temperatures of ~1200 °C. Combined with a mature, increasingly competitive supply chain, and easily accessible material that is not subject to ITAR restrictions, oxide/oxide CMCs offer opportunities across aerospace, defence and potentially many other sectors.

Despite these advantages, costs of entry often remain too high, particularly in applications where oxide CMCs compete directly with metallics and high end Polymeric Matrix Composites (PMCs). This work aims to develop as well as scale up processing routes of a proprietary Ceramic Dough Moulding Compound (CDMC) manufactured through traditional, low cost PMC routes, in order to support wider industrial adoption where their properties can be fully leveraged. Early activity has resulted in the manufacture of both flat panels and complex demonstrators produced using a baseline material, which have since been tested with specific mechanical and thermal properties determined.

The next steps for the project will involve tailoring the fibre volume fraction of the baseline material to achieve different property sets, along with evaluating alternative fibre types to expand the material's application space. These new variants will be developed and tested in specific scenarios in order to identify the most promising use cases for a tailorable, low cost oxide CMC solution.

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# How can damping capacity be used to characterize fatigue behaviour of thermoplastic composites?

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Fatigue characterization of composites requires long and expensive testing campaigns. In addition, the empirical models commonly used often lack a connection to the underlying physics. To overcome these limitations, the goal of this study was to develop a model to predict fatigue behaviour by linking it to the fatigue damage mechanisms. Additionally, this research aims to replace time-consuming tests required to construct S- N curves, with faster step-stress fatigue tests.

With this idea in mind, and having observed a stabilization in the mechanical energy dissipation during fatigue tests after the initial loading cycles, this study investigates whether the damping capacity of the material can serve as a reliable indicator of fatigue damage. Fatigue tests were carried out on samples of thermoplastic composites with different fibre orientations at R = 0.1 at different stress levels. The damping capacity was assessed by considering the ratio of total dissipated energy (area within hysteresis loops) to the total (accumulated) applied work. In addition, step-stress fatigue tests were performed, in which the maximum applied stress was increased every 500 cycles to evaluate the relationship between damping capacity and stress level. These results were compared to the data obtained from conventional fatigue tests done until failure. In addition, they were compared with the viscoelastic properties of the material (loss factor) obtained from the DMA tests. Finding a correlation between the loss factor of the undamaged material and the damping capacity during fatigue, combined with the use of step-stress fatigue tests instead of large experimental campaigns could significantly accelerate the analysis of fatigue behaviour of composites.

This study demonstrates how the use of damping capacity can be a meaningful parameter for characterizing the fatigue behaviour of composites, and explores the potential of step-stress fatigue tests to replace the long experimental campaigns required to build the S-N curves.

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# The sequential static-fatigue approach to model delamination propagations: a comparison between VCCT and cohesive implementation

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Accurately predicting and simulating delamination propagation under fatigue is critical to improving the safety and reliability of lightweight composite structures. In this work, we present an approach recently developed for this purpose, the Sequential Static Fatigue algorithm, and compare two different implementations: the first, called C-SSF, uses cohesive elements, while the second, called V-SSF, uses the Virtual Crack Closure Technique (VCCT).

Both approaches have been validated on experimental data available in the literature using standard specimens for mode I (DCB), mode II (ENF) and mixed mode I-II (MMB). An excellent accuracy was achieved, validating the SSF algorithm in the different propagation modes. Compared to a commercially available algorithm (Abaqus' Direct Cyclic), the V-SSF showed a simulation time saving of between two and three orders of magnitude. For the C-SSF, its performance against a commercial software and a user subroutine implementation are under investigation.

Additional validation was performed on a non-standard specimen, i.e. a larger DCB (175 mm x 60 mm) reinforced by two plates to cause a large and curved delamination. In this case, the V-SSF algorithm showed good results for low loads, but significant inaccuracy for larger loads. This was caused by incorrect readings of the strain energy release rate at the delamination front, which are common for the VCCT in the case of large and curved fronts. Conversely, the C-SSF confirmed the excellent accuracy also in this case.

In general, the great advantages of using the SSF algorithm are highlighted, both in terms of accuracy and computational cost. Since its implementation does not require the writing of dedicated subroutines (e.g. UMAT or UEL of Abaqus), as is the practice in the case of cohesive elements, the algorithm is also easy to adopt.

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# Evaluation of the manufacturing of slivers and rovings from recycled carbon fibers

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By 2035, it is estimated that, for the aeronautics sector alone, more than 23 kilotons of carbon fibre reinforced plastic (CFRP) waste will need to be processed annually. Consequently, increasing attention is being paid to the recycling of CFRP and the recovery of carbon fibres.

Reusing the recovered carbon fibres to re-manufacture fibre reinforcements presents a major technical challenge due to their high stiffness, brittle behaviour, electrical conductivity, and discrete length. Textile technologies are employed to transform these discontinuous fibres into either two-dimensional random structures (nonwovens) or unidirectional structures (slivers/rovings), in which fibre orientation is better controlled.

Both types of structures require fibre processing through carding, which consists of individualizing the fibres supplied in compacted form and disentangling them. This process can be followed by drawing to further align the fibres and produce a unidirectional structure.

Recovered carbon fibres are free from the polymer matrix, which is removed during the recycling stage, as well as from the original surface sizing. Therefore, resizing is necessary for subsequent composite applications.

The objective of the present study is to identify the impact of the carding and drawing processes as a function of the preparation of the recycled fibres after recycling. This analysis focuses on the mechanical and morphological properties of the fibres and on the structural characteristics of the produced reinforcements. The effect of blending carbon fibres with thermoplastic fibres prior to carding is also considered, in response to the growing interest in manufacturing thermoplastic carbon fibre composites.

This work is part of the DUCHESS project, which aims to create mats and yarns from rCF that can be used in all carbon fibre applications, in line with a circular economy approach. This project was funded by the French government as part of France 2030 and managed by ADEME.

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# An as-manufactured modelling approach to quantifying the effect of gap defects on the open-hole tensile strength of Automated Fiber Placement (AFP) laminates

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Defect formation is highly likely during the layup of flat and curved laminates using Automated Fiber Placement (AFP). Typical AFP defects include end-to-end gaps, which are often dispersed throughout the stacking sequence. The effect of layup defects has been studied using deterministic approaches that impose gaps in specific layers. However, studies that consider all types of gaps inherent to the layup process and determine manufacturing tolerances are lacking. This paper proposes a two-stage methodology to determine the reduction in open-hole resistance and stiffness. The goal is to establish a reliable, allowable design.

First, a morphological characterization of all types of gaps is performed, using computed tomography (CT) images. Intentional gaps are located in some specimens to determine their effect. Next, a parametrized model based on the morphology of as-manufactured specimens is validated through a dedicated experimental test campaign. Finally, the reduction in mechanical performance of the specimens is determined by exploring the distribution of defects on plies from a non-deterministic point of view, based on the ratio of the defective area to the area of interest.

The study shows a close alignment in capturing the evolution of damage between the as-manufactured finite model and the experimental results. The specimen-by-specimen comparison between experimental and simulated data reveals that the stiffness is unaffected by the presence of the imposed gaps. However, the open-hole resistance is reduced by around 5% from the baseline configuration, which is a pristine specimen. The non-deterministic exploration shows that a large number of defects causes delamination to occur earlier than in a specimen with a small number of defects. This study contributes to a renewed understanding of how uncertainties propagate in the design of layup composite materials, by demonstrating that reliable design allowable can be established through numerical simulations.

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# Finite element modelling of unidirectional carbon fiber notched composite under compression using in-situ X-ray scanned fiber orientation data

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Pultruded carbon fiber composites are extensively used in wind turbine blades due to their superior mechanical properties, fiber alignment, and consistent material quality. However, variations in fiber orientation can significantly reduce compressive performance, limiting the structure's load-bearing capacity. The accurate numerical prediction of compressive behavior, considering material variability and samples geometry, given computational constraints, remains an active research challenge.

In this work, the fiber orientation of real pultruded carbon fiber composite samples containing a notch was extracted and used as input for a numerical model to predict the material's compressive strength and deformation behavior. Fiber orientations along the full sample length were acquired through X-ray computed tomography (CT) at the Diamond Light Source synchrotron facility and analysed using the structure tensor method to determine the fiber orientation distribution. This consideration of the fiber orientation all the full length is a key novelty of the study, resulting in a more realistic numerical representation of the composite microstructure.

Mechanical testing of both the composite and its constituents provided the material properties for the finite element micromechanical model implemented in the Python-based GetFEM library (Poulios and Niordson, 2016). The fibers were modelled as hyperelastic and the matrix as hyperelastoplastic materials, with non-linear behavior defined by the Ramberg-Osgood material model.

The model, which incorporated the measured notch geometry, considered uniaxial compressive loading. The results include predictions of the composite's stress-strain response and compressive strength, showing good agreement with the experimental data, acquired in-situ during X-ray CT scanning. Furthermore, the model successfully predicts the initiation and formation of kink bands, as well as the plane on which they occur, capturing the damage mechanisms observed experimentally. The validated numerical model provides a reliable framework for predicting the compressive strength of pultruded composites, accounting for both the geometry and the fiber orientation distribution.

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# Transforming Textile Waste into Durable Composite Fibers for a Sustainable Future.

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Using the emerging Ioncell® process, the chemical recycling of cotton has been investigated to produce high-quality, second-generation continuous fibres for composite applications.

Driven by the growing world population and the rising global purchasing power, the textile and fashion industry consumes resources at an alarming pace. Cotton is the most common natural fiber, representing one-quarter of the total textile fiber production. Globally, 73% of all garments produced end up in landfills or are incinerated, resulting in a significant loss of natural polymers suitable for reutilization. Less than 1% of fabrics are recycled into new clothing, and 13% of the recycled materials are reused in a different way as low-value products.

Ioncell®, a technology developed for the sustainable production of man-made cellulosic fibers, offers the possibility to recover resources from different lignocellulosic waste materials (e.g., cardboard boxes, newspapers, textile waste) via fibre-to-fibre recycling to establish a circular economy. Moreover, the resulting fibres are often stronger than the original textile fibres, providing textiles of higher quality.

Herein, we present the potential of the Ioncell® process for the recycling of textile waste for composite applications. The produced fibres have been turned into textiles and further used to produce small composite demonstrators.

The properties of the starting materials and 2nd generation fibres have been evaluated in detail and compared with commercially available fibres. The results demonstrated clearly that the chemical recycling by means of the Ioncell® process causes an improvement of the fibre properties due to a higher orientation and crystallinity of the cellulose matrix. The tenacity values of cotton fibres are on average doubled and the elongation at break is improved reaching 795 MPa tenacity and 24 GPa Young´s Modulus, which is close to the common fiber specifications for automotive and boat composite applications (tenacity: 800-1000 MPa, Young`s modulus: 25 – 31 GPa).

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# Understanding the role of chemical interactions and mechanical interlocking in the adhesion of electroplated copper to ABS

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A common step in metal electroplating on polymer substrates is surface preparation using sulfochromic acid etching, a process well known for altering both the surface chemistry and morphology. Although this technique has been used for decades, the respective roles of chemical interactions and mechanical interlocking in the resulting adhesion remain only partially understood. Because sulfochromic acid is toxic and poses risks to both the environment and human health, it is crucial to clarify how this treatment enhances adhesion—and, in particular, to determine the true contributions of chemical versus mechanical mechanisms—in order to develop greener alternatives. However, this understanding remains unclear, largely because it is difficult to separate chemical effects from morphological ones, as both occur simultaneously during etching.

In this study, we introduce several sample preparation strategies to tackle this challenge. First, we reduced the etching time to reproduce the chemical changes of standard etching while limiting significant alterations in surface morphology. Second, we passivated etched samples to ensure that adhesion resulted primarily from morphological features. Third, we created samples with controlled mechanical interlocking but without modifications in chemistry to probe the mechanical interlocking contribution. All together, these tests allow to sperate regorously the different contributions. Our findings show that chemical effects are essential for proper wetting during electroless plating, whereas mechanical interlocking accounts for the majority (90%) of the final adhesion strength between electroplated copper and acrylonitrile–butadiene–styrene substrates. The methodology presented here can also be replicated to study other coating/subtrate configuration in order to elucidate the real source of adhesion.

Keywords: ABS, Electroplating, Electroless plating, Sulfochromic acid etching, Adhesion, Mechanical interlocking

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# Thermally Insulating and Flame-Retardant Glass Fiber Reinforced Epoxy Composites with Hollow Glass Microsphere/Branched Polyethyleneimine Multilayer Coatings for Building Applications

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Growing urbanization and rising energy demands have intensified the need for building materials that can reduce heat loss and improve safety. Since buildings occupy a major portion of global energy use and carbon emissions, controlling heat transfer and fire propagation through structural components has become a critical objective. Materials that provide thermal insulation together with flame resistance are therefore essential for modern building envelopes.

Glass fiber reinforced polymer (GFRP) is widely used in these applications, but its inherent thermal conductivity limits its insulating capability. Hollow glass microspheres (HGM) offer a promising route to improve this limitation due to their vacuum-filled cores, but direct dispersion of HGM within resin leads to several processing issues, including particle breakage, viscosity increase, and non-uniform distribution during resin impregnation.

To overcome these constraints, this study applied a Layer-by-Layer (LBL) assembly approach that deposits HGM onto the surface of glass fibers through electrostatic interactions with branched polyethyleneimine (BPEI), and subsequently fabricated the composite using the VARTM process. This architecture enables uniform coating and stable incorporation of HGM within the composite. As a result, the thermal conductivity progressively decreased with increasing numbers of HGM/BPEI bilayers, reaching 0.26 W/mK at 3 bilayers, which represents a 42% reduction compared with neat GFRP. Cone calorimetry confirmed enhanced flame resistance, showing reductions in peak heat release rate (from 385.9 to 138.5 kW/m²) and total heat release (from 30.3 to 21.5 MJ/m²). An increase in solar reflectance was also observed due to light scattering effects induced by the HGM layers. Although mechanical strength slightly declined because of reduced fiber volume fraction, the composites retained adequate structural performance.

These outcomes demonstrate that LBL-engineered HGM/BPEI coatings provide an effective route to improving the thermal insulation and flame retardancy of GFRP for energy-efficient building materials.

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# Manufacturing and Material Characterization of Recycled CFRP Using an Electrodeposition Resin Molding Process

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The electrodeposition resin molding method enables carbon fiber reinforced plastic (CFRP) fabrication through electrically activated resin deposition, eliminating the need for high temperature and high pressure autoclave cycles. This reduces energy consumption and aligns with current demands for sustainable and resource efficient CFRP manufacturing. In this study, recycled non woven CFRP sheet material with random fiber distribution was used, and the objective is to apply the electrodeposition resin molding method to this material and evaluate its moldability. The investigation focused on resin deposition and impregnation behavior, as well as changes in fiber volume fraction under different holding voltages, applied currents, energization times, and laminate thicknesses. Two types of resins were examined, thermosetting epoxy and thermoplastic urethane, and their impregnation responses to different electrical conditions were systematically compared. Based on these evaluations, the optimal molding conditions for each resin system were identified in terms of the minimum electrical input required to achieve sufficient resin deposition and stable composite formation. Material characterization was conducted through uniaxial tensile testing to obtain the Youngs modulus, Poisson ratio, fracture strain, strength, and the associated damage and fracture behavior of the molded recycled CFRP. The combined evaluation of moldability and mechanical performance demonstrates the applicability of the electrodeposition resin molding method for recycled CFRP and highlights the influence of resin type and electrical conditions on the final composite properties.

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# Functionalized MWCNT/PEI nanocomposite for anti-icing/de-icing applications

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Ice accretion poses a persistent and serious threat to the safety and stable operation of critical infrastructure such as aircraft, wind turbines, and power grids, often leading to significant economic losses and hazardous incidents. Traditional deicing techniques, including chemical spraying and mechanical removal, are often limited by high energy consumption, poor environmental compatibility, and inadequate adaptability to complex and variable working conditions. Therefore, the development of advanced multifunctional materials that enable efficient, energy-saving, and environmentally friendly anti-icing and deicing has become an urgent task with considerable practical importance. This study successfully fabricated a superhydrophobic nanocomposite film based on polyetherimide (PEI) and multi-walled carbon nanotubes (MWCNTs). The core innovation lies in the adoption of a synergistic material design strategy, which integrates an externally constructed micropillar array via laser etching with internal functionalization through dispersed MWCNTs. This multi-scale engineering approach successfully created an intelligent surface with hierarchical defense capabilities, combining exceptional liquid repellency with efficient photothermal and electrothermal conversion for active ice removal. Application testing confirmed the film's outstanding comprehensive performance. It exhibits a high static contact angle of 157°, and its structured surface significantly delays ice formation, extending the water droplet freezing time by approximately 5 times compared to unmodified PEI. The embedded three-dimensional MWCNT network enhances the material's heat transfer capacity and thermal stability, increasing the onset temperature of thermal decomposition by about 9%. Furthermore, the composite film demonstrates remarkable durability, maintaining its superhydrophobic characteristics and structural integrity after exposure to corrosive media and sustained mechanical abrasion. This research provides a robust and innovative technical strategy to address surface icing under extreme environmental conditions. The developed film shows broad application prospects in fields such as aerospace equipment, renewable energy systems, and next-generation power communication infrastructure, offering a reliable and efficient solution to this long-standing engineering challenge.

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# Bioinspired mechanochromic vitrimer composites based on chiral nematic cellulose nanocrystals

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The ability of certain animals and plants to change colours in nature has inspired the design and fabrication of stimuli-responsive photonic materials. Photonic crystals derived from cellulose nanocrystals (CNCs) have attracted significant research interest owing to their abundance, sustainability, and tunable surface chemistry. However, pristine CNC suffers from poor flexibility, static or inconsistent optical property, and high hydrophilicity, limiting their applicability.

Here, we report, for the first time, a stretchable and self-healable CNC-vitrimer composite that exhibits visible colour change upon application of mechanical stress. CNCs and poly(ethylene)glycol (PEG) are impregnated within an epoxy-thiol polymer matrix containing dynamic covalent ester networks (vitrimers)4. Addition of CNCs in the vitrimer matrix preserves their chiral nematic order but significantly increases the helical pitch. Stretching the composite decreases the helical pitch, inducing a tunable structural colour shift from red to green.

In-situ small-angle X-ray scattering (SAXS) combined with tensile testing reveals the reorientation of CNCs from chiral nematic to pseudo-nematic structure when mechanical stress is applied. The CNC-vitrimer also exhibits significant stress relaxation and self-healing ability, owing to tin-catalysed transesterification reaction between CNC and the vitrimer matrix. This research offers new insights into the design of programable CNC-based photonic actuators, mechanical sensors, and adaptive smart optical devices.

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# Re-Infusion-Based Repair Process and Structural Integrity Evaluation of Pultruded CFRP Spar Caps with Unimpregnated Interlaminar Defects

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The use of pultruded composite spar caps is increasing in large wind turbine blades to achieve lightweight structures with improved mechanical performance. In practical blade manufacturing, however, the spar cap is produced by stacking CFRP pultruded plates followed by a secondary resin-infusion process. During this step, interlaminar unimpregnated defects may occur when resin does not fully penetrate the interfaces between stacked layers. These defects can reduce the structural reliability of the blade, highlighting the need for an effective repair method and for verification of its structural adequacy.

This study proposes a practical repair technique for interlaminar unimpregnated defects in pultruded spar caps and evaluates its effectiveness. The repair procedure involves drilling small holes in the defective region and performing a localized secondary infusion to re-impregnate the unfilled areas. After completing the repair, specimens were taken from both properly impregnated regions and repaired regions. Their mechanical performance was compared through interlaminar shear strength (ILSS) testing to determine whether the repair recovered sufficient structural capability.

The results show that the proposed repair method provides effective reinforcement for interlaminar unimpregnated defects. The ILSS performance measured in the repaired regions was comparable to that of the fully impregnated areas, demonstrating that the repair process successfully restores interlaminar bonding quality. These findings confirm that the repair method can maintain the structural reliability of pultruded spar caps even when manufacturing defects occur. Overall, the proposed repair approach offers a valuable technical basis for addressing resin-related defects that may arise during the production of large composite wind turbine blades.

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# Strain and Damage Sensing of GFRP electrically functionalized by Self-Organized Adsorption of Graphene

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Monitoring structural materials is essential for preventing catastrophic failure, but conventional non-destructive inspection techniques such as ultrasonic testing, acoustic emission and strain gauges require expensive equipment and skilled operators and are difficult to apply over large areas. In contrast, electrical resistance sensing offers low-cost, simple instrumentation and the possibility of real-time health monitoring of fiber-reinforced polymer (FRP) structures. However, glass-fiber-reinforced plastic (GFRP) is intrinsically insulating, so additional conductive components are needed.

In this study we develop a spontaneously adsorbed graphene coating for glass fibers that imparts electrical conductivity to GFRP without degrading its mechanical properties. Edge-functionalized graphene was prepared by ball-milling graphite with potassium glutamate, dispersed in water and used to dip-coat glass fiber cloths at concentrations of 5, 7.5 and 10 g/L, followed by drying and fabrication of 10-ply laminates. Electrical resistivity, flexural properties and fiber morphology were evaluated by resistance measurements, three-point bending with in situ monitoring, scanning electron microscopy and burn-off tests.

The 10 g/L coated laminates showed flexural properties comparable to neat GFRP while retaining a resistivity on the order of $10^2$ Ω·m, indicating that sensing functionality can be added without loss of stiffness. A percolation-like transition was observed near 7.5 g/L, where nominally identical specimens split into insulating and conductive groups. During three-point bending and incremental loading tests, the electrical resistance changed almost linearly with tensile strain in the elastic regime and showed exponential or strongly nonlinear growth in the plastic regime. Furthermore, residual resistance after unloading increased with accumulated damage, demonstrating that graphene-coated GFRP can serve as a low-cost, distributed sensor for both strain and internal damage in structural components. Future work includes uniaxial tensile tests to characterize more precisely the strain–resistance relationship, as well as fatigue tests to investigate long-term sensing stability and durability.

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# Human-Inspired Robotic Prepreg Sheet Layup using Knowledge Engineering from Manual Draping Demonstrations

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The manufacturing of complex components made of fiber-reinforced plastics is still dominated by manual processes. In particular, manual prepreg sheet layup of pre-impregnated textile semi-finished products remains a labour-intensive, error-prone process that relies heavily on expert knowledge and is difficult to automate. One approach to automation is the use of an adaptive robotic system to perform the prepreg sheet layup. Previous research has mainly focused on the development of overall systems consisting of one or more robots equipped with specialized end effectors. However, the path planning and trajectory generation for these robotic systems has mostly been carried out manually by an expert. To deploy a fully automated robotic system with high flexibility and low setup costs for prepreg sheet layup, the trajectory generation itself must also be automated.

One approach to automatic trajectory generation is the analysis of manual draping techniques followed by their abstraction and transfer into executable robot trajectories. For this reason, a study with 40 participants (21 novices and 19 experts) and two different component geometries was conducted, in which the draping techniques were investigated in particular with regard to the sequence of draping individual geometric features and the textile manipulation techniques. The observed hand movements were then abstracted into explicit rules and converted into executable robot trajectories using a self-developed framework. Finally, an experimental test series on both component geometries was carried out with a mechatronic overall system and an adaptive robotic cell for prepreg sheet layup, demonstrating that human-inspired rules can enable automatic trajectory generation.

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# Rain-erosion damage assessment on wind turbine blades using MXene and carbon nanotube coatings

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Modern wind turbine blades rely on fibre-reinforced polymer composites due to their high strength-to-weight ratio. During service, the leading edges are exposed to rain, dust and pressure fluctuations, causing surface erosion that degrades aerodynamic performance and reduces annual energy yield. Current blade condition assessment relies on periodic visual inspections, which are costly and do not provide continuous information on damage initiation and growth. This work introduces carbon nanotube (CNT) and MXene nanocoatings as in-situ sensors for real-time monitoring of rain-erosion damage on wind turbine blades.

Two groups of glass fibre composite specimens, representative of blade leading edges, were prepared and spray-coated with different coatings: the first group with CNT and the second with MXene, forming a conductive surface network. The sensing principle was piezoresistive: the electrical resistance of the coating changed in response to the initiation and progression of structural damage. Both specimen groups were subjected to cyclic temperature loading, three-point bending and low-energy impact. Rain erosion was simulated by introducing controlled cracks into the coating surface.

The nanocoatings exhibited stable electrical behaviour under thermal cycling between 5 °C and 70 °C, with no measurable long-term drift in resistance after 100 cycles. Under three-point bending fatigue, resistance increased gradually by only a few per cent over 100,000 cycles as damage accumulated, whereas low-energy impact tests produced resistance changes below 2%, indicating robust durability and reliable sensing functionality. In crack-growth tests, resistance increased by more than 100% as a full-length crack developed, providing a clear electrical signature of severe surface damage. These results demonstrated that CNT and MXene nanocoatings can detect damage initiation and growth and have potential as sensors for structural health monitoring and predictive maintenance of wind turbine blades.

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# Recovery and reuse of recycled materials after solvolysis treatments

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Composite materials have been gaining interest due to their unique properties and long durability in a wide variety of applications, such as wind blades, aircrafts, sporting goods... This has incremented the issue of the EoL as over 67% of composite waste ends up in landfills or incinerated, and it will imply an exponential increase in composite waste management as composites aircrafts and wind blades among other composite components reach their end of life.

Structural thermoset composites are formed by a combination of a high value matrix and a continuous reinforcement. Current recycling technologies do not allow to revalorize both components while retaining most of their value, implying a downcycling and issues in the reintroduction of the materials into the market. In this study, we have been working on the optimization and adaptation of green solvolysis processes to separate matrix and reinforcement (glass, carbon and flax) while obtaining high value products, such as continuous fibres, retaining around 90% of the mechanical properties of the fibre, and complete textiles as products of the recycling process, making even possible to valorise these textiles in other composite parts.

Furthermore, this study has accomplished to demonstrate the potential of the solvolysis process with real aeronautical parts as well as composites from the construction, energy, and railway sectors. Separating not only the matrix and the textile but also other elements that could be present in the composite. As stated for the fibres obtained the study has also looked at the revalorisation of the organic elements obtained from the solvolysis process, where, first trials have been carried out to identify some of the obtained organic structures.

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# Development of Cellulose Nanofibre–MXene Nanopapers as Multifunctional Interlayers for Fibre-Reinforced Plastic Composites

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The development of thin, conductive interlayers is becoming increasingly important for enhancing the multifunctional performance of fibre-reinforced polymer composites. MXene-based coatings offer high charge-carrier mobility, yet they typically suffer from limited fracture resistance and poor environmental stability. In contrast, cellulose nanofibres (CNF) provide mechanical reinforcement, favourable wetting behaviour, and a topographically uniform substrate, but remain electrically insulating. This work addresses the current absence of a systematic framework describing how these contrasting material properties can be integrated into lightweight, process-compatible interlayers suitable for advanced composite manufacturing.

The objective was to determine how a coat-on integration approach, where Ti3C2Tx MXene was sprayed onto pre-formed CNF nanopaper, affects the resulting film morphology. Particular attention was given to how these morphological changes influence the balance between electrical conductivity, mechanical integrity, wetting behaviour and epoxy absorption characteristics. CNF nanopapers were fabricated by aqueous doctor-blade casting on smooth glass substrates, with the blade gap defining the wet-film thickness. MXene-only reference films were prepared by solution casting the aqueous MXene suspension onto glass substrates and drying under controlled conditions. MXene-coated CNF films were produced by spray-coating MXene onto pre-formed CNF nanopapers with intermediate low-temperature drying between passes. The resulting structures were analysed using scanning electron microscopy, profilometry, thickness, electrical resistance measurements and uniaxial tensile tests. To evaluate CNF-MXene nanopaper functionality, it was integrated as an interlayer in an epoxy-based glass fibre-reinforced polymer laminate for Joule-heating application.

Morphological characterisation showed that MXene-only films formed lamellar, crack-prone networks, whereas CNF-only nanopapers exhibited dense fibrillar microstructures. In the CNF-MXene configuration, the CNF network affected the spatial arrangement of MXene flakes, leading to more cohesive layer formation compared with cast MXene films. The resulting morphology was associated with enhanced crack resistance and more stable electrical and interfacial performance. The conductive CNF-MXene interlayer enabled uniform and easily controlled Joule-heating during composite curing.

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# Fatigue life prediction for polymer matrix composites using fracture fatigue entropy approach

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Fracture fatigue entropy (FFE) is considered as an intrinsic material property and is widely used for modeling the fatigue life of metals. Because of the simplicity and robustness of the approach in estimating fatigue lifetime with typically very few fatigue experiments, this methodology is gaining attention in composite investigations. However, the thermal and mechanical properties are entirely different for polymer matrix composites (PMCs) compared to metals. This work presents the use of FFE to predict the fatigue life of composites in different fatigue regimes and the limitation of considering FFE as an independent material property. Based on the variation of FFE across different fatigue regimes, the reason for such variation and the appropriate use of FFE to predict fatigue lives are proposed. For composites, FFE can be defined as a range that can reasonably predict the fatigue life of composites with scatter.

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# Mechanical Performance and Stability of Manufacturable Perforated Plate Lattices for Powder-Bed Fusion

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Plate lattice structures represent a frontier in mechanical metamaterials, offering theoretical stiffness and strength that surpass traditional truss-based architectures. However, their closed-cell topology presents a significant barrier to deployment, particularly in powder-based additive manufacturing where unmelted or unsintered powder cannot be evacuated. This research proposes a solution through the design of manufacturable plate lattices featuring Angelina, circular, and triangular perforations. We employed finite element analysis with periodic boundary conditions to conduct a rigorous parametric study, evaluating effective stiffness, anisotropy, uniaxial strength, and buckling behavior across three relative densities.

The numerical analysis reveals that perforated plate lattices successfully retain higher stiffness compared to the benchmark stretching-dominated octet-truss lattice, despite the reduction in solid volume. The extent of stiffness retention correlates strongly with perforation geometry, with circular cutouts demonstrating the least degradation. A critical observation was made at the ultra-low relative density of 0.009; while plate lattices maintained high stiffness, their strength was governed by premature elastic buckling, making them weaker than trusses in this specific regime. However, contrary to intuition, the introduction of perforations enhanced the critical buckling load at this ultra-low relative density compared to unperforated equivalents by altering stress distribution patterns within the plates. Furthermore, the study identified a clear transition in failure mechanisms: as relative density increases, the dominant failure mode shifts from elastic buckling to material plasticity. Additionally, a strong tension-compression asymmetry was noted at ultra-low relative densities, where tensile strength markedly exceeded compressive capability. These results establish that perforated plate lattices not only solve manufacturability issues but also offer tunable mechanical advantages for lightweight engineering applications.

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# Circular Economy Strategies for Wind Turbine Waste and Critical Materials: Insights from a Comparative LCA study

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Wind energy plays a central role in the European Union's transition toward climate neutrality; however, the expansion and decommissioning of wind turbines generate increasing volumes of composite waste and intensify reliance on critical raw materials, particularly Rare Earth Elements (REEs). These challenges simultaneously create environmental burdens and expose the EU to significant supply chain risks. Circular economy principles and Life Cycle Assessment (LCA) offer a pathway for reducing environmental impacts while enhancing resource efficiency and strategic autonomy. This study, synthesises current circular economy methodologies, EU regulatory frameworks (CEAP, ESPR, CRMA), and technological characteristics of wind turbines. It critically reviews scientific literature on recycling technologies for composite blades and NdFeB permanent magnets and analyses comparative LCA findings from two wind turbine generator configurations: direct-drive permanent magnet synchronous generators (DDPMSG) and electrically excited synchronous generators (DDSG). Advanced recycling of composite blades demonstrates potential $CO_2$ reductions of up to 16% through substitution applications in concrete. For NdFeB magnets, early-stage recycling technologies show environmental impact reductions up to 78%, substantially mitigating REE supply chain risk. Comparative LCA results indicate that DDPMSG units exhibit approximately 22% lower environmental impacts than DDSG systems when using virgin materials. Incorporating recycled materials yields further reductions of 50–70% across both generator types. Circular economy strategies, combined with emerging recycling technologies, can significantly decrease the environmental footprint of wind turbine materials while improving the EU's resilience to CRM supply disruptions. The findings highlight the importance of integrating circular design, recycling infrastructure and policy-driven incentives to support a sustainable and strategically secure wind energy sector. The study is implemented within the framework of ReBoat project, funded by the European Union's Horizon Europe Innovation Action programme under Grant Agreement No. 101182350.

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# Realistic fibrous structure of Elium-based filament wound hydrogen storage tanks

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The present research is part of the EU-funded ECOHYDRO project, which unites 15 partners from 7 countries to develop Type IV hydrogen storage tanks using thermoplastic resin for self-repairability, fire resistance, and recyclability.

This work aims to develop a multi-scale damage finite element model to predict the mechanical performance of hydrogen storage tanks with a realistic microstructure that incorporates process-induced properties. Composite samples were manufactured using wet filament winding (T700, basalt, Elium) during which several filament-wound manufacturing defects were present: i) variations in diameters, irregular position of the fibers and misalignment; ii) resin-rich zones and voids and iii) residual stress in matrix, which play a critical role in degrading the material's mechanical properties and significantly impact the structural integrity and operational performance of hydrogen tanks. Micro CT images were analyzed for a realistic description of the microstructure.

The present study employs the k-nearest neighbor algorithm (kNNA) to generate fiber distributions taking as input the statistics of inter-fiber distances of neighboring fibers with variable diameters. This method is computationally efficient and allows modelling of high fiber volume fractions [1]. The presented algorithm is applied to filament-wound structures. The Elium matrix undergoes significant shrinkage during consolidation, and together with temperature-induced expansion strains, this leads to high residual stresses and, consequently, pronounced microstructural irregularities.

The model was validated by a comparison between the kNNA generated RVEs and the X-CT and SEM images taken from filament-wound Elium tubes to study the distributions of fiber diameters, neighbor distance statistics, local fiber fraction, evaluation of resin-rich zones, and residual stresses. Furthermore, voids were introduced following the fiber-generation process.

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# Thermo-mechanical analysis on a 3D woven composite for evaluation of fatigue performance

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This work investigates the thermo-mechanical behavior and fatigue performance of a 3D woven composite developed by the Safran Group. Fatigue life in such materials depends on various factors: resin/fiber combination, weaving architecture, manufacturing process, loading conditions (e.g., load ratio, loading orientation), and environmental factors (temperature, humidity, etc.). High-cycle fatigue characterization ($10^6$–$10^8$ cycles) requires numerous time-consuming tests which results in these experimental campaigns being costly.

In order to rapidly estimate fatigue performance, thermo-mechanical analysis can be conducted. In this study, we perform this approach for constant amplitude cyclic loadings. The infrared thermography coupled with the heat build-up protocol [1], is used to identify heat sources related to the fatigue failure mechanims. This study is conducted using specimens machined out following the warp direction. A sinusoidal load is applied with constant load ratios of R = 0.05 and R= -1 at different loading frequencies, followed by zero-stress recovery period.

X-ray tomography is used to correlate the thermal signals with internal dissipative mechanisms such as viscoelasticity, friction, and damage [2]. Post-processing tools from [2], implemented in the Celenos software [3], are employed for a comprehensive infrared data analysis. To describe the complex damage evolution in the 3D woven composite, the variations of the heat dissipation and the thermo-elastic coupling are analyzed. Interrupted fatigue tests are carried out to characterize the damage scenario and its kinetics.

Furthermore, a preliminary fatigue criterion is proposed, establishing a correlation between the fatigue behavior and the thermo-mechanical analysis results using a visco-elastic empirical criterion [4], [5].

References

[1] Navrátil et al., 2022.

[2] Navrátil et al., 2022.

[3] Le Saux, Celenos, 2023.

[4] Demilly et al., 2024.

[5] de Almeida et al., 2025.

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# Wireless Passive LC Sensors for Lifetime Condition Monitoring of Non-Metallic Joints

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Non-metallic joints, such as adhesively bonded interfaces in composite structures, are being increasingly adopted in lightweight and corrosion-resistant structural systems across various industries. Joints act as inherent discontinuities that cause stress concentrations under mechanical or thermal loading, making them the weakest regions of non-metallic structures. Their reliability therefore indicates the overall service safety of non-metallic assemblies. For adhesively bonded joints, performance depends on proper curing and strong interfacial bonding, both of which are vulnerable to insufficient cure, environmental aging, moisture uptake, and hygrothermal degradation. In this context, achieving accurate in-situ monitoring of both curing during manufacturing and aging during service becomes essential for ensuring the long-term reliability of non-metallic joints.

To address these challenges, this work presents a fully printable, flexible, and wireless inductor–capacitor (LC) resonant sensor which is embedded within non-metallic joints for monitoring of evolutions. Mechanical testing confirms that the sensor does not hurt joint geometry or compromise structural performance, while enabling the joint with passive sensing capability. Experiments confirm that the LC sensor can accurately track the degree of cure, validated by differential scanning calorimetry (DSC) measurements. In addition, the sensor responds to dielectric changes in hydrothermally aged samples, demonstrating its applicability for both curing and aging monitoring within non-metallic joints.

These results clearly highlight the great potential of the printable LC sensor to provide robust, wireless, and maintenance-free sensing for reliable health monitoring of non-metallic joints. It further offers a promising and versatile pathway for enhanced state awareness of composite structures, informative maintenance decision-making, and accurate service-life prediction toward the development of next-generation smart composites.

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# Improving the surface properties of recycled glass fibers with supercritical CO2 silylation

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Recycling glass fiber composites with thermo-chemical processes and making it economically profitable is troublesome due to the low price of the pristine glass fibers combined with the decreased mechanical properties of recycled glass fibers (rGF). For the rGFs to become a more appealing alternative to pristine glass fibers, their price must decrease. Additional downside of the recycling process is that it removes the surface treatment from the fiber surface that improves adhesion with resins. The price of the rGFs could be lowered by applying surface treatment again on the fibers and combining it with the recycling process to obtain ready-to-use fibers. Supercritical recycling combined with a novel surface treatment in supercritical carbon dioxide ($scCO_2$) allows the described process chain. Reducing separate process steps will improve the yield and increase the value of the fibers. This study focused solely on applying a coupling agent in $scCO_2$ on pyrolytically recycled glass fibers. Recycling steps were excluded. Interactions between epoxy silane (3-Glycidyloxypropyltriethoxysilane) and the glass fiber surface are studied to determine if cleaning and activating the fiber surface are required before applying the coupling agent. Improvement of surface properties is determined with a high-throughput microbond device. According to the results, interfacial shear strength increased 56% for rGF that has been treated with epoxy silane in $scCO_2$ compared to recycled fiber. Carbon dioxide removed some of the matrix residues left on the fiber surface by the recycling process. This allowed the epoxy silane to react with the fiber surface and form covalent bonds according to x-ray photoelectron spectroscopy. Activation of the fiber surface prior to treatment was not needed to improve the adhesion. Other fiber types, such as recycled carbon fibers, could be treated in scCO2 to improve the surface properties.

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# Adaptive Multi-Axis Braiding of Hybrid Preforms Integrating Functional Fibers for Advanced Composite Structures

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This work presents an innovative multi-axis braiding approach designed to manufacture hybrid textile preforms that combine high-performance structural fibers with functional fibers such as conductive, heating, or phase-change yarns. The objective is to enable the production of advanced composite structures that integrate additional thermal or electrical functionalities while maintaining strict control over fiber placement, orientation, and density, even on complex three-dimensional geometries.

The proposed braiding concept features adaptive kinematics capable of modifying yarn trajectories and local braiding angles in real time. This capability allows the process to accommodate curved shapes and variable-section components without defects such as wrinkling, gaps, or misalignment. Particular focus is placed on the controlled insertion of different kind of fibers, considering their distinct mechanical and geometrical behaviours compared to structural fibers. Specific process strategies are developed to limit bending, friction, and tension loads during braiding and forming, ensuring that the fibers retain their intended properties throughout impregnation or consolidation processes.

Experimental investigations assess the morphological quality of the hybrid preforms, fiber–fiber interactions, and the preservation of functional characteristics after infusion, RTM, or thermoplastic processing. Mechanical evaluations confirm the potential of these hybrid braided architectures to enhance composite components with integrated, non-monitoring functionalities.

This study demonstrates the relevance of adaptive multi-axis braiding as a versatile manufacturing route for next-generation multifunctional composites across aeronautics, automotive, and energy sectors.

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# Contribution to the study of damage in composite/metal structures under bearing stresses

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In order to reduce $CO_2$ emissions, implementing new low-carbon modes of transport appears to be a worthwhile strategy. In this context, the development of lightweight rail infrastructures composite is being investigated to encourage the use of rail transport with light trains in French rural or peri-urban areas. In this general context, a bi material composite-metal under concentrated loads is studied. Numerically, the plastic behavior of resins under compression is accounted for by a Finite Element model. Two main composite configurations under study use basalt fibres, with either Arkema's Elium® thermoplastic resin or a thermoset epoxy resin. The samples consist of two 50 x 50 x 8 $mm^3$ layers of unidirectional composite that are glued together. A 5 mm layer of R260 steel covers the structure. Bearing stresses are induced by a cylindrical indenter in contact with the steel surface. In order to identify the initiation and propagation of damage in the composite section, stepped tests are carried out from 30 kN to 220 kN. An X-ray tomography analysis is performed between each stepped load to locate and identify damage to the structure as well as to monitor its propagation. The results show that damage is initiated by the tensile opening of the resin, which is then followed by the propagation of cracks into the core of the sample. This phenomenon occurs before damage caused by a compressive stress on the resin due to its lower tensile strength compared to its compressive strength. This phenomenon, which has also been numerically identified, appears to be induced by the sample's geometry. To isolate damage related solely to resin compression, new tests with different geometries are proposed.

Keywords: railway, bi-component, stepped tests, X-ray tomography, basalt fibres, Elium® resin

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# A homogenised 3D Hashin failure criterion with MLP surrogate for solid-element modelling of laminated composites

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Fibre-reinforced polymers are increasingly used in structures requiring high specific strength and stiffness. As manufacturing techniques mature, thicker laminates become more common, and stress states evolve from plane-stress toward fully three-dimensional loading. This shift complicates failure prediction, as ply interactions and through-thickness stresses play a key role in the onset of damage. Traditional finite-element analysis (FEA) evaluates failure criteria ply-wise, which can become computationally intensive for thick laminates or simulations with many load cases or optimisation loops.

This work investigates whether machine-learning models can approximate failure predictions obtained from a Hashin-3D criterion for a quasi-isotropic HTS145/PEEK laminate. The methodology adopts a homogenised approach, assuming each material point contains a representative volume element corresponding to a [0/45/90/-45]ns layup. A synthetic dataset is generated by randomly sampling laminate-level strain states and computing the associated ply-level failure indices (FIs).

The dataset enables several supervised learning formulations, such as regression of the maximum FI (maxFI) and identification of the first-failing ply (ffp) and its failure mode. Early training shows that a feed-forward neural network provides accurate regression of maxFI, with a mean relative error of 2.24% and an $R^2$ of 99.56%. At the same time, XGBoost performs well at identifying the ffp and the failure mode, achieving an F1-score of 94.34% and an ROC-AUC of 99.85%.

The trained models will then be assessed in a representative FEA case study by replacing explicit ply-by-ply Hashin-3D evaluations with the surrogate predictions. The comparison will focus on the predicted maxFI, identification of the critical ply-mode, and spatial localisation of highly loaded regions, using the complete ply-resolved Hashin-3D evaluation as the reference. This approach aims to examine whether such surrogates can reduce the computational cost associated with failure prediction in thick composite laminates while preserving the physical structure and interpretability of established failure criteria.

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# Experimental analyses of hardness and indentation modulus of Phosphate glass biocomposite for implant devices

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There is an increasing demand for advancements in biomaterial implants that promote the healing and repair of fractured bones. Despite the existence of metallic implants for a while, they continue to fail because of lesions, corrosion, and stress shielding. Among biomaterials, the Phosphate glass (P-glass) composite presents a sustainable option for biomedical applications. This glass combined with a biocompatible and biodegradable polymer (Poly-L-Lactic Acid), constitutes the biocomposite meant for the implant. The strategic release of therapeutic ions from this biocomposite supports the regeneration and repair of bone at the fracture site. The present study addresses the stress shielding challenge by developing a biocomposite with mechanical properties closer to cortical bone. For the preparation of the composite, melt blending technique was used, followed by hot compression moulding. The composite contains 30% by volume of quaternary P-glass ($P_2O_5$-MgO-CaO-$Na_2O$) as reinforcement and L-PLA as matrix. To evaluate the hardness and indentation modulus, the Vickers micro hardness test was performed on neat P-glass, neat L-PLA, and at the composite interface, with five indents each. The hardness of the composite interface was obtained as 140 ± 7.60 HV at a peak load of 0.98 N. As compared to neat P-glass, the hardness of the composite decreased by 73%. The modulus at the composite interface was found to be 15 ± 1.44 GPa, which was in a similar range to human ulnar bone. The modulus of the composite decreased by 78% as compared to neat P-glass. The obtained modulus confirms the potential of the P-glass composite as a sustainable alternative to metallic implants.

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# Effects of MWCNT concentration on carbon fibre reinforced epoxy composites for space antenna applications

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Earth-stationed parabolic antenna reflectors are required to receive signals for satellite communication. These reflectors are expected to be lightweight with enhanced mechanical and electrical performance. In this study, carbon fibre/epoxy composites incorporating multi-walled carbon nanotubes (MWCNTs) were fabricated to achieve the desired tensile and electrical properties. The MWCNT content chosen was 0.1, 0.2, 0.3, and 0.4 weight (wt.) % of the epoxy matrix. The MWCNT reinforced carbon/epoxy composite laminates were fabricated using the vacuum infusion technique. The composite laminates were subjected to tensile and AC electrical conductivity tests. The operating frequency range during the electrical conductivity test was ($10^{-6}$-10) MHz. The tensile modulus and tensile strength, upon adding 0.3 wt. % MWCNT into carbon/epoxy composites, enhanced by 94 % and 18 % to their base composites. Further, upon increasing the MWCNT content to 0.4 wt. %, they decreased by 12.50 % and 5.07 % than 0.3 wt. % MWCNT. The frequency-dependent behaviour of the electrical conductivity of MWCNT-reinforced carbon/epoxy composites was governed by a power law. The AC electrical conductivity ($\sigma_{a\subset}$) for 0.3 wt. % MWCNT reinforced carbon/epoxy composites increased by 44.17 % to their base composites. Upon adding 0.4 wt. % MWCNTs in the epoxy matrix, the $\sigma_{a\subset}$ reduced by 68.96 % compared to 0.3 wt. % MWCNT reinforced composite. The agglomeration of nanofillers at 0.4 wt. % MWCNT has a detrimental effect on the tensile and electrical properties of the composites. The study provides optimal filler material combinations for achieving the desired mechanical and electrical properties at the antenna reflector scale.

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# A Brief History of High-Strength Polymer Fibres

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High-strength polymer fibres have profoundly impacted diverse industries, offering unprecedented mechanical properties tailored to specific applications. The evolution of synthetic fibres began with rayon in the late 19th century, a regenerated cellulose fiber that set the stage for fully synthetic alternatives. Nylon, introduced by DuPont in 1935, marked the first entirely synthetic fibre derived from petrochemicals, catalysing advancements in polymer science. Subsequent innovations included polyester, acrylic, and polyolefins, which catered to textiles and general-purpose applications with tensile strengths under 1 GPa.

In contrast, high-performance synthetic fibres such as ultra-high molecular weight polyethylene (UHMWPE), polyaramid and polybenzoxazole (PBO) fibres are engineered for exceptional tensile strengths exceeding 3 GPa and moduli surpassing 100 GPa. These fibres are critical in aerospace, protective gear, and sports equipment due to their high strength, stiffness, and toughness. Their 1D molecular alignment maximises covalent bond strength along the fibre axis, enhancing tensile performance. However, their anisotropic properties limit compressive and shear strength, restricting their use in structural applications.

This presentation provides a historical overview and technical insight into the development and characteristics of high-strength polymer fibres, emphasising their impact on modern composite materials science and technology.

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# Evolution of recycled carbon fiber properties during nonwoven manufacturing process

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The growing demand for carbon fiber (CF), expected to reach 280.3 kilotons in 2030 [1], is accompanied by an increasing volume of CF waste. In response, new regulations aim to restrict landfilling and incineration while promoting the recycling of CF-based composites [2]. These waste streams originate from various sources: end-of-life components, manufacturing cut-offs, and expired prepreg rolls [2].

After recycling, the recovered carbon fibers (rCF), can be reprocessed into nonwoven mats. This manufacturing route typically involves fiber opening, carding into veils, cross-lapping, and needle punching. Each stage potentially induces additional fiber damage.

In this work, we investigate the evolution of fiber properties throughout the nonwoven manufacturing process. Tensile tests and geometrical characterizations of monofilaments are conducted at different stages of the process: after steam thermolysis, re-sizing, opening, carding and needle punching to quantify the impact of each step on fiber properties. The influence of feedstock type and the addition of thermoplastic fibers during carding are also assessed. The objective is to understand how the fiber origin, the fiber-surface conditions, and textile processing parameters affect the ability of producing rCF nonwoven mats. As a next step, the tensile properties, compressibility, and permeability of the resulting nonwovens will be evaluated to establish process-properties relationship.

This research is part of the DUCHESS project, which aims to establish an industrial scale process of recycling and remanufacturing carbon fibers from various sources [3]. This project was funded by the French State as part of France 2030, operated by ADEME.

[1] L. Gang, “Global Carbon Fiber Composites Market Report,” 2023.

[2] S. Pimenta and S. T. Pinho, “Recycling carbon fibre reinforced polymers for structural applications: Technology review and market outlook,” Waste Management, vol. 31, pp. 378–392, Feb. 2011.

[3] “Projet France 2030 DUCHESS”, https://duchess.wp.imt.fr/

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# Experimental and Analytical investigation of residual strains in filament wound composite rings

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Filament winding involves wrapping continuous, resin-impregnated fibres onto a mandrel in various layers at same or different winding angles, followed by curing to form a pressure-bearing composite vessel. However, significant residual stresses can develop during and after curing due to factors such as laminate thickness, curing temperature gradients, mismatch in the coefficients of thermal expansion, and resin shrinkage. These residual stresses may influence the structural performance of the final component and need to be considered at the design stage.

During fabrication of filament-wound structures, these stresses become locked into the laminate. Accurately quantifying them is essential for improving the design methodology. The outer hoop layers tend to remain in compression, while inner layers experience tensile stress. This study proposes and demonstrates a direct experimental method for measuring residual stresses of hoop-direction in filament-wound composite rings.

The method involves introducing radial cuts into the composite rings, allowing them to deform as the stored residual stresses release. The rings respond by increasing their curvature, i.e., closing further upon cutting. By measuring the mechanical load required to reopen the rings to their undeformed geometry, the magnitude of the released hoop stresses can be estimated. Digital Image Correlation (DIC) is used to capture the deformation field before and after cutting, providing full-field displacement information and enabling an independent validation of the measured stress release.

In addition to the experimental approach, the residual stresses are analytically estimated using anisotropic continuum theory applied to a curved and layered composite beam. This analytical model allows comparison with the experimentally recovered values thereby strengthening confidence in both the measurement technique and the underlying mechanics. The analytical model also offers insights into the distribution of stresses in rings of various dimensions and lay-up sequences.

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# Evaluation on Powder Impregnation Behavior of CFRTP Semipreg Sheets on Thermoforming Processes

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Carbon fiber reinforced thermoplastics (CFRTPs) are widely used in aerospace, automotive and industrial applications due to their high productivity, excellent impact resistance, formability and recyclability. However, thermoplastics have relatively high melt-viscosity, therefore they make impregnation difficult, and prepregs are commonly used as intermediate materials. Melt-impregnation methods for prepreg manufacturing includes film, commingled yarn, powder and extrusion, each with distinct advantages and limitations in terms of impregnation quality, productivity and cost. The film impregnation offers polymer quantity control and high interlayer quality, however, it requires multilayer lamination process and equipment, and impregnation is difficult with high-viscosity polymers. The commingled yarn enables high-rate heating and molding since the polymer and fibers are commingled, but impregnation uniformity issues easily occur in thick layers and large products. The film impregnation offers the advantage of high powder dispersion and reduced voids, although there are issues with uniform fixation and manufacturing cost of powder polymer. To solve the challenges during impregnation, the semipreg sheet in which powdered polymers are melt-fixated onto carbon fiber has been developed. Semipreg sheets do not require the impregnation process, enabling reduced manufacturing costs. Furthermore, they have the advantage of being easily molded into complex shapes due to the excellent formability provided by not being fully impregnated. However, impregnation is required during molding, and the powder impregnation mechanism and the superiority or inferiority of the mechanical properties of molded products manufactured using semipreg sheets remain unclear. This study aims to clarify the impregnation behavior of powder polymer during molding of CFRTP semipreg sheets. Vacuum-bag molding and insert injection molding representing typical and high-cycle thermoplastic molding methods, were employed. The polymer flow and impregnation mechanisms in these molding processes were observed and evaluated from the perspective of impregnation rate, clarifying the effects of the molding process and various conditions on the impregnation behavior.

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# Challenges in the Experimental Characterization of Bulk Structural Adhesives

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The growing adoption of structural adhesives across industrial sectors has expanded their use from secondary bonding to primary, load-bearing connections. As applications diversify, bondline thicknesses have increased significantly. While aerospace structures typically employ very thin adhesive layers, fields such as wind energy, marine and civil engineering may require adhesive joints with thickneess of several centimeters. These large thicknesses introduce challenges in achieving consistent bondline quality and demand a deeper understanding of bulk adhesive behavior, as the adhesive itself becomes a dominant contributor to structural performance.

This work examines the critical role of bulk adhesive mechanical properties under quasi-static and fatigue loading, highlighting the experimental challenges associated with producing reliable test data. Manufacturing bulk specimens is identified as a major source of variability. Besides fabrication and curing conditions that strongly influence measured properties, voids introduced during fabrication can also cause premature failure, even at minimal volume fractions. Additional uncertainty arises during specimen preparation, where misalignment, tab selection, and bonding imperfections can induce unintended bending, leading to non-uniform stress states.

Furthermore, the assumption embedded in common testing standards that different specimen geometries (e.g., ASTM Type I, II, IV) lead to equivalent material properties is questionable. Experimental results indicate that various specimen geometries can lead to different performance, especially under fatigue loading.

Overall, the findings underscore the need for stricter control of fabrication, curing, and preparation procedures, as well as a critical reassessment of standard specimen geometries, to ensure the reliable characterization of bulk adhesives for demanding structural applications.

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# Functionally graded lattices designed by machine learning: considering material orthotropy

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Lattice structure has garnered attention from diverse lightweight application fields because of its high strength-to-weight ratio as well as offering multi-functionality such as energy absorption and vibration damping. Several lattice families have been developed including truss-based, spinodoid, surface-based lattices and the recent plate-based lattices which represent high strength-to-weight ratio approaching to the theoretical bounds.

Numerical strategies to design lattice structures have also been explored, including inverse homogenisation and dehomogenisation – developed on the basis of topology optimisation (TO). Machine learning (ML) has been leveraged as alternatives to those TO-based approaches to improve the computational efficiency. Our previous work has applied both TO and ML to effectively optimise the 2D functionally graded lattice structures having high strength-to-weight ratio. Building on this TO and ML-based approach, this study incorporates two aspects; material orthotropy to explore applicability to fibre reinforced additive manufacturing (FRAM), and 3D structures by applying parametrised plate-based and truss-based BCC unit cells.

Optimal lattice structures were fabricated utilising Anisoprint Composer A3 in polyamide and short carbon fibre reinforced polyamide so that the specimens be validated in 3 point bending test based on ASTM D7264/D7264M − 15. The experimental results confirmed that the optimal structures outperformed the uniform counterparts in both isotropic and orthotropic materials. Strain fields measured by digital image correlation (DIC) showed that the optimal structure effectively delivered the load within the structures. In the validation on the 3D lattice structures, plate-based lattices had better performance than truss-based lattices, indicating the promising applicability of plate-based lattices to pursue lightweight characteristics. This study is the first attempt to consider material orthotropy to design functionally graded lattice structures, aiming to enhance the versatility and applicability of the lattice designing strategies.

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# Comparative Analysis of PLA- and PP-Based Biocomposites Reinforced with 20% Reed: Mechanical and Thermal Effects of NaOH Treatment

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The increasing demand for sustainable materials has intensified interest in renewable plant fibers. As common reed (Phragmites australis) has received limited attention in materials research, it represents a novel and locally abundant biomass resource. Although the demand for sustainable materials is growing, common reed remains underutilized as a filler or reinforcement fiber. This study investigates the performance of polylactic acid (PLA) and polypropylene (PP) biocomposites reinforced with 20 wt % reed fiber in both untreated and NaOH-treated forms. The study focuses on evaluating how alkali surface treatment modifies fiber–matrix interactions and influences composite properties in each polymer matrix.

Mechanical characterization was carried out to quantify changes in stiffness, strength, and ductility resulting from fiber addition and surface treatment. Thermal behavior was evaluated using differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA) to determine how reed reinforcement and NaOH treatment affect crystallinity and thermal stability within each polymer matrix.

For PP, adding reed fibers substantially increased stiffness, with NaOH treatment offering an additional improvement of approximately 29% compared to composites containing untreated fibers. Although reinforcement led to a slight reduction in tensile strength, the treated fibers demonstrated improved performance over untreated fiber composites.

For PLA, reed fibers significantly enhanced stiffness, with NaOH treatment providing an additional 7.5% increase relative to untreated fibers and an overall improvement of 57% compared to pure PLA. Similar to PP, tensile strength decreased with fiber addition, but alkali treatment improved strength by 14% relative to untreated fiber composites.

Overall, the findings demonstrate how NaOH treatment improves fiber–matrix compatibility in both polymers. The study advances knowledge of common reed as a locally available yet underutilized reinforcement option and demonstrates the potential of alkali surface modification to improve composite performance in both biobased and conventional polymer.

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# Instrumented nanoindentation at cryogenic temperatures: A method for fibre/matrix characterisation

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The mechanical performance of composite materials under cryogenic conditions is critical for applications such as lightweight liquid hydrogen storage for zero-emission flight, where extreme environments impose stringent reliability requirements. This work presents the development and validation of a cryogenic nanoindentation methodology capable of characterising material properties close to 77K in a high-vacuum environment. The system integrates a liquid nitrogen-cooled stage with an instrumented indentation platform, enabling precise control of thermal drift and compliance through calibration against certified reference materials.

To validate the approach, we selected Teflon® as a polymer benchmark due to its well-documented viscoelastic behaviour at low temperatures. Results demonstrate a clear transition from viscoelastic to elastic–plastic deformation with decreasing temperature, confirming the sensitivity of the method to polymer-specific mechanisms. Following validation, we applied the technique to a unidirectional carbon fibre/epoxy composite, representative of cryogenic structural applications. Indentation tests performed at room temperature and cryogenic conditions reveal a significant increase in hardness and modulus, consistent with reduced molecular mobility and enhanced matrix stiffness. These findings provide insight into the micromechanical response of composite constituents under service-relevant conditions.

The study also addresses key experimental challenges, including thermal drift correction and indenter cooling strategies, which are essential for accurate data acquisition at cryogenic temperatures. The developed protocol offers a robust route for characterising local mechanical properties of heterogeneous materials, supporting improved design and qualification of composites for cryogenic applications.

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# Life cycle screening of alpine ski delamination by solvolysis employing supercritical fluids – A novel recycling approach

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The recycling of alpine skis is a significant challenge due to their highly heterogeneous, multi-material composition and the strong adhesion between polymeric, metallic, and composite layers as well as the wood core. Alpine skis are predominantly bonded using thermoset adhesives such as epoxy resins, which provide the required structural integrity during use. However, this manufacturing concept prohibits sufficient material liberation during the application of established mechanical recycling routes. Conventional shredding and sorting processes are unable to efficiently separate the tightly adhered material compound, resulting in mixed waste fractions of limited recyclability.

To overcome these limitations, this study explores a novel recycling pathway, that employs a supercritical fluid to decompose the epoxy-based adhesive system and thereby enable the separation of the individual layers of the compound. Lab-scale trials have proven the technical feasibility of the delamination process, as long as suitable process parameters are applied. The resulting material fractions show the potential to serve as high-quality secondary raw materials. However, the application of supercritical fluids requires elevated pressure and temperature, which leads to an energy intensive delamination process.

To assess the environmental implications of the proposed recycling route, a life cycle screening, facilitating openLCA 2.5.0 and ecoinvent 3.11, is conducted. The analysis assesses the environmental hotspots of the lab-scale delamination process, including relevant upstream energy and chemical consumption, as well as downstream steps needed to prepare the recovered materials for reuse and the treatment of process residuals. After an initial hotspot analysis, the results are contextualized by comparing the impacts of the proposed process with the potential environmental benefits of substituting primary materials with secondary fractions obtained through delamination.

Overall, this study provides a first environmental evaluation of supercritical fluid assisted ski delamination as a potential route towards improved recyclability of multi-material winter sports equipment.

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# Investigation of roving spreading on impregnation quality in the wet winding process using siphon impregnation

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Innovative composite solutions for cryogenic liquid hydrogen storage are considered as a key component of future low-emission energy systems. Fiber-reinforced polymer composites have the potential to reduce weight and increase efficiency compared to metal tanks. However, their suitability under cryogenic conditions depends on the structural quality and process stability during manufacturing. The impregnation quality in the wet winding process is particularly critical, as insufficient resin penetration or increased porosity can significantly impact the failure behavior of cryogenic components.

The present study aims to systematically investigate the interaction between roving spreading and impregnation quality to raise the level of fundamental understanding of the process, as requirement for high-quality manufacturing of composites from wet winding.

Methodologically, a siphon impregnation process will be developed and integrated into an existing test rig exhibiting elements for mechanical spreading of rovings. Key process parameters such as fiber material, pressure in the pressure pot, resin viscosity, winding speed, and roving tension are investigated. The spreading behavior of the rovings will be characterized and quantitatively evaluated using light sectioning sensors measuring the roving cross-section prior to and after spreading. The impregnation quality is evaluated to determine the influence of spreading on wetting and porosity.

Preliminary results indicate that the self-developed siphon impregnation unit is suitable for application in the winding process. Preliminary tests on variations in injection pressure and winding speed indicate a linear relationship between pressure in the pressure pot and winding speed. This relationship ensures a stable resin quantity in the siphon, which is necessary for reproducible impregnation.

The results of the study provide a fundamental understanding of the interaction between roving spreading and impregnation quality. They also form the scientific basis for transferring the process to full wet winding for producing cryogenic composite structures.

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# Multi-Objective Optimization of Additive Manufactured High-Speed Small Craft

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Additive manufactured structures for the marine environment have a large and complex design space with multi-objective goals and unique constraints. The design space for additive manufacturing allows for finer control of the manufacturing parameters earlier in the design stage than conventional manufacturing methods. Iteration within this design space requires connection of various tools to understand design tradeoffs, linking computer aided design (CAD), computer aided engineering (CAE), and computer aided manufacturing/machining (CAM). These connections are complex and typically require a large effort from engineers to fully and accurately define each step during each iteration. This design space exploration effort aims to connect and automate the design and analysis workflow and explore additively manufactured structures in a multi-objective optimization framework.

This work presents a simple design case representative of a marine high-speed planing craft. A prismatically shaped hullform was chosen for this case that is based on a section slice of the Generic Prismatic Planing Hullform (GPPH), a deep V planing hull designed for use as a research demonstrator. Stiffener geometry is represented as a set of continuous variables with constraints for printability. Runs were evaluated using a shell based finite element analysis (FEA) and advanced manufacturing effects were captured using assumptions that filaments are transversely isotropic. A performance-based loading condition was developed using the ISO small craft guidelines. Particle swarm optimization is then used to iteratively assess this design space and the design is assessed to minimize cost and build time and is constrained by a passing safety factor along the hull length.

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# Influence of decompression rate and cyclic hydrogen exposure on mechanical and transport properties of type IV hydrogen tank liner materials

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Hyperbaric hydrogen storage requires the use of structures capable of withstanding very high internal pressures while maintaining a reasonable mass. While polymeric liners used in type IV tanks are not affected by hydrogen embrittlement, they are susceptible to damage through rapid gas decompression (RGD), where the gas solubilised at high pressure can lead to pore formation upon decompression.

Current literature on RGD failure in hydrogen is mostly dedicated to rubber materials, with few works discussing the impact of high-pressure hydrogen decompression on thermoplastic materials.

This study aims at enriching the available experimental database, analyzing the effect of decompression rate and number of cycles on damage onset, morphology and subsequent impact on mechanical and hydrogen transport properties.

Extrusion blow moulded samples of PA6 and PA11, representative of liner materials, were subjected to high pressure hydrogen saturation at maximum operating pressure and temperature for high-pressure H2 tanks (875 bar and 85°C) followed by decompression with rates between 1.5 bar/min and 27000 bar/min, for up to 5 cycles in a dedicated test rig. Internal damage evolution was observed post-mortem by SEM, showing the appearance of sub-micron sized pores for rates above 10bar/min, with a density varying with the decompression rate. The distance between the first blisters and the sample surface was shown to decrease with increasing decompression rate in most cases, indicating a diffusion-controlled phenomenon. Post-RGD tensile tests results showed a decrease of mechanical properties (modulus, yield strength and ultimate tensile strength) with increasing blister density. Evaluation of the impact of pore density on hydrogen permeability is ongoing.

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# The Impact of Reuse and Remanufacturing on Mechanical Properties of Alpine Skis

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Skis are hybrid composites, assembling layers of wood, glass- or carbon-fiber fabrics, polymer matrices among others. They are exposed to repeated impacts, requiring materials merging high stiffness, strength, and damping with low weight. Skis and sports equipment in general are large composite users, yet their end-of-life management remains a major sustainability challenge. Recovery routes such as pyrolysis or solvolysis can reclaim fibers but have struggled to preserve the original embedded value or return materials at sufficient quality and cost. Industry-led reuse concepts like Head's ReNew ski allow to remove the wear parts and reuse the wooden core and the fiberglass layers up to five times. This pragmatic alternative to recycling promotes product–process redesign by improving reparability as a promising route to value preservation.

This study evaluates the ReNew concept by combining standard mechanical tests with additional non-destructive diagnostics. The sample consists of ReNew skis with varying histories: new, slightly used, after fatigue test, after refurbishment. Mechanical characterization includes inter alia flexural testing to quantify global stiffness and fatigue tests to assess durability. Modal analysis and local stiffness parameters are explored as a non-destructive technique.

The tests show slight reductions in flexural values between skis with varying histories, summiting in a maximum reduction of about 11% after the fourth refurbishment, respectively, implying structural changes. To further assess these effects, the planned quantification of local stiffness and modal analysis will provide reproducible indicators of progressive change. Nevertheless, all skis tested so far met the minimum requirements for stiffness under standard protocols.

This reuse approach preserves the mechanical performance across multiple life cycles when combined with appropriate inspection and refurbishment. Quantitative mechanical and modal testing complement standard testing procedures. These findings support design for reuse and integrated inspection to promote circularity in composite-based sports equipment.

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# Mechanical recovery of Carbon Fibre/PPS laminates after repair of transverse matrix cracks.

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Thermoplastic matrix composites, such as Carbon Fibre/PPS laminates, are becoming increasingly popular for high-performance structural applications thanks to their high toughness, durability and ability to be repaired by heating above the polymer's melting temperature. However, they remain sensitive to low-velocity impacts and fatigue loadings, which causes a complex network of damage (transverse matrix cracks, delamination and surface defects). Subsequent mechanical stress can cause these micro-damages to propagate into more severe transverse cracking or interlaminar delamination, which can compromise the residual mechanical properties.

This study focuses on the behaviour of transverse cracks in CF/PPS laminates after repair, under monotonic tensile loading. Specimens with different layups were damaged up to 70% of their ultimate load to generate a high density of transverse cracks without fibre breakage. Controlled thermal repair was then applied to heal the cracks without the need for additional material, exploiting polymer chain reptation above the melting temperature. The repair cycle was repeated twice to evaluate the recovery of mechanical properties after successive damage and repair events.

The evolution of the damage was monitored using a combination of optical and infrared imaging, micro-tomography, acoustic emission and crystallinity analysis. Correlating acoustic emission data with optically observed cracks revealed a clear Kaiser effect and enabled the localisation of transverse cracks along the specimen. Previous studies on interlaminar cracking demonstrated a maximum reduction in fracture toughness (GIC) of 16% after two repairs; this study expands the analysis to include intralaminar damage.

The results provide a quantitative understanding of the impact of intralaminar cracking on the residual mechanical properties of repaired CF/PPS laminates. Understanding the repairability of these structures is crucial for predicting their service life and maintaining their performance when subjected to repeated mechanical loads and accidental damage. This demonstrates the potential of these laminates for use in durable, high-performance applications.

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# Coupling thermal and interfacial analysis for a deeper understanding of fiber–matrix adhesion in thermoplastic composites

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Keywords: Thermoplastics, surface tension, polar and dispersive components, IFSS, crystallization kinetics, fiber-matrix interface

The interfacial cohesion between fibers and the matrix is a critical factor influencing the mechanical performance of thermoplastic composites. This study investigates the interfacial phenomena governing adhesion by integrating surface energies, interfacial mechanics and microstructural analysis under the effect of temperature.

The surface tension (γL) of several polymers (polyethylene glycol, epoxy) and molten thermoplastics (PP, PLA, PB) was measured at elevated temperature using the pendant drop method ensuring the optimum measurement conditions. Results showed a linear decline with temperature. Based on these measurements the polar (γp) and dispersive (γd) components versus temperature, data rarely reported in literature, were determined using the Owens–Wendt approach, providing a quantitative understanding of the wettability of fibers by the matrix and the bonding energy of the fiber–matrix interface formation at the molten state.

Furthermore, the surface properties of fibers and matrix were correlated with the Interfacial Shear Strength (IFSS) analysis. The mechanical performance of fiber-reinforced thermoplastic composites depends on the fiber and matrix properties as well as the interfacial strength. The IFSS was evaluated using the microdroplet test, in which the load required to debond a thermoplastic droplet from a single fiber (basalt and flax, unsized and sized) was measured. This analysis provided valuable insight into the efficiency of stress transfer across the fiber–matrix interface, where a strong interfacial bond enhances stiffness, tensile strength, and fatigue resistance.

Additionally, the effect of fibers embedded within thermoplastic films on crystallization behavior was examined. Fibers can act as heterogeneous nucleating agents, accelerating crystallization kinetics and influencing spherulitic morphology near the interface. These microstructural modifications can alter the local adhesion and mechanical response of the composite.

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# Analysis of moisture-induced deformation in bio-based yarns via RH-controlled X-Ray tomography

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Currently, the textile industry ranks as the third largest polluter worldwide, driving massive resource consumption and waste generation. In this context, the EU project UPWEARS aims to create an innovative and replicable value chain by valorizing flax, cork, and paper industry by-products to produce a novel e-textile for application in country/mountain cycling suits. Achieving this goal will require the final product to meet key performance criteria, including waterproofness and/or water repellency, breathability, and stretchability. The biobased and hybrid textiles developed within the UPWEARS project combine yarns made of bio-based fibres with functional coatings. These coatings include cork, valued for its hygrophobic properties, and a lignin-based formulation designed to enable electrical conductivity. Since these textiles are intended for use in high-humidity environments, it is essential to characterize their hygroscopic behaviour to incorporate moisture-induced dimensional changes and mechano-sorptive coupling into multiscale models of textile and textile products. To this end, a relative humidity control system was developed for use within a laboratory tomograph, enabling in-situ observation of yarns complex morphological changes under controlled conditions.

Tests have been realised on regenerated cellulose (Tencel) and flax yarns, with and without coating. For each scan, one sample is placed inside the dedicated conditioning system integrated into the microtomograph. CT-scans are realised for three relative humidity values: 10%, 50% and 80%. The minimum conditioning time applied before each scan is determined thanks to Dynamic Vapour Sorption (DVS) measurements carried out prior to the testing. The post-processing of the tomography data involves material segmentation and identification, performed either through automated procedures or via machine-learning methods for the more complex yarn architectures. Results include 3D reconstructions for qualitative visual assessment, as well as quantitative measurements through measurement of dimensional variations along the yarn length, which are used to determine the directional hygroscopic expansion coefficients of each investigated yarn.

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# Multi-matrix fiber-reinforced composite with integrated shape memory alloy actuators produced by flat-knitting technology

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This work presents an innovative multi-matrix manufacturing strategy for actively deformable 3D fiber-reinforced composite components with integrated shape memory alloy (SMA) actuators and multi-axial solid-state joints. Traditional single-matrix approaches face significant limitations when combining the conflicting requirements of high structural stiffness in load-bearing segments and low bending resistance in joint areas, particularly in tubular geometries.

The developed solution employs a dual-matrix concept using flat-knitting technology to create integral 3D tubular preforms with biaxial glass fiber reinforcement. Rigid structural segments are consolidated with epoxy resin, while deformation zones utilize a flexible polyurethane system . This approach addresses the critical challenge identified through FEM analysis: the high deformation resistance resulting from the combination of stiff epoxy matrix and curved tube walls.

NiTiNOL-based SMA actuator wires and electrically conductive supply networks are structurally integrated during the knitting process using specialized binding techniques and novel machine adaptations. The actuators are mechanically anchored through form-fitting mesh integration, achieving pull-out forces exceeding 100 N, while in-situ electrical contacting is realized through silver-coated copper wires, yielding transition resistances below 3 Ω.

The multi-matrix consolidation is implemented via a modified VARI process with selective infiltration zones. Functional demonstrators achieve deflections of ≥50 mm and exhibit multi-axial joint functionality (f=2), enabling complex 3D motion sequences. This manufacturing approach opens new possibilities for lightweight adaptive structures in robotics, aerospace, automotive, and medical applications, combining high load-bearing capacity with active shape-morphing capabilities while maintaining assembly-free, integral construction.

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# Effect of temperature and loading rate on the mode II interlaminar fracture toughness of glass fibre reinforced bioepoxy composites

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Sustainable composites are essential for the transition to net-zero. A new generation of resin containing bio-derived constituents offers reduced dependence on fossil-derived products and lower overall carbon footprints. Fibre-reinforced polymer (FRP) composites are, however, susceptible to interlaminar fracture, a common failure mechanism that weakens structural integrity and leads to catastrophic failure, one of the known causes of failure in real-world components, e.g. wind turbine blades. In such real-world applications a range of dynamic and in-service temperature conditions is encountered. This research investigates the effect of loading rate and temperature on the mode II interlaminar fracture toughness (GIIc) of unidirectional e-glass fibre bioepoxy (bio-content up to 38%) composites manufactured using the vacuum-assisted resin infusion method, as per ASTM D7905, employing an end-notched flexure (ENF) test geometry. GIIc is calculated using the compliance calibration method (CCM) and the compliance-based beam method (CBBM); the latter offers a crack-length-measurement-free approach. The composite is tested with crosshead speeds ranging from 0.5 mm/min in an electromechanical testing machine to 2 m/s in a drop-weight tower machine. A previous study[1] demonstrated no significant correlation between the loading rate (1 mm/min to 3 m/s) and GIIc for unidirectional e-glass/vinylester composites; however, no general trend was observed for FRPs, and this was likely due to the variations in matrix constituents[2]. The composite will also be tested at a quasi-static rate in an environmental chamber with a temperature range of -40°C to 70°C, representing the extreme temperature range of wind turbine operational conditions. Fractographic is employed to correlate the failure mechanisms and the performance. The resulting data will provide essential information for the design and application of the fibre-reinforced bioepoxy laminates in variable temperature and mechanical environments.

[1] P. Compston et al., Compos Sci Technol, Feb. 2001.

[2] M. May et al., Compos Part A Appl Sci Manuf, Oct. 2020.

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# Linking microstructure to strain localisation in fibre reinforced composites: a PCA-based analysis of in situ biaxial XCT–DVC experiments

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Predicting failure in fibre-reinforced composites remains challenging because deformation and damage arise from complex interactions between fibre architecture, resin morphology, and multiaxial stress states. Conventional failure criteria, based on homogenised parameters from simplified uniaxial tests, struggle to capture this microstructural complexity or the localised mechanisms that govern damage initiation and growth. Achieving genuinely predictive, microstructure-informed models therefore requires new experimental and data-driven approaches capable of quantifying three-dimensional strain fields and linking them directly to underlying microstructural features.

In this work, we present a PCA-driven framework for data-driven micromechanics, applied to datasets obtained from in situ biaxial mechanical testing combined with laboratory X-ray Computed Tomography (XCT) and Digital Volume Correlation (DVC) [1]. Implemented as an Avizo plugin, the method reduces the dimensionality of large 3D strain and microstructural datasets, identifies dominant deformation modes, and projects statistical clusters back into real space via point-cloud visualisation. This enables explicit correlation between strain localisation patterns, microstructural heterogeneity, and early-stage damage relationships otherwise obscured by the high dimensionality and spatial complexity of the data.

We demonstrate the approach on E-glass/epoxy laminates with (0/90)S and (+45/−45)S layups. The (0/90)S laminate shows diffuse, mixed-mode localisation across ply interfaces, influenced by resin-rich and porous regions. In contrast, the (+45/−45)S laminate develops concentrated, shear-dominated localisation at ±45° interfaces, where fibre-orientation mismatch intensifies interfacial stresses and promotes localised delamination.

Although laboratory XCT limits observations to early damage stages, planned integration with high-resolution synchrotron imaging will enable fracture-evolution tracking. Overall, this PCA-based framework provides a powerful tool for distilling complex strain–microstructure interactions into interpretable patterns, advancing microstructure-aware prediction of composite failure under multiaxial loading.

[1] S. E. Madi et al., "In situ biaxial tensile testing of composites: coupling X-ray computed tomography and digital volume correlation with finite element simulations," Composites Part B: Engineering, p. 112815, 2025.

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# Z-Penetration: A Strategy for Stronger Interlayers in Composite 3D Printing

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Additive manufacturing (AM), specifically via Fused Filament Fabrication (FFF), has emerged as a transformative platform for producing highly customized and geometrically complex components. Despite its versatility, the widespread adoption of FFF for load-bearing structural applications remains significantly constrained by inherent mechanical anisotropy. This limitation is primarily driven by weak bonding between deposited layers, which creates preferential failure planes and severely compromises mechanical performance in the vertical build direction (Z-axis). While the introduction of fiber-reinforced thermoplastic filaments offers a potential solution for increasing stiffness and strength, standard deposition processes often exacerbate the issue by aligning fibers exclusively in the printing plane, leaving the interlayer regions unreinforced.

To address these critical limitations, this research presents a novel, patent-pending "Z-penetration" deposition mechanism. Unlike conventional printing parameters that rely on passive thermal bonding, this approach strategically modifies the physical interaction between the nozzle and the previous layer. This modification actively drives deeper polymer interdiffusion and promotes the reorientation of fibers, forcing them to penetrate across the interface of adjacent layers. This creates a "bridging" effect that significantly enhances interlayer adhesion and stress transfer. Experimental validation of this technique yielded substantial improvements in mechanical integrity. Tests conducted on pure Polylactic Acid (PLA) utilizing the Z-penetration method demonstrated a 22% increase in build-direction strength. More notably, short fiber-reinforced PLA samples exhibited a nearly 50% improvement in strength compared to specimens printed with conventional deposition parameters. These findings confirm that manipulating local flow dynamics to induce fiber bridging can effectively overcome the traditional weakness of the Z-axis, establishing a new framework for manufacturing high-performance, structural fiber-reinforced composites via additive manufacturing.

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# Graph Transformers for Effective Prediction of Progressive Failure Evolution in Composite Structures

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The aviation industry's $CO_2$ emissions present a critical challenge for sustainability, driving the adoption of novel aircraft configurations and alternative fuels. This paradigm shift demands high-performance predictive models for full-scale aircraft structures. While Finite Element Analysis (FEA) remains the trusted approach for solving mechanics problems, it struggles with scalability and computational efficiency.

Machine Learning offers accelerations to structural simulations. However, traditional Convolutional Neural Networks fail on unstructured domains due to their reliance on regular grids, making them unsuitable for complex geometries. Graph Neural Networks (GNNs) address these limitations by processing data on graphs, inherently capturing physical interactions through mesh connectivity whilst remaining resolution-independent.

Despite their advantages, standard GNN architectures face challenges when modelling damage evolution. Over-smoothing during message passing limits long-range information propagation, whilst progressive damage accumulation exhibits dual dynamics: gradual, spatially correlated growth and sudden catastrophic fracture events. Capturing both regimes within a unified autoregressive framework remains an open challenge.

We present a Graph Transformer methodology that addresses these limitations through three key features. First, we implement a frequency-controlled local-global attention mechanism that bridges neighbourhood connectivity with global domain awareness, enabling feature propagation across unstructured meshes. Second, we introduce a shock-capturing module that detects catastrophic failure through spatial gradient and temporal jump analysis, routing through regime-specific decoders. Third, we incorporate explicit Markov state transitions to model irreversible damage progression.

Our framework integrates seamlessly with commercial finite element workflows through an automated FEM-to-GNN pipeline and effectively predicts damage propagation across unseen configurations. We show various examples with clear aerospace relevance, including open-hole CFRP laminate plates, which can be simulated in just 0.32% of the time of a corresponding conventional FE simulation, while remaining resolution-independent. At the conference, we will show additional examples, including larger structural applications.

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# Finite element simulation of stamp-forming-induced deformation in thermoplastic composites

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Stamp forming of thermoplastic composite laminates inevitably generates residual stresses and shape distortions, such as spring-in and warpage, due to non-uniform temperature and pressure histories during forming and cooling. Reliable prediction of these process-induced deformations is essential for tool compensation and tolerance control in industrial components. In this work, we develop a three-dimensional thermo-mechanical finite element simulation framework to quantify stamp-forming-induced deformation in thermoplastic composite parts and to assess the influence of compliant tooling.

The model couples transient heat transfer with mechanical analysis, including contact between the laminate, a rigid punch, and either a conventional steel tool or a compliant silicone-backed tool. Temperature-dependent elastic properties and thermal expansion of the laminate are considered to capture the evolution of residual stress during cooling. From the simulations, we extract pressure distributions at the tool–laminate interface, spring-in angles at critical sections, and global shape deviations after demolding.

The results show that the compliant tooling significantly redistributes contact pressure compared with the fully rigid steel tool, leading to reduced peak pressure near corners and a noticeable reduction in spring-in. The proposed finite element framework provides physical insight into how stamp-forming process parameters and tooling compliance jointly govern final part distortion. The methodology can be directly used to support virtual compensation of molds and to screen process windows for thermoplastic aerospace structures before costly physical trials. Ongoing work extends the model to include mold expansion and more detailed constitutive descriptions of thermoplastic matrices to further improve the quantitative accuracy of deformation prediction.

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# Multiscale simulation of process-induced residual deformation on semi-crystalline thermoplastic composites

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Currently, the application of carbon fiber reinforced thermoplastics (CFRTPs) has been expanding to the aircraft secondary structural components. In the near future, it is expected that they will be applied to the primary structure as well. The CFRTPs are advantageous in short manufacturing time, weldability, and recyclability. However, it is still challenging to predict and ensure the forming quality of the CFRTP components because the solidification (i.e., resin crystallization) behavior strongly depends on the process conditions, such as temperature and pressure histories. The shrinkage of semi-crystalline thermoplastic resins during solidification is highly complex, as crystallization shrinkage and thermal shrinkage as a solid occur simultaneously. These shrinkages are difficult to distinguish and to incorporate into the computational model, making it difficult to predict the resultant forming quality.

This study aims to establish a multiscale-multiphysics thermo-mechanical simulation scheme to predict the residual deformation and stress of CFRTP components from the manufacturing conditions. The thermal simulation is carried out to capture the temperature distribution, considering the thermal conduction and exothermic crystallization. In the mechanical simulation, resin crystallization is first calculated based on the obtained temperature field. Then, the crystallization-induced stiffness change and shrinkage (during the crystallization), and thermal shrinkage (after crystallization) are considered to predict the residual deformation and stress of the CFRTP laminates. The parameters of the crystallization and thermal shrinkages are identified by in-situ strain measurement during isothermal and non-isothermal crystallization using a Fiber Bragg Grating sensor. The proposed model and parameters are verified through the comparison of the residual warpage of asymmetric CFRTP laminates between experiment and simulation.

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# Multiscale simulation of nonlinear mechanical properties of CNT-reinforced CFRTP

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Carbon Fiber Reinforced Thermoplastics (CFRTPs) are extensively utilized across a broad range of industrial fields, including the automotive and aerospace sectors. This widespread adoption is primarily attributed to the exceptional material properties of CFRTPs, which include high specific stiffness, high specific strength, superior impact resistance, high productivity, and recyclability. In this study, the reinforcement effects of Carbon Nanotubes (CNTs) were verified to further enhance the mechanical properties of these materials by introducing CNTs as a secondary reinforcement. To analyze the multi-scale interactions, a homogenization method was adopted for scale coupling. This numerical approach facilitated a comparison between two distinct reinforcement configurations: the case where CNTs are deposited on the Carbon Fiber (CF) surfaces, and the case where CNTs are dispersed uniformly within the matrix. It is generally understood that the extent to which the mechanical properties of CFRTPs are improved depends strongly on the specific parameters of the nanostructures, such as the type, length, and volume fraction of the CNTs. Therefore, this research clarified the influence of both CNT length and CNT volume fraction on the nonlinear mechanical properties of the hybrid materials. These effects were systematically analyzed for CFRTPs possessing different CF volume fractions. By evaluating these parameters, the study elucidates the relationship between the microscopic structure of the secondary reinforcement and the macroscopic nonlinear mechanical properties of the CNT-reinforced CFRTPs.

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# Numerical Simulation of Thermal Fatigue in CFRP Laminates Using an Entropy-based Progressive Damage Model

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Carbon fiber–reinforced polymer laminates operating in aerospace and automotive environments are frequently subjected to temperature fluctuations, which promote fatigue damage through thermal-expansion mismatch and matrix–fiber interfacial degradation. This study develops an entropy-based model to characterize the progressive damage of CFRP laminates under thermal cycling. The viscoelastic response of the CFRP laminate is represented using a generalized Maxwell model consisting of 15 elements, while damage initiation and progression are governed by the Hashin criterion combined with a progressive damage model. The dissipated energy generated by inelastic deformation is used to compute the thermodynamic entropy at each increment, and the accumulated entropy serves as the degradation indicator throughout thermal-cycling fatigue. All model components are implemented in Abaqus through a UMAT. For validation, a three-directionally symmetric [0/90]s laminate is modeled and subjected to constant thermal-cycling amplitudes. The predicted crack initiation sites, propagation behavior, and crack density are compared with previously reported experimental observations, showing that the entropy-based progressive damage model successfully reproduces the characteristic damage evolution of CFRP laminates under cyclic thermal loading.

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# Hygrothermal Durability and Structural Health Monitoring of Recycled Carbon Fiber Composites

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Recycled carbon-fiber (rCF) laminates promise substantial embodied-carbon savings, but their qualification is hindered by concerns over durability and in-service monitoring. This study establishes an end-to-end route that couples controlled recycling with fast curing and embedded structural-health-monitoring (SHM), then quantifies hygrothermal effects through vibration and frequency analysis. rCF mats obtained via microwave-assisted chemical recycling (MACR) and infused using Vacuum-Assisted Resin Infusion with Microwave Curing (VARIMC) to minimize voids and shorten cure. Three epoxy laminate systems were manufactured: (i) baseline rCF, (ii) rCF with 0.3 wt% graphene, and (iii) rCF with 0.3 wt% carbon nanotubes (CNT).

Hygrothermal conditioning was performed by water immersion to mass-stabilized saturation, enabling separation between transient sorption and steady-state plasticization. Experimental modal analysis with broadband excitation extracted natural frequencies, modal damping, and mode-shape curvature. Frequency reductions and damping increases at saturation were interpreted as indicators of stiffness loss and interphase softening; curvature-based damage indices supported localization of moisture-sensitive regions. Comparative trends across systems highlighted the role of nano-filler topology: graphene at 0.3 wt% is hypothesized to enhance in-plane interphase continuity and moisture-barrier pathways, whereas CNTs at 0.3 wt% preferentially form through-thickness conductive bridges-yielding distinct dynamic-stiffness retention and damping signatures under saturation.

The results demonstrate that VARIMC yields consistent laminate quality for MACR-derived rCF, and that vibration-based SHM provides a sensitive, non-destructive proxy for hygrothermal degradation across baseline and nano-modified variants. The workflow-“recycle, infuse, microwave-cure, monitor” - offers a practical path to qualify recycled composites for humid service environments while embedding condition awareness through operation, and is directly transferable to other reclaimed-fiber systems.

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# Behaviour of unidirectional  Oxide CMC for aeronautical applications

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Reducing fuel consumption and greenhouse gas emissions from aircraft are the major challenges facing the aeronautical industry. Several solutions are put forward, such as making parts lighter and operating engines at higher temperatures leading to more complete combustion. Ceramic Matrix Composite (CMC) materials reinforced with ceramic fibers meet this need with thermomechanical performance beyond the service limits of high temperature metals, with damage tolerance superior to monolithic ceramics. In this context, SAFRAN develops materials and manufactures parts in Oxide CMC to reach future environmental requirements and be competitive compared to superalloys such as Titanium or Inconel (design, process, supply chain, cost).

One of SAFRAN Ceramics' developments involves a unidirectional oxide CMC material with N610™ reinforcement with quasi-iso stacking sequence. To introduce this presentation, a microstructure analysis will be shown with a focus on the constituent's volume ratio and porosity distribution.

Understanding of the mechanical behavior is illustrated on a simple geometry for tensile loading at room temperature. Then, a second part will recall the experimental methods implemented for the tensile tests for the experimental analysis of the damage: fields of displacement and deformations by digital image correlation, instrumentation making it possible to monitor the damage in real time with acoustic emission, and observations during test and after the failure of the specimen.

Finally, the work will focus on the analysis of the damage mechanisms of the material. This experimental analysis will be completed by theorical analysis which will make it possible to understand the damage mechanisms to focus on the prediction of the mechanical behavior at the scale of the elementary laminate ply.

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# Mechanical characterization of cellulose composites through all-atom molecular dynamics simulations

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In recent years, global efforts to achieve a zero-emission society have rapidly accelerated, creating an urgent need for materials with low environmental impact. Consequently, composite materials using thermoplastic resins as the matrix and plant-derived reinforcing fibers such as cellulose nanocrystals (CNC) have garnered significant attention. CNC, extracted from natural plant resources like wood, is highly advantageous from an environmental protection perspective and can contribute to building a sustainable society. These cellulose fiber-reinforced thermoplastic polymer materials possess excellent specific stiffness, specific strength, formability, and corrosion resistance. These materials offer a wide spectrum of applications, extending from lightweight-focused transportation sectors—such as automotive, aerospace, marine, and railway systems—to information and communication technologies, medical devices, consumer electronics, and structural materials for housing and construction.

However, the intrinsic mechanical properties of CNC itself, despite its high potential, are not yet fully understood. In particular, further detailed analysis is required for its behavior at the critical nanoscale. Therefore, this study employed all-atom molecular dynamics simulations to elucidate the stable structures and mechanical properties of CNC at the atomic level. Specifically, it focused on the number of molecular chains in CNC and the cross-sectional shape they form, clarifying how these structural factors influence the stable structure of CNC. Furthermore, tensile tests were subsequently performed on CNC with stable structures to clarify how these factors affect the mechanical behavior under applied load. In addition, simulations were conducted to extract CNC fibers embedded in a thermoplastic resin matrix from the surrounding matrix. Consequently, the effects of representative surface treatments on the mechanical properties at the CNC interface were quantitatively investigated.

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# Investigation of Interface Optimization Methods in Thermoset–Thermoplastic Hybrid Structures

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The increasing demand for lightweight structures with high mechanical efficiency has driven the development of composite hybrid systems. While the general concept of lightweight and hybrid design is well established, this study specifically focuses on a novel combination of 3d robot assisted filament winding with CF-TowPreg and injection molding with short fiber reinforced PA66 GF30 to manufacture hybrid thermoset–thermoplastic components. This integrated process merges the geometric freedom and functional integration of injection molded parts with the stiffness and load bearing capacity of continuous fiber reinforced thermosets. The wound inserts enable localized reinforcement with optimized fiber placement and minimal fiber consumption, while the thermoplastic component provides surface integrity and design flexibility suitable for large scale production.

A major challenge of such material combinations lies in the limited interfacial adhesion due to differences in surface energy and chemical structure between thermoset and thermoplastic constituents, restricting effective load transfer. To address this, different surface modification methods of the CF TowPreg inserts were systematically investigated, including laser structuring, mechanical abrasion, and geometric patterning. The treated surfaces were examined using microscopy to assess topography and interfacial morphology. For this purpose, a pull out test setup was used, which was adapted by a special bottom bracket for controlled load introduction, allowing reproducible determination of interfacial shear strength.

The results demonstrate a significant influence of surface treatment on bonding performance. Compared to the untreated reference (average shear strength = 1.97 MPa), laser treated surfaces achieved an increase to 10.25 MPa, indicating a more than fivefold improvement in interfacial strength. The results indicate that adhesion depends on both effective mechanical interlocking and adsorption or chemical bonding between the thermoplastic and the CFRP surface. Surface treatment can remove contaminants, optimize surface properties, and improve adhesion, thereby enhancing overall interface strength.

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# Polymerization Shrinkage and Thermal Behavior of Light-Cured Dental Pulp Capping Materials and Cavity Liners

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Pulp capping procedure is essential for protecting the dental pulp from external irritants and preserving pulpal vitality. To improve the physical properties and handling characteristics of conventional chemical-cured materials, light-cured dental pulp capping agents incorporating resin components have been developed. However, their polymerization—accompanied by radiant energy, exothermic heat, and volumetric shrinkage—can induce thermal stress and interfacial strain. Even small increases in pulpal temperature may cause irreversible injury, making it clinically important to evaluate their thermal and shrinkage behavior. This study quantitatively assessed polymerization shrinkage and temperature rise in eight light-cured pulp capping materials and two restorative materials.

Polymerization shrinkage was measured using the bonded-disk method with an LVDT displacement sensor. Specimens were light-cured for 20s, and axial shrinkage was recorded for 600s (n = 5). Shrinkage-rate curves were derived to determine peak shrinkage rate and peak time. Temperature changes were monitored using a non-contact infrared sensor on 11 mm diameter × 0.5 mm thick specimens for 610s with first 20s and second 20s irradiations at an interval of 300s (baseline temperature 25°C). Parameters analyzed included ΔT1 at 1st peak, ΔT2 at 2nd peak, net peak temperature (ΔT1 - ΔT2), and peak time.

GC Fuji Lining LC (glass ionomer cement based) showed the greatest polymerization shrinkage (8.43%), highest ΔT1 (35.20°C), highest net peak temperature (24.19°C), and latest peak time (20.63 s), representing the strongest thermal–shrinkage response. Charm Base (resin based) exhibited the lowest shrinkage (4.36%) and the lowest ΔT1 (18.76°C).

These findings reveal substantial material-dependent differences in thermal behavior and polymerization shrinkage, emphasizing the need to consider both properties when selecting dental pulp-protective materials.

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# Modeling of kinking in CFRPs: a multiscale competition between damage mechanisms

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The intensive use of Carbon Fibers Reinforced Plastics in aeronautics applications implies to master the prediction of any behaviour up to final failure including energy dissipation. Simulation supports this goal and relies on the use of robust models for key physical mechanisms. Among them, the kinking phenomenon in compression along the fibre direction is a major one, which can lead to numerous fragments throughout the entire volume and consequently result in strong non-linear behaviour and significant dissipated energies.

While the physics of kinking is relatively well known at the scale of the fiber, its modeling at a meso-scale and its interaction with delamination has been challenging.

Previous works have focus on quasi-static loadings. A micro-modeling of a representative unit cell incorporating a carbon fiber in an epoxy matrix has been developped and is able to represent major degradation mechanisms associated to kinking. It is based on Fleck & Budiansky's kinking theory. This micro model has been used to extract the most important quantities (strength, dissipated energy, kink band size) and the associated scattering mainly due to straightness defects of fibers.

In this paper, two main activities are presented. First, an homogenized damage model is defined with a clear separation between geometric non-linearities and material non-linearities at the fiber scale. Second, simulations are used to understand the competition between the kinking (represented using the previously built homogenised model) and other degradation mechanisms, such as transverse cracking at the laminate scale.

This work is the result of a collaboration with Allix, Feld and Guimard.

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# Ageing effects in transparent protective systems

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Transparent protective systems are made of polymeric materials that are sensitive to ageing. This degradation can alter their properties and, consequently, diminish the protective performance of the composite structure. Temperature, humidity, and ultraviolet (UV) radiation are the primary ageing factors. Artificial ageing methods—such as climatic chambers, ovens, and UV-irradiation testers—allow the ageing process to be accelerated under controlled conditions. Accurate studies and diagnoses of aged materials are essential to determine whether the protective devices still meet their specifications or need replacement.

Various accelerated ageing cycles are applied to complete visors, to model systems, and to individual polymers (i.e. poly(methyl methacrylate), adhesive and polycarbonate) that constitute the transparent protective devices. For certain ageing treatments, extensive delamination has been observed. To better understand how ageing influences both structure and properties, a comprehensive study combining non destructive evaluation, mechanical testing, and ballistic testing has been undertaken.

Non-destructive analysis techniques such as spectroscopies and ultrasonic testing are employed to assess the effects of ageing. Among these, terahertz time-domain spectroscopy (THz-TDS) is especially useful for monitoring structural changes and water uptake in the samples, while ultrasonic testing is highly effective for detecting defects such as delamination.

Concerning the materials properties, mechanical testing of the devices after ageing reveals changes in flexural modulus and puncture resistance. Ballistic tests, performed in accordance with the NIJ 0101.03 standard, evaluate whether the transparent protective devices (visors) continue to provide effective bullet protection. The ballistic results show measurable modifications in the properties of aged materials compared with their non-aged counterparts. Post-mortem examinations of the samples further highlight significant differences among the various material types evaluated.

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# Energy absorption of 3D-printed PEEK/CF composite honeycombs with tubular CFRP reinforcements

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Honeycomb (HC) structures are widely utilized in aerospace and space applications due to their exceptional mechanical properties, especially light-weight and high specific strength. However, HC structures are susceptible to structural instabilities arising from their slender load-bearing elements, which can reduce their efficiency and potentially lead to sudden failure. Previous studies show that embedding tubes within the honeycomb structures can significantly improve energy absorption and compressive strength. Moreover, recent developments in additive manufacturing have enabled the integration of complex structural configurations with optimal material systems. In this study, the mechanical properties of additively manufactured PEEK/CF composite honeycomb cores embedded with tubular reinforcements are evaluated through experimental testing. The cores are fabricated using chopped carbon fiber-reinforced PEEK filament, whereas the reinforcements comprise of roll-wrapped CFRP tubes inserted into the empty cell zones of the honeycomb core in different configurations. Plain HC, as well as the tube-reinforced HC (TRHC) designs are tested under uniaxial and quasi-static compression loads in the out-of-plane direction, and evaluated for failure modes, stiffness, compressive strengths and mass specific energy absorption properties. Preliminary testing results revealed that the stiffness, strength, mean crushing force and specific energy absorption of the TRHCs increased by up to 74%, 117%, 38%, and 19% respectively as compared to their baseline counterpart. Integrating CFRP tubes contributes by resisting a significant portion of the compressive loads, thereby improving the overall load-sharing efficiency and stability of the honeycomb structure, while incurring only a minimal weight increase. This work demonstrates the effectiveness of the additively manufactured reinforced composite cores, highlighting their potential for weight-sensitive applications requiring enhanced structural performance.

#415

# Sustainable manufacturing of hollow parts from staple yarns and bladder-assisted RTM

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To fulfil the development of recycled material, it is necessary to adapt manufacturing processes to enable their use with said recycled material. This work realised in the SUSPENS project, tackles the manufacturing of complex hollow parts using a staple yarn made from carbon fibre production waste, as a reinforcement.

The selected manufacturing route comprises the following steps:

(i) Transform carbon fibre waste into a staple yarn

(ii) Manufacture a preform using Tailored Fibre Placement (TFP)

(iii) Produce a hollow part by resin transfer molding (RTM), using a dedicated bladder system.

This process route has been applied to demonstrate the possibility to make high performance products from waste material, thus reducing the environmental impact. This paper describes the process development, from challenges to solutions.

Carbon fibre production waste was turned into staple yarn by the Institute of Textile Machinery. Adjustments to the yarn design in collaboration with ITM were critical to produce a preform by TFP at a consistent and moderate areal weight.

Staple yarns were also found challenging to be used in an RTM process because of their high bulk. Flat panels were first manufactured using RTM to validate process parameters, observe laminate quality and compare their mechanical performance through tensile and flexural testing against virgin continuous fibre. Moreover, flexural specimens were subjected to hygrothermal ageing at 55°C and 95%RH for 500h and 1000h, to monitor their performance under harsh conditions.

Finally, a bladder-assisted RTM process was used to produce a hollow demonstrator part, specifically with a microbeads-filled bladder and an autonomous RTM tool. The former enables to shape the preforms onto a solid bladder, which is later filled with water to apply pressure onto the reinforcement. The latter consists in a tooling managing its own pressure and temperature, thus reducing the need for complex investments.

#416

# Influence of Sub-Curing Temperature on the Interphase Formation Between PEI and Toughened Epoxy in Hybrid Composites

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Carbon fibre reinforced polymers (CFRP) constitute a central material class in modern aerospace structures due to their specific mechanical properties. Emerging design strategies increasingly focus on hybrid material concepts that integrate thermoset and thermoplastic matrices to exploit the high mechanical properties of thermosets together with the enhanced toughness, damage tolerance, and reparability of thermoplastics. Realizing the full structural and functional potential of such hybrid architectures requires a fundamental understanding of interphase formation mechanisms at the thermoplastic-thermoset interface, particularly with respect to the thermal processing history.

This study examines the interphase evolution between polyetherimide (PEI) and a toughened epoxy matrix, with emphasis on the sub-curing temperature regime that precedes complete thermoset crosslinking. The thermoset curing cycle, conventionally incorporating an isothermal dwell at approximately 80 °C to facilitate homogeneous resin distribution prior to final curing at 180 °C, is systematically modified. Variations in dwell temperature and duration around 80 °C are introduced to elucidate their influence on resin mobility, thermoplastic-thermoset interdiffusion, and the resulting interphase morphology.

Differential Scanning Calorimetry (DSC) is employed to reproduce these thermal profiles under precisely controlled conditions, enabling continuous monitoring of thermal transitions, reaction kinetics, and possible shifts in the epoxy curing behaviour induced by altered pre-curing conditions. Subsequent morphological and microstructural analyses of the DSC-joined specimens provide insight into interphase thickness development, polymer chain mobility, and the degree of interpenetration between PEI and partially cured epoxy.

The results demonstrate that seemingly minor adjustments within the sub-curing temperature window substantially affect interphase characteristics and, consequently, the quality of thermoplastic–thermoset integration. These findings contribute to a more comprehensive understanding of interphase formation in hybrid composite systems and offer critical guidance for optimizing processing routes aimed at achieving reliable and high-performance aerospace-grade hybrid structures.

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# Understanding Thermal Degradation of CF-Epoxy in Hybrid Welding with Thermoplastic CFRP

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Hybrid welding of thermoplastic and thermoset-based CFRP components offers new opportunities for lightweight, multi-material structures, particularly in aerospace applications. However, the fundamentally different thermal and chemical characteristics of these polymer matrices pose significant challenges for achieving reliable and durable joints. During hybrid welding, intense localized heat is introduced into the bonding zone. While this enables bonding with the thermoplastic, it simultaneously exposes the thermoset epoxy, incapable of melting due to its crosslinked nature, to thermal degradation. Such degradation can compromise the structural integrity of the CF-EP component and, consequently, the overall joint performance.

This study investigates the thermal load conditions occurring during the hybrid welding process, aiming to establish a reproducible and quantitative understanding of the degradation mechanisms within the thermoset material. Two sets of CF-EP laminates were examined, differing in their consolidation approach: one cured in a heated press at 7 bar, and the other produced via vacuum-assisted consolidation on a hot plate at approximately 1 bar. Thermal loading was introduced using a ceramic hot plate combined with a stainless-steel heat accumulator to ensure consistent and reproducible heating conditions.

Analytical methods including dynamic mechanical analysis (DMA) and thermogravimetric analysis (TGA) were employed to characterize the thermal response and decomposition behaviour of the thermoset matrix. Additionally, microscopic imaging was used to assess the initial laminate quality and to evaluate changes in matrix morphology following thermal exposure. The results provide an improved understanding of thermally induced degradation in CF-EP during hybrid welding and its implications for joint performance. Furthermore, the influence of different consolidation methods on degradation behaviour and thermal resistance is compared.

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# Mild, universal and flexible catalyst-assisted solvolysis for circular recycling of fiber reinforced polymers

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Fiber reinforced polymer (FRPs) are widely used in large variety of industrial sectors, thanks to their high strength-to-weight, stiffness, lightness and durability. In structural or highly demanding applications, thermosetting matrices like unsaturated polyesters and epoxies are generally preferred, due to their superior performance related to their three-dimensional crosslinked polymeric network, combined with glass or carbon fibers as reinforcements. However, the irreversible covalent nature of these polymeric matrices prevents the effective recycling of these composite materials at their end-of-life (EoL). The proper EoL management of thermosetting composites, with recovery of high-quality recycled materials, still represents nowadays an urgent and unresolved challenge.

Within this context, this work presents a mild catalyst-assisted solvolysis process for FRPs from a variety of different polymeric matrices reinforced with carbon or glass fibers. The process is based on the use of biobased and bioderivable carboxylic acids and modified-Lewis acid catalyst. It is operated at atmospheric pressure, relatively low temperatures (≤ 200°C) and mild pH (4 – 5). At the end of the process, clean, intact reinforcing fibers can be recovered, with mechanical properties comparable to their virgin counterpart (>95% for carbon fibers, >90% for glass fibers). This process enables a selective cleavage of C-N and C-O bonds (depending on the polymeric matrix composition), with the aim of recovering valuable organic fractions, primarily composed by oligomers with residual chemical functionalities. The proposed solvolysis process is successfully validated on real EoL components, from wind turbines, sport equipment and the aerospace sector.

The developed recycling process is mild, simple, flexible, safe and economically viable, able to solvolyze composite materials in a universal fashion, without requiring prior knowledge of their precise chemical composition. Based on these considerations, it represents a significant step forward toward a more efficient circular economy of current-generation FRPs, substantially contributing to their sustainable EoL management and valorization

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# Early-stage assessment of bonded composite fuselage joints using a reduced structural model with high-fidelity material modelling

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Primary bonded joints are an enabling technology for lightweight composite aircraft structures. Compared with mechanically fastened joints, adhesive bonding avoids drilling-induced fibre cuts and cross-sectional reductions, while also providing smoother load transfer and reduced stress concentrations. Beyond joint strength, a design requirement in aircraft applications is the governing failure mode: under ultimate loading, failure should occur in the adherends rather than within the adhesive layer. Ensuring this behaviour allows certification substantiation to focus on the undisturbed composite structure. Consequently, preliminary design phases increasingly demand simulation methods that can predict not only joint strength but also the governing failure mechanism.

Longitudinal joints in composite fuselage shells can be realised as single-overlap, butt-strap, or stepped-lap joints, each resulting in different peel-to-shear stress ratios at the overlap ends. Their mechanical response becomes more complex when stiffening elements, such as stringers, are present because their stiffness, geometry, and position influence secondary bending and the resulting stresses in the adhesive. While progressive damage simulations can capture these interactions with high fidelity, their computational cost typically limits their applicability during early design stages.

Therefore, the central question is whether a reduced structural model, when combined with high-fidelity material modelling, can predict joint strength and failure mode of different design configurations, thereby enabling efficient exploration during early design.

To answer this question, representative cutouts of the fuselage skin were analysed under plane-strain conditions using progressive damage models that capture intralaminar failure, delamination, and cohesive failure in the adhesive. Joint geometry and stringer configuration were systematically varied to evaluate their combined influence on stress distributions and failure behaviour.

The approach enables mechanics-based screening of longitudinal joint concepts and associated stiffener arrangements. It supports the identification of structurally favourable configurations that remain compatible with high-rate production and provides a sound foundation for subsequent detailed damage-tolerance analyses and experimental verification.

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# Design and Processing of High-Loaded Composite Filaments for Additive Manufacturing: From Bonded Magnets to Ceramics and Metals

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The development of functional composite filaments for additive manufacturing represents a promising route toward advanced components with customized physical properties. This work presents the results of four complementary projects REMHUB (EU), MAGNEO (EU), STREAMSTEP (EU), and IRIDISCENTE (National), focused on the formulation, compounding and processing of specialized filaments for 3D printing of magnetic, ceramic, and metallic parts.

In REMHUB and MAGNEO, magnetic filaments for the 3d printing of bonded magnets were produced using modified polypropylene matrices loaded with up to 90 wt% of magnetic fillers. These fillers were sourced from AlNiCo alloys in MAGNEO and from recovered neodymium-based materials in REMHUB, enabling sustainable magnet manufacturing via extrusion-based printing.

For STREAMSTEP, an EVA-based binder was optimized with tailored processing aids to incorporate up to 85 wt% of alumina, exceeding typical loadings reported in literature. The printed green bodies are intended for subsequent debinding and sintering to obtain dense alumina components for heat-exchanger applications.

In IRIDISCENTE, a TPE modified matrix was formulated to accommodate 90 wt% stainless-steel powder, enabling the production of highly filled filaments for printing metallic green parts. After debinding and sintering, these parts yield fully metallic components suitable for medical applications.

All formulations were compounded at AIMEN with composition and processing parameters tailored to each system to ensure optimal filler dispersion and printability. Current work focuses on 3D printing trials and characterization of the resulting components. Overall, the projects demonstrate the versatility of filament-based extrusion for manufacturing functional magnetic, ceramic, and metallic materials with high filler loadings, opening new avenues for application-driven additive manufacturing.

This work is developed in STREAMSTEP project, which has received funding from the European Union's Horizon Europe Research and Innovation programme under grant agreement No 101178351.

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# Manufacturing structural power devices; challenges and solutions of novel material systems

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Carbon fiber-based structural power devices present a future of integrated power devices promising lightweight systems with more efficient component designs while minimizing material use. In the aim of achieving this concept, a range of novel materials have been developed. The primary focus for these developments is to improve electrical (and mechanical) performance, resulting in novel manufacturing challenges. Approaching these manufacturing challenges requires a novel manufacturing system. One manufacturing challenge is the use of carbon aerogel (CAG)-infused carbon fibers. This maximises surface area for supercapacitor performance but the CAG preforms are nearly impermeable to resin flow. Alongside this is a biphasic resin system, allowing load and electrical charge to be transmitted through the devices. However, with a short cure time (<45 minutes), higher than ideal viscosity (~10 Pa.s), and a complex rheological profile, infusion must be carefully controlled to ensure optimum electrical, and mechanical performance. With no possibility of through thickness resin flow and a requirement for rheological considerations, traditional liquid composite moulding (LCM) strategies cannot be utilized. The designed solution allows for a wide parameter space to be explored in an adaptable LCM strategy. Vacuum relaxation during infusion allows the preform to be under vacuum while not presenting any compaction through thickness and works alongside independent resin injection and consolidation pressures. This lack of flow restrictions means consumable flow medium is not required for infusion, resulting in almost no excess surface resin. With cells being just 0.1 mm thick, any excess resin represents a large fraction of the overall thickness, and mass, and can lead to stress imbalances after cure. These, combined with a rheological model of the resin phase-transition that has been developed to inform on the state evolution during infusion and curing, allow for novel optimum manufacturing routes of difficult resin systems to be more easily explored.

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# Thermo-chemo-mechanical characterization and modelling of a 3D interlock reinforced composite

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With the aim of modeling the generation of residual stresses in a carbon/epoxy composite with a 3D interlock woven reinforcement, the chemical and thermo-mechanical properties of both the composite and the epoxy resin have been identified. The polymerization kinetics of the resin and the evolution of its glass transition temperature with the DOC (degree of cure) were measured by dynamic DSC (Differential Scanning Calorimetry) tests. The PVT-α device, developed at the LTeN, was used to monitor the evolution of the polymerization and the volume of resin samples during different curing cycles, in order to determine the CTE (Coefficient of Thermal Expansion) and the CCS (Coefficient of Chemical Shrinkage) as a function of temperature and DOC. The chemical shrinkage was found to increase with curing temperature. The rubbery CTE decreases linearly with increasing DOC while the glassy CTE is independent of the thermo-chemical state of the resin.

From these properties of the resin, the CTE and CCS of the composite are determined using the homogenization strategy of Hirsekorn et al. (Int. J. Solids. Struct. 344-345 (2022) 111569), taking into account the architecture of the woven reinforcement at the mesoscopic scale. The viscoelastic behavior of the resin and resulting stress relaxation effects are included in the homogenized CTE and CCS.

With the PVT-HADDOC, a device developed at the LTeN by Péron et al. (Composites: Part A 101 (2017) 129–142), multi-axial strain measurements were carried out on both fully and partially cured composite samples manufactured by RTM (Resin Transfer Molding). The observed anisotropic strains caused by chemical shrinkage and thermal expansion are compared with numerical simulations of the respective temperature cycles using the homogenized behavior of the composite.

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# Characterization of mechanical behavior of unidirectional composite laminate at 20 and 77 Kelvin with novel experimental apparatus including digital image correlation

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Hydrogen storage is being explored in aeronautics as an effort to decarbonize aviation. For safety, volume and weight constraints, storage of hydrogen under liquid form inside a composite tank at cryogenic temperature (20K) emerges as a preferred solution. The design of all-composite tanks, adapted to cryogenic environment, remains an industrial challenge. In this context, this study focuses on characterizing the mechanical behavior of an AS4 8552 carbon epoxy composite at ambient and cryogenic temperature until 20K.

The general tendency at cryogenic temperature reported in extensive reviews is an increase in Young modulus and failure stress, as well as a decrease of the failure strain.

However, below liquid nitrogen temperature (77K), trends and conclusions available in literature about material behaviors are more spread and show a lack of consensus. The strong heterogeneity of the experimental procedures may explain the variability of the observations. In particular, the abrupt drop in temperature caused by direct immersion of composite samples in cryogenic liquid could cause damage to the specimen and lead to a decreased strength. In order to ensure stable experimental conditions, an advanced testing apparatus with embedded tensile machine including a cryostat in which controlled and reproducible cryogenic temperature profile up to 4K can be achieved is developed and will be presented.

Tensile tests can be performed in-situ at 20K, and the load is recorded by the use of a specific load cell, up to 25kN. The presence of a porthole in the cryostat, and of led lights inside the enclosure, makes it possible to measure the displacement field thanks to Digital Image Correlation (DIC). All these improvements seek to increase the quality and the repeatability of the mechanical tests performed on composite materials at 20K in order to assess reliable data for material law development and identification.

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# Study on Functional Fatigue Evolution for SMA Based Textile Reinforced Elastomer Composite Actuators

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Functional fatigue plays a vital role in the long-term performance of shape memory alloy (SMA) integrated textile reinforced elastomer actuators. The composite actuators are fabricated by first stitching braided SMA wires onto a textile substrate in specific orientations to achieve the desired actuation, followed by elastomer infusion using Vacuum Assisted Resin Infusion (VARI) process. Thermo-mechanical cyclic loading in SMA leads to degradation in transformation strain, increased hysteresis, and progressive changes in material stiffness, ultimately reducing the actuation efficiency of the composite actuators. This study investigates the evolution of functional fatigue in these actuators through a combined experimental and numerical approach. Temperature dependent cyclic actuation tests are performed to monitor changes in tip displacement, actuation force, and transformation temperatures over numerous cycles. The results show an initial rapid decrease in tip displacement over the cycles, followed by a slower reduction, ultimately reaching a stable displacement after approximately 250 actuation cycles. The experimental work is supported by numerical actuation modeling to simulate both the structural performance of actuators and the evolution of key SMA fatigue parameters, including residual strain, residual stress, retained martensite fraction, and defect volume fraction. Together, these investigations enable validation of the applied constitutive material model for SMA, which incorporates phase transformation kinetics, functional fatigue, and pre-strain effects. Furthermore, it provides an accurate estimation of the stabilized actuation response over extended cycles, which is essential for its effective control. The influence of textile reinforcement on functional fatigue is also studied by varying the fiber percentage in the composite structures, to understand its role in mitigating performance degradation. This work provides insights for designing more durable composite actuators by quantifying functional fatigue evolution, enabling robust control strategies for applications in soft robotics and smart material systems.

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# Hydrogen permeability of composites for type 5 hydrogen tanks

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The path to a future with energy sources from renewable sources requires the substitution of fossil energy sources. Hydrogen is a promising candidate with great potential for use in the mobility sector. Hydrogen has a higher energy density (approx. 142 MJ/kg) than conventional fuels, produces very few emissions when used in combustion or electrochemical reactions, and can be produced from renewable sources. However, the use of hydrogen as an energy source poses challenges in terms of storage. As the smallest gaseous molecule, hydrogen can easily penetrate many solid materials, leading to losses and safety risks due to possible interactions with the ambient air. Therefore, the permeation of hydrogen through materials must be reduced, existing solutions further developed and new ones found.

Although metallic materials have good resistance to hydrogen permeation, their mechanical properties deteriorate significantly due to hydrogen embrittlement mechanisms. In order to fully utilise the high energy density of hydrogen, lightweight storage solutions are required.

Tanks made of fully carbon fibre reinforced polymer (CFRP) can meet both requirements, as they offer a favourable ratio of dead weight to storage volume and exhibit high resistance to hydrogen embrittlement. However, their properties depend on temperature and pressure. Understanding how these parameters influence hydrogen permeation is crucial for the development of safe and reliable storage systems.

Using a novel test cell for measuring hydrogen permeability, various thermosetting and thermoplastic plastics as well as fibre reinforced composites have been investigated, with particular attention paid to the influences of temperature and pressure on permeation. The results reveal that these parameters influence permeation through individual and superimposed effects.

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# Enhancing the mechanical performance of shredded glass fiber composites in epoxy resin bulk moulding compounds

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Despite ongoing research on reusing glass fibre reinforced thermoset composites, effective and scalable solutions remain limited. With production volumes in sectors such as aviation and renewable energy continuously increasing, and long-life applications like wind turbine blades (WTBs) reaching their end-of-life stage, the demand for viable recycling and reuse strategies for waste glass fibre composites (GFC) is substantial.

Among the available recycling approaches, mechanical recycling currently represents the only economically feasible option. Therefore, the aim of this work was to enhance the mechanical performance of bulk moulding compounds (BMC) made of epoxy resin with shredded GFC material from post-industrial waste (PI) and from end-of-life WTB.

The investigated GFC waste materials were shredded and sieved in three different fractions to be further used as reinforcing material in epoxy resin plates which were then cut in to specimens for tensile testing. After evaluating different types of epoxy resin, the influence of coupling agents on composite stiffness was analysed. The components of the shredded WTB were identified via Infrared- and X-ray fluorescence analysis and the influence of industrial cleaning steps on the mechanical performance of the resulting composite was determined.

We found that BMCs with smaller particle sizes achieve higher elastic modulus and tensile strength values. PI and WTB waste are both easy to handle, whereby PI waste achieves higher mechanical values and shows a lower standard deviation. The performance of both materials can be improved with coupling agents, though the individual formulation must be determined experimentally. Cleaning steps for shredded WTB are essential to obtain a homogenous raw material, even though their impact on the mechanical values is low.

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# Effects of Matrix Type and Environmental Impacts on the Fracture Toughness, Damage Progress and Fatigue Lifetime of GFRP

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Reliably and accurately characterizing the mechanical properties of composites is essential for developing and designing safe, long-lasting, lightweight structures. Two of the most important properties of composites are certainly strength and fracture toughness, both of which affect fatigue life. However, determining and understanding fracture toughness remains challenging. Even standardized measurements of interlaminar fracture toughness are influenced by various parameters, such as crack initiation determination and possible fiber bridging effects. Furthermore, numerous other factors are responsible for the significant discrepancies and occasionally contradictory results reported in the literature. Consequently, measurements exhibit relatively large standard deviations, sometimes revealing significant discrepancies between composites that appear similar on paper, e.g., those based on the same resin or fiber layup. Nevertheless, accurately determining these properties experimentally is essential for understanding the damage and fatigue behavior of composites.

Consequently, this study focuses on the most relevant parameters affecting longitudinal interlaminar fracture toughness. To this end, a comprehensive test matrix was developed for glass fiber-reinforced polymers (GFRPs) using Double Cantilever Beam (DCB), End Notched Flexure (ENF), and Single Edge Notch Bending (SENB) specimens. The study distinguishes between material-specific factors, such as five different epoxy resins or curing agents, and environmental and test-specific factors, such as aging and environmental test temperature. For example, using a resin with five times lower mode I fracture toughness decreased the composite fracture toughness in mode I by about 50% and in mode II by about 30%. Finally, tensile fatigue tests were performed on multidirectional GFRP laminates to determine the effects of changes in fracture toughness on lifetime and damage behavior. Finally, all influencing parameters are clearly summarized in a chart.

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# Consequences on process parameters upon scaling up the vessel size for solvolysis-based recycling.

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Abstract:

Modern technical products are required to meet a variety of requirements, from strength to cost-efficiency, quality, etc. This trend is evident in every industrial sector – be it wind energy, automotive or aeronautical. Fiber reinforced composites being one of the key components in these sectors. However, a well-known drawback of these composites is that they are exceptionally difficult to recycle once these have reached their end-of-life. Thermal, chemical, electrical, mechanical recycling have been explored, but few have reached industrial maturity. The mechanical process involves shredding or grinding composite waste into smaller particles. Thermal recycling processes, such as pyrolysis and fluidized-bed treatment, thermally decompose the polymer matrix in order to recover relatively clean fibers, gas and liquid oil. However, chemical recycling offers a more complex approach. Here, solvents are used to dissolve and depolymerize the matrix, freeing the fibers. Based on the current available literature, in some cases, the recycling process leads to the recovery of approx. 90% or higher of the fibers' mechanical properties with about 95 wt.% of the resin being removed to reveal clean fibers. However, the question remains whether these systems can be scaled from the current state of the art of tens of grams per batch, to kilograms per batch. In DLR, solvolysis facilities are being setup up to bridge the gap between lab and industrial scale, in preparation for commercial deployment. Towards this objective, we are trying to understand - what would happen if the volume of the solvolysis reactor or/and the composite size is significantly increased? How would this increase impact the temperature and pressure? And how this affect the recycled fibers properties? To understand these crucial parameters, trials have been conducted in this work on different size reactors (100mL and 3.750mL) using identical solvent mixtures.

Keywords: Solvolysis, Recycling, Composites Material

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# Strain rate dependency on fracture toughness of plain woven AS4/8552 CFRP using in-situ synchrotron x-ray phase contrast imaging

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This study examines the dependency of fracture toughness, crack propagation and damage evolution on strain rate in AGP193-PW, a long-fibre plain-woven carbon fibre reinforced polymer (CFRP) composed of AS4 fibres and a epoxy resin. AGP193-PW has been characterised at the facilities of Universidad Carlos III de Madrid (UC3M) under quasi-static (QS) and dynamic rates, both in tension and compression loads, in multiple orientations, enabling the construction of failure envelopes and the quantification of strain-rate effects. The results reveal significant variations in tensile and compressive strength for both fibre- and matrix-dominated orientations, allowing the identification of a Maximum Stress criterion for damage initiation and a Cowper-Symonds power-law formulation to represent the strain-rate dependency of the longitudinal, transverse and in-plane shear strength.

To achieve a comprehensive characterisation of AGP193-PW, this work investigates the strain rate dependency on the fracture toughness through Compact Tension (CT) tests performed under both QS and high strain-rate conditions. QS CT tests were conducted using a Universal Testing Machine (UTM), while high strain-rate CT tests were carried out with a Split Hopkinson Tension Bar (SHTB) device, both combined with synchrotron X-ray imaging. A multimodal experimental methodology—integrating X-ray imaging, infrared thermography and visible-light recording—enabled real-time monitoring of crack growth, damage evolution and thermal effects throughout the fracture process.

CT tests were conducted on specimens with fibres oriented at 0° and 45° relative to the loading direction under three different strain rates. The results revealed a clear strain-rate dependency of fracture toughness in Mode I fracture (0° orientation) and Mixed-Mode fracture (45° orientation). With using a novelty inverse methodology that combines experimental and numerical apporach, this work allowed not only the strain rate dependency on fracture toughness, but the strain-rate dependency of the damage evolution law, providing a more complete understanding of the dynamic fracture behaviour of this woven composite.

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# Vacuum-Arc–Enhanced Additive Manufacturing of Functional High Performance Polymer Composites

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High-performance polymers, such as Polyaryletherketon family, are widely used across engineering domains that demand resilience in extreme environments, including aerospace, high-voltage systems, chemical processing, and medical applications. In many of these areas, components require tailored surface or bulk properties to withstand specific environmental conditions. This work introduces an integrated manufacturing approach that unites polymer 3D printing with vacuum-arc–based coating technologies in a single high-vacuum process. The method enables the fabrication of polymer–metal composite structures whose surface and volume characteristics can be precisely tuned. By combining layer-by-layer polymer deposition with vacuum-arc metallization, it becomes possible to simultaneously optimize mechanical strength, electrical permittivity, antimicrobial functionality, and interfacial performance—while maintaining the geometric freedom inherent to additive manufacturing.

The presentation outlines the complete workflow, beginning with high-performance polymer printing conducted under controlled thermal and atmospheric conditions. The subsequent vacuum-arc coating step—employing metal or metal-oxide layers—produces dense, strongly adherent, and highly customizable coatings without compromising part geometry or mechanical integrity. Characterization of the resulting composites demonstrates significant enhancements in functional performance, surface durability, and dielectric or electromagnetic behavior, depending on the selected coating system.

Application examples in the medical, high-voltage, and electromagnetic-shielding fields highlight the versatility of the approach. In biomedical engineering, the process supports the fabrication of patient-specific implants with antimicrobial metallic coatings that remain biocompatible and promote cell adhesion, addressing long-standing challenges related to infection control and implant integration. In high-voltage applications, the ability to tailor permittivity through composite design enables advanced dielectric components and improved insulation solutions. Additionally, the vacuum-coated polymer structures provide tunable electromagnetic interference shielding, paving the way for lightweight protective housings, electronic enclosures, and functional components for communication technologies.

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# Comparative Life Cycle Assessment of Monolayer Polypropylene Pipe and Multilayer Polypropylene Composite Pipes with Talc- or Glass-Fiber-Reinforced Middle Layer

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The environmental performance of polymeric piping systems is becoming increasingly important for sustainable infrastructure design. This study presents a life cycle assessment of multilayer polypropylene pipes composed of a high-modulus polypropylene grade, BA212E, forming the inner and outer layers, combined with a filled polypropylene middle layer (PP-MT20 or PP-GF30). The PP-MT20 grade contains 20 wt.% talc, whereas PP-GF30 contains 30 wt.% glass fiber. The functional unit is defined as one meter of installed pipe meeting a nominal ring stiffness of SN > 8 kN/m². The system boundary includes raw material production, transport of materials, transformation into pipes, and transportation of the final pipes to the installation site. Two environmental indicators are assessed: Cumulative Energy Demand (CED) and Global Warming Potential (GWP).

Beyond environmental considerations, both multilayer configurations also provide economic advantages compared to a monolayer BA212E pipe. Incorporating PP-GF30 as a middle layer reduces pipe weight and material cost by 3.6% and 5%, respectively. Likewise, the utilization of PP-MT20 yields reductions of 2.2% in pipe weight and 11% in material cost, highlighting its strong potential for cost-effective pipe design.

The environmental results demonstrate that multilayer configurations significantly reduce impacts relative to a monolayer BA212E pipe. The BA212E/PP-MT20 multilayer achieves a 16% reduction in CED and 14% in GWP, while BA212E/PP-GF30 achieves an 18% reduction in CED and 9% in GWP. These improvements arise primarily from the reduced polypropylene mass enabled by the higher stiffness of the filled middle layers, with PP-MT20 additionally benefiting from the very low embodied energy of talc.

Overall, the findings show that optimized multilayer polypropylene pipes can simultaneously decrease material usage, cost, energy demand, and greenhouse gas emissions. This work reinforces their relevance as sustainable solutions for sewerage and drainage applications and demonstrates the value of integrating LCA early in the composite pipe design process.

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# Bioinspired nanoclay glass fiber sizing for interphase structuring in epoxy resin

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Reinforcing fibers used in polymer composites are surface treated with coatings, which are most often applied during manufacturing. These coatings, commonly known as sizing, consist mainly of aqueous polymer dispersions, silane coupling agents, lubricants, and other additives. By choosing an appropriate sizing formulation, improved textile processability and better mechanical properties of the composite can be achieved with high levels of stress transfer. The incorporation of nanofillers into sizing formulations can increase fracture toughness and energy dissipation. In alternating layered natural structures, such as nacre, cracks that develop at the interface are forced to follow a route, where nanofiller particles act as obstacles. In this study, tailored glass fibers (GF) were produced using a pilot spinning line, where a new bioinspired nanoclay-based sizing was evaluated to modify the interphase morphology. The addition of varying concentrations of montmorillonite (MMT) nanoclays to the sizing composition was explored to promote crack deflection and delay crack propagation through the bioinspired brick-and-mortar structure. The change in the viscosity of the sizing was evaluated using a rheometer. Furthermore, the fiber sizing content was determined using the loss on ignition (LOI) method. Scanning electron microscopy (SEM) images were used to evaluate the fiber surface morphology. Finally, unidirectional composite plates were produced by resin transfer molding (RTM) using an epoxy resin. The crack propagation during three-point bending tests was recorded optically. At the microscopic level, the crack path was not linear, and cross-section images showed a more homogeneous fiber distribution within the composite, likely due to the separation effect of MMTs on the filaments. The incorporation of MMT resulted in an increase of 30% in composite toughness and a delay in crack propagation, thereby highlighting the significant potential of nanoclay-based sizings.

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# Fatigue life analysis for adhesive bonds in large FRP structures with heterogeneous property profiles

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Adhesively bonded joints are widely used in large, tolerance-prone FRP structures such as wind turbine blades, ships, rail components, and commercial vehicle structures. However, the transferability of material and structural characteristics derived from laboratory-scale specimens to real joints with adhesive layer thicknesses exceeding 10 mm remains limited. Particularly, the mechanisms of fatigue crack initiation and growth are not adequately captured in current design approaches, as the complex dependencies on bonding partners, surface preparation, manufacturing and cross-linking conditions in the bonding process and the bonded layer thickness are not yet sufficiently understood.

This contribution aims to clarify process–structure–property relationships in real-scale adhesive bonds and to understand thickness-dependent effects on material and structural behavior under fatigue loading. Previous investigations by the authors highlight the challenge of reproducing real-scale damage phenomenology and manufacturing-induced imperfections at laboratory scale. Residual stresses and heterogeneous through-thickness property profiles were identified as key factors that strongly affect fatigue crack initiation and propagation.

To address these limitations, an analysis approach is suggested. Adapted manufacturing methods informed by numerical process simulations are developed. These methods enable laboratory specimens to be produced with property profiles representative of large-scale structures, particularly the through-thickness gradients resulting from non-uniform curing reactions and heterogeneous residual stress states. The tailored specimens are tested under cyclic loading using an automated system for crack detection and evaluation. The experiments are supported by a sub-model-based simulation framework combining cure reaction simulation with fracture mechanics techniques (VCCT, FFM). This allows determining energy release rates at crack initiation and during crack growth, providing characteristic curves that can be robustly transferred to joints of arbitrary adhesive thickness and property profile.

First results of the proposed approach are presented, including real-scale bonding process analyses, characterization and modeling of curing behavior, development of property-profile transfer techniques, and initial property profile characterizations.

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# Benchmarking micromechanical finite element models of ud-frps against in-situ compression experiments

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The longitudinal compressive strength of unidirectional fibre-reinforced polymer composites (FRPs), which is often inferior to tensile strength, is strongly influenced by local microstructural imperfections. Understanding how real microscopic defects influence the sequence of failure events under compression is essential for improving FRP performance and guiding the design of advanced composite architectures. Realistic micromechanical finite element models (μFEM), based on fibre paths reconstructed from micro-computed tomography (μCT) of FRP samples, have been proposed to study these effects. However, conventional μFEM approaches are limited by their extremely high computational cost, even for small representative volumes.

Our recent development of a new computationally-efficient “Shell-Beam” μFEM has allowed the simulation of large composite microstructures obtained from μCT images. This framework has demonstrated novel microscopic failure mechanisms, including the coupling between torsion and kinking (results that only recently have been reported in the literature), affecting greatly the composite’s compressive strength and originating from manufacturing-induced microstructural imperfections. Although this μFEM framework has been thoroughly verified against conventional state-of-the-art μFEMs, its quantitative validation against experimental data is still lacking.

This presentation benchmarks the “Shell-Beam” μFEM using the full μCT composite volumes and in-situ experimental data, providing for the first time a one-to-one comparison between experiments and μFEM. This comparison aims to capture not only the global deformation metrics but also local deflections of individual fibres within the composite microstructure. The study establishes a robust and experimentally validated computational framework for analysing and designing fibre composites, offering new insights into failure mechanisms and supporting the interpretation of in-situ experimental observations.

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# Enhanced stability of plate-based composite lattice structure fabricated via 3D printing of polyamide/carbon fiber filament

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Cellular materials are renowned for their exceptional mechanical properties and lightweight nature, making them ideal for weight-sensitive applications, particularly in aerospace engineering. Among these, plate-based structures are especially important as they offer up to three times higher stiffness compared to truss- and shell-based architectures, however, plate structures are more susceptible to buckling at low volume fractions.

In this study, a failure-mode-informed design approach is adopted to strength the buckling and load bearing capacity of ultra-light simple-cubic plate-based structures fabricated via additive manufacturing using nylon-carbon fiber composite material. The dominant deformation patterns of baseline SC plate unit cells were analyzed using a finite-element eigenvalue solver, to identify the regions contributing to structural instability. Subsequently, material was systematically reallocated from high-stiffness regions to buckling-prone zones within the unit cell, integrating supplementary morphological features to enhance material alignment along the primary loading direction. A suite of hybrid reinforced designs was developed with different cross sections of columnar reinforcements. Baseline and hybrid SC structures having 5% and 10% relative densities were fabricated via material extrusion and evaluated experimentally under quasi-static uniaxial compression loading. Testing results showed that the hybrid structures exhibited up to 433% higher load-bearing capacity as compared to their conventional counterpart while maintaining stiffness, volumetric efficiency and near-isotropic behavior. The enhanced mechanical performance of hybrid designs stems from the improved distribution, increased bending resistance and multi-modal buckling suppression, resulting from the failure-informed material placement, allowing for higher membrane energy storage. This work underscores the efficacy of proposed failure-informed design framework in developing lightweight, high-strength architected structures using composite materials for aerospace and other critical applications where mechanical stability, strength and mass efficiency is paramount

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# Time-dependent piezoresistive behavior of graphene-based self-sensing laminates under tensile loading

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Fiber-reinforced polymer (FRP) composites have evolved beyond their conventional structural role to serve as multifunctional materials through the integration of carbon-based nanomaterials such as reduced graphene oxide (rGO) and carbon nanotubes (CNTs). These enhancements retain their intrinsic high specific strength and stiffness while enabling additional functionalities including energy absorption, EMI shielding, and self-sensing capabilities. The self-sensing functionality directly addresses the limitations of conventional sensors; such as strain gauges, Fiber Bragg Gratings (FBG) and Micro-Electro-Mechanical Systems (MEMS), whose incorporation often increases the structural weight, complicates manufacturing, and introduces potential stress concentrators. In service environments, FRP structures are frequently subjected to sustained or cyclic loads over extended periods, under which the viscoelastic response of the polymer matrix becomes dominant. Therefore, there is a clear need to investigate how embedded self-sensing networks behave under time dependent loading conditions, since understanding their response is vital for achieving accurate and durable structural health monitoring performance.

In this work, unidirectional (UD) glass fiber/epoxy laminates incorporating partially reduced graphene oxide-coated fibers were fabricated using the Vacuum-Assisted Resin Transfer Molding (VARTM) process to enable in-situ strain sensing. Stress relaxation, creep–recovery, and cyclic loading tests were performed, within the elastic region, on laminates with 0° and 90° fiber orientations to assess the time- and orientation-dependent electromechanical response. The evolution of electrical resistance, recorded parallel and transverse to the loading direction, was analyzed in relation to the applied loading history to evaluate sensing reliability under viscoelastic deformation. The results provide new insights into the long-term stability of self-sensing composites and establish a foundation for developing durable multifunctional materials for next-generation SHM applications

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# Investigation of the Mechanical and Thermal Properties of Recycled PLA in the 3D Printing Process

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The growing use of 3D printing generates significant plastic waste. This study investigates recycled polylactide (PLA) in a closed-loop system to assess its behavior after repeated processing. Virgin PLA granulate is extruded into filament, printed, and then shredded. This material is then re-extruded to evaluate the influence of repeated processing cycles on its properties.

Our work builds upon current research, particularly "A Comparative Study of 3D Printing with Virgin and Recycled PLA" by Wei et al. (2024), which investigates and compares the mechanical and surface properties of recycled and virgin PLA. That study utilized a single recycling stage. Furthermore, we draw upon the systematic literature review by Hasan et al. (2024), which analyzes the potential of recycled PLA for 3D printing. Their work provides an overview of various recycling strategies and addresses the degradation of material properties caused by repeated mechanical recycling. Our study extends this analysis through the experimental execution of multiple recycling stages, in which PLA is repeatedly printed, shredded, and re-extruded into filament, to investigate the influence of repeated processing in detail.

Using a Design of Experiments (DoE) approach, various printing and recycling parameters are systematically varied to analyze their main and interaction effects on mechanical properties. The manufactured specimens are tested for tensile strength, notched impact strength, and hardness. Additionally, Differential Scanning Calorimetry (DSC) and Thermogravimetric Analysis (TGA) are performed to investigate changes in crystallinity, thermal stability, and degradation behavior.

The objective is to determine the extent to which PLA can be recycled without the addition of new virgin material while avoiding significant degradation of its properties. The results are intended to contribute to a better understanding of material degradation in recycled PLA and to demonstrate approaches for a more sustainable use of additive manufacturing processes in academia and industry.

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# 3D printing of fibre-reinforced plastics - optimised carbon structures in different variants and with no need for complex moulds

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Fibre-reinforced plastics (FRP) are increasingly regarded as key enablers for sustainable lightweight design, with demand expected to rise in response to climate and mobility targets such as the European Green Deal. Today, around 30% of FRP components in SMEs are manufactured manually, resulting in limited reproducibility and high dependency on the workers skill. Established additive techniques, including tailored fibre placement (TFP) and automated fibre placement (AFP) or tape laying, allow two-dimensional alignment of reinforcing fibres along load paths. Their industrial uptake is hampered by low speeds, high costs, and the need for expensive moulds for complex 3D geometries. As a result, they are suitable only for selected parts and geometries.

Recently, 3D printing has emerged as a promising alternative for the fully automated production of complex FRP parts. Additive manufacturing enables complex components to be fabricated layerwise without negative moulds, supporting design flexibility even for challenging geometries. Short-fibre reinforcement is commonly used, already offering significant improvements in mechanical performance compared to unreinforced polymers. Continuous FRP printing, however, is still a nascent technology. Printed parts commonly exhibit pronounced anisotropy, and fibre alignment is strongly constrained by process kinematics.

This paper provides an overview of the current state of the art. In addition to the machines and materials, the details of the production methods will also be considered. Furthermore, the current challenges associated with additive manufacturing in general and the production of FRP in particular will be explained. For example, the spatial fibre orientation, the transfer of topology-optimised structures into printable robot paths and the fibre volume content in addition to pores and air inclusions play a significant role in this production method. The aim is to bridge the gap between traditional composite processes and next-generation FRP production in a fully automated way and with no needs for complex moulds.

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# Thermoplastic high-pressure hydrogen vessels with load-bearing capability

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In order to sustainably reduce CO2 emissions in aviation and thus making a sustainable impact on mitigating climate change, it is mandatory to drastically reduce petroleum based fuels. One promising alternative is the use of hydrogen in fuel cells. By using green hydrogen, the CO2 emissions can be next to zero as the only waste product is water. As cryogenic hydrogen needs extensive storage solutions and infrastructures, the most economical alternative for small aircrafts is seen in highly compressed hydrogen gas.

Due to the tank technology with load bearing capability developed by IVW, ultra slim vessels can be manufactured and therefore can be placed in the wing of small airplanes and drones. By doing so, space in the fuselage can be made available for freight and wing spares can be substituted.

In the researched thermoplastic design, the recyclability as well as the production speed can be improved. Therefore, we use a PA-CF tape with an altered winding process to enable true 0° and 90° winding for a vessel diameter as small as 60 mm. By using thermoplastics, we expect better permeation resistance and so a potential in manufacturing a Type V tank. This allows the thick liner being removed, which will further dive down the weight and improve the gravimetric energy density for the system as a whole. The investigations which are anticipated include the adaption of the winding process for the longitudinal fibres, impact on manufacturing and environment parameters, material characterisations (especially of the matrix due to the hot gas winding) as well as burst pressure tests.

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# Bridging Scales in Composite Materials: A Multiscale Perspective from Microstructure to Structural Performance

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Predicting the structural behaviour of fibre-reinforced composites (FRCs) demands modelling approaches that capture interactions across micro-, meso- and macro-scales. Single-scale analyses may describe selected aspects of FRC but typically fail to reflect the interacting mechanisms governing stiffness degradation, localised damage and progressive failure. These limitations become significant in high-performance applications, where even minor microstructural deviations or fibre–matrix imperfections may influence global load paths. Based on extensive experience with composite structures employed in aerospace, transportation or energy-sector applications, this study presents a coherent multiscale concept intended to address such complexities.

The aim is to develop an integrated methodology that links microstructural behaviour, ply-level damage processes and structural-scale response within a unified computational framework. The approach seeks to improve predictive reliability in stress-critical regions and to support optimisation of FRC components.

At the microscale, representative volume elements incorporating fibre waviness, voids, interfacial imperfections and residual thermal fields are analysed using finite-element micromechanics. Their homogenised properties inform mesoscale models describing ply architecture, matrix cracking and delamination. Macroscale behaviour is represented through anisotropic damage formulations and sub-modelling procedures that account for global boundary conditions and load redistribution. Bidirectional scale transitions are employed: microscale data guide higher-level analyses, while local refinement enables more detailed modelling in regions identified as critical in the structural solution.

Applications to representative FRC components demonstrate improved accuracy in predicting stiffness reduction, initiation of damage and post-critical behaviour. The multiscale transition strategy reflects microstructural influences more effectively than single-scale analyses, particularly in zones affected by geometric or manufacturing-related imperfections.

The proposed framework provides researchers and practising engineers with a systematic means to relate small-scale mechanisms to structural performance. By strengthening the physical basis of simulations and enhancing confidence in failure assessment, it supports more robust design and evaluation of advanced composite structures.

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# Enhancing CFRP interlaminar strength: Laser-drilled–polyamide fiber infusion approach

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Carbon fiber reinforced plastics (CFRP) offer excellent strength and stiffness in in-plane direction and are therefore ideal for lightweight construction applications. However, their laminar architecture limits out-of-plane performance, if there is no reinforcement through the thickness. Conventional methods for improving interlaminar strength, such as sewing or z-pinning, improve out-of-plane strength but often compromise in-plane properties due to introduced defects such as fiber ondulations, fiber breaks and locally resin-rich areas. This study presents a novel z-pinning approach that preserves in-plane properties while improving out-of-plane mechanical properties. Ultra-short pulse lasers are used to drill conical through holes with an average diameter of less than 0.7 mm, which are then filled with short fiber-reinforced polyamide using a customized three dimensional (3D) printing process. The resulting z-pins, with a fiber content of approximately 10 vol.% and an average fiber length of approx. 90 µm, effectively bridge the interlayer areas. The z-pins are evaluated before and after mechanical testing with microcomputed tomography and light microscopy. To evaluate important in-plane properties, open-hole tension tests were performed in which two additional, non-filled laser-drilled holes were strategically placed on both sides of the main test hole to simulate a worst-case scenario. Double cantilever beam (DCB) tests were performed to investigate Mode I crack propagation and its interaction with the inserted z-pins. The mechanical results demonstrate consistent in-plane strength alongside a significant enhancement in delamination resistance. Micromechanical analyses confirm successful infiltration and bonding within the laser-drilled holes. The proposed hybrid laser–3D-printing approach minimizes manufacturing-induced defects, offers high automation potential, and provides design flexibility for next-generation damage-tolerant CFRP structures.

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# Toward a better understanding of the microdroplet debonding on elementary fiber

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Organic matrix composites exhibit high mechanical properties, particularly stiffness and strength, at a relatively low mass. One of the reasons explaining these good performances is the interface between the matrix and the fibre reinforcement, which governs stress transfer between the two components and contributes to the damage development within the material. Thus, to characterize this interface, multiple tests at the macro-scale can be performed. However, this type of test will depend on several manufacturing elements such as fibre orientation, fibre distribution, and porosity. Tests at the micro-scale on elementary fibres avoid the dependencies of those elements to focus on the behaviour of the interface. One of the elementary fibre tests that allows characterization of interface properties is the microdroplet debonding test.

This test has been extensively used in the literature to characterize multiple types of interfaces and even if conditions of experimentation are different, it has been experimentally shown that the results of the microdroplet test are linked to the properties of the composite at the macro-scale. Thus, to achieve a more accurate analysis of the debonding results and to better understand the initiation and the propagation of the crack during the test, analytical and simulation methods have been developed along with post-debond observations of droplets in literature.

Performing interrupted in-situ microdroplet debonding testing coupled with X-ray computed micro-tomography to directly observe the interface during loading provides three-dimensional geometry reconstructions. These reconstructions give insight of the debonding evolution at different stages of the test. The acquired 3D reconstructions can be compared with finite element simulations to evaluate the validity of modelling assumptions and to refine the numerical representation of interfacial fracture. This combined experimental–numerical strategy contributes to a more comprehensive understanding of crack initiation and propagation mechanisms in microdroplet debonding, ultimately enabling more accurate interface characterization for composite materials.

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# Mode II fracture toughness modified laminates: Damage development under out-of-plane loading and residual compressive strength

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High-performance polymer composites offer excellent stiffness-to-weight ratios, but their layered architecture makes them susceptible to delamination. Engineered interfaces with controlled toughness can therefore be useful not only for improving damage tolerance but also for tailoring where damage accumulates within a laminate. This study investigates the effect of intentionally reducing the mode II interfacial fracture toughness (GIIC) of glass/epoxy composite laminates on delamination development under quasi-static indentation (QSI) and the resulting residual compressive strength, determined by compression-after-indentation (CAI) testing. The GIIC of 4 mm thick, sixteen-ply symmetric quasi-isotropic S-glass/epoxy laminates were reduced by up to 50% by inserting laser-perforated PTFE release film pieces at the mid-plane. Two different interlaminar contact area ratios (39% and 25%) and shapes (full cover or discs with diameters of 40 and 49 mm) are used to assess the effect of modification severity and spatial extent on the interface properties. QSI loading was applied to introduce controlled delamination without causing catastrophic propagation, and damage progression was monitored in situ using a novel backlit optical imaging technique through the translucent laminate. All configurations exhibited substantial stiffness loss (25-40%) after indentation. Load-displacement curves were broadly similar across specimens, though more severe interfacial weakening produced slightly reduced loads at equivalent penetrations. Damage morphology varied notably with interface modification. Full-coverage inserts with mild modifications produced CAI responses similar to the baseline but failed earlier, whereas more severe modifications caused an earlier onset of nonlinearity and reduction in slope in the stress-strain response. Disk-shaped modification resulted in significantly reduced final failure strains and residual compressive strength values, but a more gradual structural response. Overall, the results demonstrate that precise reductions in interfacial toughness at targeted interfaces can significantly influence delamination patterns and post-damage compressive performance, offering a means to control damage evolution within composite laminates.

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# Controlling microstructures in slurry impregnated thermoplastic tapes

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Controlling the microstructure of unidirectional carbon fibre thermoplastic tapes for high-performance applications remains a major manufacturing challenge. The effect of variability across multiple length scales on mechanical performance is only partially understood. The Delft TapeLab has established an infrastructure to explore various manufacturing routes, including slurry-based, film, and melt impregnation, facilitating both process optimisation and fundamental studies of process–structure–property relationships. In this work, a pipeline is proposed to study the microstructure of tapes produced via slurry impregnation process.

In slurry impregnation, micron-sized polymer particles are suspended in water and transferred to spread fibre tows, where capillary-driven transport deposits particles in the interstitial spaces between fibres. The mechanisms controlling particle transport are however poorly understood. To investigate this, experiments were conducted with systematic variations in slurry properties, tow spreading-, and processing parameters.

To elucidate the mechanisms of microstructure formation in the aqueous transfer liquid, experiments were conducted to characterise fibre–carrier substrate interactions with the free surface of the transfer liquid by systematically varying the liquid's surface tension and viscosity. It was observed that reducing the water's surface tension (72.75 mN/m) up to 30% using up to 10 mol% amphiphilic molecules like ethanol, led to markedly different fibre interactions and tow spreading behaviour. These findings reveal underlying physical mechanisms that govern capillary effects and influence the resulting microstructure of the composite tapes. The variability and defects in the produced tapes and their resulting microstructure are captured using 2D microscopy and 3D imaging techniques, such as X-ray computed tomography to deconvolute the levels of organisation in the fibre architecture effects, such as differential tortuosity and porosity, as a function of processing and slurry parameters.

Overall, these studies illustrate how the advanced manufacturing and characterization capabilities of the Delft TapeLab accelerate the understanding and optimisation of unidirectional thermoplastic composite processing across different length scales.

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# A probabilistic machine learning approach for hydrogen permeation in polymer composites

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Reliable prediction of hydrogen permeation in fibre-reinforced polymer (FRP) composites is essential for designing safe and efficient infrastructure for the hydrogen economy. Yet, key material parameters such as in-situ matrix, fibre, or interphase (fibre sizing) permeabilities remain extremely challenging to determine experimentally and are subject to uncertainty.

This work proposes a probabilistic machine learning (ML) approach that fuses the Bayesian Inference framework with Gaussian Process (GP)-based surrogate modelling to infer these material parameters that govern hydrogen permeation in composite materials. A physics-based Finite Element model is used as the high-fidelity reference for the GP surrogate. In particular, the high-fidelity numerical model explicitly captures fibre orientation, polymer- and fibre-rich domains, and the interphase region, enabling microstructure-based description of mass transport. Experimental permeability data are used as a prior for the polymer matrix, while the overall composite test data serve as observations in the Bayesian inference. For interphase permeability priors, two physically motivated regimes are incorporated: (i) reduced molecular mobility near fibres, and (ii) micro-void–induced enhancement of local transport.

The simulation outputs and experimental data are integrated through the GP covariance structure, which enables efficient likelihood evaluation within the Bayesian inference framework. This physics-based probabilistic emulator naturally propagates model, data, and hyperparameter uncertainties throughout the inference process, allowing thousands of Markov Chain Monte Carlo (MCMC) evaluations at negligible computational cost.

The proposed probabilistic ML framework delivers well-identified posterior distributions for constituent permeabilities and interphase thickness, enabling a true uncertainty quantification of the overall composite hydrogen permeability. The framework is readily transferable beyond mass transport (e.g., hydrogen permeability in here), enabling solution of other multi-parameter inverse problems in data-driven composite material design.

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# Recovery of thermoplastic carbon fiber tapes from wound composite structures using a mechanical peeling process

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Composite pressure vessels are a lightweight option to store hydrogen for fuel cell electric vehicles. Continuous recovery of carbon-fiber reinforced tape material from these wound composite structures offers new end-of-use opportunities for discarded pressure vessels. In case of a composite material with a thermoplastic matrix, the tapes which are recovered in a continuous mechanical peeling process could theoretically be reused directly to manufacture second-life wound composite structures. Mechanical peeling is based on reversing the manufacturing process by unwinding the tapes which requires a separation at the layer interfaces without damaging the fibers.

During the mechanical peeling process, the formation of fiber bridging is a common phenomenon and challenge. While the effect of fibers which bridge between two crack surfaces is desired in the use phase of a composite in order to prevent delamination, it is detrimental for a peeling-based recovery process since the bridging fibers are eventually broken which reduces the mechanical performance of the recovered material.

In this work, the formation of fiber bridging and influencing factors are analyzed both experimentally with peeling experiments as well as with a simulation of fiber bundles at the interface of two tape layers during peeling. The goal in the context of recovery is to prevent fiber bridging by creating loading and environmental conditions like peeling velocity and process temperature which result in a mostly damage-free separation at the layer interfaces. It has been observed that fiber bridging leads to a crack propagation within a tape layer which can trigger even more fiber bridging. So, strategies for successful tape recovery are developed and experimentally validated for a carbon fiber/PA11 wound composite. These strategies are related both to the conditions during the peeling process as well as to the manufacturing conditions of the composite.

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# A Hybrid Manufacturing Approach for Lightweight Structures Combining MEX 3D Printing and Thermoforming of Thermoplastic Composites

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The specific tailoring of local material and structural properties to maximize performance while minimizing resource use remains a key challenge in lightweight design. Material extrusion-based additive manufacturing (MEX) offers high potential for producing geometrically complex components with minimal material consumption. However, the layer-wise nature of MEX limits mechanical performance, which can be mitigated through local reinforcement using thermoplastic pre-impregnated composites (organosheets). Recent studies have demonstrated the potential of hybrid additive manufacturing (AM) to enhance mechanical performance and design freedom while reducing material waste and manufacturing steps [1].

In this study, sandwich structures of polycarbonate polymers were fabricated via a hybrid-AM process combining MEX with diaphragm-assisted thermoforming of glass-fiber-reinforced organosheets as face layers. Process development included methods for assessing interfacial adhesion and processability across a wide parameter field. (1) Injection-molded plates were used for initial joining tests (2) adapted single-lap shear tests determined parameters yielding maximum shear strength (3) 3D-printed infill plates with varying geometry and density were investigated (4) specimens were characterized through density measurements and three-point bending tests to evaluate strength increase. The hybrid-AM process combines AM design freedom with local fiber reinforcement. Remaining challenges include improving interfacial bonding strength and geometric accuracy and integrity during diaphragm forming.

[1] Dilberoglu, U.M. et al. Current trends and research opportunities in hybrid additive manufacturing. Int J Adv Manuf Technol 113, 623–648 (2021). https://doi.org/10.1007/s00170-021-06688-1

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# Experimental investigations on structural health monitoring of maritime composite structures using embedded FBG and distributed fiber optic sensors

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The increasing importance of alternative, emission-free mobility solutions in the maritime sector is opening new opportunities for the use of fiber-reinforced polymers in structural applications such as ship hulls and stiffening elements. Lightweight materials such as carbon-fiber-reinforced plastics (CFRP) enable significant efficiency gains when applied with suitable design concepts and are essential for certain vessel and propulsion architectures. However, the use of these materials with still relatively limited application in shipbuilding introduces substantial challenges regarding the design, reliability, and operational safety of highly loaded structural components. In particular, manufacturing-induced effects can influence the fatigue behavior and long-term performance of such structures. Typical shipbuilding practices involving one-off constructions or small production batches further complicate the structural integrity assessment. For novel vessel concepts, such as hydrofoil-assisted hulls, considerable uncertainty exists regarding the loads that actually occur during operation. This creates a clear need for continuous structural health monitoring (SHM). The specific objective of this work is the integration of fiber-optic sensors for direct strain measurement within the laminate structure. To this end, embedded Fiber Bragg Grating (FBG) sensors and distributed fiber-optic sensors are integrated early in the composite manufacturing process for both process monitoring and in-service load monitoring. Experimental investigations at different testing levels, from coupons and subcomponents to scaled structural tests, were carried out using instrumented specimens. The work focuses on evaluating the reliability and performance of the embedded fiber-optic sensing system under various laminate configurations and loading conditions, including quasi-static and fatigue loading. In addition, the influence of the embedded sensors on the mechanical properties of the CFRP material was examined.

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# Combined resizing and binding process for recycled carbon fibre mats for improved composite properties

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Extracting carbon fibres from end-of-life composites is a potential business case for circular economy, as the price of virgin carbon fibres is relatively high and their production an energy intensive process. However, the fibres have limited length, which makes the reprocessing challenging. Therefore, an intermediate product, mat, could enable easy use of recycled carbon fibres (rCF) and accelerate their implementation in industry. However, thermoplastic binders typically used in mats can generate a compatibility issue with thermoset resins. Simultaneously, the extraction method, such as pyrolysis or solvolysis, removes or weakens the fibre surface treatment (sizing) reducing the mechanical performance of the second-generation composites. The sizing can be reapplied, but it introduces an additional process step increasing the costs of recycling. To mitigate these issues, a combined process to resize and produce a mat from pyrolyzed rCF was developed using the sizing in dual function: to act as coupling agent in between the fibre and the matrix, but also to bind the fibres together to form a mat with sufficient integrity. These mats were compared with mats with a thermoplastic binder as well as with mats without any sizing. The aerial weight, compressibility as well as the distribution of the sizing was analysed from the produced mats. The mats were impregnated with epoxy resin to test the permeability and to produce new composites. The impregnation quality, interlaminar shear strength (ILSS), and tensile properties were evaluated from the laminates. Based on the results, the ILSS of the mats produced with dual functioning sizing was better than for the mat without the sizing. However, the distribution of the sizing in the 320 g/m2 mat is not even and therefore the methods is seen as a potential manufacturing method especially for thin mats to be used in cases where mechanical performance plays a key role.

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# Effect of the ply angle on tack between uni-directional prepreg tapes

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Prepregs, combining fibrous reinforcement with partially cured (B-stage) thermosetting resin, are used in the manufacture of composite components employing automated material placement processes. In these processes, tack between the prepreg layers is essential for the integrity of the laminate and for the minimisation of defects, such as bridging and wrinkling. Prepreg tack is dominated by the viscoelastic response of the resin and depends strongly on temperature and deposition/peel rate. Its characterisation assists optimisation of process parameters for maximum deposition efficiency and quality of the product. ASTM D8336 recommends conducting tests at a range of temperatures and rates to create a tack master curve at a reference temperature, making use of time-temperature equivalence. Plotting tack as a function of the logarithm of the shifted rate results in a Gaussian curve which can be described in terms of maximum tack and the rate where the maximum occurs.

In previous work, tack between plies of uni-directional prepreg was found to increase as the inter-ply angle increased from 0° (parallel fibre orientations) to 90° (perpendicular orientations). However, data were obtained only at one combination of test temperature and deposition/peel rate. Here, tack was measured at a range of temperatures and rates, and tack master curves were created at ply angles between 0° and 90°. Maximum tack in the master curves increases with increasing ply angle, particularly between 45° and 90°. At a given reference temperature, the ply angle affects tack at low rates, where tack is dominated by cohesive failure. In this range, there is still adhesion between the layers while the bottom layer disintegrates in cohesive failure, suggesting that the actual adhesion between layers is stronger than the measured apparent tack. As laminates are typically based on ply angles of 0°, 45°, 90°, this angle-dependence may have practical implications in material placement processes.

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# Bird-Strike and Fan Blade Off compression type failures in Composite Fan Blades

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The use of composite materials in aircraft engine applications is well established, and increasing, where their characteristics (for example: high specific strength, high specific stiffness, low thermal expansion) can provide a significant design advantage; in particular, these attributes can be made the most of in the design of fan blades.

Nevertheless, there are challenges associated with the use of composites for fan blades, with Bird-Strike and Fan Blade Off performances being amongst the most challenging ones to manage.

Therefore, the successful use of composites for fan blades must balance all of these considerations.

Rolls-Royce has been developing a new engine architecture, namely UltraFan®, which uses laminated Carbon fibre fan blades, manufactured by AFP, with Titanium leading edge reinforcement.

Compression loading areas of interest for fan blades:

Fan blade crushing during Fan Blade Off

When a fan blade is released during a fan blade off event, it will progressively crush onto the surrounding containment casing.

The casing must be sized to resist the resulting loads, so a good understanding of the factors that influence the progressive crush behaviour of composites blades is advantageous for efficient engine design.

The paper will discuss the main challenges in understanding and modelling the influence of failure modes (i.e. through-thickness compression, delamination) to the compressive failure, when this happens at high strain-rate.

Bird-Strike induced compression damage

When a fan blade is impacted by a bird, the significant rotation speed of the blades means that the associated energies are large, ~20KJ, inducing large bending deflections and potential for compression damage in the blade.

The topic will present typical examples of compression damage in composite fan blades due to bird strike and discuss the associated challenges and practicalities of modelling such damage.

#461

# 3D printed multi-functional microstructures for vitrimer-based composite bonded joints

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The wind energy sector is striving to become the leading source of renewable energy in Europe by 2030. However, a major challenge remains: most wind blades have a lifespan of 25 years and lack

clear end-of-life management, resulting in their disposal in landfills.

Wind blades are mostly made of adhesively bonded composite materials. While these joints provide excellent structural performance, their permanent, non-reversible nature prevents effective disassembly or recycling, thereby limiting circularity in the wind energy chain. To address this, innovative material design is essential for the next generation of wind blades, particularly solutions enabling controlled dismantling and reprocessing.

A promising route lies in the use of vitrimers, a new class of polymers that combine the mechanical strength of thermosets with the reprocessability of thermoplastics. Their dynamic covalent networks enable bond-exchange reactions above a specific activation temperature (the vitrimization temperature), making them debondable under thermal stimulus. The use of these polymers as structural adhesives is still barely explored.

This study aims to evaluate the performance of vitrimers embedded in 3D-printed structures as structural adhesives for composite joints. The 3D-printed structure serves as a multi-functional mesh to increase the fracture energy and self-sensing capabilities of the vitrimer-based bonded joints during quasi-static mode I loading tests. Digital Image Correlation is used to monitor crack propagation and to aid in the joint's fracture energy determination.

#463

# Bio-based lignocellulose composite with enhanced multifunctionality

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The transition to sustainable materials is accelerating innovation in lignocellulose-based composites, with cellulose emerging as a key biopolymer for multifunctional, circular-economy materials. Recent advances integrate cellulose–hemicellulose–lignin systems into bioplastics with improved thermal, tensile, and thermomechanical performance through targeted chemical modification. Nanocellulose from hemp and birch enables wood-like papers, films, and foams, while controlled ratios of xylan, lignin, nanocellulose, citric-acid crosslinkers, and dicumyl-peroxide initiators allow precise tuning of structure, functionality, and biodegradation. The resulting bio-foams span a broad stiffness range suitable for thermal and structural uses. Together, these developments demonstrate how green chemistry and component design can deliver advanced, multifunctional lignocellulosic composites for sustainable applications.

#464

# Green Proprioceptive Material Systems for Next-Generation Soft Robotics

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Global megatrends, including population growth, aging, urbanization, climate change, digitalization, and heightened connectivity, are creating an urgent demand for robotic systems that can safely co-exist and interact with humans and their environment. Yet current robotic technologies remain limited in reliability, adaptability, safe human–robot interaction, and sustainable material use. In particular, reliance on non-recyclable and toxic components hampers circularity and contributes to environmental impact. This work aims to advance the next generation of green, functional material systems by integrating material development, morphology-informed design, and advanced additive manufacturing. We focus on creating sustainable actuation and sensing materials that co-evolve with soft robotic architectures to enable nature-inspired functionalities. Specifically, the project targets the development of 3D-printable, low-voltage proprioceptive materials and structures that can be seamlessly embedded into soft robotic platforms. The overarching goal is to enable environmentally benign, multifunctional soft robots capable of safe, adaptive performance in real-world settings.

#466

# Understanding Compressive Instability Mechanisms in High-Modulus Carbon Fibre Systems

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Composites are widely used in high-performance structures. Composites are made from different constituents (fibre, resin). The aerospace sector mainly relies on intermediate-modulus (IM, ~290 GPa) carbon fibres, while the sports and leisure industries increasingly use high-modulus (HM, ~400 GPa) and ultra-high-modulus (UHM, ~460 GPa) fibres to achieve higher stiffness. All these carbon fibres consistently exhibit lower compressive strength than tensile strength, making compressive failure of the unidirectional composite ply a critical and complex aspect of their performance.

Compressive failure is generally attributed to fibre micro-buckling constrained by the resin matrix. This mechanism has been analytically described in prior studies. Increased resin stiffness has been shown to improve fibre stability. Research on nano-filled resin systems demonstrated enhanced resin stiffness and significant gains in compressive strength for IM composites, while HM composites showed minimal improvement. The evolution of compressive performance in IM materials has been extensively analysed through comparisons of multiple fibre/resin systems using four-point bending tests. Experimental results for IM systems have shown strong agreement with analytical predictions incorporating micro-buckling, shear behaviour, and fibre misalignment.

The present study extends this approach to HM materials, evaluating more than fifteen HM fibre/resin combinations. Unlike IM systems, HM composites display substantial discrepancies between experimental results and micro-buckling predictions. These differences suggest that their compressive failure may follow an alternative mechanism, potentially governed by premature fibre fracture rather than classical micro-buckling, as previously hinted in studies on nano-filled resins.

To investigate this hypothesis, an analytical model capable of computing fibre stress distributions is applied. The combined analysis of fibre type, resin behaviour, and failure response provides insights into the evolution of failure mechanisms in high-stiffness composites. The study concludes with perspectives on material design strategies aimed at improving compressive strength in HM and UHM carbon fibre systems.

#467

# Assessing the impact of fiber angle deviations and gaps on the structural performance of variable stiffness laminates

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Over the past decade, automated fiber placement (AFP) has enabled continuous variation in fiber orientation, leading to variable-stiffness laminates (VSL) with improved strength and buckling performance compared to constant-stiffness designs. Despite these advantages, AFP introduces two imperfections during the design process. First, when converting a discrete fiber angle distribution into continuous manufacturable paths, fiber angle deviations arise due to manufacturing constraints. Second, gaps appear between adjacent tows.

Although methods exist to quantify the structural impact of gaps, they are computationally expensive. In contrast, the influence of fiber angle deviations has not been investigated. This work introduces a numerical framework that efficiently evaluates the effects of gaps and quantifies the impact of fiber angle deviations, yielding a realistic representation of AFP-induced imperfections.

Fiber angle deviations are evaluated by generating the AFP head path, reconstructing the tows as B-splines, and extracting angles from the tow edges using a projection–interpolation procedure. Based on the reconstructed geometry, gap locations and sizes are identified and translated into element-wise elastic properties using the defect layer method. These imperfections are introduced independently and jointly into a finite element analysis assessing compliance and the reciprocals of the first two buckling modes.

Applied to a linearly varying fiber-angle ply, the method shows that fiber-angle deviations have a minor effect, shifting compliance and buckling responses by less than 1–2%. Gaps, however, cause notable performance losses, raising compliance by up to 5% and increasing reciprocals of the first two buckling modes by more than 15%.

The full paper will extend this analysis to additional fiber-angle configurations and multi-ply laminates to examine whether defect effects accumulate across plies. It will also evaluate design strategies aimed at mitigating the sensitivity of VSL designs to AFP-induced imperfections.

#468

# A strongly coupled thermo-mechanical model for the simulations of thermoplastic composites fast processing

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Long curing times using energy-intensive process devices, coupled with an inability to reprocess the resin, are gradually making thermoset-based composites less competitive. Thermoplastic resins, on the other hand, can be remelted and annealed at the end of a part's service life, making repairs, remanufacturing and recycling, in theory, possible. However, obtaining autoclave-level mechanical properties in any thermoplastic composite manufacturing process is not without challenges and often involves a large amount of costly and long physical trials. Good part quality relies on the adequate setting of a number of manufacturing parameters (e.g., temperature, pressure, pressure rate) that each interact with each other and that, if inadequately set, can lead to excessive voidage, poor consolidation, significant part distortion leading to assembly difficulties etc. There is, therefore, a need for numerical tools able to help optimization of process parameters and speed up process development. In this study, we propose a virtual platform that couples crystallization kinetics and consolidation models, thus allowing to assess the level of crystallization and the resulting compaction behavior of the material. Unlike traditional weakly-coupled simulations, we have developed a strongly coupled implementation that allows to best account for the reciprocal effect on each other of the thermo-chemico-mechanical phenomena at play, which simplifies the workflow. The model's predictive capabilities are validated against experimental measurements on carbon fibre reinforced PA6 processed under different cycles of temperature and pressure.

#469

# Influence of Spray Distance on Vacuum Plasma Sprayed HfC Coatings for C/C Composite protection

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Carbon fiber-reinforced carbon (C/C) composites are widely employed in the aerospace and advanced thermal protection industries due to their superior specific strength and thermal shock resistance. However, their application is significantly restricted by rapid oxidation in aerobic environments exceeding 400 °C. To mitigate this degradation, surface protection using heat-resistant materials such as ultra-high temperature ceramics (UHTCs) is required. Among UHTCs, hafnium carbide (HfC), possessing the highest melting point (3,958 °C) and excellent thermomechanical properties, is a leading candidate for such extreme environments. This study investigates the fabrication of HfC-based protective coating on C/C composites using vacuum plasma spray (VPS) process. The VPS technique was selected for its ability to melt and accelerate ceramic powders in a controlled low-oxygen environment, thereby preventing oxidation of the feedstock material during deposition. We specifically examined the correlation between spray distance and the resultant coating properties, including microstructure and adhesion quality. Experimental results demonstrated that the coating thickness varied between approximately 70 and 150 μm depending on the spray distance. As the spray distance decreases, the thermal and kinetic energy losses of the particles are reduced, and the particle deposition rate increases, resulting in the formation of a thicker coating. However, this closer proximity also generated higher thermal gradients along the thickness direction, leading to increased microcrack formation within the coating layer and reduced interfacial bonding strength with the base material. Overall, the findings highlight that although shorter spray distances improve deposition efficiency, optimizing the spray distance is essential to minimize defect formation and ensure the structural integrity of HfC-based protective coating systems for C/C composites.

#470

# Fabrication of piezoelectric particle-dispersed polymer composites and their application to microfluidic devices

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Microfluidic devices enable analysis and testing using ultra-micro samples in medical, chemical, and environmental fields, finding applications in blood tests and DNA analysis. Over the past 20 years, active research has been conducted across the spectrum from fundamental studies to applied research and product development. Key functions required for microfluidic devices include liquid delivery and mixing. Generally, microfluidic devices employing microchannels fabricated from the silicon elastomer polydimethylsiloxane (PDMS), with piezoelectric ceramics integrated as actuators, are widely utilized. However, in microfluidic devices without actuator assembly, the complexity of the geometry poses a problem, while in microfluidic devices with actuator assembly, the need for retrofitting the actuator is cited as an issue. Meanwhile, piezoelectric materials are broadly categorized into inorganic materials, organic materials, and composite materials combining these. Among inorganic materials, perovskite oxides of the $ABO_3$ type exhibit superior piezoelectric performance, but they are inherently hard and brittle. In recent years, the rapid advancement of flexible and wearable electronics has drawn attention to organic piezoelectric polymers and composite piezoelectric materials consisting of inorganic ceramics embedded in polymer matrices. Therefore, this study focused on piezoelectric mixers to verify the utility of novel microfluidic devices that eliminate the need for piezoelectric actuator assembly. This paper proposes a microfluidic device employing PDMS, widely used in microfluidics, housed within a polymer composite containing dispersed piezoelectric ceramic particles. First, the physical properties of the piezoelectric ceramic particle-dispersed polymer composite material were elucidated through multiscale finite element analysis as well as through fabrication and experimental characterization of the composite itself. Next, the obtained physical properties were incorporated into the microfluidic device housing, and the mixing performance was evaluated through piezoelectric fluid coupled analysis.

#471

# Biopolymer-Graphene Composite Ink for Sustainable Printed Electronics

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The evolution in the field of Internet of Things has expanded the use of electronic products in various sectors like healthcare, environmental monitoring, and sensing applications, developing flexible and wearable devices. Despite their advantages, the extensive use of these electronic products can pose serious environmental concerns as they end up as a key contributor to E-waste. In view of this, the need for alternative to traditional electronics has led to the exploration of various composite materials incorporating metals, polymers and carbon-based fillers for the development of functional inks suitable for printed electronics. In this context, sodium alginate biopolymer was combined with graphene nanoplatelets with the aim of formulating aqueous based environmentally friendly nanocomposite ink suitable for screen printing on paper board substrate. The water-soluble biopolymer was used due to its film-forming ability and biodegradability factor. The incorporation of graphene nanoplatelets as conductive filler enabled to improve the conductivity of nanocomposite ink as well as the mechanical stability of the films, which is a crucial factor for wearable devices.

Initially, the influence of biopolymer concentration on printability and electrical conductivity was investigated. In the second step, the ratio of biopolymer medium to graphene was systematically varied in the formulation. The best result was obtained when graphene concentration was maintained at 80 wt% for 10 layers of print with conductivity values reaching 184 S/m. The XRD and FE-SEM studies were carried out to investigate the structural and morphological features of the printed samples which confirm uniform composition and strong interactions. These findings emphasize the potential application of biopolymer-graphene nanocomposite ink for biodegradable electronic applications.

#472

# Multiscale simulation of polymer composites reinforced with cellulose nanocrystal-filled filaments and sheets

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Cellulose nanocrystal (CNC)-reinforced thermoplastic composites derived from plant biomass have attracted considerable attention as environmentally conscious materials. In this study, we aimed to clarify the upper limit of mechanical property enhancement achievable through fiber orientation control. To this end, we focused on an idealized unidirectional orientation model and evaluated its nonlinear mechanical behavior using a multiscale finite element analysis based on homogenization theory. CNC/polylactic acid (PLA) composites, in which biodegradable PLA was used as the matrix, were taken as a representative example.

We first investigated how the fundamental properties of CNC/PLA composites change with CNC content. The analysis revealed that the maximum stress increases linearly when CNCs behave as continuous fibers, whereas it increases nonlinearly when CNCs are modeled as short fibers. Based on these findings, we then developed a PLA composite model filled with unidirectionally aligned CNC filaments and evaluated its mechanical performance. When CNCs were treated as short fibers and oriented in one direction, the tensile strength increased by 39.6% in the simplified model and by 76.8% in the 3D-printed structural model.

To verify the validity of the numerical results, experimental tests were conducted using CNC-filled sheets. For ease of processing, polyvinyl acetate (PVAc) was employed as the matrix in this part of the study. However, because the purpose of the experiment was solely to confirm the reinforcing effect of CNC incorporation, the use of a different matrix material did not affect the objective. The experimental results demonstrated the same strengthening tendency, confirming that CNC incorporation contributes to the improvement of mechanical properties.

#473

# Quantifying the roles of interfacial fracture toughness and dispersion in strength degradation of graphene/CNT nanocomposites via phase-field/cohesive modeling

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Experimental studies on graphene/CNT nanocomposites consistently report a non-monotonic strength response: the composite strengthens with increasing filler content, reaches a peak at a critical loading, and then weakens. Classical homogenization approaches, such as rule-of-mixtures-based modeling, cannot reproduce this behavior because they inherently predict monotonic improvement. This discrepancy highlights a missing link in understanding the microscale failure mechanisms responsible for strength degradation.

To address this gap, we develop a microscale finite element framework that integrates phase-field fracture for matrix cracking with a cohesive zone model for filler–matrix debonding. The representative volume element consists of an epoxy matrix containing graphene/CNT fillers. Van der Waals driven agglomeration is modeled by constraining subsets of fillers to occupy restricted subdomains, while microvoids and microcracks inside the composite are idealized as a single initial crack. The dispersion state is quantified using nearest-neighbor distance (NND) statistics, providing a microstructural basis for evaluating how clustering influences the composite strength.

Parametric studies varying filler wt%, dispersion uniformity, and interfacial fracture toughness (Gc) show that the proposed model quantitatively reproduces the characteristic rise–peak–drop trend. The simulations reveal that well-dispersed fillers improve load transfer, whereas clustered fillers generate stress concentrations, promote interfacial debonding, and accelerate crack propagation. Increasing interfacial toughness or enhancing dispersion shifts the critical content to higher values, offering a mechanistic explanation for why nanocomposite performance is highly sensitive to interface design.

A key contribution of this work is its inverse capability. While matrix and filler properties are well established, interfacial toughness is challenging to measure directly. By matching simulated strength–vs.–wt% curves to experiments, the model enables estimation of effective interfacial Gc from strength trends. Overall, the proposed framework clarifies the microscale origins of strength degradation in graphene/CNT nanocomposites and provides a physics-based tool for guiding interfacial optimization and dispersion control.

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# Effect of silane coupling agent on the strength of aluminum bonded with urethane resin

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In recent years, multimaterial technology has witnessed significant and rapid development to meet the growing industrial demand for high-efficiency lightweight structures. Particularly in fields such as automotive manufacturing, aerospace, and medical equipment, advanced lightweight design not only enhances product performance but also significantly reduces overall environmental impact. However, in practical applications, ensuring robust and durable interfacial adhesion between dissimilar materials presents a major challenge due to substantial differences in their intrinsic physical and chemical properties. This issue is particularly pronounced in metal–polymer systems, where enhancing interfacial strength and long-term stability has become a critical research focus for next-generation multimaterial development.

This study systematically investigates the complex interfacial adhesion mechanisms and the enhancement effects of silane coupling agents (SCA) through an integrated approach that combines empirical experiments and theoretical simulations. In the experimental part, polyurethane (PU), known for its excellent recyclability, was used as the polymer matrix, while aluminum served as the metal substrate. The SCA was applied to act as a critical molecular bridge to significantly improve the adhesion strength between organic and inorganic materials. The interfacial adhesion performance was quantitatively evaluated through standardized tensile shear tests.

Building on the experimental results, a detailed mechanistic analysis was conducted using state-of-the-art first-principles calculations based on Density Functional Theory (DFT). Local atomic models representing aluminum, PU, and SCA were constructed to analyze the electronic structure and bonding interactions. This atomistic investigation elucidated the microscopic stress-transfer mechanisms and identified the key factors governing adhesion enhancement, providing valuable theoretical guidance for the design and optimization of future multimaterial systems.

#475

# Understanding premature compressive failure in high-modulus PAN-based carbon fibre composites: assessing the compressive behaviour of carbon fibres by nano-indentation and micro-pillar compression.

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The compressive failure of continuous carbon-fibre composites is often a key design parameter in high-performance structural applications. In most cases, failure occurs through a shear instability that leads to catastrophic, sudden and violent collapse. Confrontations between analytical or numerical modelling and experimental observations have identified two dominant contributors to this mechanism: fibre waviness induced during manufacturing and the in-plane shear behaviour of the composite ply.

Yet, in some situations—such as those involving brittle matrices, weak fibre/matrix interfaces, or certain fibre grades—the classical shear instability may not fully develop, and premature failure can occur. This work focuses on this third scenario. Such premature failure is inferred from significant discrepancies between models and experiments for high-modulus carbon fibres, highlighting the need to investigate the intrinsic compressive behaviour of the fibres themselves.

This study examines the compressive response of several grades of poly-acrylonitrile (PAN)-based carbon fibres (SM, IM, HM, UHM) through a combined experimental and micromechanical approach. High-spatial-resolution nano-indentation (≈50 nm) is used to characterise local stiffness and hardness variations along and across fibres of approximately 6 µm in diameter. Particular attention is given to the presence or absence of radial heterogeneity—specifically the possible existence of a core–shell structure. Complementary compression tests are performed on Focused Ion Beam (FIB)-machined micro-pillars extracted from precise locations within individual fibres, yielding compressive strength, compressive modulus, and nonlinear elasticity metrics.

The results are finally discussed in relation to experimental observations on corresponding composite laminates, as well as to analytical and numerical estimates of compressive strength.

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# Longitudinal tensile strength characterisation using NOL test: definition of an explicit expression based on experimental and numerical approaches

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Designing composite structures, such as hydrogen storage tanks, requires in-depth characterisation of the material's mechanical properties, including the manufacturing process influences, to ensure system reliability. Standard tests using flat coupons are not adapted to characterise filament-wound composites. Therefore, testing sub-structures manufactured by the same process is necessary to determine accurate material properties. However, interpreting these test results is challenging due to the complex loading of the substructure.

This work investigates the NOL test, or split-disk test, involving circumferential tensile loading of a ring. The tensile strength measured experimentally using the NOL test is an apparent strength significantly lower than the fibre tensile strength obtained through flat coupon testing. Finite element post-processing is required to determine the fibre tensile strength accurately. Our aim is to define a simple post-processing method for the NOL test that considers the contribution of ring geometries, material and test parameters.

A parametrised finite element 2D model was developed to automatically test a wide range of parameters and post-process the results (stresses, strains and load). It highlights the concentration of stresses (longitudinal and interlaminar shear) between the split disks, despite the absence of notches, due to the induced bending moment. A reduced experimental plan was conducted to validate the numerical results and extend the analysis to unsupported parameters, such as loading speed. Rings are instrumented with three strain gages, two located between the split disk, and submitted to both bending and traction, and one moved from 15° to significantly reduce bending part. The comparison of load-strain curves between experimental and FE analysis showed a satisfactory level of correlation. Finally, a machine learning-based model, trained on numerical data generated by the FE analysis, is developed to establish an explicit relation between the stress in the fibre direction and the NOL test variables, with a quantification of the error.

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# Performance-Preserving De-Joining of Overmolded Sections from Organosheets using Ferro-Magnetic Particles and Induction Heating

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Thermoplastic fiber-reinforced composites (TP-FRPs) provide advantages over thermoset composite systems, like the melt-processable matrix which enables the formation of cohesive welded joints without the use of adhesives and simplifies recycling. Also, it offers various possibilities for process hybridization. An efficient process chain for lightweight structures is thermoplastic overmolding, in which continuous fiber-reinforced organosheets are combined with short fiber-reinforced thermoplastics in an injection molding step. This approach merges the high specific stiffness and strength of the laminates with the geometric freedom of injection molding, enabling the integration of rib reinforcements and additional functional elements in a single manufacturing step. The result is a highly stiff, function-integrated hybrid structure with minimized assembly effort. However, with regards to recycling, hybrid components add complexity, as a joint recycling fails to account for the different performance potentials of the materials involved. This could be solved if the overmolding could be reversed, in the sense of a de-joining.

This study presents a reversible interface between the organosheet and the overmolded structures, which is based on a localized induction heating. Localized heating is reached by embedding $Fe_3O_4$ particles in the injection molding compound, which serves as localized heat sources when exposed to a high-frequency alternating magnetic field. Due to their ferrimagnetic behavior and limited penetration depth of the magnetic field, heat is generated selectively within the joining zone. This allows the thermoplastic matrix at the interface to be selectively melted without thermally degrading the surrounding continuous fiber laminate. After heating, the hybrid structure can be mechanically separated while maintaining the structural integrity of the organosheet.

To validate the concept, glass fiber-reinforced Elium composites were overmolded using a short-glass-fiber-filled PMMA compound containing varying weight fractions (05 wt% up to 25 wt%) of $Fe_3O_4$. Mechanical characterization and induction-based separation experiments were conducted to assess joint performance and disassembly capability.

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# Bonding and debonding with novel synthesized high Tg epoxy disulfide vitrimer adhesives for aerospace composite applications

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For structural aerospace components, composite materials have significant lightweight potential. Both polymeric composite matrix types, thermosets (TS) and thermoplastics (TP), offer distinct advantages and drawbacks. Although TP count to be recyclable, they require much higher temperatures (>350 °C) for processing. This increases cost and $CO_2$ emission in production significantly. TS are hardly recyclable but processable at 180 °C which makes them to date efficient for structural parts. When it comes to joining of such components, especially composites are subject to stringent certification rules. These technologies require redundancy, which is not the lightweight optimum. In this context, epoxy-based vitrimers were investigated as potential replacements for certain state-of-the-art technologies, owing to undergo molecular cleavage in response to external stimuli such as heat or media. This study focused on the development and investigation of disulfide-based vitrimer formulations, which were analyzed through physico-chemical and mechanical methods. Bis(glycidylphenyl)disulfide (BGPDS) was synthesized with a 85% yield and washed to a 99% purity to replace standard epoxy. For the first time, Bis(Glycidylnaphthyl)disulfide (BGNDS) was synthesized with and characterized as a high Tg vitrimer epoxy, which balances the loss of thermal stability found typically in disulfide vitrimers in literature. The yield achieved was 76% which was elevated to 99% purity after washing with NaOH. The naphthyl group, consisting of two phenyl groups is found in some speciality polymers and brings major thermal and mechanical rigidity into the crosslinked thermoset. Finally, these covalent adaptable network (CAN)-based resins were optimized for use as an adhesive by incorporating typical additives. Mechanical properties, including lap-shear strength, were assessed, demonstrating the rebondability of the novel tailored debondable high Tg aerospace adhesive after debonding, with an equal level of peel-off and lap shear strength.

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# Recycling of Glass Fibres through Supercritical Solvolysis: Kinetics analysis and characterization

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As wind turbine blades (WTBs) reach the end of their service life, the need for sustainable disposal methods becomes critical. Conventional disposal methods, such as landfilling and incineration, pose environmental and health risks, while thermal recycling decreases the mechanical properties of the fibres, and mechanical recycling fails to preserve fibre quality. This research investigates the chemical recycling of GFRPs through solvolysis using Super-critical Acetone (SCA) and Water (SCW) to recover glass fibres. Experiments were conducted at temperatures ranging from 300 °C to 375 °C, with an established amount of composite and solvent . Different reaction times were tested to study the influence of time on resin degradation. Characterization of the recovered fibres was performed using SEM and EDX to evaluate resin removal and fibre condition. The results demonstrated that SCA is highly effective for resin degradation, achieving up to 97.92 wt.% resin removal at 350 °C after 180 min, with clean, undamaged fibres. SCW also achieved high degradation efficiency (94.95 wt.% at 375 °C), but SEM/EDX revealed fibre degradation and breakage, highlighting SCW's harsher conditions and glass fibre sensitivity to high temperatures. Kinetic analysis revealed that most degradation occurred during the isothermal phase for SCA, while SCW showed steady degradation beginning during the heating phase. Upscaling trials confirmed that both solvents are applicable at larger scales, although challenges such as reduced heat transfer efficiency and longer heating times affected process performance. The recovered GFs were subsequently used as a reinforcement in mortar. Mechanical testing, including compressive strength and flexural strength, revealed up to 20 percent higher values compared with the reference mortar, with these improvements confirmed through $R^3$ tests. Ultrasonic pulse velocity measurements were also carried out to evaluate yield stress, green strength, and stiffening kinetics, providing additional insight into the early age development of the fibre reinforced mortars.

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# Understanding how fibre hybridisation changes FRP compressive failure behaviour via computational modelling.

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Intermittency in composite architecture has been shown throughout the literature to be beneficial in enhancing composite failure performance. This is due to the introduction of new or more complex failure micromechanisms, which may diffuse or delay damage (both initiation and propagation), and in turn improve composite performance metrics such as strength or fracture toughness. As commonly found in natural composites such as bone, the benefits of microstructural intermittency could also be compounded if applied hierarchically.

Microstructural intermittency in fibre-reinforced polymer (FRP) composites can be introduced through two primary approaches: (i) matrix modification, such as introducing locally tougher or stronger matrix regions, and (ii) fibre hybridisation. Such deliberate intermittency is typically implemented at length scales exceeding the intrinsic fibre-scale of the baseline FRP microstructure, such as at the ply scale.

For Carbon-FRPs, fibre hybridisation with both stiffer and softer fibres have shown potential to improve compressive performance. Boron-Carbon FRPs have been shown to induce damage deflection mechanisms that in turn promote increased damage diffusion and tolerance; Glass-Carbon FRPs have been shown to exhibit pseudo-ductile behaviour, allowing significant improvements in performance metrics such as failure strain over pure Carbon-FRPs.

In this work, fibre hybridisation and its role in enhancing composite performance is explored through computational micromechanical modelling, with the aim of understanding the underlying mechanisms driving the changes in FRP failure behaviour, which have already been observed experimentally. Comparisons will be made between the hybridised FRP and baseline (i.e. non-hybridised) FRP failure behaviour, including analysis of the failure mechanisms involved and changes in global stress-strain behaviour.

Improved fundamental understanding of fibre hybridisation-induced changes in FRP failure behaviour will support systematic application-based design and optimization of hybrid systems for targeted failure modes.

#482

# Cryogenic cycling effects on the gas permeability of CF/LM-PAEK

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Green hydrogen is regarded as a key enabler for the decarbonization of the aviation sector, but the onboard storage of hydrogen remains an engineering challenge, especially with regard to storage density but also to distribution and conditioning. Besides liquid hydrogen, cryo-compressed hydrogen (CcH2) is another, less-considered option that offers high storage densities combined with further potential operational benefits in refueling, dormancy, and hydrogen conditioning. However, it comes with challenges in the storage vessel design, since CcH2 is stored at high pressure and under varying cryogenic temperatures.

Despite these mechanical and thermal cycles, a CcH2 pressure vessel must retain low permeability to preserve its insulating vacuum, which puts high demands on composite materials for future linerless vessels. Especially transverse cracks that may accumulate during repeated cooling and pressurization cycles are of critical concern, since they significantly increase permeability if a through-thickness crack network is formed. The resistance of a laminate to transverse cracking is therefore a central requirement for its application in linerless vessel designs.

Carbon fiber reinforced LM-PAEK emerges as a suitable candidate for such high-performance structures due to its tough matrix and therefore great mechanical performance in low temperature environments. To assess its suitability for linerless CcH2 storage, we examine the helium permeability under high pressure conditions of both mechanically damaged and pristine CF/LM-PAEK cross-ply laminates before and after cryogenic cycling. X-ray transmission imaging is used to identify damage patterns, resulting from mechanical and/or thermal loading, that may contribute to increased gas permeation. In addition, an experimental approach for measuring permeability under varying cryogenic temperatures is introduced, providing a framework for material characterization under realistic hydrogen storage conditions.

#485

# Hybrid Reinforcement Structures for Optimised Ballistic Performance

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Hybrid reinforcement composites represent a promising strategy to enhance the impact and ballistic resistance of structural systems for defence applications, while simultaneously enabling significant weight reduction compared to metallic solutions. This work develops a hybrid composite architecture combining different high-performance fibres within the same textile reinforcement and through a tailored stacking sequence to maximise impact and ballistic resistance, according to different protection levels.

To address the complex phenomena involved in ballistic impact, hybrid reinforcement strategies are designed to combine fibres such, high-modulus and low-elongation (typically associated to the impact mechanisms in the initial interaction with the projectile) combined with low-modulus, high-elongation fibres (such as ultra-high-molecular-weight polyethylene or aramid) which enhance energy absorption through large deformation and high toughness. In this work, fibre combinations are integrated both within the same textile structure and across selected composite layers to maximise impact resistance.

Based on this hybridisation approach, multilayered composite laminates with tailored fibre distribution, orientation and stacking sequence are manufactured through processes such as compression moulding and autoclave curing. A systematic experimental programme is carried out to evaluate the influence of key design parameters on the impact performance of the developed solutions. This includes mechanical characterisation, low-velocity impact tests to analyse energy absorption mechanisms in the initial design stages, followed by high-velocity ballistic testing to evaluate the overall protective performance in accordance with relevant standards.

The proposed hybrid textile-reinforced composites are expected to achieve a favourable balance between ballistic protection and structural efficiency, enabling high energy dissipation and absorption with reduced areal density, a key requirement in defence systems where high protection must be achieved with reduced structural mass. The ongoing work will provide quantitative correlations between fibre hybridisation strategy, laminate architecture and impact performance, supported by standardized mechanical and ballistic testing.

#487

# Enhanced Resistance Welding of Thermoset Composites via Preconsolidated Heating Elements

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Resistance welding is a promising novel approach for joining thermoset composites as it delivers high productivity across preparation, assembly, moulding, processing, production and repair. The heating element (HE), acting as the conductive component, is the key to convert electrical energy into heat to melt the adhesive at the interface and form the joint. However, variability in HE manufacture, whether preconsolidated or non-preconsolidated, leaves the links between process settings, thermal behaviour and mechanical performance remain insufficiently defined.

This work advances resistance welded composite joints by applying preconsolidated HEs and non-preconsolidated HEs for benchmarking to compare their mechanical behaviour and thermal performance. HEs are preconsolidated by hot pressing with different settings of temperature, time and pressure. Mechanical performance is evaluated using Climbing Drum Peel (CDP) test, with Non-destructive testing (NDT) and Taguchi method adopted to further study the influence of preconsolidation parameters and determine the optimal setting that maximises performance. CDP results confirm the benefit of preconsolidation in increasing peel strength for joints, consistent with improved resin impregnation and a smoother bonding surface. To evaluate the thermal performance of the different elements, a custom rig is developed to map spatial distribution via Infrared (IR) thermography and quantify temperature evolution along the width and length of HEs. Two heating stages are designed to simulate the thermal history during welding. Thermal results of both HEs show a stable gradient thanks for transverse conductive paths distributing current and heat to from the center toward edges. Preconsolidate HEs show a nonlinear heating temperature rise over time and lower spatial temperature variation, thus advance joint resistance to peel loading.

The results establish a direct link from process settings to thermal behaviour to joint performance and provide guidance for scalable manufacturing of stronger, more reliable resistance welded composite joints.

#488

# Modeling the CO2 Mitigation Potential of Bio-Based and Recycled Composite Materials

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Modeling the CO2 Mitigation Potential of Bio-Based and Recycled Composite Materials

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Keywords: Life Cycle Assessment (LCA); Bio-based Composite Materials; Bio-based Resins; Natural and Recycled Fibers; Sustainable Manufacturing; Transportation Sector;

The increasing adoption of composite materials in the transportation sector presents significant opportunities to enhance sustainability across the entire product life cycle. This study performs a comprehensive Life Cycle Assessment (LCA) of innovative composite demonstrators manufactured using state-of-the-art bio-based resins and natural and recycled fibers, covering impacts from raw material production to end-of-life treatment. Particular focus is given to the substitution of conventional fossil-based materials with bio-based and recycled alternatives, as well as the evaluation of one-shot manufacturing processes for their potential to reduce energy demand and material waste. A comparative Life Cycle Assessment (LCA) is conducted to evaluate conventional composite systems against bio-based and recycled alternatives, following internationally recognized and standardized LCA methodologies. The results indicate substantial environmental benefits, with preliminary analyses showing CO2 –emission reductions on the order of 20% or more, primarily driven by the displacement of energy-intensive virgin material production. These findings offer actionable insights for manufacturers, policymakers, and stakeholders in the aerospace, automotive, and marine sectors aiming to enhance the sustainability of next-generation composite structures.

Acknowledgements

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#489

# Project Democrite: testing of composites transverse properties in cryogenic conditions for liquid hydrogen storage.

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The Democrite project is a pilot research initiative launched by the Association of European Research Establishments in Aeronautics (EREA). Through this project, EREA members such as CIRA, ONERA, INCAS, and ILOT are committed to share institutional funds to advance research on composite cryogenic hydrogen tanks for hydrogen-powered aircraft. The main goal of the project is verification of modular approach to liquid hydrogen storage onboard an aircraft, involving carbon fiber based composite tanks. One of main tasks within the project Democrite is evaluation of potential manufacturing technologies, such as filament and towpreg winding, as well as AFP process, by materials testing in cryogenic (liquid nitrogen) conditions. This publication presents results of mechanical properties testing of carbon fiber composite cylinders in cryogenic temperatures, with focus on transverse strength, modulus and strain measurements. Assessment of temperature-properties relation for different composites is provided, with comparison between strain measurement using strain gages and fiberoptics also discussed.

#490

# Comparative study of the flexural behavior of carbon fibers reinforced PEEK laminates with different lay-ups after exposure to a kerosene flame

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Over the past fifty years, polymer matrix composites are increasingly being integrated into aircrafts structural parts. However, their behavior significantly depends on their service conditions, particularly in the event of an engine fire (ISO 2685). The literature on this subject has mainly focused on thermoset-based composites, even though thermoplastics (TP) offer some advantages (weldable, easier storage conditions, short manufacturing cycles). Indeed, PEEK is an attractive matrix for high-temperature aerospace applications due to its good fire resistance ($T_{pyrolysis} \simeq 600°C$). Thus, the understanding of the mechanical behavior of TP matrix composites under fire conditions is essential. Therefore, the aim of this work is to investigate the residual flexural properties of C/PEEK laminates after an exposure to a kerosene flame (1100°C) and the influence of the different lay-ups. The main purpose of the bending tests is to evaluate the effect of flame exposure on the interface damage state, which is a key factor in the load bearing capabilities of the material.

At first, a small-scale experimental bench that has been designed to replicate the fire certification conditions is used to expose C/PEEK laminates to a kerosene flame for different durations (1, 2 and 5 minutes) without mechanical loading. The kinetics of thermal decomposition were analyzed as function of both exposure times and lay-ups. Microscopic observations revealed the degree of matrix degradation (melted matrix, porosities, carbonaceous char layer) and X-ray tomography enabled inspection of interply delaminations and the porosity network (stress concentration zones). The lay-up has negligible impact on the thermal properties such as the thermal conductivity, which induces similar pyrolysis kinetics that are observed for all lay-ups.

Then, three-point bending tests were performed to characterize the flexural properties according to exposure times and lay-ups. The reduction in ultimate flexural strength seems to be similar for all lay-ups (around -90% after 5 minutes).

#491

# Upcycling carbon fibre prepreg scraps by optimizing ply-level joining geometry for high-performance laminates

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Upcycling composite prepreg waste offers a promising route to reduce material loss and enable circular use in composite manufacturing. This work investigates a ply-level joining strategy for reusing uncured woven carbon fibre/epoxy prepreg scraps and evaluates how different joining geometries influence the mechanical performance of reconstructed laminates. The prepreg scraps were cut into rectangles, diamonds and hexagons, and joined at the ply level to form laminates. Test coupons extracted from these plates exhibited distinct seamline orientations: 90° for rectangles, 55° off-axis for diamonds, and 30°/60° off-axis with fibre misalignment for hexagons. Tensile and flexural properties were analysed using digital image correlation (DIC) and acoustic emission (AE). The tensile modulus of the rectangle and diamond laminates showed no significant reduction compared with reference laminates, whereas the tensile strength decreased by 21% (rectangle), 27% (diamond) and 55% (hexagon). These reductions are attributed to strain concentrations at the seamline, as revealed by DIC strain maps. DIC sequence images further showed that the rectangle configuration underwent a ply-by-ply progressive failure, initiated by mode I (opening) fracture at the seamline. In contrast, the diamond configuration experienced a shear-dominant mixed-mode failure at the off-axis seamline, promoting delamination and leading to abrupt catastrophic failure. Flexural modulus and strength were reduced for the diamond and hexagon samples. AE results indicated earlier and more spatially dispersed damage initiation in all seamline-containing laminates. The diamond and hexagon samples showed fewer AE hits prior to failure, suggesting their lower damage accumulation capacity. The damage evolution was examined using AE-based clustering analysis and the fracture surface observations confirmed extensive delamination migration via transverse matrix cracking in the diamond and hexagon specimens. Overall, the results demonstrate that ply-level joining geometry strongly governs the structural efficiency of upcycled carbon fibre prepreg laminates, with rectangle configuration offering the most favourable mechanical property retention.

#492

# Influence of a new sizing on recycled carbon fibres on the fibres mechanical and chemical properties

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Carbon fibre reinforced polymers (CFRP) appear to be a suitable solution to current technological challenges in various industrial sectors, yet they also raise various environmental issues. Indeed, their quantity has been exponentially increasing but a fully circular recycling methodology is missing so far [LEFEUVRE, 2017]. Studies conducted over the last few years showed that, in optimised operating conditions, pyrolysis enables the extraction of carbon fibre that retains more than 90% of its initial mechanical properties [KRAUKLIS, 2021]. However, the initial sizing disappears during the process, modifying fibres/matrix interface formation and the resulting mechanical properties of the new composite [JEANTET, 2024][ZHENG, 2022].

The aim of this study is to improve the fibres/matrix adhesion to obtain performing circular composites. To do so, the surface chemistry of recycled carbon fibres is investigated. A methodology has been developed to successively verify that : (i) the thermal and chemical treatments have been properly carried out , (ii) the chemical treatment has a beneficial effect on the fibres/matrix adhesion properties compared to virgin and recycled fibres without such treatment, and (iii) the chemical treatment has a beneficial effect on the mechanical properties of the composite.

Fibres-scale tests validated the thermal and chemical treatment conditions. The chemical treatment applied to the recycled fibres improves the average interfacial shear stress by more than 50% compared to that of recycled fibres without treatment, while maintaining mechanical properties similar to those of virgin fibres. X-ray photoelectron spectrometry, atomic force microscopy and surfaces wettability analyses provided an accurate understanding of the interfacial phenomena and the resulting fibre surface properties. Then, mechanical tests have been carried out to assess the advantages of this new surface treatment at the composite scale.

#493

# Advancing blade sustainability: erosion performance of flax fibre composites

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Extending the lifetime of wind turbine blades while ensuring sustainable manufacturing and end-of-life strategies remains an unexplored, yet critical, challenge. Conventional blade production relies on glass fibre composites, which generate substantial waste upon decommissioning due to their limited recyclability. A promising alternative involves the use of flax fibres. Flax fibres, derived from renewable resources, are carbon-negative and exhibit superior damping properties compared to glass fibres. From these characteristics, superior damping is an advantageous feature for mitigating leading edge erosion (LEE), the progressive wear of the blade's leading edge due to repetitive raindrop impact. Incorporating these fibres into a tougher and reshapable thermoplastic matrix could enable enhanced recyclability and multiple end-of-life pathways while reducing the need for repair due to LEE. This study aims to characterise the LEE resistance of flax fibre composites by understanding the underlying erosion mechanisms. Comparative analysis with conventional glass fibre composites will provide a baseline for performance evaluation. Preliminary experiments were conducted under representative environmental conditions, utilising water droplet impact to determine performance. These demonstrated the significantly superior erosion resistance of flax fibre composites compared to conventional glass fibre ones, delaying the onset of damage by over a factor of three. The dynamic mechanical properties in the relevant LEE frequency regime will provide key information about the composite's behaviour, such as potential shifts in damping across the frequency decades. Further erosion experiments will provide a deeper understanding of the damage evolution and the role of flax fibres in LEE protection, which we hypothesise is due to their high viscoelastic damping, resulting from their hierarchical microstructure that dissipates stress waves more effectively than glass fibres. This study aims to advance sustainable blade design by integrating renewable materials with enhanced durability and recyclability, paving the way for the development of a new and improved generation of wind blades.

#496

# Induction Welding of Vitrimeric Composites

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The recent development of vitrimer resins provides and intermediate solution between thermosets and thermoplastics. They are thermosetting materials that incorporate exchangeable bonds activated over a certain topological transition temperature, resulting in flow that is similar to that observed when processing of thermoplastics. This means that vitrimers have the potential of offering an attractive combination of the benefits of both thermoplastics and thermosets; ease of manufacture and environmental resistance with reprocessability and advanced performance. Cranfield University has recently developed the first disulfide based benzoxazine vitrimer with performance that meets the temperature and environmental resistance requirements of aerospace whilst critically requiring pressure levels comparable with conventional thermosetting processing for healing/recovery at 2-5bar. The unique combination of stiffness, thermal stability, and recyclability makes vitrimers promising candidates for next-generation composite structures. However, joining technologies for vitrimer-based composites remains an emerging research area, with limited understanding of how vitrimer chemistry interacts with localised heating processes such as induction welding. This work investigates the feasibility of induction welding for vitrimeric composite laminates, focusing on the induction welding parameters that govern weld formation and performance. A robotic induction welding system was adapted to allow control of the thermal profile avoiding thermal degradation. Temperature field was monitored using an infrared camera, while process parameters such as coil power, frequency, and consolidation force were recorded and correlated with weld quality. Results demonstrate that vitrimer composite laminates can be joined using induction welding, provided that heating and cooling rates are carefully controlled. The welded interfaces exhibit strong mechanical performance, highlighting the potential for efficient, repairable, and recyclable welded joints in vitrimer-based composite structures.

#497

# Predictive Modelling of Waviness-Induced Delamination in Composite L-Angles Under Four-Point Bending

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The growing geometric complexity of composite aircraft components creates considerable manufacturing challenges. A well-known manufacturing defect in laminated composites is out-of-plane waviness of the plies, which can significantly reduce mechanical strength by premature delamination. Current design practices often rely on overly conservative empirical tests, especially for structural parts such as L-angles. This research aims to develop and validate a robust, predictive numerical framework using high-fidelity finite-element models to accurately predict the mechanical behaviour of CFRP L-angle laminates with initial out-of-plane waviness defects under unfolding.

A three-dimensional, ply-by-ply finite element model of a four-point bending test on laminated L-angle specimens was developed in Abaqus/Standard, with the mesh explicitly capturing the waviness geometries measured on manufactured coupons. Failure prediction was performed using the ONERA Progressive Failure Model (OPFM), with a focus on delamination as critical failure mode. The model's predictive ability was validated against experimental results obtained from several layups, including both pristine and defective coupons that exhibited different waviness morphologies. The validation dataset includes force-displacement curves, acoustic emission data, Digital Image Correlation (DIC) measurements, and in-situ meso-structural observations.

The numerical simulations show good agreement with experimental results. The model accurately reproduces the principal failure mechanisms and their sequence, including the shift from transverse matrix cracking to delamination. In particular, the predicted delamination strength and location agree well with test observations. Furthermore, the simulations offer valuable insight into the underlying mechanics, demonstrating that waviness defects locally intensify out-of-plane tensile and shear stresses, which act as the main drivers for the delamination onset.

The validated model serves as a powerful virtual-testing tool, allowing a step from overly conservative empirical approaches toward a more accurate, physics-based comprehension of defect criticality. Consequently, it opens the possibility for enlarged manufacturing tolerances keeping relevant safety levels, and more efficient and reliable designed composite structures.

#498

# Development of High-Conductivity Phase Change Material (PCM) Composites for Passive Thermal Management and Advanced Manufacturing Integration

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This study presents the development and characterization of innovative composite materials based on organic Phase Change Materials (PCMs), engineered for passive thermal management in demanding applications, particularly the cooling of silicon photovoltaic (PV) cells. The primary goal is to mitigate PV module efficiency loss due to temperature rise by employing PCMs with optimal melting temperatures ranging from 30°C to 55°C.

Two main strategies were explored to enhance PCM stability and thermal conductivity. The first leverages Expanded Graphite (EG) as a highly conductive support matrix, fabricated via vacuum impregnation followed by cold compaction. This process yielded composites with an exceptional thermal conductivity boost, reaching up to 8.3 W/m·K — a 40-fold increase over neat PCM—while maintaining high melting enthalpy 160-220 J/g. The second strategy utilized High-Density Polyethylene (HDPE) as a stabilizing matrix via melt compounding, sometimes incorporating EG, to achieve superior shape stability and mechanical properties, with a conductivity up to 1.6 W/m·K.

The effectiveness of the composite panels (thermal capacity 11-15 kJ) was validated through outdoor experiments on PV mini-modules. Results demonstrated a significant reduction in module temperature of 15-30 °C and an energy output enhancement of up to 11%, confirming their potential for retrofitting existing systems.

Finally, the study extended the material's applicability to advanced manufacturing by developing, for the first time, a high-loading composite filament for Additive Manufacturing (AM) via Fused Filament Fabrication (FFF). The filament, based on a PCM/EG blend within an HDPE matrix, enabled the printing of parts exhibiting excellent shape stability, leakage resistance, and enhanced thermal conductivity 0.8 W/m·K. This work establishes a viable and scalable route for producing multifunctional, high-loading PCM components for advanced thermal management, extending the use of PCMs to cooling applications in electronics and batteries.

#499

# Damage mechanisms in glass fibre reinforced polypropylene composites

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X-ray Computed Tomography (XCT) is a well-established method for non-destructive testing and is increasingly used in scientific and industrial applications. For short fibre-reinforced composites, XCT enables the determination of fibre-related features and damage mechanisms. Digital Volume Correlation (DVC) applied to 3D data provides local strain information using additional fillers as markers. This contribution demonstrates the combined analysis of microstructure, damage assessment, and strain distribution.

Polypropylene reinforced with short and long glass fibres was examined. Specimens were cut from 2 mm thick injection-moulded plates. To reduce CT measurement volume, tailored geometries were used, including constant-radius samples and notched specimens to localize deformation. Fibre orientation effects were studied with specimens aligned at 0°, 45°, and 90°. Scans were performed using a Nanotom XCT system at 2 µm voxel size, and interrupted tensile tests were conducted with a Deben CT500 stage until fracture.

Microstructure characterization included fibre orientation and length, while damage mechanisms were quantified and classified. Fibre orientation was calculated on a single-fibre basis, improving defect classification. After binarization, defects were categorized into fibre fracture, fibre pull-out, matrix fracture, or fibre/matrix debonding. Displacement between loading steps was computed using fibre arrangements as features, enabling calculation of local principal strains and volume strain. This approach links deformation mechanisms to microstructure and strain evolution.

Results are presented regarding specimen geometry, stress state, fibre orientation, and length distribution. Damage mechanisms are explained by microstructural variations and local fibre density, supported by strain evolution. Finally, findings are discussed in relation to fibre length and the critical fibre length concept.

#500

# Towards model-based control for static ultrasonic welding of thermoplastic composites: identifying causal factors influencing weld machine displacement recordings

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Static ultrasonic welding can join thermoplastic composite assemblies within seconds and with minimal energy input, yet its adoption in the aerospace sector remains limited. The lack of aerospace applications is largely due to insufficient evidence that ultrasonic welding can reliably produce high quality joints outside tightly controlled laboratory demonstrators. A major barrier to generalizing laboratory success is the unpredictability of optimal process parameters, which are usually vibration amplitude, vertical displacement of the sonotrode and the welding force. Identifying optimal welding parameters in practice involves trial and error, which is manageable for small assemblies but becomes prohibitively costly for large or complex structures. Numerical modeling has long been proposed as a means to reduce this empirical search, but for such models to become practically useful, they must predict optimal weld machine control from the simulated weld stage evolution of the joint.

This study contributes to this broader modeling effort by identifying and mapping the causal factors that link true joint plastic deformation to the vertical displacement of the sonotrode, recorded by the weld machine. Prior experimental work has demonstrated that this machine displacement recording can be used to reliably determine the optimum welding time in compliant assemblies across combinations of welding forces and amplitudes. To reproduce and generalize this capability numerically, however, it is necessary to understand how the compliance evolution of the energy director interacts with additional mechanisms that influence the displacement measured during vibration. These mechanisms include the interaction between adherend vibration and sonotrode hammering, as well as the weld machine's compression compliance, sensing accuracy and control behavior. The causal map developed in this study relates these factors into a coherent conceptual framework, enabling future modeling efforts to translate simulated compliance evolution into predicted sonotrode displacement behavior.

#501

# Investigation of Bio-PA11/Coconut Fiber Composites for additive and injection molding applications through Ludovic®Based Process Optimization

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The increasing demand for sustainable materials in high-value applications has boosted the development of biocomposites based on renewable polymers reinforced with natural fibers. This work focuses on the optimization of the primary and secondary processing of bio-based polyamide 11 (bio-PA11) composites reinforced with short coconut fibers (5, 10 and 15 wt.%), aiming to improve their mechanical and thermal performance while maintaining environmental sustainability.

A particular focus was placed on optimizing the extrusion process to minimize fiber degradation and to improve distributive and dispersive mixing which strongly affects composite performance. To achieve this, the 1D simulation software LUDOVIC® was employed to model the compounding phase and predict fiber breakage under various operating conditions. The simulations allowed detailed evaluation of shear stress, residence time, and temperature profiles along the screw, enabling the identification of optimal processing parameters that preserve fiber length and ensure homogeneous dispersion within the PA11 matrix.

The optimized formulations were sent to two different secondary processing techniques (injection moulding and a granule-based 3D printing) for mechanical (flexural, tensile and impact test), thermal (HDT measurements and DSC) and optical analysis.

Results demonstrated that the integration of simulation and experimental data effectively reduced fiber damage, improved process control, and enhanced stiffness and HDT compared to neat PA11. SEM analyses confirmed a uniform fiber distribution and good interfacial adhesion, validating the predictions from LUDOVIC®. Overall, this study highlights the relevance of simulation-driven process optimization for developing high-performance and sustainable short-fiber biocomposites, demonstrating the potential of coconut fibers as viable reinforcements for bio-PA11 for lightweight applications.

#502

# Sustainable Vitrimer CFRPs: Manufacturing Pathways and Reprocessing Capabilities

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The increasing demand for high-performance yet recyclable composite structures is accelerating the development of new resin systems [1] able to combine mechanical robustness with improved end-of-life strategies [2]. Vitrimer-based carbon fibre reinforced polymers (CFRPs) represent a promising solution, as their dynamic covalent networks enable thermo-activated reprocessability, repairability, and potential recyclability while maintaining the performance required for structural applications. [3–5]

This work investigates the manufacturing and consolidation of custom-formulated vitrimer CFRP laminates produced from unidirectional prepreg tows deposited via automated fibre placement (AFP). Two processing approaches were explored: traditional autoclave curing and out-of-autoclave (OOA) hot-press consolidation. The study includes a comparative assessment of both approaches, focusing on laminate quality, interlaminar performance, and detailed microstructural characterisation. The objective is to understand how vitrimer matrices behave under different consolidation conditions and to assess the suitability of OOA hot-pressing as an efficient alternative to autoclave cure.

Additionally, a complementary study was conducted to demonstrate a key functional advantage of vitrimer matrices: their ability to undergo thermally activated network rearrangement. This property enables localised reprocessing operations. [5] A preliminary welding-like experiment was carried out on CFRP laminates, where two vitrimer-based coupons were joined by activating the dynamic covalent network without additional adhesive. This demonstrates the potential of vitrimers for repair, joining and improved recyclability pathways in composite structures.

Overall, this work demonstrates the potential of combining vitrimer resin systems with AFP layup to manufacture high-quality composite laminates with enhanced structural performance. Moreover, it provides insight into alternative consolidation strategies and demonstrates the broader functional advantages associated with vitrimer matrices, thereby contributing to the advancement of more sustainable and efficient composite manufacturing technologies

#503

# Valorization of prepreg scrap through calendaring-based recycling

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The growing use of carbon fiber–reinforced plastics (CFRP) has increased the need for effective waste management, especially for uncured carbon fiber prepreg discarded during the preform-shaping stage of aeronautical manufacturing.

This work investigates the production of composite panels manufactured from prepreg scrap strips processed through a calendaring-based consolidation methodology. The approach consists of calendaring prepreg scraps and subsequently stacking and bonding them to manufacture panels. The calendaring process induces fiber misalignment, diminishing the influence of the original fiber orientation on the mechanical properties. The post-calendaring fiber orientation was examined using wide-angle X-ray scattering (WAXS). The resulting 2D X-ray patterns make it possible to analyze the extent of fiber misalignment and the corresponding loss of orientation.

Tensile tests showed a marked reduction in strength in the fiber-parallel direction, driven by reduction fiber–matrix adhesion and resin-rich regions formed during recycling. In contrast, tensile properties in the perpendicular direction improved, with reduced scatter, due to the random fiber reorientation induced by calendaring, previously observed.

Mode I interlaminar fracture toughness exhibited high variability as the altered fiber paths hindered stable crack propagation, whereas interlaminar shear strength slightly decreased relative to reference laminates but showed higher peak loads because of heterogeneous local stress states. Compression tests mirrored the tensile behavior, with decreased strength parallel to the fibers and improved performance in the perpendicular direction, although defects such as voids and resin-rich zones were observed microscopically.

Overall, the study highlights the need for improved control of void formation and resin distribution to enhance the performance consistency of recycled panels. Nevertheless, the calendaring-based process demonstrated clear advantages by promoting fiber dispersion, which enhanced transverse properties and contributed to improved interlaminar shear response.

#504

# Unravelling the Mechanisms of Electrochemical CFRP Recycling

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The growing use of carbon fiber reinforced polymers (CFRPs) in various industries is expected to generate substantial streams of end-of-life (EoL) waste in the coming decades, particularly from the aeronautics and wind energy sectors. This trend raises major environmental concerns, as CFRPs are notoriously difficult to recycle. Without effective recycling strategies, large quantities of CFRP waste will accumulate, posing a serious sustainability challenge.

Among the recycling methods currently under investigation, electrochemical recycling has emerged as a promising approach. Operating under ambient conditions and without the use of aggressive chemicals, this technique offers a more sustainable route for recycling CFRPs. By applying an electrical potential between a CFRP anode and a cathode immersed in an electrolyte composed of NaCl and KOH, the polymer matrix can be separated from the carbon fibers through a combination of two mechanisms: chemically, via oxidative species generated in solution, and mechanically, due to the peeling action of gas bubbles produced during water electrolysis. However, the degradation mechanisms involved in this process remain poorly understood, and the nature and fate of the by-products formed from matrix decomposition are still insufficiently studied.

This study aims to improve the understanding of electrochemical recycling and establish the basis for optimizing the recovery of high-quality carbon fibers. Recycling experiments were conducted under different applied voltages and durations. The degradation of the polymer matrix was monitored through in-situ video recordings, coupled with gas chromatography (GC), and post-mortem analysis, revealing new insights on the degradation mechanisms with respect to the applied potential. Special attention was also given to the detection of gaseous and liquid by-products using GC and nuclear magnetic resonance (NMR) spectroscopy, respectively. Multiple gaseous hydrocarbons and organic liquid compounds were identified, providing new insights into the chemical reactions occurring during electrochemical CFRP recycling.

#505

# Self-Sensing Braided Composite Rebars for Next-Generation Concrete Structures

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The growing demand for durable and resilient infrastructures has intensified the need for advanced reinforcement materials capable not only of improving structural performance but also of enabling continuous safety assessment. This work presents the development of Braided Composite Rebars (BCR), an innovative reinforcement solution produced by a braidtrusion manufacturing process, that combines braiding and pultrusion to generate highly customizable fibre-based composite systems. Unlike traditional steel rebars, BCRs offer significantly reduced weight, enhanced durability and immunity to environmental degradation, addressing long-standing corrosion-related issues in civil engineering applications.

To further enhance the functionality of these composite reinforcements, this work integrates self-sensing capabilities by embedding functionalized piezoresistive fibres within the rebars, enabling seamless integration and real-time Structural Health Monitoring (SHM) of concrete structures. The sensing principle relies on the piezoresistive effect, achieved by functionalizing selected fibres with conductive carbon nanoparticles. Different nanoparticle loadings (up to 2.5 wt.%) and deposition solutions containing plasticizers (up to 15 wt.%) were investigated to optimize electrical conductivity, sensitivity, and stability under service conditions.

A comprehensive mechanical and piezoresistive characterization campaign was conducted on the functionalized fibres, on the composite BCRs incorporating those fibres, and on BCRs embedded in a cementitious matrix to replicate structural service conditions. The assessment focused on damage detection capability, fracture behaviour, signal stability, and durability under environmental exposure. The results confirm that the embedded sensing path remains robust and responsive while the mechanical performance of the BCRs meets the requirements for reinforced concrete structures.

The proposed smart BCRs therefore act simultaneously as structural reinforcement with SHM sensing, contributing to the creation of next-generation intelligent infrastructures with improved lifecycle performance, enhanced reliability, and more efficient condition-based maintenance strategies.

#506

# Remarkably stable damping in UD flax/epoxy composites at increasing fiber volume fractions

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Plant fiber composites are increasingly considered as sustainable alternatives to glass and carbon composites due to their low density, reduced environmental impact, and intrinsically high damping. Despite this potential, the mechanisms governing their dynamic behavior is insufficiently documented and are not well captured by existing models, making it difficult to reliably predict damping at the composite scale. In synthetic composites, increasing the fiber volume fraction is known to enhance stiffness while simultaneously reducing damping, which raises the question of whether plant fiber composites follow the same trend.

Previous studies on thermoplastic plant fiber composites have suggested that damping remain constant with increasing fiber content. To investigate this behavior in thermoset systems, dynamic mechanical analysis and vibration tests are performed on flax fiber composites with fiber volume fractions of 25%, 35%, and 47%. The results show that stiffness increases by approximately 30% over this range, while the damping remains essentially constant at $\eta \approx 0.015 \pm 0.005$, demonstrating a clear deviation from the classical stiffness–damping trade-off observed in synthetic fiber composites.

To extend this analysis beyond the tested configurations, a multiscale finite element model is developed, incorporating intrinsic fiber loss factors from the literature (0.6–1.1% for plant fibers and 0.1–0.2% for synthetic fibers). The simulations confirm that, across a wider range of fiber types and stiffness–damping contrasts, the damping of plant-fiber composites remains nearly constant for each fiber type, with typical values falling within the 0.8–1.5% range depending on the fiber considered, while the fiber content increases. In contrast, synthetic fiber composites show a marked decrease in damping, falling from about 0.3–0.4% to 0.1–0.2% with increasing fiber volume fraction. These findings show that plant fiber composites offer a good compromise between stiffness and damping, enabling stable dissipation performance at high fiber contents and expanding their suitability for vibration-sensitive lightweight structures.

#507

# Lightning strike damage suppression in copper z-pinned carbon fibre composites

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International Air Transport Association (IATA) statistics show that an aircraft is struck by lightning every 1000 hours, equivalent to one strike per aircraft every year, making it an inevitable occurrence. Significant amounts of fibre reinforced composites are used across these sectors. However, the polymeric and laminate nature of composites means that they intrinsically possess low thermo-electrical conductivity, especially in the through-thickness direction (z-direction), making them prone to component life-ending ablation damage resulting from lightning strike. Traditional thermo-electrical energy dissipation regimes focus on the transferral of energy away for the strike location along the material surface (e.g. addition of conductive meshes), resulting in considerable damage spread along the surface alongside significant delamination damage, which is unacceptable in safety critical parts or in structures where repair is difficult due to remote locations e.g. autonomous aircraft and offshore wind. Therefore, the industrial need is twofold: (i) a method to significantly improve composites' thermo-electric conductivity and (ii) to inhibit delamination damage initiation and propagation. Here we show that by the introduction of large diameter through-thickness copper reinforcing pins (0.5-1.0 mm), it is possible to significantly reduce lightning strike damage magnitude and spatial spread through efficient thermo-electrical energy dissipation. The work evaluates the thermo-electrical and thermo-mechanical response of the hybrid structure to lightning strike. Experimental and numerical simulation results show that the insertion of z-pins creates conductive channels in the top and bottom surfaces of the laminate, which greatly improves the conductivity of the laminate in the thickness direction and contributes to the increase of conductivity in the in-plane direction. Under lightning strike conditions, contrary to the established doctrine, the transfer of energy through the thickness results in significantly lower damage areas and significant reductions in peak temperatures by more than 50%.

#508

# Multi-Stage Infusion for Integrated Composite Structures

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The manufacture of tidal stream turbine blades increasingly relies on thick carbon fibre composite sections to withstand high cyclic loading from tidal currents and wave-driven turbulence. In the blade root, where loads are concentrated, the required laminate thickness creates significant challenges for manufacturing using vacuum resin transfer moulding (VRTM). Single-shot infusion of these thick regions can lead to resin flow difficulties, long infusion times, and a higher risk of defects such as dry spots or inconsistent fibre fraction. Multi-stage infusion is one potential route to improve process robustness by infusing the laminate in several controlled steps rather than all at once. However, there remains limited understanding of how partial curing between infusion stages may improve interlaminar strength and fracture performance.

This study evaluates the mechanical performance of semi-cured interfaces created through staged infusion. Glass fibre laminates were produced with a commercial room-temperature epoxy resin system to represent typical marine composite manufacturing practice. Baseline single-shot laminates were compared against specimens where an intermediate partial cure was introduced prior to secondary infusion. Cure levels were selected to reflect realistic processing windows. Interlaminar shear strength (ILSS) testing, Mode I (DCB) and Mode II (ENF) fracture toughness characterisation were carried out, alongside inspection of fracture surfaces to identify changes in failure behaviour.

The results highlight the dependence of interfacial properties on the degree of initial cure. The outcomes help define acceptable cure windows and processing limits for multi-stage infusion of composite sections. This work provides practical guidance for improving manufacturability while maintaining structural integrity in tidal turbine blades and other large VRTM-produced components.

#509

# Analysis of the thermo-mechanical behaviour of an aeronautical composite–metal bolted assembly under kerosene flame exposure

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Due to their high specific strength, polymer matrix composites are widely used in aerospace designs, including nacelles of aircraft engines. Nevertheless, metallic parts are also crucial for functional and structural purposes. The metal-composite assemblies in nacelles (typically hinges bolted onto composite panels) present a vulnerability in case of an engine fire, especially if they bear mechanical loads. Their designs are subject to fire safety requirements. A deeper understanding and characterisation of their thermo-mechanical behaviour in the event of a fire is essential for future nacelle developments.

The considered assembly is a carbon-epoxy coupon bolted to an Inconel plate, which is exposed to a kerosene/air flame (1100°C) for 15minutes. The specimen undergoes tensile loading either after fire exposure to determine residual tensile properties, or during fire exposure, thus providing in-situ tensile properties. The experimental setup includes monitoring of the rear surface temperature field by infrared measurements. Visual monitoring of damage and strain field measurements by DIC are performed during tensile testing.

To characterise the impact of this thermal exposure on the assembly's mechanical behaviour, a transient thermo-elastic Finite Element model was developed. This modelling accounts for mechanical properties dependence on temperature from point to point. The aim was to understand how the increase in temperature affects the redistribution of the mechanical field near the bolt and the load transfers between plies in this specific context of high thermal gradients and complex thermal and mechanical interactions between the constituents of the assembly. The influence of bolt torque-induced tension and in-flight mechanical loading on the mechanical field was highlighted. The impact of damage gradient and woven orientation on strain and stress concentration of the assembly was characterised. The critical assumptions (heat transfer coefficients, boundary conditions, composite thermal decomposition as temperature-dependent properties) will be discussed. Subsequently, experimental results will be compared to the model.

#510

# Mesoscale finite element modeling of flax fiber composites with automated material calibration

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Flax fiber reinforced composites (FFRCs) have emerged as a sustainable alternative to traditional non-renewable materials. However, reliable predictive modeling of the mechanical behavior of FFRCs is essential to evaluate their structural performance for potential applications in the aerospace sector. In response to this, the current work proposes a mesoscale modeling approach using the commercial finite element (FE) software Ansys LS-Dyna. This approach involves the independent modeling of composite plies and cohesive layers, as well as the automated calibration of material models and their validation using experimental data. To account for the nonlinear behavior of flax fibers, an elastic damage model (MAT_58) is employed for the composite plies. Cohesive layers are modeled through a bilinear traction-separation law (MAT_138), thus enabling the simulation of delamination.

An automated framework is used for the calibration of the material models, combining real experimental data with virtual testing via non-linear dynamic FE simulation. The experimental evaluation includes tensile, compressive and shear tests on flax fiber/epoxy composites, as well as double cantilever beam (DCB), and end-notched flexure (ENF) tests to determine interlaminar properties. Since not all model parameters can be determined through direct experiments, the optimization tool LS-Opt is utilized to identify optimal values for these parameters based on experimental results.

Validation shows good agreement between numerical predictions and experimental results, demonstrating the suitability of the modeling approach to capture in-plane and interlaminar behavior of FFRCs. Challenges associated with accurately modeling the nonlinear response of continuously reinforced natural fiber laminates are also discussed.

Overall, this research contributes to bridging the gap between sustainable material innovation and industrial simulation practices, supporting the transition towards environmentally responsible composite engineering.

#511

# Repair of Thermoplastic Composites with Customized AFP Patches: Analysis of the Heat-Affected Zone and Its Influence on Repair Quality

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Fiber-reinforced thermoplastic composites (TPCs) are increasingly considered for aerospace applications due to high specific strength and stiffness, recyclability, and especially potential for high-rate production. In addition, they open up new possibilities for repair targeted at restoration of structural integrity after damage. This study deals with a thermoplastic patch repair process. The process starts with identification and preparation of the damaged area, followed by scarfing to create a stepped geometry that maximizes contact between patch and substrate. Custom patches, matching the shape and material of the damaged region, are then inserted. Finally, induction heating locally melts the thermoplastic matrix to fuse the patch with the substrate, while vacuum-assisted pressure ensures intimate contact. Both, substrate and patch are manufactured from carbon fiber reinforced PPS tapes via AFP.

In this study, influences on the heat-affected zone (HAZ) are investigated. This includes variation of welding parameters, patch thickness and the use of consolidated or unconsolidated patches. Temperature distribution in the HAZ is monitored using embedded thermocouples. The repair quality is then evaluated by optical microscopy, CT-imaging and mechanical tests. Results are correlated with the HAZ to derive process–structure–property relationships.

Initial results show, that patches with a single layer and up to seven layers can be successfully welded. Welding three individual single-layer patches into a stepped scarf with a graphite susceptor restored up to 95% of the performance.A 7-layer patch welded in one shot achieved 66% of the original performance using a metal susceptor, while the same configuration with a graphite susceptor reached only around 38%. Typical defects included pores at the interface when metal susceptors were used, as well as edge effects from copper mesh. Graphite susceptors significantly reduced porosity and and enabled a homogeneous temperature field.

This knowledge supports the optimization of induction-based repair strategies and advances the application of TPCs in aviation.

#512

# Mechanical Recycling of Carbon Fibre-Reinforced Thermoplastics: Effects of Processing Strategies on Structure and Mechanical Performance

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With the growing demand for high-performance composites, the use of carbon fibre-reinforced thermoplastics is steadily increasing, highlighting the importance of effective recycling strategies. Unlike thermoset matrices, thermoplastic systems such as poly(aryl ether ketones) (PAEK) can be remelted and reshaped, making them particularly well suited for mechanical recycling.

In the present study, mechanically recycled carbon fibre-reinforced low-melting PAEK composites are processed via two approaches: direct compression moulding and low-shear mixing followed by compression moulding. The materials are systematically compared in terms of mechanical performance, morphology, and reproducibility. Low-shear mixing is expected to improve fibre distribution and orientation, yielding more homogeneous structures and more consistent properties compared to direct compaction of the recycled material. The recycled material is first comminuted in an impact cross mill. For the approach involving low-shear mixing, the material is subsequently processed in the mixer, with the specific mechanical energy input quantified to establish its correlation with changes in structure and mechanical performance. Tensile and bending tests, conducted according to DIN EN ISO 527-4 and DIN EN ISO 178, are performed to evaluate the mechanical properties. Fracture surfaces of the tested specimens are examined using laser scanning microscopy to characterise the failure mechanisms. In addition, cross-sectional micrographs are analysed to determine the fibre orientation and to compute quantitative metrics describing fibre evenness and clustering in the processed composite. Differential scanning calorimetry is used to determine matrix crystallinity and potential thermal degradation. Comprehensive structure–process–property relationships are established for both processing routes, demonstrating how mixing quality directly affects morphology, fibre orientation, and mechanical performance in recycled carbon fibre-reinforced thermoplastics. The findings provide valuable guidance for optimizing recycling strategies and improving the reproducibility and reliability of mechanically recycled high-performance thermoplastic composites.

#513

# Flax Composites with Improved Interfacial and Compressive Behaviour Through Bacterial Calcium Carbonate Biomineralization

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The demand for sustainable, high-performance, and lightweight materials is increasing, driven by the needs of modern transportation and the clean energy transition. Composite materials incorporating wood or natural fibres present promising alternatives. Among these, flax fibres have gained attention due to their carbon-capturing nature and favorable specific mechanical properties. However, when embedded in polymer matrices, flax fibres exhibit inferior mechanical performance primarily due to their chemical composition and discontinuous fiber architecture. Besides, they exhibit poor interfacial adhesion with polymers, which in turn further deteriorates the mechanical performance of their composites. This deterioration is especially pronounced in the compressive properties of UD flax fabrics consist of long continuous twisted flax yarns. Here, we introduce a biomineralization strategy using microbially induced calcium precipitation (MICP) to address the issues in the interfacial and compressive performance of flax composites. By tuning salt concentrations in the process, we achieved controlled deposition of micron-sized mineral particles on flax yarns, resulting in a significant increase in fiber surface area. Through controlled biomineralization and theoretical analysis, we systematically studied the influences of biomineralization on the flax yarns, showing that the minerals can inhibit fiber bridging at the fibre and bundle levels, altering the interphase/failure mechanisms within the samples. These morphological changes led to a significant improvement in the interfacial and interlaminar properties of the resulting thermoset composites, leading to a notable gain in the flexural strength, compressive strength and especially toughness of the composites. On the other hand, due to the particle deposition, it led to a decrease in fibre volume fraction, influencing the compressibility of the flax fabrics, which in turn led to a decrease in stiffness. The findings highlight a novel pathway for tailoring composite performance through bio-inspired surface engineering, offering a scalable and environmentally friendly approach to enhance natural fiber composites for structural applications.

#514

# A Multi-Tool-Framework for Quantifying Geometry, Material and Structural Parameters of EoL Wind Turbine Blade Spar Caps for Second-Life Applications

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Within the paradigm of the circular economy, the composite sector faces significant challenges in the management of end-of-life (EoL) fibre-reinforced polymer structures. In the case of EoL wind turbine blades (WTBs), the structural components consist of fibre-reinforced thermosets for which circular reuse pathways are largely absent. Conventional recycling technologies frequently result in degradation of mechanical components, while high-quality recycling processes remain financially unviable. Consequently, alternative strategies, such as structural repurposing, are gaining increasing relevance in research and practice. In order to enable large-scale structural repurposing of EoL WTB components, it is essential to perform the segmentation of the large composite structures and to conduct a robust assessment of the EoL material condition. It has been demonstrated in previous studies that the extraction of unidirectionally reinforced spar-cap beams from various WTB models is feasible. For the beams under consideration, characteristic parameters were identified at the geometric, structural and material level.

The present contribution proposes a multi-tool approach that consolidates different technologies and data sources to efficiently quantify these parameters. The framework integrates a number of different methodologies, including image-based extraction of geometrical and structural parameters from cross-sectional scans, and material-level parameter estimation via correlation with WTB generation indicators (WTB length and year of design). The multi-tool approach has been explicitly designed to prioritise efficiency while maintaining sufficient accuracy for decision-making. The quantified parameters are utilised as input for predicting the EoL stiffness properties of extracted spar-cap beams. The predictions were validated by sub-structural experimental investigations, which demonstrated a good agreement with the measured mechanical response. The resulting stiffness profiles facilitate the sorting process for assigning beams to potential second-life applications.

Overall, this work supports the establishment of structural repurposing pathways for composite structures from EoL WTBs as a key pillar of a future circular economy for composites.

#515

# Parameters for running an autoclave and their influence on the energy consumption

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Autoclaves have a wide range of applications in industry. They are used in sectors such as the food industry, construction, glass production, medicine and the production of composite materials. In the medical sector, for example, the autoclave is used to sterilise products at high temperatures and with steam under high pressure. In the production of composite materials, high temperatures and high pressure are also used, but with inert gas or air instead of steam. The overall aim of this process is to achieve high and consistent quality of the products. This research focuses on the use of autoclaves in the composite sector for areas of application like the aerospace, space or mobility sector.

In short, an autoclave is a pressurised container with a steel shell and insulation. Additional systems for heating, cooling and pressure control are also part of the infrastructure. The energy required to operate these systems depends on various process parameters. One important parameter to consider is the size of the autoclave. Another important parameter is the temperature cycle, which consists of heating and cooling ramps as well as dwell phases. In addition, the filling level and the materials used for the mould and the product influence the energy consumption, especially during the heating phases.

Taking into account the influence of different parameters on energy consumption and bearing this in mind when reviewing state-of-the-art autoclave considerations in Life Cycle Assessments (LCA), it is evident that parametric LCAs would significantly improve the quality and reliability as well as the transparency of the Life Cycle Inventory (LCI) data. This study will address this topic and demonstrate the impact of parameters on the LCIs of autoclave cycles using primary data.

#516

# Multifunctional Composites For Energy Storage

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Structural dielectric capacitors represent a specialised category of multifunctional materials. In this study, they are designed following the principles of Fibre Metal Laminates, comprising of two aluminium panels (0.07 mm thickness) that sandwich a randomly oriented glass veil interlayer. The glass veil is impregnated with the thermoplastic resin Elium 188 0, and the panels are fabricated using Vacuum Assisted Resin Transfer Moulding (VARTM).

This configuration combines the high mechanical performance of structural composites with the ability to store electrical charge.

To enhance adhesion between the composite layers, techniques such as plasma treatment and anodising have been applied. The impact of these treatments on shear strength was evaluated through single lap shear tests conducted in accordance with ASTM D1002-10. Testing was performed using an INSTRON 3369 50 kN Static Test Machine at a crosshead displacement rate of 1.3 mm/min.

The shear strength increased significantly with extended plasma treatment duration, with samples treated for 8 minutes showing a 91.35% improvement compared to those treated for 4 minutes. Furthermore, samples treated for 8 minutes exhibited the highest adhesion, 108% compared to the untreated baseline. Anodised samples also demonstrated superior performance, achieving a 37.62% improvement over untreated ones.

In efforts to improve the system's energy storage abilities, additives, such as $BaTiO_3$ and nanoparticles like carbon nanotubes (CNTs) are incorporated into the resin matrix.

To assess the influence on electrical capacity, Cyclic Voltammetry (CV) measurements are employed.

These samples are also tested mechanically to see the effect of the additives on the shear strength.

#518

# Repairable Composites for Hydrogen Storage: Investigating Damage and Healing in Thermoplastic and Vitrimer-Based Composites by Gas-Permeability Measurements

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The development of repairable composite materials is essential for advancing sustainable engineering and extending the service life of structural components. However, assessing both damage and subsequent healing processes of fiber reinforced polymers (FRP) remains a significant challenge. In this study, we employ gas permeability analysis, a technique commonly used in the development of hydrogen storage systems, to quantify the healing efficiency of thermoplastic and vitrimeric composites. By measuring gas permeability in pristine, damaged, and healed specimens, we aim to provide a novel, sensitive, and non-destructive metric for evaluating healing efficiency.

For this purpose, circular permeability specimens were manufactured from a carbon fiber-reinforced Polyamide-6 thermoplastic tape (tFRP) and from a glass fiber-reinforced vitrimeric resin (vFRP). Ultrasonic scans and gas permeability analyses were performed in the pristine state before controlled impact damage was introduced. Post-impact permeability measurements as well as ultrasonic scans revealed significant increases in leak rate and damaged area, indicating the formation of complex damage networks throughout the composite structures.

While the tFRP was repaired in a full autoclave consolidation cycle, the vFRP was subjected to several short curing processes by applying temperature and pressure in order to investigate the time- and temperature-dependent healing processes at polymer level. Measuring gas permeability and performing ultrasound scans after each healing process allows for an assessment of the healing processes taking place.

The study demonstrates the suitability of gas permeability testing for making a global statement about the damage structure from the micro to the macro level. In addition, comparing the permeability before and after healing processes allows these to be evaluated. Therefore, it appears to be a good method for describing and investigating cross-scale healing processes using a single measured value and by this introducing composite materials with improved repairability in the future.

#520

# Complex loading and fatigue damage of composite sandwich structures

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Background/Problem

Carbon-fibre reinforced plastic (CFRP) bonded to a lightweight aluminium honeycomb structure (HS) provides an attractive building block for mass-sensitive structures such as ground, air, and space vehicles. Their high specific strength and stiffness enable novel design approaches; however, their use is not yet widespread due to the complexity of interactions within sandwich components. Fatigue studies allow us to assess product lifetimes under realistic loading conditions and thereby increase confidence in service performance. Preliminary studies have shown that CFRP–HS structures behave predictably under continuous fatigue loading, although several distinct failure mechanisms have been identified. This paper addresses the need to predict lifetime under combined loading, with a focus on identifying damage modes and tracking their propagation.

Methods:

- Three-point bending fatigue tests: This loading produces a combination of normal and shear stresses, representative of the complex conditions these structures typically experience.

- CT-based damage characterisation: Repeated CT scanning is used to track damage initiation and propagation within a single specimen.

- Numerical damage prediction: Finite element analysis is used to predict the life of sandwich structures prior to fabrication.

Expected Results:

- Improved understanding of dominant damage modes, including skin–core debonding, honeycomb collapse, and CFRP laminate damage.

- Identification of appropriate damage-accumulation laws for combined loading at multiple stress levels.

- Demonstration of lifetime and damage-evolution prediction using finite element models that incorporate combined loading as separate load cases.

Conclusion

A key contribution of this study is the incorporation of load cases at varying stress levels. This approach is crucial for modelling structural response more realistically, especially under fluctuating service conditions typical for these sandwich systems.

#521

# Accelerating flow prediction in arbitrary fibrous microstructures with latent models

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We introduce a more efficient alternative to our previous work on predicting the velocity and pressure fields in arbitrarily sized fiber-reinforced microstructures with an image-based machine learning (ML) model. We achieve that by using a two-stage procedure. In the first stage, we pre-train a variational auto-encoder (VAE) that compresses the velocity and pressure fields of various microstructures into a reduced latent space that captures their essential characteristics. The trained VAE is able to reconstruct the flow fields from the compressed latent space with excellent accuracy. In the second stage, we train a convolutional neural network, specifically a U-Net, that learns to predict the latent representation of the flow fields from an encoded representation of the microstructures. The decoder section of the pre-trained VAE is then used to map the predicted latent representations into the corresponding full pixel space. Taking this approach resulted in an ML model that delivers the same level of accuracy previously attained, while being an order of magnitude smaller in terms of parameter count (from ~500 million down to ~40 million). This reduction in model size in turn resulted in a significant speedup of model prediction during inference time. This approach also opens the door to the possibility of generalizing the latent model to accommodate multiple image resolutions. This generalization can be attained by pre-training multiple VAEs, with each of them mapping flow field images of different resolutions to the same latent space. During our presentation, we will go through the theoretical motivations as well as the implementation details behind this choice of performing learning in the latent space.

#522

# Development of highly integrated, modular wall and roof elements in sandwich construction made of fibre composite for the purpose of facilitating the modular and flexible construction of warehouses

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Abstract und introduction:

The aim of this study is to develop lightweight sandwich construction elements made from fibre composites. This work is part of the ZIM-Project “Composite Construct”, which involves the development of highly integrative modular surface elements, with the objective of facilitating the efficient construction of a self-supporting, modular and thermally insulated lightweight hall.

The utilisation of a modular sandwich construction made of Fibre-reinforced plastic (GFRP) with thermal insulation, consisting of vacuum insulation panel (VIP) and expanded polystyrene (EPS), as surface elements of a hall is advantageous in several ways. It is both lightweight and easy to handle event in big dimensions. Secondly, it provides excellent protection for the thermal insulation and high weathering resistance. In combination with detachable connecting elements and large GFRP profiles as the main load-bearing structure, it can effectively replace traditional building materials such as steel and metal-insulation sandwich panels for warehouses or comparable hall structures.

Experimental investigations:

The innovation of this construction is its sandwich design, consisting of a vacuum insulation panel core and an outer reinforcement layer. This provides insulation and absorbs the loads of the hall.

This study proposed a range of design and manufacturing approaches for the GFRP-layers of this sandwich structure, including hand lamination with full or partial wrapping, vacuum infusion, and fibreglass semi-finished panels. Samples from each approach were then subjected to environmental and mechanical tested.

Conclusion and outlook:

The sandwich structure, which combines GFRP with an insulating core, shows great promise as a component for warehouse wall and roof elements. It has been demonstrated by experimental evidence that the structure in question provides adequate thermal insulation whilst simultaneously complies with the technical requirements in a civil-engineering application. Subsequent research will focus on two main areas: continued research into the structural system and further optimisation of its connection techniques.

#523

# Compressive strength prediction with a micromechanics-inspired material model

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Understanding the failure mechanisms of fibre composites in longitudinal compression has improved significantly due to advances in experimental techniques, such as X-ray nano- and microtomography, and in-situ high-frequency radiography. It has been shown both experimentally and with the use of micromechanical models that the spatial distribution of fibre orientation and fibre volume fraction can significantly influence the longitudinal compressive strength of composites.

In this contribution, a ply-level micromechanics-inspired computational model is applied to a unidirectional laminate with microscale features resolved by X-ray computational tomography. The model explicitly considers the waviness and spatial distribution of the fibre volume fraction in the sample. The composite is considered a two-phase material with an effective matrix model. Material degradation is driven by matrix shearing via plasticity and continuum damage. Geometric nonlinearity is induced by the finite rotation of initially misaligned clusters of fibres. The formulation connects different failure mechanisms at the microscale and results in a simplified characterisation of the material.

The computational model builds on previous developments, where the connection of the model to the LaRC05 stress-based failure criterion was shown for a specific carbon/epoxy composite for fibre kinking filure. In the present development the model is enhanced by adding plasticity to the matrix model to increase ductility in shear. To improve the predicted elastic response, an improved up-scaling homogenisation scheme was also developed. The models are implemented in Abaqus/Explicit as a VUMAT subroutine, and structural simulations are carried out for compression coupon specimens, and the simulation results are compared with experimental data.

#525

# Toughening of additively manufactured photopolymer-derived ceramic using bioinspired nacre-like structure and epoxy infiltration

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Photopolymer-derived ceramics fabricated via additive manufacturing offer unique advantages in terms of design flexibility and thermal stability; however, their inherent brittleness limits their broader structural applications. In this study, bioinspired nacre-like microstructural design was employed as a strengthening and toughening strategy to produce silica-epoxy composites. Layered structures were fabricated using digital light processing (DLP), followed by debinding, sintering, and epoxy infiltration to create a brick-and-mortar architecture. Microstructural analyses confirmed effective epoxy infiltration that sealed sintering-induced cracks and pores, enhancing densification and interfacial bonding. Mechanical testing showed significant enhancements, including a 210% rise in flexural strength, 64% higher modulus, and a five-to-sixfold increase in fracture toughness relative to monolithic silica ceramic. Various toughening mechanisms related to nacre-structure such as crack deflection, tablet pull-out, epoxy deformation, strong ceramic-epoxy interfaces that facilitated load transfer, and ceramic crack sealing by epoxy, were found responsible for enhancing the mechanical properties of composites. This work demonstrates the potential of combining bioinspired structural design with additive manufacturing to reduce the brittleness of ceramics, thereby paving the way for their broader structural applications.

#526

# Adsorption dynamics of CO2 on electrospun carbon nanofiber aerogels doped with ZIF-8 derived carbon

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CO2 capture technology plays a vital role in the transition from fossil fuels to clean energy. Several nanomaterials characterized with different structures have been investigated for CO2 capture. In this study, zeolitic imidazolate framework-8 (ZIF-8) crystals were directly grown on polyacrylonitrile (PAN) carbon nanofibers to fabricate the ZDC/PAN nanocomposites by means of electrospinning and hydrothermal reaction, where three zinc precursors were selected for comparison. In order to improve the manipulation, the aerogel technology was applied to make the structural materials. Finally, the samples were carbonized to generate porous structures. Results showed that ZIF-8 crystals were grown successfully on PAN fibers. Zinc atoms partly evaporated at the high temperature carbonization process, resulting in additional and noticeable pores on the fiber surface. It was found that the microporosity, surface chemistry and the CO2 adsorption capacities of the ZDC/PAN aerogels were dependent on the zinc precursors. For ZDC/PAN aerogels, the highest CO2 adsorption capacities, observed on the sample using zinc acetylacetonate as zinc precursor, at 25 oC were 1.22 and 2.89 mmol/g at 0.15 and 1 atm, respectively, which were better than pure PAN aerogels. This could be attributed to the pore volume, nitrogen content, and zinc content. The CO2 adsorption isotherms could be fitted well by Freundlich equations. The isosteric heat of adsorption implied that the CO2 adsorption on ZDC/PAN aerogels were the synergic effects of physical and chemical adsorptions. Adsorption column experiments were conducted to investigate the adsorption dynamics. As the adsorption temperature increased, the breakthrough times of pure PAN aerogels decreased, while the ZDC/PAN aerogels exhibited the opposite behavior. The breakthrough curves can be fitted using the Wheeler equation, with an R-squared value greater than 0.97. The results showed that loading ZDC onto PAN carbon nanofibers produced inconsistent results regarding the CO2 equilibrium adsorption capacity and the breakthrough times.

#527

# Validation of a Novel Wireless Monitoring Approach for the Filling and Curing Stages in Vacuum-Assisted Infusion of Carbon Fiber-Reinforced Composite Parts for Aerospace

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In recent years, the aerospace industry has witnessed substantial advancements through the adoption of composite materials, which enable the design of lighter structures exhibiting superior mechanical properties. Nevertheless, the manufacturing processes for these composites remain challenging to monitor and lack adequate standardization. Consequently, there is a growing need to develop intelligent control technologies capable of efficiently supervising the production cycle.

In case of parts fabricated by infusion process, special attention needs to be paid to resin injection or filling and curing stages. Defects that influence the final mechanical and structural properties of the part, such as porosity, dry zones or inadequate resin curing degree can be faced during the process and are still difficult to monitor. Most of the technology currently available for monitoring the manufacturing process consists of disposable sensors that are incorporated within the infusion assembly. Additionally, the conductivity of carbon fiber makes the implementation of any wireless technology difficult.

The technology developed in this work aims to develop sensors and analyzers based on the usage of ferromagnetic microwires to be embedded in aerospace composite structural parts, in order to monitor manufacturing and structural health throughout the whole life cycle of the component and minimize the potential errors.

The data acquired with this new monitoring technology during the filling and curing stages has been studied and validated by comparing it to an already commercialized dielectric analysis system (DEA), with which the ionic viscosity of the resin was monitored during the process.

Although the knowledge acquired in this project was oriented toward a specific manufacturing method, the results obtained could be extrapolated to other sectors working under similar conditions. Thus, an increase in quality and added value is achieved in composite parts fabricated with this technology, ensuring that rigorous requirements are met.

#529

# Integration of Multifunctional PCL Layers for Enhanced Performance in Smart Composite Systems

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Intelligent composite structures represent advanced material systems that combine high mechanical performance with adaptive or self-sensing functionalities, enabling real-time monitoring of structural health and targeted influence over failure processes. Interlaminar polymer layers play a key role in controlling the local behaviour of composites, as they can effectively tune energy absorption, crack propagation and interlaminar interactions. Owing to its compatibility with epoxy matrices, poly(ε-caprolactone) (PCL) is a promising base material for the development of multifunctional interlayer systems.

This research aimed to develop functionally modified, additive-enhanced, patterned PCL layers, created by FFF (fused filament fabrication) 3D printing and investigate their behaviour in detail. In the current stage of the study, various flame retardant additives were incorporated into the PCL matrix, and a custom-developed, flame-retarded 3D-printed PCL filament was produced with the aim to tailor the interlaminar response and enhance overall performance of the composite. Test specimens produced from these modified PCL filaments enabled a comprehensive evaluation of the thermal, rheological and morphological properties of the materials, providing insight into how the additives affect the structure, processability and potential multifunctionality of PCL.

Using the modified filaments, composite specimens were successfully manufactured, allowing the systematic investigation of the effects of interlayer modification. Mechanical tests were carried out on the composite samples and evaluated using acoustic emission (AE) and digital image correlation (DIC) techniques to map the deformation behaviour and characterise the nature of damage processes under load. To assess the fire-related characteristics of the system, cone calorimetry was applied to examine how the flame-retardant-filled PCL interlayers influence the combustion behaviour and heat-release response of the composites.

#532

# A coupled czm-pfm framework for low-velocity impact damage analysis of composite laminates

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Composite materials are extensively utilized in aerospace and automotive sectors due to their superior specific stiffness and strength; however, they remain susceptible to low-velocity impact (LVI) events. Such impacts often induce complex, barely visible impact damage (BVID) which severely compromises structural integrity. Accurately predicting these transient failure processes is computationally challenging due to the complex coupling arising from the inherent anisotropy of the laminated architecture.

To address these challenges, this study develops a numerical framework for simulating LVI damage based on the phase-field fracture method, implemented within the MOOSE finite element environment. By defining direction-dependent critical energy release rates relative to the fiber orientation of each ply, the phase-field evolution equation naturally captures the competition between intralaminar damage and interlaminar delamination. The coupled system of elastodynamics and the phase-field order parameter is solved using the HHT time integration algorithm. This implicit scheme ensures energy stability and provides robust numerical dissipation for high-frequency noise, which is critical for convergence in dynamic fracture problems.

The numerical framework is validated against drop-weight impact experiments recorded by a Fast Digital Image Correlation (FDIC) system. Unlike conventional setups that rely on back-surface monitoring, the present measurements focus on tracking the transient displacement field directly on the impacted side. This experimental perspective offers complementary insights into the contact mechanics, specifically capturing the localized indentation evolution and the dynamic rebound phase. Preliminary results indicate that the simulated force–displacement curve and impact–rebound process exhibit reasonable agreement with experimental observations. Furthermore, the predicted phase-field damage distribution is evaluated against post-impact tomography images, demonstrating the model’s ability to reproduce both surface deformation and internal damage morphology. This work provides a physics-based and computationally efficient framework for studying the dynamic response and damage evolution of composite materials under impact, offering valuable guidance for the design of impact-resistant composite structures.

#533

# Advanced Polyester Textile-reinforced Epoxy Composites for High-Voltage Insulation

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Resin Impregnated Synthetic (RIS) technology has recently emerged as an appealing dry insulation concept for high-voltage transformer bushings, offering a robust alternative to conventional Resin Impregnated Paper (RIP) systems. The replacement of cellulose by synthetic textiles significantly reduces moisture sensitivity, thereby improving dielectric stability, operational reliability, and service lifetime of the insulation. To support the industrial deployment of RIS technology, polyester-based textile reinforcements have been investigated to quantify their thermomechanical and dielectric performance when integrated into epoxy–anhydride composite systems.

Composite laminates were manufactured using controlled vacuum infusion to ensure homogeneous flow, optimal wet-out, and low void content across different textile architectures, including knitted, non-woven and multidirectional polyester fabrics. Differential Scanning Calorimetry (DSC) was used to determine the degree of cure and glass-transition temperature, while Dynamic Mechanical Analysis (DMA) provided insights into stiffness evolution, damping behavior, and temperature-dependent viscoelastic transitions. These measurements enabled correlations between textile morphology, fiber–matrix interactions, and crosslinking density. Mechanical performance was assessed by standardized three-point bending tests to evaluate flexural modulus, strength, and failure mechanisms. Dielectric properties were studied by measuring permittivity and dielectric loss as a function of temperature to assess the impact of textiles and composites on insulation performance. Comparisons with the neat epoxy matrix established the specific contribution of polyester fibers to final composite performance.

Results indicate that the selection of the synthetic textile plays a critical role in determining the overall performance of RIS composites. Proper optimization of textile morphology can significantly enhance load transfer and electrical robustness. These findings demonstrate that polyester fiber-reinforced epoxy systems constitute a high-performance, cellulose-free alternative for next-generation transformer bushings, offering improved resistance to moisture ingress, superior dielectric stability, and enhanced durability under mechanical, electrical, and thermal stresses. Their implementation is therefore a key step toward more reliable and more environmentally resilient power-distribution infrastructures.

#534

# Interfacial Fracture Toughness Characterization of Sandwich Composites: Effects of Core and Face-Sheet Architectures under Mixed-Mode Loading.

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The deployment of sandwich specimens across various sectors, including industry and defense, is rapidly increasing, primarily due to their superior specific mechanical properties. A critical failure mode in these structures, especially when subjected to Low-Velocity Impact (LVI) loading, is interfacial delamination occurring between the core and the face-sheet. While crucial to structural integrity, this specific type of delamination, characterized by its complex mixed-mode nature at the interface, has received limited attention in the existing literature, leaving significant questions regarding its initiation and propagation mechanisms.

This work addresses this critical gap by conducting an experimental and analytical investigation into the fracture toughness of sandwich specimens under conditions representative of LVI damage. The study systematically explores the influence of material selection by examining the effects of different core materials, specifically aluminum and Nomex honeycomb, paired with various face-sheet architectures, including Unidirectional (UD) fiber-reinforced composites. Specifically, the face-sheets will utilize both Aramid and S-glass fibers reinforcement materials. The core and the face-sheet will be co-cured together, and different types of adhesives will be used.

To gain a detailed insight into the deformation and failure processes, the experiments will be monitored using Digital Image Correlation (DIC). This non-contact optical technique will provide full-field displacement and strain measurements, which are essential for accurately characterizing the damage evolution and monitoring the crack during propagation.

A significant challenge in determining the true fracture toughness of these asymmetric specimens is the inherent mixed-mode loading condition, which deviates from a pure Mode I failure. Consequently, the study will evaluate the selection of the most appropriate data reduction scheme, based on Linear Elastic Fracture Mechanics (LEFM) and the J-integral approach, for accurate fracture toughness calculation.

The findings will provide essential data and refined analytical tools for the reliable design and certification of high-performance sandwich structures.

#535

# From Laminate Theory to the Slope: An Interdisciplinary Learning Approach with Composite Skis

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Engaging students with composite materials through authentic, application-oriented learning environments remains a key challenge in engineering education. This contribution presents an interdisciplinary teaching module at OST – Eastern Switzerland University of Applied Sciences in which students from all engineering and non-engineering programmes collaboratively design, manufacture, and evaluate functional composite skis. While the primary aim is educational, the module follows a structured, engineering-driven methodology that links material selection, laminate architecture, and manufacturing processes with objective performance measurements and user-centred evaluation.

Participants develop ski concepts based on mechanical and functional criteria, translate these into laminate designs, and implement appropriate process routes such as vacuum-assisted infusion or prepreg layup. The resulting prototypes are characterized using a dedicated test rig, allowing students to quantify bending stiffness, torsional rigidity, and mass distribution. These data are compared with subjective assessments collected during a supervised on-snow field test. The combined dataset highlights the relationship between fibre orientation, layer count, core materials, and perceived ride characteristics—providing a direct, experiential understanding of structure–property interactions in composites.

The module's interdisciplinary character broadens perspectives beyond purely technical considerations, incorporating baseline reflections on ecological and health-related aspects of winter sports without shifting the focus away from composite engineering. Observations from multiple cohorts indicate improved conceptual understanding of fibre-reinforced polymers, stronger process awareness, and increased student motivation resulting from the integration of hands-on manufacturing with systematic testing.

The work outlines the pedagogical rationale, workflow, and assessment concept, and discusses how linking composite design with objective and subjective performance data can serve as an effective model for project-based learning in advanced materials and lightweight structures. The approach demonstrates that highly tangible, real-world composite applications can attract diverse student groups and foster sustained interest in engineering.

#536

# Influence of PCR Polymers on Fatigue Life of Short-Fiber-Reinforced Composites

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The yearly increase in plastic waste creates a large pool of potentially reusable material. Industries, especially in Europe, are responding by raising the share of post-consumer recycled (PCR) polymers in their products as part of the transition towards a circular economy. However, using recycled polymers in technical applications such as structural components requires a better understanding of how recyclates affect material properties relative to the virgin material. This is of particular relevance because unavoidable contaminants are introduced during collection and sorting, as well as polymer chain degradation caused by mechanical recycling may happen.

This study investigates the fatigue life of short glass fiber-reinforced polypropylene (PP) when PCR-PP is incorporated into the virgin matrix. Three matrix formulations were examined: 0 % PCR (virgin PP), 10 % PCR, and 40 % PCR, each containing 40 wt% short glass fibers. Injection molded plates were used to mill specimens both parallel and transverse to the flow direction, enabling an assessment of mechanical behavior related to fiber alignment. Tensile tests were performed, followed by fatigue tests to quantify the influence of increasing PCR content on cyclic performance.

Furthermore, fractographic analyses were carried out on the tested specimens to identify correlations between fracture mechanisms and PCR content. An empirical model was derived from the experimental data to describe the mechanical properties as a function of the recycled content.

These findings contribute to a deeper understanding of the structure-property relationships in recycled short-fiber-reinforced thermoplastics and support the broader goal of sustainable and reliable material utilization in engineering applications, moving towards a circular economy.

#538

# Numerical Characterization of Flax Fiber Composite Variability: From Morphological Description to Fluid Flow Simulations

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The proposed work aims to provide a numerical characterization of the manufacturing process of flax-fiber composites produced by liquid resin infusion. While this technique is widely implemented in the composite industry, its adaptation to natural fibers remains particularly challenging. This difficulty arises from the strong morphological variability intrinsic to flax fibers, as well as from the non-uniform mechanisms governing resin flow through the porous medium they form. As a consequence, the infusion process often exhibits a certain lack of reproducibility, which complicates both process control and product quality. Numerical modeling therefore represents a valuable tool for estimating the key parameters driving these phenomena (permeability, capillary pressure ...), predicting the resulting saturation fields, and ultimately quantifying the uncertainties associated with the manufacturing process.

The problematic is present at different observation scales. Here, we focus on fiber-level scale. Individual flax fibers are generated numerically to build realistic geometries capable of capturing their intrinsic irregularities. This is achieved by processing optical microscopic images to geometrically characterize the flax cross-section and then using the resulting statistics to generate similar shapes via Fast Fourier Transform techniques. Based on these geometries, Representative Elementary Volumes (REVs) are then generated to reproduce the observed morphological distribution of technical fibers within a yarn. Finite-element simulations will be used to describe the stationary resin flow at the fibers level, relying on the numerical resolution of the Stokes equations to evaluate relevant micro-structures properties such as permeability.

As a perspective for the continuation of this research, yarns will be treated as equivalent homogeneous media, allowing us to move toward a larger-scale description. REVs will again be constructed at this level to simulate resin infusion within yarn structures using a coupled Stokes–Darcy modeling strategy.

#539

# An experimental and numerical investigation of 3D woven structures failing by kink-band propagation

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Our work aims to improve a continuum damage model for 3D woven composites by accounting for an energetical size effect occurring on the compressive critical energy release rate associated with carbon fibres kinking. For aeronautical parts made of 3D woven composites such as the FAN blades, it was shown that under a flexural mode of solicitation, the face loaded in a compressive mode is the limiting factor due to carbon fibres kinking. Additionally, the need for larger composite parts as pointed out the criticality of considering size effects on the structural properties to failure. For the studied material, a quasi-brittle failure due to a non-negligible fracture process zone at the crack tip creates a deterministic size effect on the compressive strength.

Measurement of the compressive fracture toughness through the size effect method in carbon fibres reinforced polymers has already been carried out for unidirectional and 2D woven structures, but to our knowledge, no study was previously made on 3D woven composites. In order to determine it experimentally, various sizes of Double Edge Notched Compression and Compact Compression specimens were tested to investigate both stable and unstable crack propagation. The use of high-precision crack-monitoring equipment shows a complex profile of crack and reveals the difficulty to detect the crack tip location. The tests have pointed out the criticality of considering the crushing phase occurring in the vicinity of the crack tip.

Based on those experimental results, the parameters of a continuum damage model coupled with a non-local regularization method are identified to reproduce the size effect. This model is implemented in the FEM code Zset at Onera and explicitly introduces the residual crushing stress as a new parameter identified experimentally, allowing us to dissociate the energy dissipated by the carbon fibre kinking from the energy dissipated by the crushing.

#540

# Biodegradation studies of natural fiber-reinforced melamine and phenol formaldehyde polymer composites in soil and wastewater systems

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Throughout history, materials have played a significant role in technological advancements, from using naturally available materials like wood and stone to creating and developing metals and polymers. The widespread use of polymer composites across various industries, including packaging, construction, and medical applications, has provided significant benefits in performance, durability, and cost-effectiveness. However, the environmental footprint of these materials has become a pressing concern, especially regarding their persistence in natural environments such as soil and water systems. The biodegradation of polymer composites in soil and wastewater is a complex yet essential area of study for reducing environmental pollution. To address this issue, there is an urgent need for sustainable materials. By understanding the factors that influence degradation and applying this knowledge to design eco-friendly materials, researchers can promote a circular economy and a cleaner environment. As demand for environmentally friendly options increases, biodegradation research will be vital in shaping the future of polymer science and waste management. In this study, Melamine formaldehyde (MF) resin with a density of 0.93 g/cm3 and Phenol formaldehyde (PF) resin with a density of 1.15 g/cm3 were used to create composites with different fiber orientations. The composite samples were tested for biodegradability in soil and wastewater systems. The one with jute as an outer layer showed promising results for biodegradability. MF resin demonstrated better biodegradability compared to PF resin. Incorporating natural fibers, such as jute and flax, improved biodegradation rates (up to 84.5% and 67.8% mass loss in soil, and 95% and 35% in water, respectively), contributing to a carbon-negative footprint.

#541

# Experimental and numerical characterization of buckling-induced skin-stringer delamination growth in thermoplastic composite panels

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Thermoplastic composite panels representative of fuselage skin–stringer assemblies were tested under quasi-static compression to characterize skin–stringer delamination growth in the post-buckling regime. Experiments were paired with high-fidelity simulations that combine XFEM and cohesive-zone elements to capture ply-level delamination, matrix cracking, and crack migration. A novel crack-front monitoring methodology was developed that infers delamination position from surface strain concentrations measured by multi-scale 3D Digital Image Correlation (DIC): a local, high-resolution DIC around the delamination front supplemented by global DIC for whole-panel displacements. The monitoring method defines (i) the spatial resolution required to resolve superficial strain peaks at delamination fronts and (ii) a robust strategy to estimate front location from the measured strain fields. Method accuracy was validated against through-thickness ultrasonic C-scans obtained by interrupting tests at multiple loading stages, yielding quantitative maps of delamination area, depth and position during stable crack growth. Simulation results, showing ply delamination, matrix damage and crack migration, were compared to experimental observations, revealing key interactions governing the damage evolution in stiffened panels under post-buckling compression. The combined experimental–numerical approach provides validated, high-resolution data critical for improving predictive models of post-buckling damage progression in thermoplastic stiffened structures.

#542

# Fatigue assessment of marine composite propellers

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The maritime industry is under growing pressure to improve vessel efficiency, reduce emissions, and lower lifecycle costs. Composite propellers are emerging as a promising alternative to the traditional metallic propellers, offering potential cost savings through increased efficiency and reduced maintenance requirements. The industry is increasingly focusing on the feasibility of using composite materials for propellers and developing robust design evaluation tools for their certification. The CoPropel EU research project has the objective to present a holistic approach that realizes the practical application of composite propellers and to increase the Technology Readiness Level (TRL) of composite propellers. Similarly, in the ECoProp project, the focus is on design optimisation and structural health monitoring for flexible propellers. For both projects, one of the key aspects of the design of such composite propellers is linked to the fatigue life. Indeed, those rotating parts must sustain a considerable number of cycles (more than 107) during their lifetime. The new Bureau Veritas (BV) fatigue methodology is applied to the 2 propellers designed in CoPropel and ECoProp projects that are respectively made of CFRP and GFRP. This fatigue methodology relies on a ply-by-ply approach as required by BV composite rules. A formulation, based on laminate failure theories, is proposed to separate the macro-mechanical stresses into equivalent fibre and matrix stresses. SN curves for those stresses are obtained at different ratio from uni-directional composite test data, and linear interpolation in a Constant Fatigue Life (CFL) diagram is used to determine the damage in the composite plies. This methodology is developed to give fast results for design engineers and to minimize the amount of required tests. Results in terms of stresses and damages are checked against BV rules and guidelines and compared to the fatigue life of the propellers.

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# Designing Durable Hydrogel-Lattice Composites for Personalised Biomechanical Interfaces: An Experimental and FE Modelling Study

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Hydrogel–lattice composites represent a promising new class of soft–hard hybrid materials for next-generation wearable human interfaces and biomedical devices. Their ability to combine the compliance of soft tissues with the structural stability of engineered lattices opens new pathways for personalised orthotics, cushioning systems, and tissue-integrating implants. However, their long-term mechanical durability, energy-absorption capability, and structure–property relationships remain insufficiently understood.

This study presents a comprehensive experimental and computational investigation of hydrogel-infused gyroid lattices manufactured via biocompatible SLA 3D printing. Gyroid structures with varying porosities were fabricated and infused using hydrogels with different crosslinking densities (10-50%). Extensive characterisation—including static compression, cyclic fatigue (1–4 Hz to 10,000 cycles), viscoelastic response, and energy dissipation—was conducted to quantify the mechanical performance of the hybrid composite. Results show that hydrogel integration enhances energy absorption and reduces peak transmitted stresses. Fatigue tests demonstrated stable long-term behaviour under moderate strain amplitudes, confirming suitability for applications involving repetitive loading.

To complement the experimental findings, a finite element (FE) framework develops to simulate the mechanical behaviour of hydrogel-filled gyroids under physiologically relevant loading conditions. Using hyper-elastic and viscoelastic constitutive models calibrate from experiments, the FE simulations predict stress distribution, strain localisation. The model provides mechanistic insights into failure modes, the role of porosity on load transfer, and guidelines for tuning both lattice geometry and hydrogel chemistry.

Together, the experimental and modelling results establish a validated pathway for designing durable, energy-absorbing, and customisable hydrogel-lattice composites. These findings directly support the development of high-performance orthotis, soft-tissue mimetic implants, and adaptive biomechanical interfaces, paving the way for next-generation personalised biomedical devices.

#545

# Tailoring of Local Matrix System for Reduced Material Effort for High-Performance Composite Structures

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The demand for high-performance composite structures in turbomachinery drives the need for advanced material architectures that can withstand extreme centrifugal and bending loads. This work presents a novel dual-tailoring approach, combining tailored fiber placement (TFP) with spatially adapted matrix properties, to enhance the structural robustness of carbon-fiber-reinforced polymer (CFRP) impellers. By aligning fiber paths with principal stress trajectories and selectively introducing toughened matrix systems in highly stressed interface regions, the design mitigates matrix-dominated failure modes that typically limit operational speeds. The potential of this hybrid reinforcement concept is demonstrated using advanced numerical models of a composite impeller with tailored material properties. A comprehensive finite element analysis (FEA) framework, including Cuntze-based failure criteria and interlaminar shear assessment, was developed to evaluate the impact of local matrix adaptation on stress redistribution and damage progression. The results from the numerical simulations indicate a significant reduction in critical failure risks while maintaining global stiffness and mass efficiency. This study establishes modeling guidelines for dual-tailored composites and highlights the potential for sustainable, high-performance solutions in advanced turbomachinery. Future work will focus on experimental validation and the transferability of the approach to other complex composite structures.

#546

# Permeability analysis of adhesives for lightweight hydrogen tank development

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The aviation industry is in need to reduce its $CO_2$ emissions in order to reach the goals set by the Paris Agreement. One solution for meeting this goal is the switch to hydrogen as energy carrier. To ensure a lightweight tank structure, CFRP is a promising choice of material. Differential manufacturing concepts, in which the tank is produced in individual segments and subsequently joined, reduce overall complexity and simplify the manufacturing process. However, this raises the question of suitable joining techniques. Bolts and rivets create additional defects that impair hydrogen tightness, making these methods less favorable. For this reason, bonding the segments is being considered as a possible manufacturing process. In addition to more even stress distribution compared to rivets or screws, paste adhesives also offer the possibility of compensating for tolerances in large, flexible components.

The leak tightness of fibre-reinforced composites as tank materials is already subject of research. However, the suitability of adhesives for bonding tank segments made of these materials in terms of permeability has received little attention. Therefore, the present study will examine the permeability of various adhesives, including film and paste adhesives as well as adhesives containing additives, and investigate their suitability for bonding CFRP hydrogen tank components. A permeation test bench developed in-house is used for this purpose. Understanding these material properties, not only in isolation but also in combination with the tank material, is crucial for subsequent design. For this reason, the results for the permeation of adhesives are compared with CFRP and put into perspective.

#549

# Predicting Fabric Permeability from Yarn Architecture

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Permeability governs the resin flow through the porous textile network of preforms during the filling phase of liquid composite molding processes. This study presents an efficient and accurate framework for the a priori estimation of fabric permeability by extending idealized unit-cell models to incorporate quantifiable geometric parameters of the dry textile architecture, including yarn-structure, yarn-tortuosity and weave heterogeneities. The proposed model aims to establish a link between optically measurable fabric characteristics and permeability tensors, enabling robust optimization of mold filling processes without extensive experimental calibration of each respective textile preform. Flow modeling and the prediction of microscopic textile permeability are commonly based on unidirectional, parallel arrangements of cylindrical fibers in longitudinal or transverse direction to the flowing resin. Although numerous models exist for calculating microscopic permeability, their applicability to undulated fabrics remains not finally resolved. This study provides a comparative overview of permeability prediction models and evaluates their performance against experimental measurements of three different carbon fiber fabrics. Furthermore, the adaptation of idealized models to undulated fabrics with varying yarn architectures and weave-dependent heterogeneities is discussed. A methodology is proposed that analyzes the dry fabric structure, considering yarn dimensions, intra-yarn fiber volume content, and weave-dependent yarn transitions. An experimental setup is introduced to measure the anisotropic permeability of textile preforms with high spatial resolution using a sensor grid comprising 46 capacitive sensors for resin flow detection. The results demonstrate that incorporating yarn architecture into established permeability models improves their agreement with experimental data. The presented application-oriented framework enhances predictive accuracy without requiring complex computational procedures.

#550

# Application of a shear-lag model to patch-based recycled carbon fibre composites

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The reuse and recycling of composite waste is a growing priority. Converting industrial composite scrap into new structural and non-structural products can deliver environmental and economic benefits provided a substantial fraction of the mechanical performance of virgin composites is retained. Patch-based discontinuous composites (PBDC) offer a promising route to reusing carbon fibre: they provide high design flexibility, easier processing and show comparable strength, stiffness and damage tolerance of continuous composites.

In aligned PBDCs, mechanical properties depend strongly on matrix shear behaviour and patch overlap length. Varying overlap length changes the stacking from regular to staircase and shifts the response from higher toughness to higher strength. Two through-the-thickness stacking configurations are possible: (a) regular and (b) staircase. Therefore, for effective part design, accounting for the matrix's true behaviour, the overlap lengths, and possible effects of patch morphology should be considered.

We apply an analytical shear-lag model to Fairply, a commercially available reused carbon-fibre PBDC supplied by FAIRMAT. Configuration with unidirectional and woven patches, in both regular and staircase stacks are considered. As a model input, we will measure the neat matrix shear stress-strain response using two specimen types: (i) ASTM D5679/D5379M-98 (Iosipescu), and (ii) the specimen designed by Fiorini et al. (2025). The resulting curves will be used directly into the analytical shear-lag model to compute the PBDC response. Similarly, an extensive experimental characterization will be performed on the patch material itself to understand its intrinsic properties. The experimental validation is performed at the composite level by performing the tensile tests on Fairply specimens with different patch orientation: 0°, 45° 90°. For the 45° orientation, an extension of the model will be sought.

Overall, this study seeks an efficient modelling strategy for the Fairply, thus proposing a holistic experimental calibration and validation campaign.

#551

# Silver-based molecular inks for lightning strike protection of carbon fiber reinforced polymer composites

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Carbon fiber–reinforced polymer (CFRP) composites, unlike metallic structures, require additional protection against lightning strikes when used on external aircraft surfaces. This requirement often results in significant weight penalties, diminishing the weight-saving advantages of composite materials. In this study, two silver (Ag)-based molecular inks (MINKs) were evaluated as potential replacements for commercially used epoxy-impregnated expanded metal foils (EMFs). Small-scale current-carrying capacity (CCC) tests were first conducted to determine the breakdown current density. The CCC results indicated that silver coatings with thicknesses between 3.5 and 7.0 µm performed comparably to the baseline EMFs. Cross-hatch adhesion tests on coated CFRP substrates demonstrated excellent adhesion between the inks and the composite surface. Subsequently, bench-scale simulated lightning strike tests were performed using a standard Zone 2A waveform (100 kA) on panels coated with the selected inks and the EMF. Non-destructive evaluation methods, including ultrasonic testing and eddy current analysis, were used to assess damage to both the CFRP substrate and the lightning protection layer. Compression testing of struck specimens showed that 7 µm-thick coatings retained residual compression strength similar to that of EMF-protected CFRPs. Overall, the findings demonstrate that MINKs can form conductive coatings that provide adequate lightning strike protection for CFRP substrates while reducing weight by approximately 75% compared to conventional epoxy-impregnated EMF systems.

#553

# Dynamic interfacial fracture for laminates

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Dynamic interfacial fracture or delamination considers effects of time-dependent loads on the behaviour of fracture. For fundamental engineering configurations to study the fracture behaviour or to measure the fracture toughness of composite laminate, such as double cantilever beam (DCB), end notched flexure (ENF), the corresponding analytical models were developed to account for the wave propagation and structural vibration associated with external dynamic loads, and finally, the accurate assessment of the crack driving force (energy release rate, ERR) can be obtained. To account for the dynamic effect, dynamic factor was defined as the ratio between dynamic component of ERR to the quasi-static ERR, and its evolution against time was studied. The respective developed models were then verified by numerical and published experimental data, showing excellent agreement. These derived theories can be applicable in various applications, such as to design experimental setup, to measure dynamic fracture toughness, or to provide guidelines for structural design.

#556

# Evaluation of mechanical properties of pultruded carbon/glass hybrid composites according to fiber volume fraction

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Fiber-reinforced polymers (FRPs) are widely recognized as lightweight, corrosion-resistant alternatives to metals. Among FRPs, Carbon FRP (CFRP) provides high specific stiffness and excellent corrosion resistance; however, it also has several limitations, including high cost, low electrical conductivity, and brittle failure behavior. In contrast, glass FRP (GFRP) offers relatively high elongation and cost-effectiveness compared to other types of FRP, but it suffers from low stiffness and high sensitivity to hygrothermal environments. To mitigate the trade-offs between different types of FRPs, hybrid FRPs incorporating two or more types of reinforcing fibers have attracted increasing attention. However, due to the broad design space including variations in fiber types, volume fractions, and spatial arrangements research on hybrid FRPs remains relatively limited. This study experimentally investigates how the carbon/glass fiber volume fraction affects the mechanical properties of hybrid FRPs. To leverage complementary characteristics, carbon fibers were placed in the inner region and glass fibers in the outer region. Five carbon:glass volume fractions were examined (100:0, 60:40, 40:60, 20:80, and 0:100). Mechanical performance was characterized by tensile, compressive, and apparent interlaminar shear tests, and manufacturing quality was assessed via void content and fracture surface microstructural observations. As the carbon-fiber volume fraction increased from 20% to 60%, tensile strength rose from 33.37–47.22%, compressive strength from 30.99–40.02%, and apparent shear strength by an average of 8.3%. Additionally, the change in porosity observed with increasing carbon fiber content was relatively minor. This indicates that increasing carbon fiber content enhances the mechanical performance of FRP without affecting its internal quality. These findings suggest that carbon/glass hybrid FRPs can be tailored to meet practical requirements across applications including civil and construction sectors while offering a pathway to materials that combine robust properties with improved efficiency in the global FRP market.

#557

# Multistep Homogenization Modeling of High-Filler-Content Polymer Composites

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Abstracts

High-filler-content polymer composites are widely used in automotive, aerospace, and electronic applications due to their excellent mechanical properties. However, as the filler fraction increases, accurately modeling their macroscopic behavior becomes increasingly challenging. This study proposed a multistep homogenization modeling approach, in which low-filler-content representative volume element (RVE) models are sequentially homogenized in multiple steps to predict the effective properties of high-filler-content composites. The method was applied to polylactic acid (PLA) composites reinforced with cellulose nanocrystals (CNCs), and its validity was confirmed by comparison with experimental results. Furthermore, the multistep procedure made it possible to analyze composites with filler contents exceeding 80%, a range that is difficult to handle using traditional homogenization techniques. In addition, this approach allows identification of the effective filler volume fraction parameter used in the Halpin–Tsai model, providing further insight into the mechanical behavior of highly filled polymer composites.

#558

# Comparison of piezoelectric filler-dispersed composites with different matrix polymers

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To explore piezoelectric polymer-based composites containing piezoelectric fillers for potential applications in flexible and printable devices, we employed PDMS, PLA, PP, and PVDF as representative polymer matrices and compared the piezoelectric properties of the resulting composites.

#559

# Effect of material combination on the magnetoelectric properties of hybrid particle-dispersed polymer composites with periodically-poled checkerboard structures

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In order to discover innovative microstructures that surpass conventional structures, a multiscale analysis was carried out for polymer-based hybrid particle-dispersed composites consisting of a piezoelectric phase and a magnetostrictive phase. Homogenization was employed for the scale coupling, and the periodically reversed polarization structure that had been identified in our previous study on ceramic composites was applied to polymer-based composites to verify its effectiveness on the magnetoelectric effect. In addition, the effects of the matrix properties and the material combinations of the piezoelectric and magnetostrictive particles on the magnetoelectric characteristics were also clarified.

#560

# Identification of a two-mechanisms cohesive zone law for delamination of architected hybrid joints

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Promoting the development of long-scale dissipation mechanisms through the design of specific bond architectures has been shown to delay delamination propagation in laminated composites and bonded joints. Such architected hybrid joints can be described via Cohesive Zone Models (CZM) involving multiple dissipation mechanisms, whose parameters can be obtained by inverse identification from delamination tests. Here, two bond architectures are considered, involving glass mat or 3D printed TPU interfacial inserts within a unidirectional carbon fibres, epoxy matrix composite. The introduction of inserts promotes the development of a bridging mechanism which dissipates additional energy over a large process zone, resulting in delayed crack propagation under macroscopic mode I conditions. Previously published Double Cantilever Beam (DCB) test results enabled us to quantify the contribution of such additional mechanism to the global force-displacement response, as well as to identify a R-curve behaviour with simple data reduction methods. Here, the same experimental results are used to identify a CZM consisting of two mechanisms, associated to the main crack advance within the composite and to the bridging provided by the inserts, respectively. Different identification strategies have been adopted: on one hand, a Particle Swarm Optimisation (PSO) algorithm to achieve the best fit of the load-displacement response; on the other hand, (Integrated) Digital Image Correlation to extract full-field beam-like displacements from pictures taken during the test. The resulting CZM parameters can be used to simulate the response of architected hybrid joints under different configurations, but also to achieve further insight on the energy dissipation mechanisms at the different scales.

#561

# Fabrication of GFRP using a bio-based furan resin and enhancement of its mechanical properties with a small amount of alicyclic epoxy

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Furan resin, produced by polymerising furfuryl alcohol (FA), is a promising bio-based thermosetting resin. It has excellent chemical resistance and flame retardancy, while exhibiting mechanical properties equivalent to widely used epoxy resins. FA is extracted from the inedible parts of sugar cane and corn. As most conventional thermosetting resins are petroleum-based and there are concerns about the depletion of raw materials, furan resin is attracting attention as a potential alternative to resins such as epoxy and phenol.

However, the applications of furan resin are currently quite limited, due to the difficulty of controlling its polymerisation. FA polymerises in the presence of an acid catalyst, and this polymerisation is accompanied by the formation of water. As the polymerisation progresses, the viscosity increases, and the water is not released from the resin into the atmosphere and becomes voids. Furthermore, the short pot life of FA makes it not easy to composite with reinforcing fibers. The rapid polymerisation and viscosity increase make FRP fabrication difficult.

In this study, furan/glass fibers composites were fabricated using an acid adsorbent. The adsorbent employed functions to adsorb the catalytic acid up to a certain temperature, thereby suppressing polymerisation at room temperature. Consequently, viscosity increase was also controlled, enabling the successful fabrication of glass cloth laminates. Furthermore, the effect of silane treatment for glass fiber surface on mechanical properties was investigated. Results indicated that the surface treatment improves resin/fiber interface adhesion and increases the mechanical properties of the composite. These results suggest that acid adsorbent and fiber surface modification represent effective strategies for expanding the applications of bio-based furan/glass fiber composites.

#562

# Molecular Dynamics Simulations on the Adhesive Properties of Thermosetting and Thermoplastic Resins

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Although thermosetting CFRP is currently used in aircraft structures, the transition toward thermoplastic CFRP aimed at improving productivity and recyclability has made the adhesion between their respective matrix resins a critical issue. While experimental studies have progressed, numerical evaluations remain limited, and weak interfacial adhesion has also been reported. Therefore, this study employs molecular dynamics simulations to elucidate the adhesive properties between thermosetting and thermoplastic resins.

The thermosetting matrix was modeled as a DGEBA/4,4'-DDS epoxy network (27,383 particles), while PEEK (85,100 particles) and PPS (84,854 particles) were selected as thermoplastic matrices. All simulations employed the AMBER force field. Thermoplastic resin models were equilibrated through temperature variation, volume control, and pressure control from ambient to elevated temperatures to obtain flat surface structures. The epoxy network was crosslinked under temperature and volume control before being brought into contact with the thermoplastic surfaces.

Three interfacial systems—epoxy/epoxy, epoxy/PEEK, and epoxy/PPS—were constructed, and their interfacial energies were evaluated using fully equilibrated structures. To provide experimental reference values, double cantilever beam (DCB) tests were conducted using specimens composed of thermoplastic CFRP (PEEK or PPS), an epoxy adhesive layer, and thermoplastic CFRP. The simulation results showed the interfacial energy ranking: epoxy/epoxy ≫ epoxy/PPS > epoxy/PEEK. In contrast, the fracture energies obtained from the DCB tests followed the order PPS > PEEK, showing a consistent relative trend.

Based on these findings, ongoing work focuses on enhancing interfacial adhesion by simulating plasma surface treatments at the molecular scale.

#563

# Reversible bonding of hybrid metallic-composite shafts

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Shafts are common machine elements used to transmit power through machinery. An annular, carbon fibre reinforced polymer (CFRP) composite shaft provides a mass reduction greater than 50% as compared to an equivalent hollow steel shaft. This paper demonstrates the viability of transferring power into a composite shaft via a thin walled metallic (AISI 4140) collar that is reversibly bonded to the outer diameter of the shaft. Joint reversibility allows the metallic collar to be removed/replaced through the life of the composite shaft. A polyvinylidene fluoride (PVDF) thermoplastic film (0.2 mm nominal thickness) forms the bonding agent permitting reversibility; the bonding process is the proprietary thermoset composite welding (TCWTM) technology developed by ACS Australia. Variations in the shaft diameter to bond width were explored by testing bond resistance to failure under separate axial and torsional loading conditions. Axial loading of the tubular joint is shear, rather than peel, dominated and bond width is effective in controlling the shear strength capacity. For a 50mm diameter tube, increasing bond width from 12.5 mm to 20 mm (60%) increased bond strength from 26 MPa to 29 MPa (12%). However under torsional loading, a stress concentration develops at the free edge of the joint; the joint width has a minimal impact on the shear stress level at these free edges. Testing showed that the overall bond strength for a 50 mm diameter tube decreased from 31 MPa to 20 MPa as the bond width increased from 20 mm to 40 mm, respectively. In other words, additional bond width did not overcome the high edge stresses, but did contribute to a lower average shear stress. Further testing showed that indeed, joint reversibility was possible with re-bonded specimens (axial and torsional) performing as good as the original bonded specimens.

#564

# Enhanced Damping Behaviour in CFRP Laminates Enabled by a Novel Polyurea Interleaving Concept

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The introduction of interleaf layers has long been explored as a means to enhance the damage tolerance and dynamic performance of carbon fibre reinforced polymer (CFRP) laminates. However, the use of polyurea—a highly ductile, energy-absorbing elastomer—as an interleaf material has scarcely been investigated, despite its promising viscoelastic and fracture-modifying characteristics. This study presents a novel polyurea-based interleaf system for CFRP laminates and evaluates its influence on flexural performance, interlaminar fracture toughness, and damping behaviour.

The results suggest that the polyurea interleaf provides notable improvements in interlaminar toughness, accompanied by measurable gains in damping capacity without major reductions in flexural properties. The enhanced energy dissipation is attributed to the intrinsic viscoelasticity of the polyurea layer and its ability to delay crack initiation and propagation at the ply interfaces. These findings indicate that polyurea represents a promising new class of interleaf material for advanced composite structures where vibration reduction and damage tolerance are of primary importance.

The study offers a new route to multifunctional CFRP laminate design with potential use to aerospace, transport, robotics and vibration-sensitive structural applications.

#565

# Development of Bio-Based PCB Materials

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Printed circuit boards (PCBs) are used in all electronic devices, serving to mechanically support electronic components while providing electrical connections, and ensuring interlayer insulation, heat dissipation, and signal integrity for stable device operation. Typically, glass epoxy substrates are employed, which consist of glass fibers as reinforcement and epoxy resin as the matrix. However, PCBs contain a complex mixture of metals and resins, making separation and recovery processes challenging. Consequently, recycling is currently economically infeasible, leading to widespread disposal.

In response to the global shift toward a low-carbon society, we are developing bio-based PCB materials. While there are examples of biomass-derived resins used as the matrix or natural fibers as reinforcement, few studies have applied bio-based materials to both reinforcement fibers and matrix resins simultaneously. Moreover, applications to multilayered, rigid PCBs using thermosetting resins have not been reported.

To address this, we explored replacing conventional glass epoxy substrates by incorporating bio-based materials into both reinforcement fibers and matrix resins. For reinforcement, flax and ramie fibers were selected based on their mechanical properties. In manufacturing rigid PCBs, stacking multiple layers of substrate material is necessary, which requires handling uncured resin impregnated into reinforcement fibers, known as prepregs. We successfully prepared prepregs by blending general-purpose epoxy resin with bio-based epoxy resin, suppressing resin flow at room temperature and enabling composite formation with natural fibers. These prepregs were laminated and thermally cured to produce substrates suitable for PCB applications. We evaluated their mechanical, electrical, and water absorption properties, as well as the influence of water uptake on electrical performance. The results of these evaluations are presented in this study.

#566

# Durability Evaluation in Water Environment of Fiber-reinforced PLA with Hydrolysis-control Function

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Biodegradable polymers used as matrix of the green composites can be hydrolytically degraded during their usage. The material systems with the hydrolysis-control function, where their hydrolysis could be suppressed during usage and accelerated after disposal, would be desired to be developed. We have been investigating the hydrolysis-control functionalization of polylactic acid (PLA) as a representative biodegradable polymer by the introduction of the photo-dissociable protecting groups into the carboxy end groups. Since, the creep durability of PLA should be improved for its practical use, the reinforcing fibers should be composed with PLA. This study aimed to evaluate the tensile creep properties in the water environment of the hydrolysis-controlled PLA reinforced by the fibers. The density of the added photo-dissociable protecting groups was 0, 10, 20, and 30 wt%. The hydrolysis-controlled PLA sheets were unidirectionally composed with the fibers. Here, the carbon fibers were used as the reinforcement, in order to avoid the change in the mechanical properties of the fibers during the creep tests. The tensile creep tests perpendicularly to the fiber direction were conducted in the water environment. Here, the creep specimens were installed into the tubes filled with water. The applied tensile stresses to the creep specimens were 20, 40, 50, and 80 % of their static tensile strength perpendicularly to the fiber direction. As a result, the creep fracture time for the specimens with the introduction of the photo-dissociable protecting groups of 20 wt% was the longest within the range of this study. The excessive introduction of the photo-dissociable protecting groups induced the decrease in the creep fracture time. Therefore, it can be suggested that 20 wt% is the optimum condition to protect the carboxy end groups of PLA for the improvement in the creep properties in the water environment.

#568

# Transition-Metal Nanowire–Integrated Carbon Fiber Electrodes for Structural Batteries

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Structural batteries that simultaneously provide mechanical support and energy storage are essential for next-generation robotics and unmanned aerial vehicles (UAVs), where minimizing non-load-bearing battery mass is critical. For integration into curved structural skins, these batteries must retain electrochemical stability under bending and deformation. In this work, carbon fiber electrodes functionalized with transition-metal nanowire architectures were developed to improve mechanical resilience and charge transport efficiency. The nanowire morphology offers a high surface area and interconnected conductive pathways that enhance electron transport and $Li^+$ diffusion. Hydrothermal growth on woven carbon fabrics enabled uniform nanowire coverage and strong interfacial bonding, resulting in improved durability under mechanical deformation. Pouch cells assembled from electrodes subjected to repeated bending exhibited discharge characteristics nearly identical to those of cells prepared without bending, indicating negligible performance degradation. Furthermore, the nanowire structure reduced internal resistance and enhanced rate capability through optimized ionic and electronic transport channels. These results demonstrate a practical electrode design strategy for curved structural battery skins and highlight the potential of mechanically robust, high–surface-area electrodes for lightweight and energy-dense systems in robotics and aerospace applications.

#569

# Development of the two-way shape memory alloys and polymer composite smart actuator

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Shape memory materials (SMMs) are one of the promising smart materials since they can change their shapes in response to external stimuli such as temperature, light, or even chemical solutions. However, most conventional SMMs, including shape memory polymer composites (SMPCs) and shape memory alloys (SMAs), exhibit only one-way actuation, recovering their permanent shape only once after deformation. This restricts their use in applications that require reversible motion, including thoese in the aerospace sector. Shape memory actuators could replace heavy and complex motor-based systems in deployable structures yet still require additional mechanisms to recycle and reuse them after completing their missions.

In this study, a high-performance two-way SMA/SMPC hybrid actuator is developed, and its actuation mechanism is investigated. The two-way performance is strongly dependent on the hybrid actuator's compatibility of its constituent and structural design, particularly regarding recovery ratio and actuation speed. Therefore, to enhance the thermo-mechanical properties of the SMPC layers and enable larger reversible deformation, the stoichiometric ratio of the shape memory polymer (SMP) is chemically adjusted, and carbon fiber reinforcement is introduced. The developed SMA/SMPC hybrid actuator with a stoichiometric ratio of 0.55 and reinforced with a carbon fiber sleeve, showcased an increase of the recovery ratio and speed by 800 % and 485 %, respectively, compared to pristine SMP layers with stoichiometric ratio of 0.70. Furthermore, by incorporating a transverse curvature, the actuator exploits a snap-through effect, achieving remarkably fast recovery speed during bending deformation and over 99 % recovery ratio during deployment. Finally, the feasibility of applying the proposed two-way hybrid actuator to deployable systems is demonstrated by replicating plausible scenarios. Overall, the results demonstrate the potential of two-way hybrid actuators for advanced applications, offering rapid and fully reversible actuation with enhanced structural performance.

#571

# Flexible composite protection for a dynamic world

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Due to recent geopolitical developments, many countries are reinvesting in their defensive capabilities, which has led to increased demand for protective materials resistant to ballistic threats.

Although many applications can be well served by traditional materials (e.g. steel and concrete), composite materials provide advantages which make them indispensable in areas where high performance and low weight have priority. This can be seen in the dominance of aramid and UHMWPE fiber-based composites in the body armor and helmet segments, where user comfort demands light end-products. This evolving nature of threats, however, has also led to such composite materials finding their way into vehicle armor, in addition to the existing protection systems. This added armor supplements the existing materials due to the unique properties afforded by composite materials, this mixture of materials provides a higher level of protection for the occupants. In vehicular applications, these materials must be space and weight efficient, to minimize the loss of interior volume and not increase the overall mass of the vehicle. These considerations place considerable constraints on the material properties of the composite armor, meaning that materials developed for personal use are not capable of covering all requirements. Alone the range of fiber grades available is a testament to the spectrum of capabilities asked of these materials.

This work provides a summary of strategies to improve impact and ballistic resistance properties of composite materials. In addition, results are presented on the effect of specific resin formulation and optimization of composite layer architectures with the aim of improving flexibility, workability and ballistic resistance. By balancing chemical and structural innovations, we aim to advance lightweight protection solutions to address emerging needs and provide increased useability.

#572

# Development of sustainable SMC composite for automotive applications

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There is a growing need in the mobility sector to develop materials and components that are both circular and sustainable, and this also applies to composite materials. This presentation highlights recent developments in thermoset composites made with bio-based resins and glass fiber reinforcement.

One of the most widely used composites in the automotive industry is Sheet Molding Compound (SMC). SMC is a compound consisting of unsaturated polyester resin (UPR), glass fibers, mineral fillers, and various additives. Current formulations typically rely on petroleum-based polyester combined with a high content of styrene, which serves as a reactive diluent. However, styrene is highly volatile, leading to significant emissions during molding and storage. This raises potential compliance challenges with environmental regulations such as VOC limits and REACH.

Within the SUSPENS project, bio-sourced alternatives to petroleum-based polyester and styrene were investigated, along with alternative reactive diluents. The trade-off between bio-content and performance was identified at 50%, while styrene content was successfully reduced up to 50%.

The developed resin was integrated into an SMC compound designed to include fire-retardant additives, with the objective of molding a top cover for a battery housing in a Battery Electric Vehicle (BEV). Plates were compression-molded using this SMC compound, and their mechanical properties were compared against standard SMC and commercially available bio-based SMC formulations. Fire resistance performance was also evaluated.

Processability was assessed by molding complex parts—specifically an automotive battery housing—via compression molding. The evaluation compared the new formulation to a reference part produced without bio-based materials.

This work is part of the EU-funded SUSPENS project (February 2023 – June 2026), which aims to develop composites with a significantly higher bio-based material content.

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#573

# In-situ process monitoring and residual strain detection in 3D printing via optical fiber sensing

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ABSTRACT

This work integrates distributed optical fiber sensors into 3D-printed carbon-reinforced Nylon coupons to monitor fabrication and residual strains via Optical Frequency-Domain Reflectometry (OFDR). Comparing acrylate, polyimide, and uncoated fibers, results show polyimide and uncoated variants withstand high printing temperatures (275^∘ "C" ), offering superior strain transfer and data fidelity compared to thermally degraded acrylate coatings.

Keywords: Structural Health Monitoring, Fused Filament Fabrication, Optical Fiber Sensors, Residual Strain.

## INTRODUCTION

Fused Filament Fabrication (FFF) enables rapid thermoplastic composite production but suffers from thermally induced residual stresses and lacks reliable in-situ monitoring (Caminero et al., 2013; Kousiatza et al., 2019; Paloschi et al., 2023; Quan et al., 2015). While Fiber Bragg Gratings are successfully used in traditional laminates (Karalekas et al., 2008), this study applies distributed sensing (Rayleigh backscattering) to the FFF process. We investigate the feasibility of real-time monitoring and the critical influence of fiber coating materials on sensor survival and residual strain detection in high-temperature printing environments.

## METHODOLOGY

Short carbon fiber-reinforced Nylon coupons (175×25×2 〖" mm" 〗^3) were printed with layer thicknesses of 125μ"m" . SMF-28 optical fibers with three coating variations: double-layer acrylate, polyimide, and uncoated, were embedded at the neutral axis (layers 8-9). A Luna ODiSI 6102 system (0.65" mm"  resolution, 20" Hz" ) recorded distributed strain and temperature. Measurements tracked the nozzle position during printing and mapped residual strain fields post-fabrication.

## RESULTS

Real-time monitoring successfully captured the thermal history and nozzle location. However, data quality relied heavily on the coating. The 275^∘ "C"  printing temperature melted acrylate coatings, causing poor strain transfer with large transition lengths (L≈4" cm" ) and high noise (σ_ε≈100με). In contrast, polyimide and uncoated fibers remained stable, exhibiting sharp transition areas (L≈2" cm" ) and uniform residual strain profiles (σ_ε≈10με). This validates the use of stripped or polyimide-coated fibers for effective "smart" composite manufacturing.

#574

# Needs and Opportunities for Image-Based Analysis of Composite Features

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Image-based analysis is a critical enabler for understanding composite materials, from microstructural characterisation of defects to initialising digital design technologies. Through recent collaboration in the community, questions have been identified around the transferability of methods into image-based analysis workflows. This interactive session invites participants to share experiences, challenges, and aspirations for image-driven approaches in their research.

Through guided discussion, we will explore:

- What shared challenges do we face in capturing and interpreting composite features through imaging?
- How can we pool resources and expertise to overcome limitations in current imaging techniques?
- What collaborative frameworks could accelerate automation, AI-driven feature extraction, and data sharing?

This final presentation in the special session aims to create a space for dialogue, networking, and co-creation of a roadmap for future collaboration. Participants will leave with actionable ideas and potential partnerships to drive innovation in image-based composite analysis.

#575

# Optimizing the staggering of singularities in Automated Fiber Placement

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Automated Fiber Placement (AFP) is a highly efficient and versatile process for manufacturing composite structures. However, due to geometric complexity and the nature of the deposition process, AFP introduces inevitable heterogeneities in the final parts. When these heterogeneities occur systematically and at predictable locations, they are referred to as singularities. Among them, resin-rich areas are the most common and detrimental. These singularities can lower various mechanical properties, particularly when they repeat through the thickness of the laminate. To avoid the proximity of singularities, the staggering method offsets plies with the same orientation. Although staggering has been shown to significantly reduce the influence of singularities, there is currently no consensus on how it should be applied.

In the search of optimization of staggering application, the present work proposes a strategy to model the staggering effects, using a realistic representation of singularities. The proposed modeling uses gradients of mechanical properties derived from observations of fiber volume fraction variations on the edges of resin rich areas. Numerical simulations of laminates containing singularities are performed for different ply offsets in order to quantify the influence of staggering. These simulations reveal general trends in how the distance between singularities affects the overall mechanical response.

In parallel, two sets of composite plates were manufactured and tested under four-point bending to compare with the simulations and to validate the proposed model. The first set was provided by an aircraft manufacturer, while the second was specifically designed and produced for this study. Digital image correlation was used to capture local deformation fields, and acoustic emission monitoring was employed to assess the initiation, intensity, and location of damage events.

Based on numerical and experimental results, guidelines for effective application of the staggering method are proposed, to mitigate effects of AFP-induced singularities.

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# Investigation of the clamping process of CFRP tool interfaces in conventional tool holders

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Substituting tool steel with carbon fibre reinforced polymers (CFRP) in motor spindles of machine tools increases overall performance and improves energy efficiency. However, the high-precision interfaces of the CFRP motor spindle to attached components such as bearings or the tool holder interface continue to be made of steel. During a tool change, the tool holder is pulled into the tool interface by a clamping unit. The taper of the interface is subjected to tribological loading. Wear on the taper reduces the precision of the tool holder clamping. The use of CFRP on one side of the interface additionally increases the number of tribological influencing factors.

To gain an in-depth understanding of the friction and wear behaviour of highly loaded CFRP interfaces, the clamping process during tool changes is investigated using two in-house developed tribology test rigs. To enable an economical investigation of the multitude of material-dependent tribological factors in CFRP, a block-tube test set-up abstracted from the application case is used.

Based on the findings from the fundamental investigations, endurance tests of the clamping process are performed on the pull-in test rig using tool holders and conical CFRP specimens that replicate the CFRP interface at the motor spindle end. Based on the insights from the abstracted set-up, a fibre orientation of ten degrees is used in the CFRP interface. The tool holder is pulled into the CFRP interface using a pull-in force of 18 kN. Laser displacement sensors record the pull-in displacement of the tool holder, enabling measurement of tool holder tilting. Wear of the CFRP specimens and steel reference specimens is assessed optically and through pull-in diagrams. The findings to date confirm the potential of ground CFRP functional surfaces for high-precision tool interfaces and provide the foundation for developing design recommendations for tribologically loaded CFRP interfaces.

#577

# Synergy between Optical and Embedded Sensor Techniques in Structural Health Monitoring of Composites

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Carbon fibre reinforced polymers (CFRP) are increasingly used in lightweight, safety-critical structures, making fatigue damage detection and lifetime prediction essential for cost-efficient maintenance. Current Structural Health Monitoring (SHM) approaches are challenged by the complex interaction of microstructural failure mechanisms in composites, leading to conservative design margins and scheduled service intervals. This work establishes an experimental foundation to support sensor-integrated SHM strategies through fatigue characterisation of a quasi-isotropic carbon/epoxy laminate.

A combined monitoring approach was employed under tension–tension fatigue loading at different stress ratios and frequencies. Global stiffness evolution was continuously tracked from force–displacement data, while Digital Image Correlation (DIC) enabled full-field strain visualisation for localisation of surface damage initiation. Complementary X-ray micro-computed tomography (μ-CT) provided internal validation by revealing transverse matrix cracking, delamination growth and final fibre-dominated failure.

A characteristic three-stage stiffness degradation pattern was consistently observed: (i) rapid initial decline due to early matrix damage, (ii) a dominant intermediate plateau phase representing approximately 60% of total life during delamination growth, and (iii) final accelerated degradation linked to fibre fracture. These trends strongly correlate measurable stiffness loss with underlying physical damage progression.

The findings demonstrate how optical measurements enhance the interpretability of global degradation metrics and highlight the necessity of combining them with embedded sensing for continuous in-service surveillance. Especially for validation purposes, optical measurement techniques represent a valuable complement in thin-walled structures, where embedded sensors may be limited by size or placement constraints. They further support optimised sensor positioning by providing insight into local strain concentrations and critical damage initiation zones.

#578

# Damage-Induced Electrochemical Degradation in Structural Supercapacitors

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Integrating energy storage into load-bearing composites is a promising approach to reduce mass and enhance efficiency in aerospace applications. Structural supercapacitors (SSCs), or power composites, combine Carbon Fiber (CF)-based electrodes with a polymer electrolyte to enable multifunctional performance through simultaneous load-bearing and energy storage. Few studies have addressed how mechanical damage affects SSC electrochemical performance. This work investigates the mechanically induced electromechanical degradation of reinforced SSCs and establishes a predictive framework for performance loss under mechanical stress.

Reinforced SSCs were fabricated using unidirectional CF electrodes, glass-fiber reinforced polymer electrolyte (GPE), and metal current collectors (CC). Electrochemical performance of pre- and post-failure samples was assessed using cyclic voltammetry (CV) and electrochemical impedance spectroscopy (EIS) following three-point bending. Significant reductions in specific capacitance and increases in internal resistance confirmed the sensitivity of SSC performance to mechanical damage. Observed failure mechanisms included CF/CC delamination, CF/GPE debonding, and void formation, which disrupted CF/CF contacts and the continuity of the conductive network.

A multiscale modeling framework was implemented to quantify the physical degradation mechanisms. Micro-scale representative volume element (RVE) geometries and ion-transport models captured CF/GPE/CC interactions for pre- and post-failure states, providing effective electrochemical–mechanical properties. Simulation results revealed how local mechanical damage propagates through the conductive network and degrades electrochemical performance. Experimental measurements validate the predictive capability of the continuum FE framework.

This combined experimental and computational study defines the structure–property–performance relationships in reinforced SSCs, providing quantitative insight into how mechanical damage compromises charge transport. The results establish a foundation for designing damage-tolerant, multifunctional composites for structural energy storage in demanding aerospace environments.

#579

# Influence of winding pattern on the mechanical properties of wound composite structures

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Filament winding is widely used to manufacture composite structures reinforced with continuous fibers, providing superior mechanical properties along the designed tow paths. However, achieving these high-performance characteristics requires the tows to follow complex trajectories on the mandrel surface. This creates a winding pattern with fiber crossover regions formed by intersecting tows and stacked regions where the tows are aligned continuously. The resulting winding pattern can vary depending on parameters such as the total number of winding cycles and the skip index, even when the winding angle and number of tows remain constant. These distinct winding patterns can significantly affect the mechanical performance of the composite structures.

In this study, a parametric modeling approach is developed to numerically investigate the influence of the winding pattern on the mechanical behavior of filament-wound cylinders. The finite element model is constructed using key parameters such as winding angle, total number of cycles, bandwidth and skip index. To capture the regional variations within the winding pattern, spatially varying mechanical properties were assigned to the model based on the local pattern types—namely, the fiber cross over regions and stacked regions. The frequency of fiber cross over region varies depending on the winding patterns. The mechanical properties of these regions were determined using statistical volume elements (SVEs), which account for the variability in tow geometry. To validate the numerical approach, torsional and tensile tests with ZDT (Zug-Druck-Torsions) specimens were conducted on filament-wound cylinders fabricated with different winding patterns. The numerical results showed consistent trends with the experimental predictions confirming that the winding pattern significantly influences the mechanical performance of the composites. This study establishes a parametric modeling framework that explicitly considers the winding pattern, enabling improved prediction and optimization of filament-wound composite structures.

#580

# Friction-Controlled Loading and Steady-State Behavior of Yarns under Tensile Loading

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Fiber assemblies serve as the fundamental mesoscopic building blocks for textile composites. The mechanical performance of textile reinforcements is fundamentally governed by the complex interaction between their hierarchical geometry, inter-yarn friction, and transverse compaction capabilities. Understanding the mechanical behavior of yarns, particularly under tensile loading, is critical for optimizing the architecture and mechanical properties of the final composites. This study investigates the non-linear mechanics and avalanche dynamics of twisted yarns, focusing on the interplay between yarn geometry, inter-ply friction, and transverse compaction.

The tensile experiments on hierarchical yarn assemblies with varying architectural parameters, including specific yarn lengths, twist angles and ply number were performed. The response reveals a distinct stick-slip phenomenon characterized by discrete stress drops, indicative of internal rearrangement and frictional slipping events between yarns. Two vital mechanical stages of the stress-strain curve, the elastic stage and the friction separation stable stage, are identified.

In the elastic part, a stress hardening with a quadratic scaling law ($\sigma \sim \varepsilon 2$), attributing the hardening mechanism to the geometrically induced increase in transverse pressure and subsequent continuous frictional locking phenomenon, is observed. Furthermore, in the friction separation stable stage, statistical analysis demonstrates that the probability density function (PDF) of these avalanche sizes follows a power-law distribution, as observed in other configurations, suggesting the yielding process is governed by critical dynamics. These findings provide essential physics-based constitutive insights into the avalanche behavior caused by friction and offer a comprehension for modeling the mechanics of textile composite reinforcements.

#581

# Numerical simulation of liquid resin impregnation in a real digitized reinforcement during Liquid Composites Molding processes accounting for capillary effects

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Liquid Composite Molding (LCM) processes are important for producing high-quality composite materials but are prone to defects like voids due to the dual-scale internal structure of fabrics. This structure features large differences (up to several orders of magnitude) in porosity and permeability between the fiber tows and the inter-tow spaces. The fibrous tows fill at a different rate than the inter-tow spaces because of the difference of porosity and permeability between both domains. This disparity in flow rates can reach several orders of magnitude, leading to a non-uniformity in the flow front, a primary cause of defect generation. Resin infiltration inside fiber tows is affected by the capillary pressure at the flow front which depends on several parameters. Therefore, accurately modeling capillary effects is essential for a comprehensive model of LCM processes. This work developed a robust numerical model to simulate resin impregnation in a digitized, real E-glass plain-weave reinforcement obtained via X-ray micro-computed tomography (CT). The simulation uses the hybridPorousInterFoam solver, which is based on the Darcy-Brinkman approach and smoothly transitions between Darcy's equations in porous regions and Navier-Stokes in free space. The solver was modified by implementing the isoAdvector advection scheme to mitigate numerical instabilities caused by the high viscosity ratio between resin and air. Capillary effects are modeled in this framework through multiscale parameters in the drag and surface tension forces. The key findings of this work include the successful mitigation of numerical instabilities, very good agreement between the simulated and experimental flow front advancement, and a parametric study confirming the significant effect of capillary pressure on multiphase flow in these dual-scale porous media.

#582

# Sustainability and Cost Assessment of Structural Components for Cryogenic H2 Aircraft Tanks

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Aviation accounts for a significant share of global warming when considering both $CO_2$ and non-$CO_2$ effects, underscoring the urgency of reducing climate impacts across all segments of air transport. Hydrogen propulsion is widely regarded as a promising pathway towards achieving net-zero emissions in commercial aviation. Among the key technological challenges is the integration of cryogenic hydrogen storage systems that meet strict safety, performance, and certification requirements. One potential configuration positions a cryogenic tank inside the fuselage, behind the passenger cabin. To enable redundancy in accordance with certification rules, such a tank may be implemented in a tandem arrangement.

The tank architecture typically consists of a double-walled structure with an outer tank, an inner tank, and an intermediate insulation layer such as multilayer insulation (MLI). The inner tank is subdivided into three structural parts—two domes and a cylindrical mid-section—to facilitate the installation of additional subsystems. Understanding the ecological and economic implications of these structural parts is essential for guiding material selection, manufacturing strategies, and design optimization in early aircraft development phases.

This paper presents an integrated environmental and economic assessment of the domes and cylinder section of such an inner tank. The methodological approach mirrors established LCA and cost-assessment frameworks. First, the manufacturing process chain is mapped, followed by the development of a detailed Life Cycle Inventory populated with primary process data. The environmental assessment is conducted using OpenLCA in combination with the Ecoinvent database to quantify the potential impacts of the structural parts. In parallel, a cost evaluation is performed, considering direct manufacturing costs and estimating the potential cost effects of scaling towards serial production. Together, these results provide a comprehensive understanding of the sustainability and economic performance of key structural components in future cryogenic hydrogen aircraft tanks.

#583

# Process Diagnostics and Microstructural Control of VPS-processed Molybdenum disilicide/Zirconium Carbide Multilayer Coatings

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Molybdenum disilicide ($MoSi_2$) and Zirconium Carbide (ZrC) are prominent candidate materials for ultra-high temperature applications due to their exceptional thermal resistance. To leverage the combined advantages of these materials, Vacuum Plasma Spraying (VPS) was employed to fabricate defect-free multilayer coatings. In this study, an optical process diagnostic system was introduced to systematically analyze the formation mechanism of $MoSi_2$/ZrC multilayer coatings. The temperature (Tp) and velocity (Vp) of in-flight particles were measured in real-time to quantify the melting state of the feedstock powders. Simultaneously, the substrate temperature (Ts) was continuously monitored throughout the entire coating process. Through the analysis of diagnostic data, the correlation between the coating formation behavior and internal porosity was quantified according to specific ranges of particle velocity, particle temperature, and substrate temperature.X-ray diffraction (XRD) analysis performed on coatings fabricated under optimized conditions confirmed that intrinsic phase stability was maintained without oxidation during the high-temperature plasma process. Furthermore, cross-sectional Scanning Electron Microscopy (SEM) analysis revealed a laminated structure with uniform thickness and the formation of strong mechanical interlocking between the layers.

This study demonstrates that diagnostic-based process control, beyond simple deposition, is an essential element for manufacturing highly reliable $MoSi_2$/ZrC multilayer environmental barrier coatings.

#584

# Predicting the Fatigue Life of Material-Extrusion 3D-Printed Biodegradable Composites Reinforced with Continuous Fibres

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Additive manufacturing of composites reinforced with continuous fibres enables the design of components with superior mechanical properties. Traditionally, these composites have utilized synthetic matrices and fibres. However, the growing demand for carbon neutrality and recyclability is shifting the focus toward combinations of natural fibres and biodegradable matrices. Previous studies have shown that among natural-fibre composites, the combination of a biodegradable polylactic acid (PLA) matrix and continuous flax fibres offers the best static and fatigue performance. For these materials to be reliably used in load-bearing components, it is crucial to accurately predict their fatigue life under cyclic loading, especially in the presence of geometric stress concentrators. To address this challenge, we investigated various fibre volume fractions, fibre arrangements, and notches of different shapes and severities in additively manufactured PLA-continuous flax fibre composites to develop a method for predicting their fatigue life. Predicting the fatigue life of these composites is complicated by the inherently non-uniform distribution of fibres within the material. This complexity necessitated a two-level methodology. In the first stage, a homogenized distribution of maximum principal stresses was obtained by transforming local stress variations into a continuous field for further analysis. In the second stage, fatigue life was predicted based on this homogenized stress state. The theory of critical distances employed proved to be highly effective, yielding engineering-accurate fatigue life predictions for all combinations of composites and notch geometries. Notched composites were successfully evaluated using both point and line methods. While both approaches tended to be conservative, the line method consistently generated predictions closer to experimentally measured fatigue lives. Significantly, the predictions from both criteria fell within the scatter band of the base material.

#585

# 3D-micro-DIC as a full-field technique for residual strain analysis using incremental hole drilling in additively manufactured nylon composites.

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Residual stresses are internal stresses that exist in most materials, mainly caused by manufacturing conditions. These stresses affect the material's behavior and can lead to warping and early damage. Obtaining an accurate measurement of residual strains, which can indicate the magnitude of residual stresses, is thus crucial yet challenging. Incremental hole drilling is one of the techniques used for residual strain measurement by progressively removing material and recording the resulting deformations, mainly using industry-standard strain gauges, solely providing data at a few specific points. Here, the novel optical monitoring technique of 3D micro-Digital Image Correlation (DIC) is leveraged. This full-field technique allows capturing a full distribution of surface strains, enabling fine full-field measurements also very close to the drilled hole. Additively manufactured composites are one of these materials that contain residual stresses arising from the deposition process. In fused filament fabrication, layer-by-layer deposition introduces nonuniform cooling and shrinkage gradients between the different layers, while the difference in fiber and matrix properties causes thermal mismatches within the part. In this study, the full-field 3D micro-DIC method to monitor strain relaxations of additively manufactured fiber-reinforced nylon composites in the incremental hole drilling method is studied. The fiber-to-nylon layering is varied, and the impact on the residual strains is studied. The study showed that the use of 3D micro-DIC enabled the capture of a full spatial strain distribution and strain gradients. The analysis confirmed that varying the fiber-to-nylon layering through the thickness alters the residual strain behavior, both in radial distribution and in drilling depth profiles. Finally, the study enabled the optimization of layering configurations with respect to the fiber-to-nylon ratio based on the measured residual strains.

#586

# Prediction and Validation of CFRP Deformation during Autoclave Curing with Orthotropic 3D-Printed Molds

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This study establishes a comprehensive finite element (FE) framework to predict, analyze, and experimentally validate the thermo-mechanical deformation, cyclic response, and long-term durability of carbon fiber-reinforced plastic (CFRP) laminates and 3D-printed composite molds during autoclave curing. Unlike conventional metallic tooling, additively manufactured (AM) molds exhibit pronounced orthotropic anisotropy caused by the layer-by-layer deposition process, which generates direction-dependent stiffness, thermal conductivity, and residual stress. To accurately represent these phenomena, the FE model defines orthotropic material properties aligned with the printing orientation and performs a fully coupled temperature–displacement analysis that simultaneously solves for transient heat transfer and structural deformation. The coupled simulation accounts for thermal conductivity, resin cure shrinkage, and interfacial thermal mismatch between the mold and laminate throughout the curing cycle. Predicted temperature gradients, stress distributions, and deformation fields are validated through dimensional measurements using a coordinate measuring machine (CMM) and 3D optical scanning, confirming strong agreement between numerical predictions and experimental observations. To assess reliability under manufacturing conditions, thermo-mechanical simulations are conducted under repeated thermal and pressure cycles representative of the autoclave environment. The analysis captures stress accumulation, strain localization, and potential failure initiation within the 3D-printed mold, providing insight into weak zones and expected service lifetime. Sensitivity studies reveal that incorporating AM-induced orthotropic anisotropy significantly enhances model fidelity and numerical stability compared with isotropic assumptions. The integrated framework provides a quantitative basis for optimizing curing parameters such as temperature, pressure, and dwell time, while enabling virtual evaluation of mold deformation, geometric conformity, and dimensional precision. This methodology demonstrates practical applicability for aerospace and automotive CFRP manufacturing, offering a reliable and cost-effective pathway to implement AM-based composite molds in large-scale production while improving thermal stability, dimensional accuracy, and tooling reliability.

#588

# Matrix and Fibre Degradation over Multiple Reuse/Recycling Steps

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The reuse of composite materials is desirable for a circular economy. Especially in the case of adhesively bonded hybrid laminates, the selective separation of composite layers (debonding on demand) enables the reuse of the composite. Where the reuse is not feasible, the reclamation of the fibres is of importance. The mechanical properties, fibre-matrix adhesion and price of recycled fibres are among the key indicators for a successful adaptation of recycled fibres. Thus, this work contributes to a better understanding of the reusability of fibres and more sustainable solutions of the waste management.

Carbon fibres (CFs) are of particular interest since recycled CFs can have a lower price compared to virgin CFs. Pyrolysis is a promising process for industrial applications. A challenge is the pyrolytic carbon that remains on the surface of the fibres after pyrolysis, typically decreasing fibre-matrix adhesion.

Adding to existing research, the degradation of the matrix and CFs over multiple reuse/recycling steps is further investigated. For that purpose, virgin CFs are embedded in an epoxy matrix. As a first step, samples are thermally cycled above the Tg of the matrix, representing thermally activated debonding. Structural changes in the matrix are monitored via NIR. As a second step, similar samples are prepared for fibre reclamation. The matrix is pyrolysed and single fibres are extracted for mechanical testing. The rest of the fibres are embedded again in the epoxy matrix for the next recycling cycle. A post-pyrolysis-treatment via oxidation is aimed at to improve adhesion and to evaluate degradation due to oxidation over multiple cycles.

The mechanical testing is done via single fibre fragmentation tests to determine the degradation of the fibre-matrix adhesion. Furthermore, single fibre tensile tests are carried out to determine the degradation of mechanical properties of the CF itself.

#589

# Improving Electrical Reliability of Fibre Composites through X-Ray Computed Tomography and Machine Learning-Based Defect Characterisation

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Modern sustainable power grids rely on large insulators capable of withstanding severe electrical and mechanical stresses. Fibre-reinforced polymer composites (FRPC) are widely used due to their excellent multifunctional properties. While their mechanical performance is well understood, dielectric breakdown mechanisms in heterogeneous FRPCs remain less researched. Microstructural features, such as voids and defects, are known to play a decisive role in electrical performance. Prior studies suggest that elongated voids along fibre–matrix interphases and between fibres, as well as hollow fibres (“high-seed fibres”), are significantly more critical than spherical voids in resin-rich regions. While mechanical failure in composites often requires the accumulation of multiple defects, a single small critical void can trigger electrical breakdown, highlighting the need for characterisation methods adapted to electrical performance.

This work introduces a multi-scale approach combining X-ray computed tomography (XCT) with machine learning (ML)-based segmentation to detect, classify, and quantify voids in FRPCs. Laminates, produced by various methods (filament winding, resin transfer moulding, and vacuum infusion) and with different E-glass fibres, were scanned (voxel sizes ranging from 0.44 µm to 5.6 µm) with a Zeiss Xradia 620 Versa. Although defects are easily detected by the eye, the low contrast between voids and resin makes it difficult to use conventional segmentation. To overcome this, ML algorithms, trained in Dragonfly 3D World were employed, which succesfully segmented and categorized voids by type. Ongoing work focuses on correlating dielectric strength with void characteristics across scales, leveraging the segmentation and classification framework described here. This approach aims to deepen the understanding of FRPC microstructure and electrical failure mechanisms, supporting the design of next-generation composites for high-voltage applications.

#590

# Experimental Multiaxial Fatigue Testing of Composite Profiles on a 6-DoF Hexapod

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The service life and damage behavior of fibre-reinforced polymers are influenced by complex multiaxial loading conditions, as they frequently occur in lightweight structures. However, conventional fatigue tests, are predominantly based on uniaxial load cases and therefore provide only limited capability to represent realistic loading paths. The aim of the present study is the experimental characterisation of the fatigue behaviour of carbon-fibre-reinforced rectangular profiles under multiaxial loading using a six-degree-of-freedom hexapod test rig. The test system enables the application of combined loading modes such as bending-compression, bending-torsion or tension-torsion, thus allowing a systematic investigation of load interaction effects on damage initiation and progression.

To reduce thermally induced effects at higher test frequencies, a cooling system with internal air flow was implemented to limit specimen heating during cyclic loading. Before the fatigue tests began, quasi-static baseline tests were conducted to calibrate stiffness, deformation patterns and boundary-condition effects of the test setup. These reference data form the basis for subsequent normalisation and interpretation of cyclic degradation processes. The cyclic loading scenarios consisted of fully reversed multiaxial load paths, realised through superimposed torsion-bending and torsion-compression combinations. During the experiments, strain gauges and complementary a digital image correlation system were employed to capture local strain fields and the evolution of stiffness over the service life. The results reveal pronounced interaction effects between the combined loading modes. In particular, torsional components led, depending on the laminate configuration, to accelerated delamination initiation and altered degradation rates compared to purely uniaxial loading scenarios.

The study demonstrates the high suitability of the hexapod test rig for reproducible multiaxial fatigue investigations and provides a robust data basis for future multiaxial fatigue criteria. Moreover, the approach opens new perspectives for realistic fatigue-based design of fibre-reinforced polymer structures in early development phases.

#591

# Self-Healing Mechanisms and Mechanical Property in Polyrotaxane-Modified Epoxy Vitrimers: A Molecular Dynamics Study

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This study investigates the effect of polyrotaxane (PR) addition on the toughness of DGEBA–AFD epoxy vitrimers using molecular dynamics (MD) simulations. Initially, the S–S reformation behavior of AFD was incorporated into the MD simulation to replicate the self-healing process at damaged sites. The results showed that the presence of PR significantly accelerated the reformation process, promoting local chain movement and network reorganization at the damaged sites. This process contributed to a more efficient repair of the damaged network structure. Next, tensile simulations were conducted to evaluate the mechanical properties with PR addition. PR was found to reduce network constraints and promote sliding motion of the ring molecules, effectively suppressing stress concentration. As a result, PR addition improved tensile strength, enhanced ductility, and increased energy absorption before failure, thus demonstrating an overall enhancement in toughness. These findings were consistently observed in both the experimental data and MD simulations, highlighting the positive impact of PR on the material's mechanical performance. Therefore, this study demonstrates that adding PR enhances the toughness of epoxy vitrimers by facilitating network reorganization, suppressing stress concentration, and improving fracture resistance. These results provide valuable insights into the design of high-performance self-healing polymers and contribute to the development of dynamic network materials for structural applications, suggesting PR as a promising additive for future advanced polymer designs.

#592

# No wind energy without composites: The early years as seen from Denmark

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The development of wind energy since around 1900 is presented with focus on the activities in Denmark. Early pioneers worked as individuals, and built their own wind mills for local practical purposes. Interest in exploring wind energy on a wider scale started in the 1960´s and accelerated with the oil crisis in 1973. At this time the potential of fibre composite materials for the rotor blades was recognized. Two early activities for building wind turbines in Denmark used very different approaches. The Tvind project was based on a vast amount of voluntary manpower, while the Nibe project used conventional engineering technology. The Tvind project used 27 m rotor blades made of unidirectional glass fibre epoxy composites, the Nibe project used 20 m rotor blades made of glass fibre polyester composites made from transversely oriented glass fibre tapes. After a slow start with small wind turbines, the development of rotor blades gained momentum with improved composite materials using optimal placement of glass and carbon fibres in a polymer matrix and with improved structural designs of the blades. The study of fatigue behaviour of composites became an important activity as the size of wind turbines increased from about 100 kW power to more than 10 MW power. The sizes of the required rotor blades increased with lengths from about 5 m to over 100 m, and with weights from about 100 kg to more than 50 tons. This increased scale of the blades presented new problems such as handling and transporting, erosion of the leading edge of the blades, end of life management of composite materials, and siting of wind turbines moving from land to offshore.

#593

# Shielding of Carbon Fibre Polybenzoxazine Polymer Composites with POSS Incorporation and HDPE Sandwich Structures Against Space Radiation

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The growing emphasis on long-duration space missions underscores the need for effective radiation protection for both astronauts and spacecraft electronics. Although they constitute only about 1% of Galactic Cosmic Rays (GCR), high-energy heavy ions (HZE) remain a major source of potential biological and material damage. Building on previous work carried out within two ESA-led international programmes (AO-2020-EMA and AO-2022-IBPER), where polybenzoxazine (PBZ) modified with polyhedral oligomeric silsesquioxanes (POSS, at 5 wt%, 10 wt%) is currently being exposed to the low Earth orbit (LEO) environment on the International Space Station (Kong et al., Composites Part B, 2024, 276:111311), this study extends the concept to a structural shielding architecture. Here, POSS-incorporated (10 wt%) carbon fibre-reinforced polybenzoxazine (CFR-PBZ) composites are employed as the load-bearing skins of a novel sandwich system featuring a high-density polyethylene (HDPE) core. The CFR-PBZ skins provide high mechanical performance suitable for structural applications as well as protection against ATOX erosion, while the hydrogen-rich HDPE core enhances attenuation of HZE and moderation of secondary neutrons generated through HZE fragmentation. A honeycomb configuration is integrated into the HDPE layer to further improve stiffness and load-bearing capacity. Prototype sandwich structures were irradiated with a 1 GeV/n Fe ion beam at GSI, Darmstadt, and corresponding FLUKA Monte Carlo simulations were conducted to estimate dose rate and secondary particle production. Thermal analyses were performed to characterise the viscosity, thermal stability, and glass transition behaviour of the composite constituents. Compared with conventional shielding concepts, the proposed composite architecture demonstrates enhanced radiation protection at a significantly reduced surface mass, a key requirement for aerospace applications. These results highlight the potential of advanced multifunctional composite systems for spacecraft hulls, habitat modules, and radiation-sensitive equipment.

#596

# Investigation of innovative mechanical recycling methods for vitrimer-matrix composites

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Despite their lightweight benefits, the sustainability of fibre-reinforced composites might be questionable, since their complex end-of-life management makes their incorporation into a circular economy cumbersome. In the last decade, recycling has gained increasing attention. The established approach for thermoset composites consists of a two-step process: fibres reclamation, performed through thermal or chemical methods; and their reformatting into a new product. Instead, mechanical methods consisting of shredding and grinding cause a substantial downcycling of the material due to extensive fibres length reduction, despite offering many advantages such as reliance on mature technologies and lower energy consumption. For this reason, mechanically recycled composites are used as reinforcing fillers in polymer compounds and cements.

In parallel, the use of new constituent materials represents an active research field: vitrimers, a recent class of polymers characterized by associative covalent adaptable networks, have emerged as attractive alternative matrices. Vitrimers-matrix composites combine the structural performance of thermosets with the reprocessability, repairability, and recyclability of thermoplastics.

In this study, a novel mechanical recycling method exploiting the unique properties of vitrimers is investigated. The use of a vitrimer matrix enables the reprocessing of cured material above the topology freezing temperature, eliminating the need for fibre liberation. Virgin laminates were manufactured using basalt fibres impregnated via vacuum infusion. The laminates were then delayered into their original plies, minimizing fibre damage. The individual plies were subsequently reformatted into either continuous laminates or patch-based architectures. The proposed approach aims to overcome the performance limitations of conventional mechanically recycled composites by preserving fibre length. Both the manufacturability and mechanical performance of the resulting laminates were evaluated, providing evidence of the method’s effectiveness.

#597

# Temperature dependent vitrimer matrix composites fracture behavior

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Vitrimers are polymers bearing dynamic covalent bond within their crosslinked network. By undergoing associative bond exchanges these dynamic crosslinking bonds can rearrange the material topology network rendering it reprocessable and repairable. Using vitrimers as matrices represent the new frontier of circular composite materials since they combine the properties of thermosetting matrices at service temperature, allowing also reprocessing and intrinsic repair of matrix and interface damages. The possibility to extend the useful life of a component by repairing it, or to reprocess and repurpose decommissioned ones, contributes to the mitigation of the increasing waste generated by the composite sector.

Since the reprocessing and healing properties of vitrimers are usually controlled by heat, that increases the bond exchange rate, it is crucial to determine the material behavior approaching and surpassing this activation temperature, i.e. topology freezing temperature (Tv), to fully exploit the possibilities offered by these materials and correctly design the reprocessing and repair processes. In this work the effect of temperature on the mechanical and fracture behavior of vitrimer matrix composite is investigated.

Thermo-mechanical and stress relaxation tests on the vitrimer resin are used to identify the vitrimer’s characteristic temperatures, i.e. Tg and Tv, and define the reprocessing temperature window. Mechanical tests are used to assess the material properties and their temperature dependence within this interval. Interlaminar fracture tests are used to investigate the interply properties of the laminate at reprocessing conditions: as temperature increases the fracture toughness of the vitrimer-composite was recorded to increase as the ductile behavior of the matrix was enhanced, leading to larger plastic deformation.

This study contributes to setting the foundation of the use of vitrimer matrix composite for structural application while keeping the focus on their End-of-Life management.

#598

# Influence of Microbond Sample Preparation Method on Interfacial Strength in Flax, Glass, and Carbon-PLA

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This work directly compares the effect of two sample preparation methods on the interfacial shear strength (IFSS) measured using the microbond technique for the first time. PLA fibres were wrapped around a specimen fibre's circumference and secured in a single overhand knot. Alternatively, PLA was dissolved in chloroform (5%wt./vol.) and the polymer was applied as a solution using a pipette. Both tied and solution cast samples were heated to 180oC for 15 minutes to form the PLA microdroplets. Apparent differences in droplet geometry were evaluated by means of optical and hot stage microscopy. SEM was carried out to examine the failure mode of tested droplets, and DSC performed to identify differences in the thermal properties of tied versus solution cast droplets.

The IFSS obtained for microdroplets prepared by solution method was 50%, 29%, and 15% higher than that of the tying method for flax, glass, and carbon, fibres, respectively. Droplets prepared via solution method yielded embedded lengths that were much smaller than those prepared by the tying method. For flax fibre, droplets prepared by solution method had an average embedded length of 97.0 ± 36.1µm compared with 121 ± 20.5 µm for tied droplets (p-val 0.0022). This greatly improved the testing success rate for flax samples, increasing from 37% for tied samples to 78% for solution cast. An approximately 30% increase in droplet aspect ratio was also observed for each fibre type. Further theoretical and experimental analysis was conducted to evaluate the effect of preparation method on wettability.

The ease and efficiency of sample preparation, greater reproducibility, improved testing success rate, and increased fibre wetting all make solution casting an attractive sample preparation method. These advancements all streamline experimental procedures and provide greater confidence in the accuracy of interfacial shear strength measurements.

#599

# Genotype-Structure-Property Relationships in Fibre Nettle: A Multiscale Study from Fibre-Level Properties to Composite Performance

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Nettle (Urtica dioica L.) has a long history as a fibre crop for the textile and composite industry. First cultivation efforts were undertaken before 1950 by the scientist Gustav Bredemann, based on different nettle wild types to optimise the plant for biomass yield and bast fibre content. Improved nettle clones were developed in the 1990s, resulting in a wide range of fibre-nettle clones available today. In this context, the term “clone” refers to genetically identical, vegetatively propagated nettle lines with consistent, breeder-selected fibre traits.

Fibre bundles from a historically older nettle clone (B13) and two modern genotypes (L18 and Z10) were analysed regarding their mechanical properties. Injection moulded and hot-pressed composites were produced from the fibers and characterised. Additionally, the effect of longer cultivation times (1 year and 2 years) on fibre bundle and composite properties were studied to test the hypothesis that fibre nettle cultivation needs two years to be established before biomass for fibre production can be harvested.

Comparing the fibre yield after decortication and cleaning from the different clones, significantly lower values were found for the B13 clone (5,62 %) compared to Z10 (12,17 %) and L18 (12,07 %). The same difference was observed for the fibre bundle tensile strength and the tensile strength of the composites from hot-pressing. Fibre bundles of the L18 clone showed the highest tensile strength (319 MPa) and B13 the lowest (211 MPa). Comparing the fibres from the Z10 clone from one-year-old and two-year-old plants, significant differences in fibre yield, morphology and mechanical performance were observed, with lower yield and finer fibre bundles from the one-year-old samples at lower mechanical properties. The overall findings confirm that the L18 and Z10 clones outperform the historically earlier-developed B13 clone, suggesting they are better suited for innovative nettle fibre-reinforced composites.

#600

# Optimizing Subcritical Hydrolysis Degradation of Composite Matrices to Enable Carbon Fiber Recycling

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Recycling carbon fiber–reinforced polymers (CFRP) remains a critical bottleneck for a circular composites economy. Chemical depolymerization of the matrix enables selective recovery of high-quality carbon fibers while minimizing damage to their microstructure. In addition to acids, bases, and alcohols, water operated in the near- or supercritical regime provides a reactive yet benign medium with tunable solvating power.

Epoxy (EP) matrices commonly employ amine or anhydride curing agents, which dictate hydrolytic behavior: amine-cured EPs are hydrophilic but possess hydrolysis-resistant backbones, whereas anhydride-cured EPs are less hydrophilic yet contain ester linkages amenable to cleavage. Vinyl ester (VE) resins likewise contain ester groups, but steric shielding within their network and an otherwise robust architecture confer high chemical resistance even in corrosive environments.

This work reports a design-of-experiments study on hydrolytic depolymerization of an anhydride-cured EP immersed in near-critical water. Temperature, isothermal hold time, and water amount were varied systematically. The mass loss of cubic specimens served as the response metric. Temperature exerted the dominant influence on degradation, with hold time producing a significant secondary effect. Within the investigated window, the amount of water only weakly affected mass loss. Decomposition proceeded primarily at the specimen surface, consistent with diffusion-controlled transport or surface-reaction-limited kinetics.

Complementary tests on VE under comparable conditions were performed to benchmark material-specific hydrolytic stability. VE exhibited markedly slower degradation, attributable to steric protection of ester groups and the chemically resilient network.

The results outline process windows for water-based chemical recycling of CFRP, enabling matrix removal while preserving fiber properties. They provide guidance for scaling near-critical water treatments and for tailoring conditions to resin chemistry across mixed CFRP waste streams.

#601

# Recyclable Sandwich Components - Using Hybrid Vitrimers for Disassembly

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Current interior cabin components in commercial aircraft are typically constructed from aramid honeycomb cores and face sheets made of glass-fiber-reinforced phenolic resins. This material system presents significant recycling challenges. In response, the “CirKle” project, funded by the German government (LuFo VI), is focused on the development of a recyclable sandwich structure for these interior applications.

One existing recycling strategy, solvolysis, enables the recovery of fiber layers from complex laminates. However, this method has limitations, as the recovered layers often require trimming. This leads to an application-dependent and uncontrolled reduction in fiber length over successive recycling cycles.

This presentation focuses on the disassembly of sandwich components as an alternative recycling strategy. A promising approach is the design of hybrid vitrimer systems that combine permanent thermoset networks with dynamic vitrimer segments. By strategically tailoring the glass transition temperatures of the matrix materials in the core and face sheet, it is possible to facilitate both the welding and disassembly of the components while preserving the mechanical integrity required for structural applications.

In the proposed design, the recyclable sandwich structure consists of a face sheet composed of a fiber-reinforced hybrid vitrimer and a core containing a pure vitrimer matrix. The glass transition temperatures of these two materials can be precisely modified by adjusting the fraction of permanent crosslinks within the hybrid matrix and by altering the curing temperature. The separation of the face sheet and core is then conducted at a temperature where the dynamic covalent bonds of the core's vitrimer are active, while those in the face sheet's hybrid vitrimer are less so. This differential activity enables the preservation of the original fiber length and orientation within the face sheet with minimal technical intervention.

#602

# Characteristics of PZT/Alkali-Activated Composites for Piezoelectric Sensors

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Piezoelectric sensors are commonly used in structural health monitoring (SHM) to enable real-time monitoring and detection of structures. In addition to piezoelectric lead zirconate titanate (PZT) sensors, piezoelectric cement (PEC) sensors have also been proven effective for SHM of concrete structures. Literature indicates that the effective frequency of the electromechanical spectrum generated by the PZT sensor is difficult to determine, while the PEC sensor is easier to identify. Alkali-activated materials (AAM) are used as cement binders to achieve sustainability by utilizing industrial byproducts, thereby reducing energy consumption and carbon emissions. AAM has similar properties to ordinary Portland cement (OPC), but with improved chemical resistance and electrical conductivity. This study investigated the electrical and piezoelectric properties of a PZT/AAM sensor fabricated with AAM as the matrix (substrate) and PZT as the inclusion. The PZT/AAM sensor is a novel type of piezoelectric sensor. Ground granulated blast-furnace slag (GGBS) and Class F fly ash are used as binders, and sodium hydroxide (NaOH) serves as an alkali activator. AAM binders were prepared with varying slag-to-fly ash volume ratios and alkali equivalents (3–9%). The piezoelectricity of the PZT/AAM sensor is achieved by using 50% PZT by volume and a polarization process. Experimental results show that the AAM hardening phase diagram has been successfully established. With increasing fly ash content and decreasing alkali equivalent, both the relative permittivity and piezoelectric strain constant (d33) increase. However, the piezoelectric voltage constant (g33) shows an opposite trend. Piezoelectric alkali-activated composites have the potential to be used as sensors and actuators.

#603

# Numerical-Experimental Print-Scale Investigation of PA11 Short-Fiber Composites in SLS

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Selective Laser Sintering (SLS) enables the fabrication of complex polymer composite parts without support structures, making it highly suitable for high-performance applications that require intricate geometric detail. The reliability of the SLS process is strongly influenced by temperature evolution during printing, which is governed by, e.g., laser parameters, part placement, and nesting density. This complexity is further amplified in composite polymers, where short fibers introduce anisotropic thermal behavior that affects heat transfer. This study presents, for the first time, a combined numerical-experimental approach to investigate these interactions and their impact on part quality at the full print scale.

A continuum, low-fidelity, print-scale model was developed for PA11 short-fiber composites to simulate heat transfer and crystallization kinetics during SLS. Extensive experimental differential scanning calorimetry (DSC) data were incorporated to accurately model material crystallization behavior. Validation was carried out on a Lisa X SLS printer with in-situ thermal imaging to capture the temperature field throughout the build. The numerical-experimental approach allowed systematic evaluation of how laser parameters, part placement, and nesting density affect thermal history and part quality.

Key findings suggest that parts near the build plate edges experience faster cooling and reduced thermal uniformity, an effect amplified by the dramatically increased thermal conductivity from carbon fiber reinforcement. The anisotropic conductivity of the short fiber reinforcement drives enhanced lateral heat flow, causing excessive heat to accumulate in the narrow gaps between parts at high nesting densities. These results demonstrate the interplay between process parameters and composite material behavior, providing quantitative insight for improving part quality.

By integrating efficient computational modeling with experimental validation, this work establishes a framework for optimizing SLS processes for complex composite materials. This approach provides a pathway to enhance process reliability and reduce defects, supporting broader adoption of SLS in advanced polymer manufacturing.

#604

# Closed-Loop Recycling of Resistance-Welded Thermoplastic Composite Joints: Influence of Heating Element Material on Disassembly and Rewelding

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Thermoplastic composites (TPCs) are employed across various industries, including aerospace, automotive, maritime, energy, and sporting goods. In contrast to thermosetting plastics, thermoplastic matrices can be reversibly melted again. The capability opens up new opportunities for recycling, reuse, and reshaping into new components, leading to a growing interest in the research of repair and recycling techniques for TPCs.

This study investigates a fully closed-loop recycling process for resistance-welded TPC joints. The process comprises three stages: (1) resistance welding of carbon fibre-reinforced low-melt polyarylether-ketone (CF/LM-PAEK) laminates, (2) debonding via resistance heating, and (3) subsequent rewelding of the separated adherends. Special emphasis is placed on the heating element (HE). For welding with a stainless-steel HE, an optimal separation temperature of 285 °C and a traverse speed of 175 mm/s has been identified, yielding clean debonding and fully reweldable surfaces. Since CF HEs—often combined with a glass fibre-reinforced insulation layer—are also widely used, this work further compares a stainless-steel HE with a CF woven HE in both insulated and uninsulated configurations to examine how the HE material affects the process performance. In comparison to stainless-steel HE, a CF HE exhibits a less uniform temperature distribution, which could significantly influence the debonding behaviour. Furthermore, the deterioration of mechanical properties, compared to the initial joint strength before the separation and subsequent rewelding step when using the CF HE, is quantified. Joint performance is evaluated by measuring lap-shear strength, as well as intralaminar shear strength.

The findings provide new insights into HE selection and support the development of sustainable repair and recycling strategies for fusion-welded TPC structures. By systematically evaluating the reparability of fusion-bonded TPC coupons produced with different HE configurations, this study establishes key criteria for assessing the practical feasibility of a circular-economy approach to TPC components.

#605

# Inverse Design of Polymer Properties Using Molecular Dynamics Data and Machine Learning

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In this study, we establish a machine-learning framework that makes use of polymer property data obtained from molecular dynamics (MD) simulations to clarify structural features that influence thermomechanical performance. First, we utilize an existing dataset consisting of approximately 1,000 polymer structures and their corresponding thermomechanical properties, which is available in the public “radonpy” repository providing semi-automated evaluations of polymer property data. To improve the diversity and representativeness of this dataset, we apply a self-organizing map (SOM), an unsupervised learning method, to generate additional samples while maintaining the underlying distributional characteristics. The augmented dataset is then used to train a deep neural network, which enables inverse analysis for identifying structural factors that exhibit strong correlations with enhanced thermomechanical performance. A notable aspect of this study is the use of structure-directed descriptors—such as the numbers of functional groups and benzene rings—as design variables, instead of relying on conventional molecular fingerprints. These descriptors directly represent tunable molecular design parameters, allowing the resulting structure–property relationships to be more interpretable and practically meaningful. Overall, the proposed framework can identify structural features associated with high thermomechanical performance and provides a data-driven basis for the rational design of high-performance polymer materials, offering useful insights that may accelerate the systematic exploration of broader chemical design spaces.

#606

# Computational and experimental study on the honeycomb cell deformation during the curved surface forming

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Directly bending honeycomb core materials into the designed surfaces remains the most cost-effective approach to manufacture curved sandwich structures [1]. However, non-appropriate in-plane mechanical properties of honeycomb cell architectures could cause severe deformation rebound [2]. Therefore, predicting the cell deformation during the forming becomes critical for assessing the conformability of the honeycomb panel to the designed curved geometry at the design stage.

This aim of this work is to identify the critically deformed cells during the curve formation of honeycombs via finite element analysis (FEA) using ABAQUS/Explicit. The single-curvature and the dome shape will be studied as the deformation cases. The honeycomb cell employs a non-hexagonal cell architecture, which is reported to exhibit an enhanced curved-shape formability [3]. The simulation process involves a bottom mould fixed in space. A top mould with the same curvature bends the honeycomb panel towards the bottom mould quasi-statically. The cell deflection on the honeycomb top surface is captured to compare with the experimental measurement.

The model will be validated by an experimental measurement on the cell deflection during the bending. The test setup for capturing cell wall deflection is based on a video gauge facing downwards, and the honeycomb is bent into the mould. The cell wall deflection is calculated based on the difference between a baseline image taken when the honeycomb is undeformed, and an image taken of the deformed panel. The cell deflection is calculated by the coordinate difference between the sampling points taken on the two images.

References

[1] Zhao et al. Compos Struct 2021;277. DOI:10.1016/j.compstruct.2021.114604

[2] Wei et al. J Mech Phys Solids 2024;193:105890. DOI:10.1016/j.jmps.2024.105890

[3] Pütz et al. CEAS Space Journal 2023;15:203–11. DOI:10.1007/s12567-022-00444-1

#607

# Statistical Evaluation of Surface Variability on Mode-I Performance of Adhesively Bonded Composite Joints

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As composite technology continues to evolve, adhesive bonding is a promising method for achieving efficient, lightweight joints. Yet, the reliability of these joints remains a key challenge, driven by the complex interplay of multiple parameters governing the bonding process. Despite advancements in adhesive technologies, reliability issues remain a critical challenge within the aerospace industry, especially for primary structures, where they can significantly impact joint performance, structural integrity, and ultimately aircraft safety and efficiency resulting in limited application in secondary structures.

This work investigates the influence of variations in the manufacturing and bonding processes on the Mode-I fracture behaviour of adhesively bonded composite joints. Focusing on surface treatment parameters, two sets of carbon-fibre adherends bonded with an epoxy-based adhesive were prepared, one subjected to atmospheric plasma treatment and the other cleaned only with isopropyl alcohol, and their performance was compared via Double Cantilever Beam (DCB) testing. Statistical assessments were then used to quantify the post-treated surface variations in key parameters both spatially across the samples and between repeat samples. Studied parameters included changes in the surface roughness and surface free energy, which in addition to those for thickness and fracture toughness values were used to generate the respective probability distribution functions. The results obtained from the analysis provide the crucial first steps for quantifying uncertainty propagation from the testing to the simulation and design phases of adhesively bonded joints in Mode-I loading. In addition to these, key correlations between the surface preparation parameters and the resulting Mode-I fracture behaviour were also established through the Analysis of Variance (ANOVA) method to quantify to what extent the specific bonding conditions enhance adhesion consistency and fracture toughness.

The outcomes ultimately contribute towards improving the predictability of adhesive bonding processes in aerospace applications, supporting the development of more efficient and lighter aircraft structures.

#608

# A mesoscopic continuum damage material model for filament wound [±α] plies

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Filament wound CFRP pressure vessels are widely used for storage and transportation of pressurized gaseous substances. Especially for the development of a future hydrogen economy, these vessels play an important role since due to its low density the storage of substantial amounts of hydrogen requires rather high pressures of 350 bar to 700 bar and beyond. Due to the nature of the winding process, filament wound plies feature an angle-ply like microstructure where the [+α] and the [-α] plies – in contrast to classical laminates – cannot be separated in the rigorous sense. Hence, the structural integrity assessment in most cases is performed on the mesoscopic level of the [±α] plies.

The present contribution is directed to the formulation, implementation and validation of a continuum mechanics damage material model for filament wound CFRP materials formulated on the level of the [±α] plies. The model adopts the classical Puck failure model reformulated in strain rather than stress space. The approach of a strain state point in strain space is assumed as the damage driver in the damage evolution equation. As in the static Puck failure criterion, fibre and inter-fibre damage and fracture are treated as separate damage effects, accounted for in terms of separated damage variables. Assuming micro plasticity as the predominant damage mechanism, a model capable of both static and fatigue damage due to pressurizing cycles is obtained.

The model is implemented as a user defined material model into a commercial finite element code. The model is validated against an experimental data base of standard tensile tests on plane specimens as well as split disk experiments on filament wound [±α] CFRP materials with different winding angles. Finally, the approach is demonstrated in the integrity assessment of a filament wound reference pressure vessel.

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# X-ray µCT microstructure correlated with mechanical properties in short-fibre-reinforced SLS printed composites

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Selective Laser Sintering (SLS) is an Additive Manufacturing technology which uses a laser to fuse polymeric powder particles to build parts layer-by-layer. Commercially available short-fiber-reinforced thermoplastics offer enhanced mechanical properties compared to neat polymer, but it is known that the material properties are highly sensitive to build orientation and laser energy density (ED). In this work we investigate bio-based polyamide 11 reinforced with short carbon fibers (PA11-CF). Tensile testing specimens were fabricated at various ED values and oriented in three principal directions: X (aligned with powder spreading), Y, and Z (in build direction). The specimens were examined using microscale X-ray computed tomography (µCT) to analyze porosity and fiber orientation within the printed parts.

The µCT analysis revealed a distinct relationship between ED and microstructure: as ED increased, porosity decreased, plateauing when approaching and exceeding the manufacturer's nominal ED values. The same trend was observed for the tensile properties. Furthermore, significant morphological anisotropy could be observed. Pores were primarily flattened within layers, consistent with melt coalescence and thermal gradients. Due to powder spreading dynamics, the fibers are mostly in-plane, with a preferred alignment in X, which matches the recoating direction. Consequently, the X-specimens showed the highest elastic modulus and tensile strength, followed by the Y-samples. The parts in build direction exhibited properties that were two to six times lower than their X-oriented counterparts, showing that inter-layer bonding is considerably weaker than in-plane. This supports our previous observations regarding in-plane porosity and limited inter-layer reinforcement.

Overall, the results establish quantitative process-structure-performance links for PA11-CF and show that the mechanical properties are strongly influenced by build orientation and process energy due to fiber orientation and porosity. Notably, the effect of orientation is primarily attributable to fiber alignment, as the porosity influence diminishes at sufficiently high energy density values.

#610

# The history of fibre-hybrid composites

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Fibre-hybrid composites are composites that contain two or more fibres in a single matrix. Fibre-hybridisation is often used to counteract the drawbacks of one fibre type or to create synergistic effects. The concept emerged shortly after the invention of carbon fibre and was quickly adopted in the sports and racing industries in the late sixties and early seventies. This presentation will describe the historical development of this exciting field, which often exhibited discrepancies between industrial use and academic research. While the industry often used fibre-hybrids to lower costs relative to all-carbon fibre composites, academia seemed to be mainly interested in understanding the synergies that arise. Although industrial adoption of fibre-hybrid composites remained strong, academic interest declined during the eighties, but revived in the late nineties. As improved models and characterisation techniques became available, the academic understanding of damage development improved. We will conclude by describing the most recent developments in the field and how we expect them to evolve in the future, with a focus on four topics: (1) recycling and reuse, (2) new preforms, (3) pseudo-ductility, and (4) new fibre types or combinations.

#612

# Bio-inspired Metal-Composite Joints with Stiffness Gradients

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Reliable joining of fibre-reinforced polymer-matrix composites to metals remains one of the key technological challenges to overcome when developing multi-material structures and components. Bio-inspired concepts, such as surface patterning, adhesive patterning, and stiffness grading in the adherends and/or adhesives, to name but a few, are currently being actively explored in metal-composite joint design with a view to achieving enhancements in joint strength and performance [1-4].

In this work, bio-inspired tubular metal-composite adhesive joints are investigated with a view to establish the effects of stiffness variation in the adherend and the adhesive on joint performance. Axial tension, torsion, and internal pressure loading are considered. The developed 3D FE models have been extensively validated using results from the literature. Stiffness variation in the adherend or adhesive is implemented via user defined field subroutines. Several profiles of stiffness variation in the adhesive and the adherend are examined and compared with reference joint configurations without stiffness variation. The investigated stiffness variation profiles are shown to reduce asymmetry in stress distributions in the adhesive and reduce maximum stresses in comparison with the reference joint configuration. The results demonstrate that a combination of overlap length and a stiffness variation profile in the adhesive can reduce stresses and improve joint performance.

1. Wei, Y., et al. (2024) Adhesively bonded joints – A review on design, manufacturing, experiments, modeling and challenges. Composites Part B: Engineering 276:111225.

2. Hamilton, A., et al. (2023) Optimisation of interlocking microstructured adhesive joints via finite element modelling, design of experiments and 3D printing. International Journal of Adhesion and Adhesives 120:103292.

3. Kaiser, I., et al. (2021) Bio-inspired patterned adhesives single-lap joints for CFRP and titanium. Composites Part B: Engineering 224:109182.

4. dos Reis, M.O., et al. (2020) Functionally graded adherends in adhesive joints: An overview. Journal of Advanced Joining Processes 2:100023.

#613

# Phase field prediction on the micro-mechanical behaviour of composite materials subjected to transverse compression

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Abstract: The presented research focuses on the development and application of a high-fidelity phase-field (PF) model to investigate the micro-mechanical behaviour of fibre-reinforced polymer (FRP) composites under transverse compression. As a typical multiphase material system, FRP composites consist of randomly distributed fibres embedded in a polymer matrix, with an interfacial transition zone (ITZ) that governs load transfer and damage initiation. In this study, the PF damage framework is adopted to simultaneously capture matrix cracking and fibre–matrix interfacial debonding in a unified and thermodynamically consistent manner, avoiding the need for predefined crack paths or complex interface tracking algorithms. To validate the proposed model, virtual compressive tests are performed on statistically representative volume elements (RVEs) that explicitly account for realistic fibre distributions and ITZ characteristics. The simulated stress–strain responses, damage patterns, and failure modes are systematically compared with corresponding experimental data. The close agreement between numerical and experimental results demonstrates the robustness and predictive capability of the PF model in reproducing the progressive failure mechanisms of FRP composites under transverse loading. Following validation, the model is employed to conduct comprehensive parametric studies on the effects of fibre spatial distribution, ITZ thickness, and key phase-field parameters, including the critical strain energy release rate ($Gc$) and the length scale ($l$) The results reveal the strong sensitivity of macroscopic mechanical behaviour and microscopic damage evolution to these parameters. In particular, variations in ITZ properties and phase-field length scale significantly influence crack initiation and final failure patterns. Overall, the proposed PF modelling framework provides a powerful and versatile tool for understanding and predicting the micro-mechanical behaviour of FRP composites, offering valuable guidance for material design, optimisation, and performance assessment.

Keywords: Composite material; Phase Field (PF) model; Interfacial transition zone (ITZ); Micro-mechanical behaviour; Compressive damage.

#614

# Bake it till you make it! Modelling the curing of composites with graph neural networks.

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Numerical simulations, such as the finite element method, are commonly used for the thermo-chemo-mechanical modelling of the curing behaviour of fibre-reinforced polymer composites. These methods are computationally expensive, especially for complex geometries and boundary conditions, and a trade-off must be made between accuracy and computational cost. The time consumed by these simulations also poses a bottleneck for high-throughput computation tasks such as mould design or cure cycle optimisation. Recently, deep learning models have shown immense potential as surrogate models for accelerating physics simulations.

In this work, we propose a graph neural network based on the MeshGraphNet architecture to predict the evolution of temperature and degree of cure through the thickness of a composite material with carbon fibres and RTM6 epoxy matrix. Current works on modelling cure with AI are limited to specific part geometries and simple 1D through-thickness simulations. We demonstrate how modelling the finite element discretised mesh of a 2D domain as a graph enhances the model's robustness in generalising to different geometries. Our approach accurately captures the temperature overshoot within the material thickness due to exothermic cross-linking reactions. Our model's predictive performance agrees very well with that of finite element cure simulations, with a mean error of 1.03 °C in temperature predictions and a mean error of 0.01 in degree of cure predictions across the validation set. More importantly, these simulations are generated in 0.6 seconds on average, achieving nearly 96% reduction in run-time compared to numerical solvers like COMSOL. We then couple the trained model with a genetic algorithm for fast multi-objective optimisation of the cure cycle for a thick part, with the objectives of minimising both the process time and peak temperature within the part, thus obtaining a Pareto front with multiple cure cycles as optimal solutions.

#615

# Delamination and Repair in Epoxy-Vitrimer Multi-Matrix Composites

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The increasing demand for sustainable high-performance composites has highlighted the limitations of conventional thermosets matrices, in particular their poor repairability and recyclability. Recently, vitrimers, a new class of polymers, have attracted the attention of the scientific community because, although they have the mechanical and durability characteristics of traditional thermosets, they can be reprocessed and repaired like thermoplastics, once the Topology Freezing Temperature (Tv) has been exceeded; in this regard, vitrimers emerge as a promising solution, offering the advantages of both thermosets and thermoplastics.

Research has demonstrated that composite structures' life cycle can be easily extended through simple repair procedures if vitrimers are used as matrices. However, would be antieconomic to replace conventional epoxy throughout whole structures: the incorporation of vitrimer only in strategic areas, i.e. those more prone to damage, wear and delamination, would be more efficient. The creation, through existing manufacturing methods, of multi-matrix composite structure that combines conventional and self healing matrices would represent a novel route towards a more circular composite industry.

The aim of the present study is to examine the delamination behavior and repair methodology for an epoxy-vitrimer multi-matrix glass fiber composite. The specimens were manufactured by hand layup process, using VITRIMAX T130 and high temperature epoxy resin as matrices, and unidirectional glass fibers as reinforcement phase. Three different curing strategies were tested to determine which one provides the highest Mode I Interlaminar Fracture Toughness, and the optimum healing cycle was evaluated by studying the influence of temperature, time and pressure on the fracture toughness retention.

This work can guide the development of more resistant, repairable and circular

composites materials, paving the way for their applications in a wide range of challenging industrial sectors.

#617

# Beyond Processing Parameters: Strip Alignment as the Key to High-Performance Recycled CFRTP via Direct Compression Moulding

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Continuous fibre-reinforced thermoplastics (CFRTP) are increasingly used in industry due to their high mechanical performance, short processing cycle times, storability, re-meltability, and good formability. However, their growing use generates large amount of production offcuts and end-of-life parts, while efficient recycling strategies remain limited. Mechanical recycling is a promising pathway when fibre length can be preserved above the critical threshold, ensuring effective load transfer and enabling the recycled material to retain high mechanical performance.

This work evaluates the mechanical recycling of CFRTP through direct compression moulding focusing on fibre-length preservation and support sustainable lightweight applications in the automative sector. Industrial CFRTP offcuts were cut into strips and processed in two conditions: randomly oriented and bi-directional (0/90). Since long fibres in the strips remained undamaged during recycling, high-quality mechanical performance was achieved. Preliminary tests varying the overlap ratio showed that efficient inter-strip load transfer is essential for obtaining structurally sound parts.

a systematic evaluation of processing parameters including temperature, pressure, strip orientation, overlap ratio, and cutting angle was performed. Energy consumption during compression moulding was also monitored to assess the industrial and environmental competitiveness of the recycling route.

The results demonstrate that while temperature and pressure have minor influence within stable processing windows, orientation and cutting angle are the dominant factors governing part quality. Bi-directional layups showed significantly superior properties compared with randomly oriented configurations, and specimens cut along the fibre direction exhibited the highest mechanical performance. However, one must consider that improper process parameters such as temperature and pressure may lead to strip deformation, displacement, or loss of overlap, ultimately causing premature failure. Taken together, the findings show that controlled strip orientation, preservation of long fibres combined with optimized moulding conditions, provide a robust and energy-efficient recycling route for CFRTP, supporting circular material use in lightweight automotive components.

#618

# Examining the Effects of Controlled Polymer Ablation as a Surface Treatment of Composite Materials for Paint Application in Aerospace

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In aerospace applications, coating performance is critical to the protection of structural components against environmental degradation as well as maintaining and enhancing aerodynamic integrity. A common protective coating utilised in the industry is paint. Paints can offer a wide range of protections for surfaces such as chemical, environmental, and mechanical. They can help prolong the performance and service lifetimes of composites in the relevant applications. Surface pre-treatment techniques are commonly employed to enhance paint adhesion. There are number of traditional surface preparation and bonding techniques available for composite substrates. However, many of these techniques can be unreliable and often serve as a barrier to the wider adoption of composite materials due to a lack of confidence in the adhesive strength of the paint to the composite surface.

This study investigates Controlled Polymer Ablation (CPA) as an innovative surface pre-treatment method designed to improve paint adhesion, durability, and weatherability on polymer-based aerospace substrates. A comprehensive adhesion programme was designed and completed across epoxy carbon fibre, glass fibre, and copper mesh composite substrates, comparing polyurethane coatings and epoxy primers under both ambient and environmental conditions. The effect of shelf-life (i.e. time between treatment and painting) was also considered. Testing included ASTM pull-off and cross-cut methods alongside hot/wet and fuel immersion exposure to replicate real service environments. The samples were then evaluated using a combination of visual assessment as per the relevant ASTM standards as well as optical and scanning electron microscopy techniques for more detailed investigations into the associated failure mechanisms and surface morphologies.

#619

# Influence of Loading and Environmental Conditions on Adhesively Bonded Composite Joints: Assessing Controlled Polymer Ablation as a Surface Pre-Treatment

Mohamed Beshr[1], Róża Paterek[1], Aaron Byrne[1], Shubham Sharma[1], Cian Madigan[2], James Clancy[2], James Nicholas Barry[2], Brandon Crosbie[3], David Murray[3], Tomás Flanagan[3], Joseph Mohan[1]

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Lightweight composites are being increasingly used in the aerospace sector due to their superior strength-to-weight ratio and the resulting improvements in fuel efficiency. However, surface preparation for bonding of these materials remains a key challenge. This surface preparation process is crucial for the bonding of composite joints which need to be capable of withstand cyclic loading without premature failure. Current surface treatment methods can damage the substrate and are difficult to automate. Controlled Polymer Ablation (CPA) offers an automated alternative that uses atmospheric pressure plasma to selectively remove the polymer surface of the composite, without damaging the underlying fibres. The development and optimisation of this plasma ablation process could remove a significant barrier to the broader use and of lightweight composites in structural applications of the manufacturing process across the aerospace industry.

A significant challenge in the implementation and testing of these joint systems lies with the durability and reliability of the adhesive bonds withstanding high-rate, fatigue and hostile environmental conditions encountered in service.

Controlled polymer ablation was evaluated as a pre-treatment technique for enhancing adhesively bonded composite joints. This study utilised Hexply 8552/5H composite laminates bonded with Solvay FM300 film adhesive. The performance of CPA treated joints was compared to industry standard techniques, such as wet peel ply, dry peel ply and sanding. The resulting joint systems were tested using single-lap shear (SLS) and mode I double cantilever beam (DCB) tests under quasi-static, high-rate and fatigue conditions at room temperature. Additionally, the joint systems were also pre-conditioned at 85 % RH at 80 °C until the weight of the samples stabilised.

Key performance criteria, including residual strength, failure mechanisms, and overall durability under high-cycle fatigue loading, were evaluated using a combination of mechanical testing and failure surface visualisation via optical and scanning electron microscopy.

#620

# Mind the gap: Improvement of the life cycle inventory for epoxy resins

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Sustainability demands for lightweight structural materials now routinely call for life cycle assessment (LCA) to quantify potential environmental burdens. Fibre-reinforced plastics (FRPs) are especially challenging, because proprietary manufacturing data are rarely disclosed, leading to incomplete or missing primary information. A critical bottleneck is the construction of a robust life cycle inventory (LCI) for epoxy resin systems, which are characterised by a wide range of hardeners, reactive diluents, and other additives. Consequently, many LCA practitioners use proxy data that may not reflect the specific chemical composition of the resins in question.

This study examines the implications of using such imprecise data and the resulting uncertainties by conducting a cradle-to-gate life cycle assessment (LCA) of three commercially relevant epoxy resin systems. First, a modelling strategy is developed in which the selection of databases and data sources is tailored to the properties of each resin system. Using this strategy, a detailed LCI is created for each resin, taking into account all relevant chemical compounds contained therein. The environmental impact assessment is then carried out, with results analysed from individual resin components and correlated with their chemical structures. To benchmark the sensitivity of the outcome, the results are compared against a proxy dataset and subjected to a sensitivity analysis in accordance to DIN EN ISO 14044.

The analysis reveals that variation in additives, curing agents, and production processes can significantly alter impact indicator results across the key categories such as global warming potential, resource use, and human toxicity. The findings underscore the necessity of developing comprehensive LCIs for synthetic resins and highlight the fact that neglecting these factors may lead to misleading conclusions. Future LCA work should therefore prioritise accurate, system specific data acquisition to ensure reliable environmental evaluations of epoxy based lightweight composites.

#621

# Dynamic biobased epoxy networks with diamine hardeners for sustainable and circular thermosets

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Due to economic reasons, fibre-reinforced composite materials used in aircraft interiors are currently not adequately sorted or recycled. As a result, approximately 15% of all aircraft parts that end up in landfills originate from the aircraft cabin. The recyclability of these materials is further complicated by the permanent covalent cross-links in the cured (including bio-based) thermosetting matrix materials which make recycling extremely difficult or even impossible [1]. A transition to a circular economy for structural fibre-reinforced thermoset composites therefore requires advanced cross-linked polymer networks that combine high mechanical performance with reprocessability and recyclability [2,3]. Dynamic covalent polymer networks (vitrimers) represent a promising class of materials in this regard, as they allow topological rearrangement of their covalently cross-linked networks via thermoactivated bond-exchange reactions [4,5]. Amine hardeners are widely used in epoxy systems because they initiate ring-opening polymerization of epoxide groups, forming highly crosslinked networks with excellent mechanical strength and adhesion. Compared to alternatives such as anhydrides or phenolic hardeners, amines offer faster curing at lower temperatures, better compatibility with a variety of epoxy resins and the ability to incorporate functional motifs for advanced material properties [6,7].

Herein, we investigate biobased epoxy resins cured with dynamic diamine hardeners incorporating acetal and disulfide functionalities and evaluate their applicability as dynamic epoxy-amine networks in fiber reinforced composites for aircraft cabin interior applications. Resin formulations were prepared by stoichiometric mixing of biobased epoxy monomers and dynamic diamines. The influence of acetal and disulfide hardeners on cure kinetics, thermal and thermo-mechanical properties were systematically investigated. With the most promising dynamic network identified, effects of temperature and humidity on the network performance was further evaluated. The results highlight the potential of biobased dynamic epoxy systems to combine sustainability with functionality, offering pathways for repairable, recyclable composite structures.

#623

# Influence of Injection Moulding Parameters and Post-Consumer Recycled PP Content on the Mechanical, Thermal, Processing, and Optical Properties of Virgin-rPP Blends

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This study explores the combined impact of injection molding process parameters and blend ratios of post-consumer recycled (PCR) polypropylene (PP) with virgin PP on mechanical, thermal, processing, and optical properties with primary focus on automotive applications.

A comprehensive Design of Experiments (DoE) approach was employed to systematically vary seven key processing factors: melt temperature, screw rotational speed, holding pressure, mold temperature, injection rate, packing pressure, and recyclate blend ratios. The recyclate content was varied in four levels ranging from 0% to 100% to assess the influence of post-consumer recycled polypropylene on the material and component performance comprehensively. Specimens were evaluated for tensile strength, Charpy impact resistance, and hardness to assess mechanical behavior and durability. Thermal stability and melting characteristics were analyzed using thermogravimetric analysis and differential scanning calorimetry to understand degradation and phase transitions. Melt flow rate measurements provided detailed insights into the material's processability under different molding conditions. Furthermore, colorimetric analyses quantified optical changes linked to material compositions and processing variables, essential for applications where appearance is critical, such as uncoated body parts like bumpers and uncoated interior components.

The results reveal significant interactions between processing conditions and recyclate proportions, jointly affecting both functional and aesthetic properties of the polymer blends. Optimized processing parameters demonstrate potential for partially mitigating typical declines in mechanical performance associated with increasing recycled content. These findings are crucial for advancing circular economy initiatives by enabling the use of recycled polypropylene in demanding automotive interiors and exterior components without compromising performance requirements.

EU regulations under discussion propose 20% recycled plastics in new vehicles within six years after enactment, rising to 25% within ten years, pending final approval by Council and Parliament. This study provides essential processing insights to prepare the automotive industry for compliance, enabling effective use of recycled PP while maintaining performance standards.

#625

# Dynamic Covalent Networks: Thermal Cure Kinetics and Closed-Loop Recyclability of Vitrimers from Bio/Epoxy with imine hardener

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Thermoset polymers formed from covalent bonds offer mechanical stability, but cross-linking renders the polymer network infusible and restricts self-healing properties. Hence a new class of dynamic covalent adaptable networks (CANs), or vitrimers are promising materials to combine the properties of thermoplastics and thermosets. Vitrimers are thermosets, which can change their network connectivity by thermally activated bond exchange reactions. The aim is to develop the vitrimer hardener with the combination of high performance and versatile recyclability for the application of interior construction profiles. The synthesis of imine-based hardener (Schiff base imine) from bio-monomers (vanillin and isophorone diamine) was optimized for 2 h and 4 h. The decrease in the carbonyl stretching band (C=O) of vanillin at 1675 $cm^{-1}$ and the formation of a new imine band (C=N) at 1630-1640 $cm^{-1}$ confirmed the successful imine formation. The effect of different % of vitrimer hardeners in the commercially available epoxy resin (bisphenol A diglycidyl ether - DGEBA) was compared by real time Fourier Transform Infrared Spectroscopy (FTIR) followed by the multivariate analysis (MVA) and Differential Scanning Calorimetry (DSC) measurements. The principal component analysis (PCA) studies highlighted the influence of imine in epoxy through scores and loading plots. The apparent activation energy from cure kinetics (Ea-C) of epoxies with different ratios of synthesized bio hardeners provide valuable information not only about the appropriate ratio of hardener to epoxy but also about the mechanistic aspects of the curing process. The 40 % of imine to DGEBA shows 50 J $mol^{-1}$ until 50 % of the reaction extent and then decreases to ~30 J $mol^{-1}$. The future focus is to utilize these results for the development of recovery and reformed vitrimer composites for high-performance applications.

Keywords:

Vitrimers, Recyclability, Schiff base imine chemistry, Multivariate data analysis, Cure kinetics, Construction panel.

#626

# Thermoelastic stress analysis of translaminar compressive failure in carbon fibre-reinforced composites

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The compressive performance of fibre-reinforced composites remains a critical limitation in demanding applications in aerospace, automotive and marine structures. Under compression, these composites undergo abrupt failure driven by a combination of microstructural instabilities such as fibre kinking, matrix defects, delamination, and fibre pull-out. A deeper understanding of how these damage modes initiate and evolve is crucial for improving material design. Strain energy release rate associated with translaminar fibre failure in compression is one of the important material properties for reliable design in applications involving damage and crack growth. Unfortunately, its value can be difficult to evaluate with standard methods for which the crack induces a lot of secondary damage types. The local buckling of fibres leads to the kink band at the crack tip followed by a phenomenon of crushing. Then to evaluate the fracture toughness of this crack, it is necessary to separate these two phenomena - kink band and crushing. It has been reported that while initiation energy can be calculated using the Compact Compression (CC) specimen, the propagation energy values cannot be reliably measured because of the difficulty to account for the contact stresses in the faces of the kink. In this paper, infrared thermography has been used to follow compressive failure mode developed during CC test of CFRP composites to estimate the internal heat sources associated with the dissipative phenomenon from temperature measurement on the sample surface. Thermoelastic Stress Analysis (TSA) was conducted by cyclically loading the specimen at specific load intervals to characterize the evolution of damage and the underlying failure mechanisms. This combined optical and thermal imaging approach offers new insights into the fibre-dominated fracture and is capable of advancing the understanding of compressive failure in high-performance composites.

#627

# Weibull Modelling of Anisotropic Dielectric Strength in Unidirectional Glass Fibre Composites

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Reliable high-voltage insulators are critical components for modern power grids and sustainable energy systems. Increasing transmission voltages reduces grid losses but significantly increases the risk of electrical breakdown, making advanced insulating materials critical. Glass fibre reinforced polymer composites (GFRP) have emerged as leading candidates due to their superior mechanical performance compared to traditional insulating materials. However, unlike their well-characterized mechanical properties, the electrical breakdown of anisotropic GFRPs remains poorly understood, despite their widespread use. In-plane breakdown is a critical but complex multi-scale phenomenon influenced by fibre orientation, interphase properties, voids, micro-cracks, and constituent permittivities that create local electrical field variations. Previous studies have observed that breakdown often propagates along fibre–matrix interfaces, making the fibre direction electrically weak in contrast to mechanical strength [1].

This work introduces a Weibull-based statistical model that incorporates anisotropy and local field variations to predict electrical breakdown in unidirectional (UD) GFRP subjected to uniform electric fields. UD laminates were manufactured from Hybon 2002 E-glass/VTC401 prepregs. Over 150 tests (ASTM D149-20) were conducted to investigate breakdown strength across systematically varied fibre angles relative to the field, electrode gaps, and cross-sectional areas. Results show how strength increases with increased angles, confirming fibre direction as the electrically weak axis. Size effects were observed, with electrode gap distance exerting a stronger influence than cross-sectional area, consistent with literature [2]. The proposed model accurately reproduces these trends, demonstrating strong predictive capability. To the authors' knowledge, this approach of correlating fibre orientation with breakdown performance and identifying governing field components has not been previously reported.

[1] Zhao et al., "Interface damage driven electrical degradation dynamics of glass fiber-reinforced epoxy composites," Compos Sci Technol, vol. 233, Mar. 2023

[2] Stark, "On the size dependence of the dielectric breakdown strength of solid insulators at room temperature," J Eur Ceram Soc, vol. 42, Feb. 2022

#628

# Novel Approach for an open-pore micro-structured interphase in carbon concrete composites

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Carbon fiber-reinforced concrete (CRC) has been shown to offer significant advantages over steel-reinforced concrete, including high tensile strength and corrosion resistance, which eliminates the need for a protective concrete layer, saving valuable resources. In order to fully exploit these advantages, the textile is subjected to impregnation, which offers several benefits: it provides protection for individual filaments, it enhances the handling of textiles during production and it enables the full force transmission across the entire yarn cross-section. Epoxy resins and polymer dispersions are utilized as impregnation materials in this context. However, this process facilitates a smooth interface with the concrete, with insufficient material or form-fitting bonding behavior to the concrete matrix, leading to premature, brittle failure.

The present study proposes an interphase design, incorporating an open-pore microstructure that is intended to avoid brittle failure and therefore enhance fracture toughness. To achieve this, open pores are introduced into the outer surface of the impregnated carbon yarns during the manufacturing process. This allows the concrete matrix to penetrate the pores, thereby increasing mechanical interlocking.

The production process of the carbon yarns incorporates epoxy resin impregnation, and the sacrificial particle templating technique. The carbon yarns are first impregnated with resin. Thereafter, particles are applied, serving as templates for the subsequent pores. Following the curing of the resin, the particles are eliminated through a leaching process, thereby leaving open pores. Sucrose crystals were utilized as sacrificial particles due to their cost-effectiveness and high water solubility, which facilitates rapid removal without the need for toxic solvents. This approach offers precise control of the size and shape of the pores.

Yarn pull-out tests were performed with a limestone calcined clay cement matrix (LC3), followed by microscopic characterization to investigate the bond behavior as a function of the microstructured interface.

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# Preparation and application of new building blocks for high value Vitrimers

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Key requirements for construction materials in the aerospace industry include optimal performance, strength and sustainability. Aerospace vehicles, such as aircraft, must endure extreme conditions, including high and low temperatures, intense radiation and harsh chemical environments. This affords enhanced mechanical strength, thermal stability and resistance to degradation. To achieve high fuel efficiency, lightweight materials are essential.

Two important types of polymers used in the aerospace industry are thermoplastics, which have linear polymer chains and can be processed through heat applications, and thermosets, which crosslinking between the molecules forming network-like structures. Unlike thermoplastics, thermosets cannot be modified after modification. However, Thermoplastics require significant higher temperatures for polymerization compared to thermoset formation.

A promising approach to combine the advantageous properties of linear and crosslinked polymers is the use of Vitrimers – interconnected molecules with structural units which can be selectively opened and closed. One method for creating thermosets with Vitrimer properties involves modifying established building blocks for polymerization that contain disulfide units. A notable building block is 4-Amionphenyl disulfide, which can be activated with epichlorohydrin. The resulting molecule, synthesized with a yield of 75%, contains four epoxy groups suitable for crosslink formation.

The reactive groups, of the new Vitrimer building blocks, are expected to yield a high glass transition temperature of approximately 180°C, along with enhanced strength and an increased elastic modulus. As observed with non-Vitrimer analogues, coupling is anticipated to occur at relatively low temperatures around 135°C.

Based on the properties detected in the new Vitrimer-based materials, derivatives will be synthesized in the future with the aim of further optimization.

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# FFT- and Image-Based Phase-Field Simulations for Descriptor-Based Structure–Property Relationships in Fiber-Reinforced Polymers with Manufacturing-Related Imperfections

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Probabilistic variations in the spatial distribution of constituents, such as fiber clustering in tape materials or the presence of binding yarns, can lead to significant deviations in the mechanical behavior of high-performance composites.

To quantify these effects, this work integrates FastFourierTransform(FFT)-based phase-field simulations with image-derived microstructural data to establish descriptor-based structure–property relationships for manufacturing-induced imperfections.

Microstructural fields are extracted from micrographs using advanced segmentation algorithms, enabling detailed characterization of constituent distributions.

The two-point radial autocorrelation function S2(r) is employed to determine characteristic correlation lengths and, from these, statistically representative volume sizes.

This ensures that the selected regions accurately reflect the spatial variability arising from clustering, stitching yarns, or matrix-rich zones, minimizing bias from undersized domains.

Once the minimal RVE is identified, the corresponding microstructural segments — already represented as equidistant voxel-based volume meshes — are directly embedded into a unilateral FFT-compatible grid.

This allows the micrographs to be used as-is without additional meshing, enabling an efficient transition from experimental imaging to numerical simulation.

Damage evolution under quasi-static loading is then computed directly on the voxel grid using an FFT-based phase-field formulation exploring the crack initiation and propagation.

To manage the computational demands of large microstructural simulations, we employ a GPU-optimized FFT solver based on the FFTMAD framework and reimplemented with CuPy, achieving substantial speed-ups over CPU-based approaches.

This enables extensive simulation campaigns across many microstructural realizations, supporting robust statistical evaluation of damage sensitivity.

By integrating spatial descriptors with image-based FFT simulations, the framework allows systematic identification of microstructural patterns that enhance or reduce fracture-relevant properties.

Constructing the S2 descriptor using dimensionality-reduction techniques such as singular value decomposition (SVD) or principal component analysis (PCA) yields compact representations of complex spatial correlations, enabling efficient comparison across large datasets.

Overall, this approach provides new insights into manufacturing-induced variability and supports microstructure-informed material design.

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# Stamping and AFP for Next-Gen High-Rate Flaperon Manufacturing

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This study presents the design, development, and manufacturing of structural components for an aircraft flaperon—a control surface that integrates the functions of both flap and aileron—using high-performance continuous fiber-reinforced thermoplastic composites (CFRTP). The integration of these functionalities into a single structure offers significant advantages in terms of weight reduction, aerodynamic efficiency, and enhanced maneuverability, which are critical for modern aerospace applications.

The project employed APC2-AS4 from Syensqo, a composite material with a PEEK matrix, selected for its excellent mechanical properties, reduced environmental impact, and suitability for advanced processing techniques. Two manufacturing technologies were implemented: stamping for internal ribs, automated fiber placement (AFP) by in-situ consolidation for upper and lower skins without autoclave. For the lower skin, the process integrates 11 ribs in a single step, enabled by AFP's capability to deposit and consolidate complex geometries while minimizing secondary joints. Each process was optimized by analyzing key parameters such as infrared heating, transfer speed, stamping pressure, and cooling rate for stamping; nip temperature, compaction pressure, and layup speed for in-situ consolidation.

A major objective was to minimize residual stresses during each stage to enable final assembly without post-processing cycles. All components were validated through micrographic analysis and non-destructive testing (NDT), confirming structural integrity and dimensional accuracy.

Preliminary results demonstrate the industrial feasibility of autoclave-free processes for primary structures, achieving a structural weight reduction compared to metallic solutions. Manufacturing time was reduced for ribs and for skins. These findings highlight the scalability potential of this approach for control surfaces in commercial aircraft, UAVs, and military platforms, contributing to more sustainable and efficient aerospace manufacturing.

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# Life Cycle Assessment of a Geometrically Highly Flexible Lightweight Hydrogen Tank

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Hydrogen-based mobility is considered a key solution for achieving the 2050 climate neutrality target of the European Green Deal by reducing greenhouse gas emissions and dependence on fossil fuels. However, the storage of hydrogen requires high-pressure tanks made of carbon-fiber-reinforced polymers (CFRP). Carbon fibers production is both energy and resource intensive. Furthermore, the environmental performance of hydrogen tanks is scarcely documented in the literature.

This study presents a life cycle assessment (LCA) of the manufacturing process of a novel geometrically highly flexible lightweight hydrogen tank composed of carbon fibers and a bio-based epoxy resin matrix. The LCA was conducted in accordance with ISO 14040 and ISO 14044 standards following a cradle-to-gate approach. The study aims to identify the environmental hotspots within the manufacturing process, document the overall environmental performance of the investigated hydrogen tank, and evaluate the potential environmental benefits of using a bio-based epoxy resin. To avoid burden shifting, the study considers multiple environmental impact categories beyond the Global Warming Potential (GWP).

The life cycle inventory (LCI) was established using primary data specific to the tank manufacturing process, complemented by secondary data from databases and literature sources. The modeling was carried out using the LCA for Experts software developed by Sphera. The results show that carbon fiber production is responsible for 35% of the total GWP of the studied tank, whereas the production of the bio-based epoxy resin contributes only 2%.

Additionally, the use phase and end-of-life stage were explored under different scenarios. The studied tank features a narrow geometry (140 mm in diameter and 2,000 mm in length), offering improved design flexibility and the potential to be integrated as structural element for new applications. The absence of bonding between the composite and metallic components enables disassembly, thus providing new opportunities for recycling and circular design strategies.

#633

# A comparative assessment of experimental tests for coupled-criterion-based Adhesive joint failure analysis

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Adhesively bonded joints are increasingly used in industrial structures, yet predicting their failure remains challenging when adhesive debonding governs the global response. Reliable experimental configurations are therefore required to characterize fracture initiation at the interface and to identify the associated failure parameters.

This work relies on Leguillon's Coupled Criterion (CC), which combines a stress-based condition with an energy-based requirement. Through an inverse application of this criterion, an adapted test configuration should enable the simultaneous identification of the critical stress and the critical energy release rate.

With this objective, the study examines several configurations: the standardized Thick Adherend Shear Test (TAST, ASTM D5656), the three-point bending test (3-PB, ISO 14679), and a recently optimized four-point bending (4-PB) test dedicated to adhesive failure.

The TAST, widely used to study shear-dominated behaviour, offers a convenient framework for applying the CC to fracture initiation. However, the unstable nature of crack propagation in this configuration prevents a full characterization of initiation. The rapid transition from initiation to catastrophic debonding makes it impossible to define a characteristic crack length, which is essential for identifying both CC parameters.

In contrast, the 3-PB and 4-PB tests exhibit stable crack propagation over a significant portion of the interface. This stability allows the definition of a crack-arrest condition directly linked to the energetic requirement of the CC. As a result, bending tests provide an appropriate experimental basis for analysing initiation parameters within a consistent theoretical framework.

Combining numerical simulations with experimental measurements from bending tests confirms the robustness of this approach for identifying the initiation stress and critical energy release rate. These values are then compared with those obtained from other dedicated configurations.

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# Facing challenges in the incorporation of natural fibres in recycled post-consumer polypropylene matrices

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Due to the rising demand for more sustainable alternatives to virgin polymer materials, alternative carbon sources have to be found, for example, through the recycling of post-consumer plastic waste, such as polypropylene (PP). To further improve the sustainability, a second waste stream, fibres from linseed flax, was added. Due to the polarity of the flax fibre and the non-polarity of the PP, the adhesion between fibre and matrix needs improvement, which is commonly achieved through the incorporation of maleic anhydride grafted PP (MAPP). However, using MAPP at concentrations of 1 to 5 % with the recycled PP (rPP) showed no improvement in interfacial shear strength (IFSS), which remained around 4.8 MPa. Using a 2 % MAPP concentration in virgin PP increased the IFSS from 5.9 MPa to 11.1 MPa. DSC measurements revealed the presence of polyethylene (PE) and other constituents in the rPP. A combination of virgin PP (vPP) and PE in the same ratio as the rPP showed an improvement with the presence of MAPP (from 4.5 MPa to 8.3 MPa). The tensile properties of injection moulded specimens containing 20 % fibre content show minimal improvement through the usage of MAPP, increasing the tensile strength from 22.25 MPa by 5 % and the Young's Modulus from 1915 MPa by 7 %. Using a virgin material matrix, the specimens exhibit a higher Young's Modulus and tensile strength compared to their recycled counterparts. By compounding a masterbatch with 60 % fibre content and vPP with 6 % MAPP, and then diluting the compound with rPP, a tensile strength similar to the virgin materials was achieved. Efforts have been made to analyse the constituents of the rPP to provide an explanation of the deactivation of the functionality of MAPP, through NMR, IR, and GCMS, finding (decayed) additives, limonene, pinene and polystyrol.

#635

# Development of advanced Carbon Fibre-based electrodes towards their integration into high-performance Structural Supercapacitors

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Structural energy-storage devices have gained significant attention as a promising route toward the electrification of transport systems.[1] This interest is driven largely by the increasing demand for lightweight solutions capable of meeting the $CO_2$-reduction goals set for 2030.[2]

In structural supercapacitors (SSCs), the electrodes, separator, and electrolyte are specifically engineered to provide both energy-storage performance and mechanical integrity, enabling substantial reductions in overall system weight and volume. And given the widespread adoption of carbon fibre reinforced polymers (CFRPs) in automotive and aeronautical applications, considerable research efforts are focused on exploiting carbon fibres as functional electrode materials.[3],[4]

The present work focuses on the development of advanced carbon fibre (CF)-based electrodes (EDLC) with enhanced capacitance and their integration into SSCs . To reach this goal, several strategies have been explored to functionalise the CF surface with active materials such as activated carbon and graphene. The most promising CF electrodes have been subsequently selected and incorporated into SSC devices manufactured by Vacuum-Assisted Resin Infusion (VARI). The resulting sandwich-structured SSCs comprise two layers of functionalised CF serving as electrodes, separated by two layers of glass fibre (GF) acting as separator, and infused with an optimised resin/electrolyte mixture that provides both mechanical integrity and sufficient ionic conductivity.

The research includes the electrochemical characterisation of the CF electrodes and SSCs (by CV, GCD, EIS); microstructural analyses (SEM) to assess the CF(electrode)/matrix(resin/electrolyte) interface; rheology of the resin/electrolyte formulations and optimisation of the VARI process parameters (curing temperature and time).

[1] Fightpath 2050, Europe's vision for aviation,The European Commission, 2011, https://doi.org/10.2777/50266

[2] Schäfer, A.W. et.al. .J. Nat. Energy 2019, 4, 160 – 166.

[3] Deka, B. K et.al. Composites, Part A. Applied Science and Manuf. 2016, 87, 256 – 262.

[4] Senokos, E. et.al. Scientific Reports 2018, 8:3407

#636

# A-Priori-Informed Instance Segmentation of µCT Scans of Woven Fiber Composites on the Mesoscale

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The accurate representation of the mesostructure of woven fiber-reinforced composites (FRCs) is essential for reliable numerical simulations of their mechanical behavior and processing characteristics, as it represents the volume where the fibers reside. Although imaging and image-processing techniques have advanced considerably, the quantitative 3D characterization of FRCs - especially carbon-fiber-reinforced, woven materials - remains challenging. In particular, segmentation and modeling of individual rovings are complicated by compaction effects during manufacturing, which cause shifts, deformations, rotations of fiber bundles. These features are especially relevant for permeability prediction, as flow paths are strongly governed by mesoscopic geometry.

This work presents an automatic workflow that leverages a-priori information such as weave pattern, textile architecture to improve the segmentation and reconstruction of individual rovings from X-ray micro-computed tomography (µCT) data. Reconstruction was performed using the GeoDict software. The approach was developed using a Resin Transfer Molding (RTM) sample, which includes 2/2 twill G-weave with 5 yarns/cm in warp and weft (3,000 carbon fibers, 7 µm fiber diameter). µCT scans were acquired using a Zeiss ZEISS Xradia 520 Versa 3D X-ray microscope with absorption and phase contrast at a voxel size of 10 µm.

Fiber orientations were extracted using the Jeppesen structure tensor or classifier-based methods. In the first reconstruction step, geometric templates of individual layers were generated from known weave patterns, and their parameters were optimized by maximizing the Intersection over Union (IoU) with segmented data. In the second step, roving cross-sections, approximated as ellipses, were fitted to the segmented data using the same metric. Both steps include positional and rotational degrees of freedom.

The combined template-based layer separation and ellipse-based roving reconstruction yielded an automated model achieving more than 80% voxel-wise agreement with segmented data. The resulting geometries provide a robust basis for mesoscopic simulations, including permeability prediction and mechanical property analysis.

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# Automated characterization of delamination onset and growth in multidirectional glass/epoxy laminates

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Delamination in multidirectional composite laminates remains difficult to characterize, particularly when several interfaces delaminate and interact with matrix cracking. Current practice often relies on manual inspection of damage, making the process tedious and subjective. This work uses DelaDect, an in-house tool for automated crack and delamination detection, to quantify delamination onset and growth in laminates. With this tool, we are presenting an image-based workflow used to quantify delamination at more than one interface by the example of laminates containing a transverse ply with different outer-ply orientations.

Uniaxial quasi-static tensile tests are performed on glass/epoxy laminates with constant transverse-ply thickness and two lay-up families: cross-plies [$0^o/90^o$]s and angle-plies [±θ/90]s. High-resolution images are taken throughout loading and processed with DelaDect. The procedure separates edge delamination, initiating from the free edge, from diffuse delamination nucleating at cracks in the laminate interior, and quantifies their areas as functions of applied strain and crack density. This yields damage metrics directly comparable across laminate configurations.

The experimental results show that outer-ply orientation strongly influences the onset and evolution of delamination. In cross-ply laminates, delamination initiates close to transverse crack saturation and evolves as a mixed pattern of diffuse and edge delamination at the 90°/0° interfaces. In contrast, angle-ply laminates are dominated by edge delamination, with earlier onset and larger delaminated areas, and they exhibit clear secondary delamination developing at -θ/+θ interfaces from the free edge at higher strains. These results show that DelaDect is a valuable tool for understanding the damage evolution in multidirectional laminates by providing a reproducible and quantitative characterization of matrix cracks and delamination.

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# Do Delaminations Matter? Understanding Their Structural Impact on Wind Turbine Blade Spar Caps

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In wind turbine blades, the spar caps serve as the primary load-bearing substructures for the aerodynamic loads. In an effort to improve structural performance, larger blades have transitioned from exclusively glass fibre-reinforced polymer (GFRP) structures to incorporating pultruded carbon within the spar cap laminates. Integrating this material has introduced significant manufacturing challenges: the high thickness and density of pultruded carbon components hinder the infusion process, increasing susceptibility to dry spots and delaminations. For GFRP spar caps, these types of defects have been known for compromising the overall integrity of the blade.

However, for pultruded carbon spar cap laminates, the behaviour of delaminations remains insufficiently understood. To address this gap, an element-level test was developed to capture the structural implications of such defects, focusing on damage mechanisms and local strain distribution. Representative specimens were fabricated using real blade materials through vacuum-assisted infusion and subjected to uniaxial tensile loading to replicate realistic spar cap stress states. Both pristine (baseline) and defect-embedded specimens underwent quasi-static tensile testing.

Experimental findings revealed that the introduced defect had negligible effects on the laminate's stiffness and strength. Nevertheless, through-thickness strain measurements obtained via digital image correlation, combined with failure mode analysis, indicated defect propagation and complete interface delamination between pultruded carbon components for defected samples. Further characterisation under bending loads, complemented by acoustic emission and ultrasonic imaging, is planned to provide further insight into the local structural implications of delaminations in wind turbine blade carbon spar caps. Understanding the impact of these defects can contribute to a more comprehensive damage tolerance analysis, reducing unnecessary repairs and improving manufacturing efficiency for wind turbine blades.

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# Influence of hydrothermal exposure on the network stability and performance of an epoxy–anhydride vitrimer for aircraft cabin composites

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Vitrimers are polymer networks featuring dynamic covalent bonds that enable reshaping, healing, welding and recycling without loss of structural integrity [Alabiso, 2019; Sharma et al., 2022]. Their combination of high performance and reprocessability makes them promising candidates for aerospace applications, where durability, weight reduction, and sustainable end-of-life concepts are becoming increasingly critical [Mahoney et al.,2025]. However, unlike conventional epoxy-based aerospace composites with inherently low moisture uptake, vitrimer networks may be more sensitive to prolonged moisture exposure due to their dynamic bond-exchange chemistry and high number of functional groups [Wu et al., 2021; Mandal et al., 2024]. Such moisture absorption can plasticise the network, alter the bond exchange kinetics, and reduce mechanical and thermal stability. This emphasises the need for appropriate vitrimer formulations for long-term durability. In previous studies, epoxy–anhydride vitrimers applicable as matrix resin for fiber reinforced composites have been developed [Giebler et al., 2020; Mayer-Kriehuber et al., 2025]. By varying the chemical composition, thermoset resin formulations with glass transition temperatures between 80 °C and 250 °C were produced and characterised using thermal and thermomechanical methods. These resins provide the mechanical stability of conventional thermosets while providing enhanced reprocessability. In this work, environmental effects on the network performance of the finalized composition are investigated. Neat resin specimens are exposed to aging conditions simulating aerospace environmental conditions (e.g., 70 °C temperature and 95 % relative humidity). Moisture uptake is quantified through gravimetric analysis, while physical and chemical aging effects are studied by, e.g., thermal analysis and spectroscopy. In addition to these analytical test methods, a comprehensive mechanical characterization is performed. Finally, the applicability of the studied system for their use as matrix material for fiber reinforced composite structures in aircraft cabins is critically assessed.

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# Microscale Permeability Prediction of Fibrous Textiles using Finite Basis Physics-Informed Neural Networks and Domain Decomposition

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The flow of resin through fibrous textiles during Liquid Composite Moulding (LCM) processes is a multiscale phenomenon and can be characterised into three different scales: the flow between individual fibres (microscale), flow between fibre tows (mesoscale) and flow through multiple layers of fabric (macroscale). Permeability is a measure of the material's resistance to flow according to Darcy's law. The recent experimental and virtual international permeability benchmark exercises demonstrate two possible pathways for characterising the permeability at different scales to provide input data for accurate filling simulations of LCM processes. Machine learning (ML) methods offer an additional and potentially efficient virtual approach for characterising the material properties of fibrous reinforcements used in composite manufacturing. Previous studies on using ML for microscale permeability prediction have used image- or feature-based data-driven approaches, which require large amounts of training data. In contrast, Physics-Informed Neural Networks (PINNs) only require the governing equations and boundary conditions to train the network. The training of PINNs, however, is known to be difficult, especially for problems with high frequencies and multiscale features due to the spectral bias of neural networks. To overcome the limitations of PINNs, Finite Basis Physics-Informed Neural Networks (FBPINNs) were developed, which use domain decomposition to reduce the complexity of the problem. Instead of using one large network over the entire domain, the domain is split into many overlapping subdomains, with a neural network placed in each subdomain. In this study, FBPINNs are used to solve the Stokes equations to approximate the microscale permeability of fibrous textiles. As the number of fibres (i.e., the frequency) in the domain increases, regular PINNs demonstrate a loss in performance, whereas FBPINNs maintain their superior accuracy and training efficiency, achieving an L2 error of 2.3% against finite element simulations after 70,000 iterations, compared to 95.4% when using regular PINNs.

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# Towards Sovereign Digitalization in Composite Material Development: A Shift to “Science as a Service”

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The rapid evolution of advanced composite materials demands high-throughput experimentation and multi-sensor measurements, yet reproducibility remains limited by fragmented data-acquisition and ad-hoc analysis workflows. We present an open-source, device-agnostic platform that couples automated data capture with a centralized, time-series-aware data hub. Sensor streams are pushed directly to the hub, eliminating manual transcription and ensuring provenance-rich datasets that are instantly available to all collaborators. The platform incorporates digital process documentation in a FAIR manner, ensuring data is findable, accessible, interoperable, and reusable.

Beyond acquisition, the platform encourages a “science-as-a-service” paradigm in which containerized analytics expose well-defined API endpoints. Down-stream tools request calibrated material summaries, or machine-learning insights without managing complex Python environments or dependency conflicts. This composable service layer enables chaining, versioning, and on-demand scaling of evaluation modules, thereby tightening the feedback loop between experiment and model.

The solution is purely based on open-source licensed products, profiting from community contribution and enabling customization for transparent and reproducible research - a core principle emphasized in our sovereign-digitalization vision. While the deployment leverages cloud technologies, the architecture utilizes on-premise installation, allowing institutions to retain sovereign control over sensitive data while still benefiting from the same modular service stack.

We validated the approach by manufacturing carbon-fiber-reinforced composite plate demonstrators via resin-transfer molding, incorporating a broad sensor suite that continuously captures machine-side parameters, environmental conditions and material-state data in real time. All measurements are pushed automatically into a central time-series hub and referenced by an integrated digital-process-documentation service, adding FAIR-compliant provenance metadata.

The framework significantly reduces data handling complexity and improves reproducibility across experimental iterations. Connecting domains throughout the advanced composite material development can be easily achieved by this approach. Thus, future work will focus on direct feedback to the experimental controller for adaptive process tuning coupling live-data with in-situ process simulation.

#642

# Time-dependency of self-reinforced polypropylene and biaxially oriented polypropylene laminates

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Biaxially oriented polypropylene (BOPP) and self-reinforced polypropylene (SRPP) laminates are favoured at Samsonite due to their low density, high stiffness, good impact resistance, and recyclability. BOPP are thin films achieved by drawing heated polypropylene along two perpendicular directions. In contrast, polypropylene tapes tend to have a much higher drawing ratio than films but only in one direction. This results in greater stiffness in the tape direction.

As both tapes and films are polypropylene, their combination enables effective hot compaction while maintaining good adhesion. Laminates are created by stacking films or a combination of BOPP films and SRPP, then consolidating them under heat and pressure. Both films and tapes have a multilayered structure and intricate production processes, which often result in internal stress buildup. That is why it is essential to observe properties of the shells over time to guarantee stability and consistent quality of the suitcases. Such monitoring is particularly critical for suitcases, as they are often stored before testing and sale. We therefore performed a six-month study with regular flexural and differential scanning calorimetry (DSC) testing to quantify the effect and determine the time frame when the properties reach a plateau.

For both laminates, the most significant changes occurred within the first week. The degree of crystallinity remained stable throughout. Approximately three weeks after production, both BOPP and SRPP laminates show stable flexural properties, confirming that the laminates are ready for testing with constant characteristics. Since time is the key factor influencing these changes, storing SRPP and BOPP laminates for three weeks before testing is recommended.

This study seeks to deepen understanding and quantify these time-dependent effects across a broader range of materials, thereby improving storage management and end-product quality.

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# Compressive Performance of Hierarchical Pultruded Rod Based Composites

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Fibre-reinforced polymer composites perform well under tension, leaving performance under compression as a limiting factor for many use cases. Natural composites such as bamboo, wood and bone perform well under compression using a hierarchical structure: building up from the molecular via various sub structures to the macroscale. This concept has been implemented in fibre-reinforced polymer composites using pultruded rods as the intermediate structure, creating a hierarchy of fibres->rods->structures. This can include different polymer matrices within and surrounding the rods.

Hierarchical composites have been manufactured using resin transfer moulding, oven and autoclave processes. The concept has been applied to a variety of structures including but not limited to flat panels where the rods are sandwiched between pre-impregnated material, a bio-inspired lattice cone and cylindrical structural members.

Individual rods have been tested under compression using the NextCOMP 'cradle' modified 4 point bend method. Rod based composites have been tested in buckling and using the Imperial College compression-shear method.

As natural composites include features to control behaviour under compression, so overbraids have been introduced to add support to the rods. This includes our novel 'fuzzy carbon' braids where the braid geometry and process is designed to induce partial breakage of carbon tows, results in fibres extending into the surrounding polymer matrix, increasing the fibre-matrix contact region. These fuzzy overbraids have been shown to change the failure behaviour of the hierarchical composites.

This presentation will summarise results from this programme of work and consider the future of hierarchical composites. The rod based approach opens up a new design space, with the potential to create novel composite structures and shapes for a wide variety of applications.

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# Process Platform and Sustainability from Agro-Industrial Residues to Circular High-Performance Elastomers via an Integrated Hydrothermal-Catalytic Platform

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We establish an integrated process platform that upgrades lignin-rich streams from agro-industrial residues into circular, high-performance elastomers with industrial-grade performance. The route combines (i) hydrothermal fractionation/activation to tailor molar-mass distribution and phenolic functionality; (ii) green-catalyzed chemical modification (e.g., epoxidation and methacrylation) in alternative solvent systems; and (iii) solvent-free copolymerization and reactive extrusion under industry-relevant conditions. Segment-structured, bio-based architectures are designed to be compatibilized with PHA/PLA, prioritizing moderate processing temperatures and short cycle times. The platform is validated through rheology, DMA, tensile/tear, fatigue, abrasion, and thermal ageing, as well as functional tests in seals and flexible components. LCA and TEA are coupled to the development from the outset to minimize carbon footprint and costs, and to define circularity strategies (chemical recycling via transesterification and dynamic covalent bonds). The resulting materials exhibit properties comparable to or exceeding petrochemical references (tunable modulus, low hysteresis, favorable compression set), together with relevant emission reductions. Overall, the concept demonstrates the technical and environmental feasibility of a continuous, statistically controlled process and supports scaling toward pilot operations (TRL 5-6).

KEYWORDS: AGRO-INDUSTRIAL RESIDUES; BIO-BASED POLYMERS; DYNAMIC COVALENT NETWORKS; GREEN CATALYSIS; LIGNIN-BASED ELASTOMERS.

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# Physics-Based Surrogate Modelling for the Development of High-Performance Bio-Based Elastomers

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Developing bio-based elastomers with industrial-grade performance is hindered by the complex chemistry of renewable feedstocks and the high experimental cost of formulation. Lignin-derived polymer systems are particularly attractive, yet difficult to optimize due to their structural variability. Here, we introduce an AI-guided digital formulation twin that accelerates the design of bio-based elastomers by coupling chemistry, processing, mechanics, and sustainability in a single framework. The model integrates polymer descriptors (functionality, oxidation index, polydispersity), process variables, and copolymer composition. Machine-learning models combined with Bayesian multi-objective optimization identify optimal trade-offs between key performance indicators such as storage modulus across 0-60 °C, controlled dissipation, fatigue resistance, and permeability while explicitly enforcing processability and cost constraints.

To strengthen predictive capability, we implement a physics-based machine-learning (PBML) strategy. Experimental data from targeted mechanical tests on fabricated elastomers where tensile, compressive, dynamic, and others responses will be fused with constitutive models to train algorithms that learn the links between molecular structure, processing parameters, and mechanical behavior. The resulting surrogates progressively reduce the need for physical testing and deliver finite-element-ready parameters for virtual component validation.

The framework operates in adaptive design build-test-learn cycles with uncertainty quantification and SHAP-based explainability to prioritize promising chemistries and processing windows. Validation combines rheology, DMA, and fatigue testing with functional trials in technical seals and flexible protective components. The methodology is coupled in-line with life-cycle assessment (LCA) and techno-economic assessment (TEA) to co-optimize performance, cost, and carbon footprint, demonstrating significant impact reductions and industrial scalability. Overall, this approach establishes a transferable route for AI-guided, physics-informed, sustainable formulation of high-performance bio-based elastomers.

KEYWORDS

PHYSICS-BASED MACHINE LEARNING, BAYESIAN MULTI-OBJECTIVE OPTIMIZATION; DIGITAL FORMULATION TWIN; LIGNIN-BASED ELASTOMERS; MECHANICAL PERFORMANCE PREDICTION; FEM-READY PARAMETERS; LCA/TEA; DESIGN-BUILD-TEST-LEARN CYCLES; SUSTAINABLE MATERIALS DESIGN.

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# Interfacial Engineering of Flax-Based Bio-Composites via PCL Coatings: An Experimental and Computational Analysis

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This work aims to optimize the interfacial properties of bio-based composites, facilitating the design of new sustainable materials for lightweight structures. Specifically, the efficiency of surface engineering of flax fabrics using a poly(ε-caprolactone) coating applied by immersion in a dichloromethane solution is assessed. Variable PCL concentrations (2.5, 5 and 10 wt.%) and immersion times (10, 20, and 40 s) were investigated. Before coating, flax twill fabrics were treated in a 3% NaOH solution for 3 hours to remove surface impurities. Fiber reinforced composites were manufactured by vacuum infusion using a recyclable and partially bio-based epoxy resin named Polar Bear.

Scanning electron microscopy (SEM) and thermogravimetric analysis (TGA) were used to evaluate the morphological features morphology and thermal behaviour of the engineered fibres. SEM observations showed the PCL coating distribution and its deposition over the fibre surface, whereas TGA emphasized the enhanced thermal stability achieved through surface modification. The mechanical behaviour of the laminates was assessed by flexural, tensile, impact, and short-beam shear (SBS) tests, which showed that load transfer efficiency and interlaminar fracture resistance are significantly affected by both PCL concentration and immersion time.

SBS test results were then used to develop a numerical model in Abaqus, wherein the fibre-matrix interface was simulated using a cohesive zone approach. The different numerical models included changes in both PCL layer thickness and porosity to reflect realistic interfacial conditions and, simultaneously, to link microstructural features with the observed delamination mechanisms. The numerical results were in good agreement with the experimental observations, thus validating the model and, at the same time, stressing the important role of coating parameters on the interfacial strength. These results give valuable insights into the optimisation of high-performance bio-composites, pointing out the possibility to tailor the interfacial properties of sustainable structural materials through proper coating strategies.

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# The Flax Files: Processing–Structure Relationships in Continuous Natural Fiber Thermoplastic Tapes.

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Continuous natural fiber-reinforced thermoplastic (NFRTP) tapes are emerging as sustainable alternatives to glass and carbon fiber for secondary lightweight structures in automated manufacturing. Yet, unlike their synthetic counterparts, natural-fiber tapes remain underdeveloped. Flax fibers are particularly promising due to their low density, mechanical performance, and renewability, but their thermal sensitivity and limited compatibility with many thermoplastics challenge consistent tape quality.

This study investigates the continuous production of flax fiber-reinforced thermoplastic tapes and examines how matrix chemistry and processing parameters affect impregnation quality, microstructure, and thermal stability. Polypropylene (PP) and polyamide 11 (PA11) were chosen to represent non-polar and polar matrices, enabling assessment of how polymer polarity and melt viscosity influence interfacial bonding and fiber wet-out.

Four key parameters were evaluated in the Delft TapeLab using a melt-impregnation setup:

- Processing temperature (180–250°C): balancing melt viscosity, flow, and flax degradation.
- Calendering pressure: effects on consolidation, void reduction, and matrix infiltration.
- Pulling speed (0.6–2.0 m/min): its influence on residence time, melt penetration, and thermal damage.
- Calender configuration (open/closed): impact on tape uniformity and surface quality.

Tape quality was assessed through FTIR, optical/SEM imaging, DSC, TGA and mechanical testing. Low pulling speeds (<1 m/min) at temperatures above 195°C caused visible fiber discoloration, indicating heat-driven degradation. For PA11 at 210°C, speeds below 0.8 m/min led to both discoloration and complete loss of the nylon stitches—absent at higher speeds—further supporting a degradation mechanism. FTIR confirmed reductions in peaks at 1730 and 1240 $cm^{-1}$ associated with hemicellulose and lignin.

By correlating matrix type and processing conditions with microstructural and chemical responses, this work identifies key factors—temperature, pressure, and matrix chemistry—that govern flax-reinforced thermoplastic tape quality, informing optimized protocols for high-performance bio-based composite tapes

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# Experimental and Numerical Investigation of 3D Woven Carbon-Fibre Composites at the Microscale

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The forming process is a critical stage in the manufacturing of textile composites, as it imparts the curved, three-dimensional geometry to the textile preform. During forming, the fibres assume their final shape and orientation, becoming the primary load-bearing elements within the complex interaction of textile architecture, component geometry, and process boundary conditions. However, the draping process can also introduce distortions into the textile structure. In woven fabrics, deformations occur primarily through in-plane shear, as the interlacing points between warp and weft yarns allow rotational movement. This rotation generates friction between the yarns. As the shear angle increases, the yarn cross-sections deform, altering the contact areas at the binding points and further increasing frictional forces. Additionally, membrane tensions induced during forming intensify the friction at the crossing points due to the increased normal loads between the intersecting warp and weft yarns. The microstructure of 3D woven carbon-fibre (CF) reinforcement has been investigated both in the undeformed state and during forming, with particular attention to changes in roving cross-sections and undulation. These features vary significantly under the tensile and shear deformations that occur during draping and, in turn, influence the overall deformation behaviour of the fabric. To study these effects, a method is being developed that enables detailed analysis at the roving level. Microscopic examinations of the fabric in both its initial and deformed states provide insight into the roving cross-sectional shape and waviness and how these characteristics evolve throughout the deformation process. Robot-assisted high-frequency eddy current testing technology is being further developed to record and reconstruct the complete thread path of preforms made from 3D CF woven fabrics. Eddy current testing with fibre orientation measurement and finite element simulation provide fundamentally new insights into the deformation behaviour of multi-layer woven fabrics, enabling a better understanding of the draping process.

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# Physics Informed Machine Learning for Multi Zone Optimization of CFRP Aerospace Components

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We present an integrated design framework for multi zone optimization of aerospace-grade carbon fiber reinforced polymer (CFRP) components, combining high-fidelity finite element simulations with physics informed machine learning (PIML) models. The approach addresses the current limitations of composite laminate design, namely, the dependence on expert-driven iterative processes, high computational costs, and the incompatibility of black-box models with aerospace certification requirements.

The framework builds on a database generated from flexural simulations and experimental validation of CFRP coupons under various loading modes. This dataset links stacking sequences to mechanical response and failure indices, enabling the training of predictive surrogate models. These models are used to explore the design space efficiently and identify high-performance laminates while incorporating physical constraints and manufacturability criteria.

SHAP based explainability is embedded to quantify the contribution of each lamination parameter, ensuring traceability and model transparency in line with aerospace standards. The framework is demonstrated on a stiffened beam representative of secondary aircraft structures, optimized under multiple load cases to minimize mass while meeting buckling, stiffness, and failure constraints.

Lamination parameters are optimized in a continuous design space and reconstructed into manufacturable stacking sequences that satisfy symmetry, balance, and blending rules. The final design achieves a 10-15% mass reduction compared to a baseline configuration, with preserved structural margins and fabrication feasibility.

This work illustrates how data driven approaches can be reconciled with certification driven design workflows, enabling the transition to fully digital, traceable, and efficient composite structure development. The proposed framework supports the adoption of real-time, optimization guided engineering in aerospace composite design.

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# Truly integrated sensors for Structural Health Monitoring of Composite Structures in Cryogenic Applications

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Currently, huge undertakings to develop concepts for fossil free aviation are being made. For instance, hydrogen gas can be used in fuel cells generating electricity for motors. To minimize volume, hydrogen must be stored in liquid form in tanks at very low temperature (-253°C). These tanks should also be lightweight structures, which may be obtained using carbon fibre reinforced polymer composites (CFRPs). However, pressure and temperature changes during fuelling can cause microcracks, which then cause gas leakage. These microcracks result in significant impact on the structural integrity of composite tanks, leading to safety issues. To mitigate this risk, smart online monitoring and structural damage detection should be considered. Various non-destructive methods have been developed to detect damage and monitor the composite tanks. Optical fibre sensors are one of the most widely used methods for structural heath monitoring (SHM) of composite tanks, but the low operating temperature and the fragile nature of optical fibres limit their usage.

Recently, functional polymeric materials reinforced with carbon-nanoparticles (CNPs), such as carbon nanotubes (CNTs) have opened a new horizon for high-performance composites in advanced sensing applications. This reduces maintenance costs and boosts the safety and reliability of the composite tanks in cryogenic applications.

In this work, robust and corrosion-resistant sensors that are based on polyimide (Kapton) substrate and CNTs were processed, then embedded into CFRPs, where their role is to transduce strain into electrical resistance signal. These CFRPs were thereafter tested for SHM. Tensile and 4 point bending tests were conducted following cyclic loading and unloading force, and strain was measured while collecting simultaneously electrical resistance values. Moreover, morphology analysis was done to investigate the failure mechanism of composites and link it to the presence of the embedded sensors. Results show that integrating sensors in the tested CFRPs for use in SHM was successfully validated.

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# Terahertz spectroscopy for non-destructive evaluation of defects in glass fiber composite sandwich panels

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Non-destructive evaluation methods for characterizing damage and defects in glass fiber reinforced composite and sandwich structures is of great importance for wind turbine blade inspection both while in-service and in the manufacturing stage. Ultrasonic testing (UT) is a commonly used inspection technique. An ultrasonic wave is fully reflected when reaching a defect. This means that the top defect is shadowing for any other potential defects below, which is referred to as the shadowing effect. For similar reasons, it can also be a challenge for UT to scan through porous structures such as foam materials. An emerging alternative or supplement to UT is Terahertz (THz) spectroscopy, which uses electromagnetic waves instead of elastic waves. In THz spectroscopy the wave is not fully reflected at defects and thus does not face the same challenges with shadowing effects from defects. Therefore, THz spectroscopy can also easily scan through foam core materials in sandwich structures.

In the current study, we demonstrate the potential of a novel THz cross-correlation spectroscopy device by GLAZE Technologies, which is both lightweight and affordable. The THz device is used to visualize different types of defects in glass fiber composite sandwich panels similar to what may be observed in real wind turbine blades. The results show that the THz device can detect all the considered defects in panels of 25mm and 40mm thickness. In addition, it is possible to visualize the individual flow channels in the foam core of the sandwich panels. The results also demonstrate the ability to detect features below defects including - but not limited to - the back side reflection of the panels. The study clearly demonstrates the possible advantage of using the GLAZE THz device for inspection of wind turbine blades both during manufacturing and while the blade is in-service.

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# Investigations into residual load-bearing capacity of damaged and artificially aged flax-fiber-reinforced composites

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The transition to sustainable lightweight materials is essential for reducing greenhouse gas emissions in shipbuilding. Biobased fiber-reinforced plastics (FRPs), particularly natural fiber-reinforced plastics (NFRPs) using flax fibers, offer promising environmental benefits compared to conventional FRPs. However, NFRPs are more sensitive to weathering, especially when surface damages impair protective coatings, thereby raising concerns about their long-term durability and load-bearing capacity in marine environments.

The present work investigates the effect of artificially induced damages on the weather resistance of coated flax fiber-reinforced epoxy composites. A reproducible methodology has been developed to simulate realistic impact and scratch damages in NFRP laminates, reflecting typical operational stresses in shipbuilding. Test specimens were manufactured with unidirectional and bidirectional flax fiber non-crimp fabrics and a quasiisotproic layup, by vacuum infusing with a biobased epoxy resin (SR InfuGreen 810) and subsequently by coating with a 1K-PU clear coat (G8 Super) or with a 2K-EP/2K-PUR multilayer system (RELEST Protect). The specimens were subjected to controlled damage and exposed to artificial aging. The damage characteristics were analyzed by non-destructive testing, while the mechanical performance before and after aging is evaluated by compression after impact (DIN EN 6038) and tensile tests (DIN EN ISO 527-4).

The results show that the combination of damage and weathering/aging reduces the mechanical integrity of the specimens. Swelling can be observed in the damaged area. The decline in structural integrity is therefore primarily attributable to the water absorption of the hydrophilic flax fibers and the decrease in the fiber-matrix-adhesion. The results provide insights into the relationship between damage, coating integrity, and mechanical performance, and support the development of more durable, sustainable composites for marine applications by considering realistic damages and weathering effects.

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# Investigating the morphology of prepreg composite reinforcements under varying tape-laying parameters and their influence on mechanical properties

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Prepreg composite reinforcements exhibit complex morphology during tape laying. This morphology is strongly governed by process parameters and in turn controls the resulting mechanical performance. This study systematically investigates the morphology and mechanical properties of unidirectional prepreg tapes under varying lay-up parameters, including lay-up angle, tape width, compaction pressure, and temperature. Optical microscopy, surface profilometry, and micro-CT are employed to quantify key defects such as tow misalignment, fiber waviness, gaps, overlaps, bridging regions, and resin-rich pockets. These morphological descriptors are correlated with in-plane tensile and flexural properties obtained from standard coupon tests. They are also related to out-of-plane bending stiffness relevant for forming. The results show that higher compaction pressure and moderate roller temperature reduce inter-tow gaps. However, they may intensify local waviness near geometric discontinuities, which creates a trade-off between stiffness and defect tolerance. We further find that variations in lay-up angle and tape width produce distinct prepreg morphologies. Mechanical properties are evaluated using multiple testing methods. These tests identify combinations of tape lay-up parameters that minimise critical defects while maintaining or enhancing stiffness and strength. The study provides mechanistic insight into how tape-laying conditions shape the mesoscale morphology of prepreg reinforcements. It also offers data-driven guidelines for selecting process parameters to achieve reliable mechanical performance in automated composite manufacturing.

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# Comparative in-situ assessment of residual curing strains in carbon fiber cmposites with vitrimer and epoxy matrices using embedded FBG sensors

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This study investigates the evolution of curing-induced residual strains in unidirectional carbon-fiber composites with a vitrimeric epoxy matrix, compared to a conventional thermoset epoxy reference. The vitrimer system, featuring dynamic covalent bond exchange, is hypothesized to enable partial stress relaxation, thereby mitigating the residual strains typically generated in composite processing.Unidirectional carbon/epoxy laminates were manufactured via vacuum-assisted resin infusion, embedding Fiber Bragg Grating (FBG) sensors oriented at 90° relative to the fibers direction to monitor matrix-dominated, transverse strain evolution throughout the curing cycle. The same fiber architecture were used for both matrices.The in-siut FBG measurements revealed distinct curing behaviors for the two systems. The vitrimeric matrix exhibited a delayed and attenuated strain buildup during the chemically driven shrinkage stage, followed by an overall reduction in final residual strain compared withthe conventional epoxy. This trend is consistent with the vitrimer's capacity for topological rearrangement through bond-exchange reactions, allowing partial relaxation of curing stresses even after gelation.

These results provide direct experimental evidence that vitrimer matrices can effectively mitigate process-induced residual stresses In fiber-reinforced composites. Such behavior highlights their potential for manufacturing high-performance structural parts with improved dimensional stability and reduced risk of cure-induced defects.

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# Elastomeric PLA-based electrospun mats for the structural modification of CFRP laminates

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The limited delamination resistance and low damping ability of laminated composites can still restrict their use in demanding applications. Different methods have been proposed to increase the delamination resistance of carbon fiber-reinforced polymers (CFRPs). In particular, interleaving electrospun nanofibrous mats has emerged as a promising strategy to enhance the interlaminar behaviour of laminated CFRPs. Thermoplastic polymers, such as polyamides and polyesters, are commonly used in mats production. On the other hand, rubbery nanofibers have lately been proposed as innovative materials to mitigate composite delamination while enhancing other properties, including damping capability. While amorphous low-Tg polymers, such as rubbers, are efficient in enhancing interlaminar fracture toughness, their tendency to cold-flow often results in film formation, making the production of fibres challenging. Blending elastomers with semi-crystalline polymers has been shown to mitigate this issue, enabling the formation of continuous fibrous structures.

This study investigates the electrospinning of natural rubber (NR), poly(lactic acid) (PLA) and polyethylene oxide (PEO) blends (NR/PLA/PEO) to fabricate microfibrous interleaves aimed at improving the delamination resistance of CFRP laminates. The effect of environmental parameters (especially relative humidity) on fibre morphology was investigated to produce both smooth and porous fibres. Selected mats were integrated into CFRP layups, and the resulting laminates were subjected to interlaminar fracture toughness testing, employing Double Cantilever Beam (DCB) and End Notched Flexure (ENF) methods to quantify Mode I and Mode II interlaminar delamination resistance. A direct comparison with unmodified CFRP specimens enabled an evaluation of the influence of rubber content and mats morphology on interlaminar failure behaviour.

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# A multidisciplinary optimisation framework for fibre-reinforced composite materials

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The high standards of modern societies have amplified the challenges of developing new products. These products must meet strict structural and sustainability requirements while remaining cost-effective to guarantee competitiveness. Meeting these often conflicting requirements simultaneously is a significant challenge. To address these demands, creating multidisciplinary optimisation tools is vital.

Due to their extensive design possibilities, these tools become even more valuable for fibre-reinforced polymer (FRP) composites. These materials can be tailored by combining various proportions of virgin or recycled fibres and resins. Furthermore, different fabric structures, manufacturing processes, and recycling methods can dramatically influence the final components' carbon emissions, structural performance, and costs. As a result, all these interconnected variables must be integrated into a comprehensive multidisciplinary optimisation framework. This proposed optimisation framework addresses this challenge by developing the following four modules using Finite Element and Python tools:

- Material: Defines the range of virgin/recycled fibre/matrix combinations to study and the component geometry to generate the design solution space.
- Ecological and cost: Calculates the operation cost and environmental emissions of manufacturing and recycling processes.
- Structural: Integrates a Modified Rule of Mixtures (MRoM) model to estimate mechanical properties.
- Holistic optimisation: Uses advanced optimisation algorithms to calculate the optimal material combinations to minimise cost and carbon emissions whilst accomplishing mechanical requirements.

In conclusion, this multidisciplinary optimisation framework addresses the challenge of identifying optimal FRP composites while accounting for complex factors, including cost, sustainability, and mechanical performance. It is achieved using customised cost, ecological, and structural models that calculate essential parameters from studied fibre/resin combinations.

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# Local Assessment of Electrical Behavior of Thin-Ply CFRP for Aerospace Manufacturing

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The growing demand for high-performance aerospace materials has increased interest in fiber-reinforced composites, particularly thermoplastic composites (TPCs). Compared to thermoset systems, TPCs offer advantages such as weldability and recyclability, enabling end-of-life recovery. Understanding their electrical properties is essential for applications including (induction) welding and in-situ process monitoring during manufacturing.

Despite rising interest, the electrical behavior of TPCs remains underexplored. This gap stems from their intrinsic anisotropy and from manufacturing-induced complexities in the microstructure, such as local defects or deviations from ideal fiber architecture, that make both characterization and modeling difficult. Variability in fiber distribution, broken fibers, and in-plane waviness are among the microstructural features suspected to influence conductivity.

The objective of this work is to relate the surface and internal characteristics of unidirectional carbon-fiber-reinforced TPC tapes to their measured electrical response. Conductivity is assessed using both direct current (DC) and alternating current (AC) methods across a range of specimens. Cross-sectional microscopy provides detailed microstructural information, enabling identification of fiber distributions and localized damage cases.

Measurements on unidirectional, carbon-fiber-reinforced Toray Cetex TC1225 tapes show conductivities of roughly 30,000 to 40,000 S/m for undamaged specimens, consistent with reported literature values, while reduced conductivity appears when fiber breakage, lower fiber content, or other defects are present. To contextualize these findings, conductivity results from various carbon-fiber-reinforced TPC tapes are compared, considering the effects of manufacturing route, fiber type, fiber distribution, and localized defects, as well as differences between DC and AC measurement methods. Together, these observations highlight the strong link between microstructural features and electrical behavior and underscore the relevance of conductivity measurements for current-based manufacturing processes such as welding, Joule heating, and sensing.

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# From Limitation to Function: Toward Localized 4D-Printing Control for Morphing Complex Multi-Material Composite Parts

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Additive manufacturing of thermoplastic composites includes continuous-fiber 3D printing (CF-3DP) and automated fiber placement with thermoplastic tapes (AFP-TP). These technologies enable localized heating and precise fiber-orientation control, allowing reinforcement to be placed only where functionally necessary. However, strong material anisotropy combined with transient, heterogeneous thermal fields generates complex localized residual stresses, which may relax and cause unwanted distortions in the final part.

Despite extensive efforts to understand in-situ consolidation mechanisms in AFP-TP and CF-3DP, major knowledge gaps persist. Consequently, AFP-TP continues to be used to produce predominantly quasi-isotropic preforms that require subsequent isothermal consolidation in an oven or autoclave. Similarly, CF-3DP systems remain largely confined to laboratory environments.

4D printing offers an alternative approach by converting these limitations into functional opportunities. Rather than minimizing residual stresses, it exploits them to induce controlled shape changes, enabling moldless manufacturing. Prior demonstrations include self-forming thermoset laminates deforming during cure and morphing driven by printing-speed modulation in neat thermoplastic polymers. Yet, no existing studies have examined morphing in complex multi-material thermoplastic laminates combining neat polymers and composite plies.

This work investigates how processing parameters in high-performance thermoplastic multi-material additive manufacturing govern residual stress generation at both the microscale (constituents) and macroscale (laminate). Understanding these mechanisms allows identification of thermal conditions capable of activating morphing through controlled residual-stress evolution, including relaxation and crystallization effects. Leveraging the inherent ability of additive manufacturing to locally tailor materials and thermal histories, the proposed approach enables flat multi-material laminates to transform into complex, semi-structural double-curvature geometries.

Overall, the findings demonstrate a viable pathway for using 4D printing to fabricate complex composite components without molds or energy-intensive processing routes.

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# Preliminary Investigation of the Mechanical and Electrical Behaviour of GnP-reinforced Elium® Nanocomposites

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Abstract

The integration of health monitoring techniques into load-bearing components is critical to improving operational safety, extending service life and, in turn, reducing emissions. Graphene-reinforced thermoplastic polymer composites offer a promising route, combining mechanical strength with self-sensing capabilities, enabling real-time detection of stress and damage. In recent years, the recyclable matrices such as the acrylic thermoplastic Elium® resin offers a more sustainable alternative to traditional thermoset composites. This resin is liquid at room temperature and constitutes a competitive alternative to common epoxies due to its processability, recyclability and mechanical properties. However, despite its potential, the influence of nanofillers such as graphene nanoplatelets (GnP) on the mechanical and electrical properties of the resin remains understudied. In this work, the effects of incorporating GnP into the thermoplastic Elium® 188 O resin are analysed. A complete characterisation of the mechanical and electrical response of the nano-reinforced polymer is provided. Specifically, the influence of parameters such as GnP grade, concentration and mixing methods is systematically evaluated. Different combinations of GnP grades (H-25 and C-750) and weight percentages (0-2 wt%) were mixed with the resin using high shear mixing to provide an optimal dispersion. Elium®-GnP nanocomposites were then subjected to thermal-aided curing to facilitate successful polymerisation, as per previous studies. Nanocomposites were hence casted into moulds complying with the standards for tensile (ISO 527) and flexural (ISO 178) tests. Resistance measurements showed that the incorporation of GnP allowed the formation of a conductive network. A parametric study on the tensile and flexural properties was conducted to compare the properties of pristine Elium® resin, pristine epoxy and the GnP-reinforced counterparts. Overall, this work provides a foundation for the subsequent manufacturing of GnP-reinforced Elium® composites via resin infusion, enabling the implementation of lightweight, recyclable, and intelligent materials.

Keywords: Elium®, Graphene, Thermoplastic, Nanocomposites, Health-monitoring, Conductivity.

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# Potential environmental impacts of the production of a representative state-of-the-art aircraft cabin structure

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Fibre reinforced polymers (FRP) already play an important role in reducing the weight of aircraft and, as a result, limiting climate-impacting emissions. FRP are used both for aircraft primary structures and interiors. When analysing aviation environmental impacts with Life Cycle Assessment (LCA), the impact of the use phase currently far outweighs that of other phases in most LCA categories. However, aspects of manufacturing and solutions for potential circularity of components or materials are increasingly gaining importance.

In this presentation, preliminary environmental hot spots of a cabin stowage structure representative component investigated in the German Federal Government's funded project LuFo-VI CirKle* will be highlighted. The state-of-the-art component is a sandwich panel containing a honeycomb core made of aramid fibres and phenolic resin combined with glass fibre phenolic prepregs on both sides. As data collection in the Life Cycle Inventory (LCI) phase is a major challenge, corresponding data gaps and impacts of assumptions as well as proxy data on uncertainty of the results are discussed. The system boundary includes raw material extraction, their processing into the representative component and potential recycling activities. The assessment is carried out at component level, focussing on the production and end-of-life respectively recycling life cycle phases. Additionally, an extension to the aircraft and fleet level and use-phase is considered within the project.

Furthermore, an outlook is given on potential circular materials under development within the CirKle project in comparison to the state-of-the-art materials. Here, challenges are the different technology readiness levels (TRL) of emerging circular materials and high uncertainty in comparative LCA.

*Cirkle: ReCycling Werkstoffe für Flugzeug Kabinenbauteile; EN: Recycling materials for aircraft cabin components

#663

# Process monitoring for a full-scale wing-box using hybrid Fiber Optic Sensors in a One-Shot Liquid Resin Infusion process (LRI) - FLASH-COMP “Flawless and sustainable production of composite parts through a human centred digital approach”

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Integrated Fiber Optic Sensors (FOS) are widely used for structural health monitoring (SHM), and more currently for process monitoring during composites manufacturing giving its capabilities for resin front flow tracking, vacuum/pressure levels, temperature and resin cure monitoring. The FLASH-COMP project aims to introduce novel inspection and monitoring technologies to develop a digital solution to predict defects during manufacturing, aiming to reach a zero-waste approach in composites industries for different sectors. In this way, it is implemented a hybrid-FOS solution using Fiber Bragg Grating (FBG’s) sensors and distributed All Grating Fibers (AGF’s®) sensors into a full-scale 1.2 m aircraft wing-box demonstrator that is manufactured by a One-Shot Liquid Resin Infusion process (LRI), integrating both the skin and stiffeners without additional assembly steps. Aspects such as surface quality and performance have to be maintained by integrating the FOS into removable layers in the component surface, while the sensors are embedded in LRI compatible materials to increase its handling capabilities and enhance their fragility, alongside allowing it to be implemented at industrial scales. Both FOS technologies can retrieve essential process data: vacuum levels and temperatures, minimum viscosity points, cure monitoring and clear resin flow monitoring, especially the AGF’s due to its spatial resolution. Process data is retrieved in a real-time approach to feed simulations models and possibly apply corrective actions to prevent flaws and defects in the final component. Considerations have to be taken in the amount of data generated and the repeatability in the sensors signals when process parameters or geometry change.

#664

# FEM-driven design of a lightweight, modular composite hatch cover for ships

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Lightweight construction in shipbuilding is crucial for enhancing efficiency and performance, particularly regarding hatch covers, as their position on the ship deck significantly affects stability. Reducing the weight of these components not only improves fuel efficiency but also increases the overall stability of the vessel. The use of the liquid thermoplastic resin Elium by Arkema further improves recyclability and reduces the overall CO2 footprint. This shift towards lightweight solutions is essential for meeting modern environmental regulations and ensuring the longevity of maritime assets.

Within the research project DOM4Composite, structural designs optimized for disassembly and assembly, made from thermoplastic fiber-reinforced composites (FRC), are being developed. A lightweight hatch cover is being created as a demonstrator within this project. The focus is on the use of standardized parts to ensure modularity and facilitate repairs during operation. In accordance with Lloyd's Register, 2022, Part 4, Chapter 7, Section 12: Steel Hatch Covers for Bulk Carriers, a load test will be conducted on a large test rig to achieve a strong correlation between structural analysis using FEM and real component testing.

The results show that significant weight reduction can be achieved with FRC construction. For the foredeck hatch, which is exposed to the highest loads due to large wave impacts, FEM analysis indicates that the connections are subjected to elevated loads. Therefore, separate component testing of the connections was carried out to ensure a safe bolted joint. Overall, these results make a valuable contribution to improving efficiency and sustainability in maritime shipbuilding.

#665

# The longitudinal compressive response of glass/carbon hybrid composites with different modulus carbon fibres

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Fibre-reinforced composites typically demonstrate lower mechanical strength when subjected to longitudinal compression compared with tension. The primary reason for the lower unidirectional compressive strength is the shear instability of the composite. Research shows that the compressive failure of carbon fibres can occur in two distinct modes commonly recognized as fiber crushing and the development of kink-bands.

A hybrid effect was previously demonstrated with a 20% increase in the tensile failure strain for thin carbon plies hybridized with glass. Three different prepregs of thin ply carbon/epoxy were supplied by North thin ply technology, NTPT. Toray T1000, intermediate modulus fibres, Toray M55J, high modulus fibres, and Nippon Graphite Fibre YSH-70A, ultra-high modulus fibres were used as the low failure strain materials. The thin plies of carbon were hybridized with a higher failure strain material of S-glass/epoxy. The aim is to study the hybrid effects in compression of the low failure strain material in G/C hybrid composite. The use of thin plies in the compression of G/C hybrid laminates can potentially provide support against instability.

A suitable compressive test method for uni-directional fibre-reinforced composites is to incorporate the composite into the top skin of the sandwich structure that is subjected to a four-point bend test. The four-point bend test was adapted from the ASTM D5467 standard. This method can provide measurements of the longitudinal compressive strains with consistent gauge section failure. Ultra-high modulus fibres demonstrate multiple fibre fragmentations during failure at 0.12%. High modulus fibres demonstrate fibre fragmentation with an increase in the compressive failure strains compared to the baseline value of 0.31%. Intermediate modulus fibres show that kink-bands typically occur at compressive strains of 1.1%. Hybridization of intermediate modulus carbon fibres can delay kink-bands, demonstrating an increase in the compressive performance that can reach a failure strain beyond 1.9%.

#666

# Multiscale approach for development of end to end methodology for determination of build stresses in large composite structures

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In the assembly process of large composite structures, accumulation of assembly tolerances leads to gaps between components. The assembly of composite parts needs shimming to avoid high levels of build stresses, resulting in a dedicated station in the assembly line which leads to increase in assembly cost and lead time. The aim of this study is to simulate the progressive failure of composite bolted joints, in the presence of various gap profiles using mesoscale continuum damage mechanics models for predicting failure phenomena, at different scale levels (from coupons to large components). This would facilitate deeper understanding of the severity or detrimental effect of built stress in the assembly, in order to avoid extensive shimming.

A simulation method at the coupon level is developed using the constitutive law developed by the Universities of Porto and Girona, and subsequently extended to the component scale, with hybrid bolted joints to assess the local bending moments and fastener loads induced by the gap closure (without shimming). Considering the large scale and the hybrid nature of the joint in the component model, two key strategies are employed; firstly co-simulation strategy is employed to understand the fatigue behaviour of metallic components on the hybrid joints. A detailed mesh incorporating failure models is implemented in the area of interest, while the remaining area utilises a coarse mesh to maximise computational efficiency. The second strategy is to use the insights from coupon level studies to derive trilinear laws to define the behaviour of the connector, which represents the assembly bolts. The results from the two strategies are compared with experimental measurements to study the effect of various gap profiles (in relation to fastening sequence): local and global gaps. This study provides a robust alternative computational tool for detailed build stress study in composite structures.

#667

# High definition thermo-mechanical finite element modelling of fused filament fabrication: validation and comparison with existing simulation tools

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This study introduces a high-definition thermo-mechanical modelling framework for fused filament fabrication (FFF) that accounts for bead-scale deposition and evolving heat exchange with the environment. Existing finite element models of FFF typically rely on layer-wise or region-wise element activation, with simplified thermal boundary conditions applied on fixed external surfaces, which limits their ability to resolve local temperature gradients and accurately predict warpage. The approach divides each printed bead into a sequence of small activation cells following the deposition path and continuously updates the external surfaces after each activation to apply convection and radiation only on the newly deposited material. This enables a more realistic representation of the transient thermal history during printing, while remaining compatible with standard Abaqus workflows.

The framework is implemented in Abaqus/Standard using sequential element activation combined with a custom Python script that generates a structured mesh, step-wise activation sets and time-dependent surface definitions. A transient heat transfer analysis with prescribed temperature boundary conditions on the newly activated cells, together with step-wise updated external surface sets, is sequentially coupled to a mechanical analysis to predict residual stresses and warpage. The temperature fields are compared with the dedicated Temperature for Fused Filament Fabrication (T4F3) thermal simulation tool, and the complete workflow with Abaqus's integrated AM Modeler plug-in. The approach is also extended to dual-nozzle printing, enabling layer-wise deposition of materials with different properties. The results demonstrate that bead-scale activation with continuously updated external thermal boundary conditions significantly affects temperature gradients and warpage, highlighting the importance of high-definition FFF modelling for reliable prediction and optimisation of the process.

#668

# Deviations in laminates with local reinforcement patches: Transferable to plant fibre composites?

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The design of fibre reinforced polymer composites increasingly expands towards bio-based materials, driven by sustainability demands and the need to reduce environmental impact. However, plant fibre reinforced composites introduce substantially greater variability than conventional composites based on synthetic fibres, such as carbon or glass, particularly regarding geometric properties, draping behavior and mechanical performance.

The mfkCoDe (CompositeDesigner) approach is a simulation-based tool to design components according to the bionic principle of force flow and reinforces them locally with patches. The approach takes into account geometric deviations such as warping as a result of draping and allows to set limits to tolerable manufacturing inaccuracies to achieve desired requirements. This work aims at extending the mfkCoDe methodology, originally developed for synthetic fibres, to plant fibre-based composites, enabling a structured and deviation-tolerant design workflow.

Our proposed contribution presents the existing mfkCoDe approach and addresses its applicability for the design of plant fibre-based composites. Particular attention is paid to the differences between these fibre systems, which are evident, for example, in aspects such as the varying, non-circular fibre cross-section as well as higher scattering of properties in the raw materials. Accordingly, the existing approach in mfkCoDe will be adapted to meet these specific requirements. The submitted contribution will present a concept for integrating these adjustments in the design in order to (a) limit the resulting variations in the components and (b) to predict them as accurately as possible.

The article concludes with an initial case study describing a composite structure of flax fiber reinforced epoxy with regard to scattering of mechanical properties.

#669

# Processing and Repair of Fibre-Reinforced Polymers and Fibre-Metal Laminates by Power Ultrasonics

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Processing of fibre-reinforced polymers and fibre-metal laminates such as forming, joining, and repair, is challenging due to high viscosities, crosslinked polymer networks, and limited reprocessability. Power ultrasonics offers a fundamentally different processing approach based on the superposition of high-frequency oscillations and moderate forming forces to overcome these limitations, enabling rapid forming, joining, and repair of various composite systems within a few seconds. It is assumed that ultrasonic oscillations locally increase polymer chain mobility, significantly reduce the effective processing viscosity, and activate dynamic bond-exchange reactions in a vitrimer network. Ultrasonic oscillations were transmitted through a specifically designed sonotrode, enabling rapid in-situ impregnation, consolidation, and forming of stacked layers. As a result, multi-layer ellipsoidal structures were consolidated in a nearly defect-free manner. The ultrasonic process was successfully applied to natural-fibre-reinforced polymers, high-performance thermoplastics such as PEEK and PPS, as well as fibre-metal laminates including titanium layers. Across all material classes, the process is characterized by very low forming forces, short process times, and cost-efficient tooling. Compared to conventional composite processing, this enables a highly energy-efficient and scalable manufacturing route. Beyond primary shaping and joining, power ultrasonics was also demonstrated as an effective tool for the repair of damaged composite structures. Local ultrasonic energy input allows targeted re-melting or re-consolidation and bonding. Mechanical testing confirmed a significant recovery of stiffness and strength after repair. Overall, ultrasonic forming, joining, and repair represent an efficient technology for a wide range of fibre-reinforced polymers and fibre–metal laminates, with promising potential for high-volume applications in aerospace, automotive, and renewable-energy sectors.

#670

# In-situ monitoring of thickness evolution in carbon/paek laminates during vbo consolidation

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The consolidation of thermoplastic composites through the Vacuum Bag Only (VBO) method combined with resistive heated tooling provides a cost-effective and energy-efficient alternative to conventional autoclave or oven-based processes. In fact, this approach yields optimal composite laminate compaction with minimal energy consumption during the consolidation phase. However, since the applied pressure is limited to atmospheric pressure, accurate, time-dependent monitoring of laminate thickness evolution is essential to ensure final part quality, particularly porosity.

In this work, a dedicated small-scale test bench, integrating resistive-heated tooling and embedded sensors, was developed to experimentally reproduce and monitor industrial VBO consolidation. Carbon/LMPAEK laminates of various thicknesses were manufactured via Automated Fibre Placement (AFP) and exposed to different consolidation parameters to identify the key factors governing this process.

The main finding is the identification of a critical temperature threshold above which the laminate porosity decreases drastically and promptly. Reaching this threshold reduced final porosity to below the usual aerospace acceptance limit (typically < 1%). Moreover, this low-porosity state remained stable and unaffected by further temperature increases beyond the threshold. Another key observation is that the laminate thickness reduction during consolidation consists of distinct, temporally separable stages: laminate thermal expansion, compaction, and crystallisation. These stages were successfully and accurately tracked at the laminate level.

This comprehensive experimental dataset provides a robust basis for predictive modelling of both final porosity rate and the through-cycle thickness evolution. These results establish a framework for advanced VBO control strategies, enabling thermal cycle optimization while ensuring compliance with stringent quality requirements for high-performance aerospace composites.

#671

# Self-heating effect of multidirectional carbon fiber reinforced composites under biaxial tension-tension fatigue loading

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Multidirectional composites employed in aviation, automobile, and wind turbine industries are often subjected to the biaxial tension-tension fatigue load, which leads to mechanical fatigue damage and self-heating effect. However, most fatigue studies on thermo-mechanical behaviors focus on uniaxial fatigue loading, which is not applicable to biaxial fatigue due to coupling effects. Therefore, this study aims to investigate the temperature rise in multidirectional composites under biaxial fatigue loading and to explain fatigue damage evolution from a thermodynamic and solid-mechanical perspective. Firstly, an improved specimen design is proposed for two multidirectional composites (cross-ply [(0/90)6]s and quasi-isotropic [(0/45/90/-45)3]s) using finite element simulation and the Tsai-Hill failure criterion. Secondly, a biaxial tension-tension fatigue test is conducted using infrared thermography and DIC (Digital Image Correlation) to ascertain the mechanical and thermal properties of the two composites. Finally, mechanical and thermodynamic information are correlated to analyze the influence of the biaxial fatigue loading on the self-heating effect. The findings indicate that the biaxial fatigue load produces a much higher temperature rise in the cross-ply composite than in the quasi-isotropic composite, and the trend in temperature variation indicates the initiation of damage or a change in the damage mode.

#672

# Online Spinning of TPU/GF Hybrid Yarn for Thermoplastic Multi-Matrix Fiber-reinforced Plastics

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Thermoplastic multi-matrix fiber-reinforced plastics (TP MM-FRPs) enable the integration of sharply distinct zones of variable stiffness within a single reinforced structure by combining different polymer matrices around continuous fibers. This architecture supports components requiring localized compliance or rigidity without relying on mechanical hinges or bonded interfaces. Applications in soft-actuated systems, minimally invasive medical tools, and other lightweight elements benefit from such continuous yet functionally graded preforms. The key advancement for producing these MM-FRPs is the availability of hybrid yarn systems pairing glass fibers with thermoplastics that exhibit either soft or stiff behavior. Elastic segments are created by combining glass filaments with thermoplastic polyurethane (TPU, Shore A ≈ 70), whereas rigid regions are established using glass fibers co-processed with a stiff polymer like polypropylene or high-hardness TPU grades (Shore D ≈ 80).

This work investigates an online melt-spinning route for TPU/GF hybrid yarns as an integrated approach for forming multi-matrix preforms. Processing highly soft TPU in the melt presents significant challenges: it induces pronounced stick-slip phenomena at contact points along the spinning path, complicating filament attenuation and the achievement of stable draw ratios. Nevertheless, while solvent-free, melt spinning offers environmental and operational advantages. The simultaneous spinning of both filament types enables direct combination of TPU filaments with glass fibers within a single continuous line. The study analyzes spinning instabilities, thermal windows for filament formation, additive and sizing effects, adhesion behavior during hybridization with glass reinforcements, and parameters affecting filament uniformity and hybrid yarn integrity. The presented results demonstrate how online hybrid spinning strategies can streamline thermoplastic MM-FRP preform manufacturing and broaden their use in technical and biomedical engineering, while also improving recyclability and sustainability.

#674

# Effect of slurry characteristics on the quality of Carbon fiber-PEEK thin-ply prepreg tapes manufactured by wet impregnation

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Carbon-fiber thermoplastic prepreg tapes are vital for developing tougher, more sustainable composite structures. High-performance polymers like PEEK offer excellent mechanical properties for aerospace applications, but achieving high fiber volume fraction (FVF) via melt impregnation is difficult due to high melt viscosity of PEEK. As a result, wet impregnation using a water-based slurry of micron-scale polymer particles is preferred. Low-viscosity slurry enables spontaneous tow impregnation, followed by water removal and melt consolidation. However, the influence of slurry characteristics on FVF, fiber distribution, and defects remains poorly understood, with limited research on viscosity, particle size distribution, or thickeners.

This study, conducted at the Delft TapeLab, investigates a kiss-roll impregnation setup where a polymer-rich slurry film is picked up by a rotating roller and transferred to fibers through capillary wetting. Rheological characterization showed non-Newtonian behavior in PEEK slurries, and an analytical model was developed to relate viscosity to particle content and shear rate. At a shear rate of 200 $s^{-1}$, a 10% increase in PEEK content by weight led to a 25% increase in viscosity, accurately predicted by the model. Higher viscosity, in conjunction with the roller speed, increased particle pickup and slurry-film thickness on the roller. This affected FVF directly, causing over 30% decrease in FVF for a 10% rise in PEEK content.

Tow spreading was optimized for different tow sizes to achieve homogeneous fiber distribution and consistent particle pick-up across tape width. Particle size distribution also influenced FVF, as particles larger than 1 µm tend to sediment quickly, altering the effective viscosity of the slurry available for pickup; continuous mixing mitigated this. Environmental effects on slurry viscosity and FVF during continuous operation were also examined. Overall, the results provide a foundation for optimizing wet impregnation by controlling slurry rheology, composition, and fiber spreading to produce consistent, thin-ply PEEK prepreg tapes.

#675

# Thermal and Mechanical Influence of Interlaminar Defects in RTM-Manufactured Carbon Fiber-Reinforced Polymer Laminates

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Carbon fiber reinforced polymer laminates are widely used in aerospace structures because they offer a very high strength to weight ratio and good performance under demanding service conditions. Resin Transfer Molding is an efficient manufacturing method for producing high quality composite components such as fan outlet guide vanes (FOGVs) in aeroengines. However, defects formed during processing, including voids and interlaminar separations, remain difficult to avoid and can influence the way damage initiates and propagates. These defects may reduce stiffness, alter internal stress distributions, and lead to premature failure. For this reason, understanding their effect on the mechanical response of composite laminates is an important step towards improving structural reliability.

In the present study, controlled delaminations were introduced before manufacturing by placing thin Teflon films during the lay-up of CFRP laminates. This approach enabled us to create precise and repeatable artificial defects that act as representative substitutes for interlaminar voids. The mechanical behavior of the manufactured plates was examined using four point bending tests to investigate how delamination size and distribution influence flexural response. To reproduce realistic operating conditions found in aeroengines, bending tests were carried out at both low and high temperatures. This allowed an assessment of how variations in temperature modify the behavior of the matrix and affect damage initiation, stiffness reduction and interlaminar cracking behavior. By establishing correlations between delamination characteristics, thermal conditions, and flexural performance, this work contributes to the development of improved defect-tolerant CFRP structures. The insights gained support the refinement of predictive models for damage evolution in composite materials and provide guidance for designing more reliable and efficient aerospace components. Ultimately, this research advances the broader goal of enabling lightweight and sustainable aviation through a deeper understanding of how manufacturing defects influence the performance of RTM-manufactured CFRP laminates.

#676

# Coextrusion of profiles with graded mechanical properties to reduce stress peaks

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Lightweight structures made of fibre-reinforced thermoplastics often suffer from weak interfaces between continuous-fibre tapes and non-reinforced regions. These discrete material transitions lead to stress concentrations and delamination under load due to pronounced stiffness differences between the layers. This remains a key factor limiting the mechanical efficiency and reliability of hybrid components. To overcome these limitations, this study investigates the coextrusion of thin, graded profiles as semi-finished products combining unidirectional (UD) tape and long-fibre-reinforced thermoplastic (LFT) melt to create material-inherent transition zones. The resulting profiles serve as inlays for injection moulding, enabling locally reinforced components with improved inter-layer adhesion, load transfer, and robustness.

A specially adapted coextrusion setup allows controlled merging of two UD-tapes with different fibre-volume-contents and one LFT stream, with precise adjustment of fibre volume content and layer thickness to define the mechanical gradient. This enables a continuous transition from highly oriented UD regions to randomly oriented long-fibre domains, reducing stiffness jumps and improving stress distribution. Graded morphologies with different gradient widths and reinforcement ratios are produced. The profiles are back-moulded and characterised in terms of morphology, bending stiffness, and failure behaviour.

Previous results have shown show that the graded transition leads to more progressive failure and delayed crack initiation compared with conventional discrete tape-matrix interfaces. The gradual change in fibre content facilitates stress redistribution and improved bonding between layers. Such graded semi-finished products open new design possibilities for locally optimised, recyclable composite components.

This work provides a promising route towards scalable, resource-efficient hybrid components with tailored reinforcements, contributing to the broader vision of intelligent, sustainable production technologies for high-performance polymer structures with load-dedicated graded architectures.

#677

# Modification of a flax fibre textile using a surface barrier discharge plasma in oxidating, inert and reducing gases

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With the global transition towards renewable resources, natural fibres such as flax fibres are used more frequently in fibre reinforced composites for technical applications. One drawback of these nature-grown fibres is their hydrophilicity, as absorbed water inside the fibres leads to weakening of the resulting composite material. Plasma treatment is a possible solution to tackle this issue by changing the fibre surface functionality and reducing the adsorption capacity for moisture. At the same time, the chemical and morphological modifications may as well contribute to enhance fibre-matrix adhesion within the resulting composite. In general, it has to be differentiated, if loose fibres, yarns or textiles are embedded in a polymeric matrix. This not only influences the properties of the resulting composites, but also the method of surface treatment with plasma, as textiles present challenges quite different from those during the treatment of particles or individual fibres. Particularly the plasma treatment of different fabrics from natural fibers such as flax are much less researched up to date.

In this study, a surface barrier discharge plasma at atmospheric pressure is used to treat a satin weave flax fibre textile. Thereby, a variety of gas mixtures containing oxygen, hydrogen, nitrogen and argon are utilized to provide oxidative, inert or reductive working atmospheres. The outcome of the plasma treatment of flax fibres is analyzed in terms of wettability, moisture and water-uptake. Moreover, the chemical changes are studied using attenuated total reflectance Fourier-transform infrared spectroscopy and X-ray photoelectron spectroscopy. The changes in surface morphology of the textile are characterized by confocal laser scanning microscopy.

#678

# A Unit Cell of Minimum Size Containing a Single Fiber Tow for Characterizing Effective Properties of Plain Woven Composites

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Unit cell modeling of plain woven composites is essential for predicting their effective properties, which are strongly influenced by the complex interlacing architecture of fiber tows. Conventional unit cell models, defined solely by translational symmetry, often contain redundant geometric symmetries that result in a large number of degrees of freedom and high computational cost. These limitations reduce their practicality in applications that require extensive repeated simulations, such as optimization and uncertainty quantification studies. This work extends the concept of a minimum single fiber tow unit cell, originally formulated for mechanical property characterization, to simultaneously capture the thermal behavior of plain woven composites. By rigorously applying all geometric symmetries inherent in a plain weave, the model establishes consistent relative displacement and temperature boundary conditions that enable accurate representation of the periodic behavior with minimal geometric complexity. A parametric geometric description is further developed to accommodate high fiber tow volume fractions without tow interference, addressing a key limitation of conventional periodic modeling techniques. Finite element simulations are performed to evaluate both the effective elastic constants and thermal conductivities under various geometric and material parameters. The results show that the proposed minimum unit cell reproduces the effective properties of a complete periodic model with negligible deviation while achieving a substantial reduction in computational cost. In particular, the simplified model decreases computational time by more than an order of magnitude without compromising predictive accuracy. Furthermore, the unified framework provides a versatile platform for coupled thermo-mechanical simulations, enabling the analysis of heat transfer and structural interactions as well as the evaluation of process-induced effects. The proposed methodology offers a robust and efficient basis for multiscale modeling, optimization, and digital material design of woven composite systems.

#679

# Treating uncertainties in the failure load prediction of fiber-reinforced composites with acoustic-emission testing

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Previous works have shown that acoustic-emission (AE) testing, a non-destructive, passive method, can be used to predict the failure load of fiber-reinforced polymers (FRPs). The method requires following a specific loading and unloading scheme to obtain the Felicity-, Energy- and other characteristic ratios. Given a large enough database, a model can be trained to relate the recorded AE ratios to the failure load. In these works, it was found that theses relations hold similarly for small FRP specimens as well as for complex structures such as carbon fiber overwrapped pressure vessels. This novel technology could be applied in the regular inspection of pressure vessels to improve the operational safety or to qualify pressure vessels for lifetime extensions or second life applications after the end of their nominal service period. This could potentially save costs and benefit resource efficiency. For meaningful failure load predictions, it is essential that uncertainties in the model and in the data are estimated and tracked. This can be achieved by a fully Bayesian treatment of the two-step prediction procedure. A Bayesian Neural Network serves as model to obtain individual predictions at the current load level. This has the advantage of delivering probabilistic outputs and better generalization of the model. This step is followed by a grid search to reconstruct the probability density function of the failure loads given all previous model predictions for the ongoing test. We present preliminary results of tests conducted on CFRP specimens under tensile load and on pressure vessels. Based on these, the influence and predictive quality of models resulting from different test objects, such as different CFRP layups and specimen- vs. vessel scale, are discussed.

#680

# Microstructural Analysis of Compacted Continuous Fiber 3D Printed Parts Using In-Situ X-ray Computed Tomography

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Additive manufacturing (AM) has gained attention due to its ability to produce complex components without costly tooling and reduced material waste. Recent developments make it possible to reinforce the printed parts with continuous fibers. However, these continuous fiber 3D printed (CF3DP) parts show inferior mechanical properties compared to conventionally manufactured composite laminates. This is mainly due to low fiber volume content, high void content, insufficient interlayer bonding, and high fiber waviness. In-situ compaction during the printing process can reduce void content and improve layer bonding, but the influence of compaction force on the microstructure needs to be investigated.

In this work, a custom printhead equipped with a heated compaction roller was used to print continuous fiber specimens under various compaction forces (1 N, 10 N, 20 N, and 30 N). To investigate how compaction influences internal morphology and defect evolution, in-situ X-ray computed tomography (CT) was performed during 3-point bending. All scans were then acquired using a Tescan CoreTOM system at 7.2 µm voxel size.

The CT results show a significant influence of the compaction force on the microstructure. Low-compaction specimens show high void content and fiber waviness, whereas higher-compaction specimens leads to reduced porosity and improved fiber alignment. Void content decreases from 22.6% at 1 N to 9.3% at 10 N, followed by 7.9% and 6.1% at 20 N and 30 N, respectively. This shows a diminishing but continued consolidation at higher compaction forces. Under bending, initial failure is initiated by layer separation in low-compaction specimens, whereas highly compacted samples show better-bonded interfaces with less delamination. The presented framework offers a promising methodology for evaluating printing parameters using in-situ CT and supports future optimization of CF3DP processes. Future studies will focus on correlating CT-based microstructural results with mechanical performance using systematic mechanical testing.

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# Characterization of acrylic resin surface energies

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The present study, conducted as part of the Carnot Mines AVICAR project, investigates the interfacial interactions between a reactive thermoplastic matrix, the Elium® resin (Arkema), and carbon fiber reinforcements. Elium® is a low-temperature curable acrylic resin that represents a promising alternative to traditional epoxy resins, thanks to its recyclability and compatibility with recycled carbon fibers, which aligns with the need for sustainable composite solutions.

However, the mechanical performances of such composites critically depend on the quality of resin impregnation, which is directly influenced by fiber wettability, the surface tension of the resin, and the surface chemistry of the fibers (e.g., sizing agents, thermal treatments).

To address these challenges, this study develops a novel methodology to characterize surface energies of acrylic resin across different compositions, distinguishing its polar and dispersive components. The approach is then extended to sized carbon fibers to evaluate how their surface properties affect wettability, and resin permeability during infusion processes. Indeed, Elium® exhibits a lower total surface tension (30 mN/m) compared to a conventional epoxy resin (47 mN/m), but with a polar component of 5 mN/m identical to that of the epoxy resin, highlighting both differences and similarities in their interfacial behavior.

Unsaturated permeability of the reinforcement estimated with three liquids having distinct surface tension revealed significant variations in obtained permeability values, highlighting the critical influence of the polar component of the surface energy on capillary pressure and resin flow through fibrous reinforcements. These findings provide key insights into the interfacial phenomena governing the performance of acrylic-based composites. Future work will leverage these results to optimize Elium® resin formulations and fiber sizing strategies, tailoring the polar/dispersive surface energy ratios to enhance fiber wet-out and improve fiber/matrix adhesion in sustainable composite systems.

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# Concurrent density- and fiber orientation-based topology optimization of 3D transversely isotropic composite structures with strength constraints

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Additive manufacturing techniques require the development of computational design tools capable of generating complex geometries while respecting industrial restrictions. Topology optimization provides an efficient framework to obtain innovative and optimized material distributions within a design space, in an iterative manner. This topic has been studied extensively for isotropic materials and increasingly for anisotropic ones. One major challenge in optimizing composites lies in addressing both topology and anisotropic behavior simultaneously. The incorporation of strength constraints in the topology optimization of 3D structures remains rare in the literature [1]. In this work we focus on the concurrent density- and orientation-based topology optimization of 3D transversely isotropic composite structures. The density is parametrized using the SIMP interpolation scheme. Special attention is paid to the parametrization of the transverse isotropy axis (which is defined by the direction of fibers in the case of fiber-steered composites). We consider the anisotropic elliptic failure envelope of the Tsai-Wu criterion that is oriented along the direction of the transverse isotropy. The optimization is driven by the gradient-based Split Method of Moving Asymptotes (split MMA) algorithm [2]. The density is stabilized by a Helmholtz filter to suppress checkerboard problems and mesh-dependency. Optimization problems with minimization of the compliance under volume and strength constraints are presented on 3D academic numerical examples, considering fiber-steered composite materials. We use Z-set, a finite element software developed by ONERA and Ecole des Mines de Paris. This work is funded by Airbus Atlantic and the authors are thankful to Attilio Chiappini for the scientific discussions.

[1] S. Nozawa and G. Serhat, "Topology and fiber path optimization of composite structures: A critical review," Mater. Des., Mar. 2025

[2] L. Vertonghen, F.-X. Irisarri, D. Bettebghor, and B. Desmorat, "Gradient-based concurrent topology and anisotropy optimization for mechanical structures," Comput. Methods Appl. Mech. Eng., Jul. 2023

#683

# Ceramic coatings for protection of polymer composites from high energy events

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While carbon-fibre reinforced polymers (CFRP) offer excellent specific properties, polymer matrices degrade rapidly under thermal loads such as laser irradiation. In this study, the protective role of a thermally sprayed stabilised zirconia ($ZrO_2$) ceramic coating was investigated for its promising high melting point [1], strong infrared reflectivity [2], and low thermal conductivity [3].

Ablation tests were conducted using a high power, continuous-wave fibre laser at varying power increments. A diagnostic setup incorporating pyrometry, thermocouples and a filtered camera enabled real-time observation of the material behaviour and the collection of key performance metrics including frontal and substrate temperatures as well as coating and substrate perforation times.

Thickness emerged as the dominant performance parameter, with a four and ninefold increase in survivability in thicker coatings (T2 and T3) relative to the thinnest (T1). It was observed when porosity and surface roughness was varied, this produced negligible benefit and, in some cases, reduced performance. However, thickness was unintentionally reduced in the manufacturing and when reduce mass is accounted for, higher specific properties are calculated. Higher specific performance is associated with higher coating reflectance but this is caveated with the uncertainty of the coating material integrity and bond strength.

Thermal measurements show the coating maintains a protective barrier until its phase-stability limit [4], beyond which an abrupt coating perforation follows, due to a drastic drop in reflectance and material integrity [5][6].

Following perforation, indications of thermite reactions were observed and supported by SEM-EDX analysis of the separation of reaction products. This adds an additional thermal burden to the underlying CFRP substrate, which leaves potential for more effective shielding materials and strategies to be developed.

In summary, the T2 and T3 plasma-sprayed coatings, considered in this high energy study, were able to extend the survivability envelope of CFRP substrates significantly beyond the T1 structure.

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# Ai-enhanced multiscale predictive modelling for characterising recycled, bio-based, and virgin plastic materials

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The transition to a circular plastics economy requires robust approaches for predicting the mechanical, thermal, physical, and rheological behaviour of heterogeneous material systems derived from recycled polymers, bio-fillers, and hybrid polymer blends. However, significant variability in feedstock composition and microstructure presents major challenges for process optimisation in extrusion and injection moulding. Within the EcoPlast project, this study aims to develop predictive modelling methods that characterise these complex materials and supply high-quality datasets and homogenised properties for downstream AI-based digital twins.

This work presents an integrated computational framework combining numerical homogenisation using representative volume elements (RVEs) with AI-driven property prediction, employing the in-house developed EasyPBC tool to compute effective elastic properties, Specific heat capacity, Poisson's ratios, density, and thermal expansion coefficients, and other thermomechanical properties for materials containing stochastically distributed bio-fibres, wood-powder fillers, and blends of virgin and recycled polymers. The approach captures microstructural variability, including constituent uncertainties, filler geometry, and material distributions, beyond the capability of classical analytical homogenisation, while introducing a new set of boundary constraints that improve the computational efficiency, which will be coupled with an AI framework. Material property datasets provided by partners include mechanical, thermal and density measurements for individual constituents (bio-fillers, recycled polymer, virgin polymer) and hybrid compounds. These multi-point datasets enable statistical calibration of the RVE models and serve as training and verification data for the AI predictive engine. By integrating homogenised properties, uncertainty ranges, and experimentally verified datasets, the resulting AI model supports process-ready digital twins capable of optimising extrusion and moulding parameters for recycled and bio-composite feedstocks.

#686

# Compliance Free Mechanical Characterization of Single Carbon and Glass Fibers Through a Versatile Video-Extensometry Method.

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The mechanical characterization of single fibers is critical for high performance composite design. The correct experimental determination of the elastic modulus, strength and overall stress-strain behaviour are a necessity.

The well-known standards (ISO 11566, ASTM D3822) for single fiber tensile testing on high-stiffness fibers like carbon and glass fibers have several drawbacks. One of the main downsides to these test methods is that they (i) propose to use a fiber frame for inserting the specimens into the testing machine, and (ii) they almost exclusively rely on crosshead/clamp displacement to derive strain. These factors result in improper and biased mechanical characterization, usually underpredicting the fiber properties such as modulus.

The new compliance-free method that we want to present provides much lower variability than the established methods, while still being relatively simple and low-cost. It is based on a non-contact optical technique using telelenses. It allows to directly measure fiber strain, removing the artefacts introduced by machine and fiber frame holder compliance. Furthermore, it allows accurate testing of even short fibers with limited gauge length.

We present a thorough analysis of single fiber measurements for a range of carbon fibers varying in moduli and tenacity, as well as glass fibers, performed on a state-of-the-art tensile machine dedicated to single fiber testing. We show that our direct strain measurement accurately captures the distinct non-linear elastic regime of carbon fibers, as well as show that indirect strain measurements consistently result in too low moduli values (by approximately 10%).

The goal of this work is to eliminate machine-related parameters, minimising issues caused by sample preparation and operator handling, to create a more robust testing procedure of single fibers using hardware that is feasible for both research lab and industrial quality environments.

#688

# Identification of the damage mechanism in a ceramic matrix composite / protection {CMC-EBC} system under tensile test

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Ceramic matrix composites (CMC) are used in aeronautics for extreme thermomechanical conditions. Their low density and high refractory properties make them relevant materials for critical parts such as turbine blades. To prevent the CMC degradation for long life duration under the oxidizing and high temperature atmosphere of the engine, the material has to be coated with an environmental barrier coating (EBC). Main failure mechanisms of CMC and EBC under various environment are well-identified. However, little research deals with the synergic effect of the EBC and the CMC.

The initiation and the propagation of cracks between the CMC and the EBC are key information to predict the lifetime of the system. Indeed, under thermomechanical loadings, several factors have to be investigated to predict the stress distribution and damage evolution of the {CMC-EBC}, especially the kinetics of first cracks: interfaces, material morphologies, thermal properties and part geometry.

This study focuses on the understanding of the cracking of a SiCf/SiCm CMC coated with an ytterbium disilicate top coat. Tensile tests are performed at ambient temperature to established the initial crack behavior. Owing to damage closure phenomenon, specific instrumentations are installed for direct in-situ surface observation: microscopy, digital image correlation, and acoustic emission. Cracking scenarios are highlighted, explained by morphological characteristics of the {CMC-EBC} system (internal defect, microstructure…) and compared to analytical models.  Finally, this experimental method can be improved in order to quantify the impact of high temperature which induces thermal dilatation, creep phenomenon...

This work paves the way for a full understanding of the {CMC-EBC} system and to determine whether the EBC can enhance the lifetime of the aeronautical part if its damage threshold is greater than that of the CMC, depending on the thermomechanical constraints applied.

#689

# Localized heating of high-performance composites with short and continuous carbon reinforcements

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Thermoplastic additive manufacturing of high-performance parts at large scale is one the most active topics of research in the field of next-generation composites, expected to accelerate structural design space, manufacturing output and sustainability. However, there are still key developments to be matured for AM to provide similar mechanical properties as those obtained by conventional manufacturing processes. Three key developments focus on i) understanding the thermal effect when shifting from desktop to large format (m scales), ii) printing continuous fibre-reinforced materials increasing +1.000% the ultimate strength and iii) obtain isotropic properties through thickness as compared to those on printing direction, currently falling in the range of 50-60%. This work presents a systematic study of AM parameter space on desktop and large format AM on the influence of i) integrated heating systems (CO2 laser and infra-red lamp) to process high-performance thermoplastics requiring 400-500ºC of printing temperature (PC and PEKK) and ii) the impact of continuous carbon fibre reinforcement and related manufacturing limitations.

Laser heating of the substrate during printing of PC-20%CF showed to be an efficient heating source to achieve +140 - 240ºC gradients at 50-100 mm/s of printing, respectively, increasing the σz ultimate strength in the range of +55%, while IR lamps enable multidirectional printing achieving +40% increase, yet a limited heating capability at fast printing speeds based on the lower effective heating power as compared to laser. On the other hand, printing of PEKK samples from pure polymer, short-fiber reinforced and continuous-fibre reinforced showed a gradual increase of ultimate strength from 73,5MPa to 90,5MPa, and 848,8MPa, while introducing laser heating drastically increased up to 1.493MPa (16x), demonstrating to be the differential factor for high-performance composites by AM. The role of manufacturing engineering setups is extensively discussed, paving the way towards next-generation composites by AM.

#690

# Data driven acoustic emission classification of failure mechanisms in CFRP Tensile Tests

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The safety assessment and design optimization of hydrogen storage depends on accurately characterizing the structural stability of composite overwrapped pressure vessels (CPVs). Acoustic emission (AE) testing is a promising approach for CPV condition monitoring. However, reliable classification of failure mechanisms remains challenging due to the complexity of the failure modes, including matrix cracking, fiber-matrix debonding, and fiber breaks.

This study proposes a damage monitoring pipeline that integrates AE with machine learning (ML) to classify and predict damage types in carbon fiber reinforced polymer (CFRP) tensile tests. Quasi-static tensile tests were conducted on CFRP specimens with different stacking sequences of carbon fiber plies. Obtaining labeled data is difficult as AE signals are complex and in-situ observation of microscopic failures is challenging. An unsupervised Gaussian Kernel Density Estimation (KDE) was applied to frequency domain AE features to identify dominant clusters as low, mid, and high frequency groups, corresponding to potential failure mechanisms. For further validation of unsupervised labels, macro-scale finite-element (FE) simulations of the tensile specimens were performed. Simulations were evaluated regarding force-displacement agreement with experimental data, together with the prediction of failure initiation and total failure of the specimens utilizing the Puck failure criteria and the maximum-strength criterion. Later, the validated labels served as ground truth for supervised model training. ML models were trained to learn discriminative patterns, enabling reliable damage classification across the tensile test experiments.

Results indicate the proposed ML pipeline performs well in identifying potential failure patterns. Integrating KDE-based labeling with FE validation improved the reliability of the training labels. ML models trained for each experiment achieved consistently high performance across standard metrics. The proposed approach shows strong potential for enhancing reliability of damage characterization in composite structures and is potentially capable of generalizing to full vessel-scale applications, thereby improving efficiency and safety of hydrogen storage systems.

#691

# Assessment of the Stiffness–Damping Trade-Off in Hemp/Elium® Composites for Wind Turbine Applications

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Conventional composites reinforced with carbon or glass fibers exhibit excellent mechanical properties but suffer from limited vibration damping, which can negatively affect performance and fatigue life, and addressing this limitation requires complex and costly technical solutions that increase the weight and cost of the system. Plant fibres, such as hemp, offer a promising alternative thanks to their inherently higher damping properties, paving the way for their use in structural applications.

The aim of this study is to optimize the structural damping of a bio-based wind turbine blade made of hemp fibers and Elium® resin, while maintaining sufficient stiffness. To achieve this goal, a multi-scale approach is adopted, from constituent properties to full-scale structural behaviour.

The central question is how the elastic and damping properties of these new constituents affect the global behaviour of a complex structure. More specifically :

– can a reactive thermoplastic such as Elium® significantly enhance the damping of the composite and the associated structures?

– do hemp fibers offer a relevant compromise between stiffness and damping?

To answer these questions, a material-scale comparison is conducted between a benchmark flax/glass–epoxy composite and a hemp–Elium® composite, focusing on the stiffness–damping balance. The elastic and damping properties are identified using two complementary methods: an inverse approach (FEMU) based on vibration tests and a direct approach (DMA). Initial results on the pure resins show that Elium® has a loss factor about twice that of GreenPoxy® (~6% vs. ~3%), indicating strong improvement potential. The comparison is then extended to various hygrothermal conditions to assess the effects of temperature and humidity.

To investigate potential effects at the composite and structural scales, a higher-scale study is performed on a blade prototype. The objective is to determine whether material-scale trends persist at the structural level or whether geometry and boundary conditions alter the response.

#692

# Functionalizing flax fibers through metakaolin dispersion for the formulation of enhanced geopolymer composites

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Abstract

The anthropic footprint on climate compelled the scientific and industrial community to find sustainable alternative materials and processes with low environmental impact. In this context, the most strategic challenge in reducing CO2 emissions involves the development of alternatives for Portland cement-based binders. Geopolymers are inorganic materials with a sustainable profile due to the lower consumption of energy and the possibility to use industrial wastes and are produced by the alkaline activation of aluminosilicate precursors, such as metakaolin. Nevertheless, the intrinsic brittleness of geopolymers under tensile and flexural loading promotes the use of natural fibers such as flax as reinforcement. This is because natural fibers possess a significantly higher tensile strength than compressive strength, making them ideal for improving the geopolymer's performance.

Nevertheless, as flax fibers are lignocellulosic, they exhibit weak adhesion to geopolymers matrices. To improve the fiber-to-matrix bonding, this work aims to investigate the feasibility of a two-step surface treatment. The proposed approach consists of an initial alkaline pre-treatment (using a NaOH or NaHCO3 solution) followed by a subsequent coating with metakaolin-based aluminosilicate particles, which is achieved by immersion in a 5wt.% metakaolin aqueous solution for times ranging from 3 to 12 hours. Raw, alkalinized and metakaolin-treated fibers were fully characterized using SEM, optical microscopy, TGA, and tensile tests, while the fibre-to-matrix bonding was investigated via pull-out tests.

The experimental results evidenced the efficacy of a proper aluminosilicate deposition, which yielded a beneficial effect on the interfacial fiber-matrix adhesion in comparison to solely alkalization. Furthermore, it was proven that the environmental impact and cost of alkaline pre-treatment can be reduced by using a more eco-friendly chemical, paving the way for less corrosive and more sustainable functionalization processes.

#693

# Graphite-metal composites fabricated by spark plasma sintering

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Carbon allotropes represent a family of materials with enormous potential in the field of heat dissipation due to their high thermal conductivities. Particularly, diamond has one of the highest thermal conductivities among all known materials, but its utilisation is limited due to the cost of this material, which is used in combination with copper and aluminium in some advanced applications. Graphite also has a very high thermal conductivity and a lower cost than other carbon allotropes. Nevertheless, it has several problems because the obtaining of dense components is complicated if high temperatures and pressures and controlled atmospheres are not employed. The utilisation of metals is a potential solution to obtain dense components of graphite, and the suitable technology to obtain these dense constituents is the spark plasma sintering. This investigation presents the results about the fabrication of graphite-chromium composites considering different variables: the chromium content, the method of preparation of the composites (ball milling or colloidal synthesis), the sintering temperature and the utilisation of not of carbon fibres. The composite, sintered by spark plasma sintering, with 15 vol. % Cr3C2 (215 W·m-1·K-1) allows for significantly improving the thermal properties with respect to the graphite (17 W·m-1·K-1) in the in-plane direction. The incorporation of carbon fibres improves even further the thermal conductivity (360 W·m-1·K-1) in this direction. The thermal conductivity in the through-plane direction is one order of magnitude smaller when a second (or third) phase is employed. Regarding the mechanical properties, the Cr3C2 is responsible for the greater flexural strength (>100 MPa), since the graphite itself, sintered in the SPS reports a value of 24 MPa. As it was observed in the different properties, the graphite-metal composites exhibit an anisotropic behaviour, which was studied by synchrotron measurements, being potentially employed in applications where directional heat dissipation is demanded.

#696

# Prediction of the tensile response of multidirectional laminates

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Classical Laminate Theory (CLT) is the standard analytical framework used to describe the mechanical behavior of laminates composed of Fiber Reinforced Polymer (FRP) layers. Given the mechanical properties of each layer, CLT provides an analytically straightforward procedure to determine the strain field under prescribed external loads or, conversely, to compute the reaction forces resulting from an imposed strain field, and is therefore widely implemented in commercial structural analysis software.

A fundamental assumption of CLT is the linear elastic behavior of each layer. This is motivated by the common modeling approach for FRP plies, which are typically idealized as linearly elastic up to failure in all in-plane directions.

Nevertheless, experimental results show that the evolution of both the transverse Young's modulus (E2) with transverse strain (ε2) and the shear modulus (G12) with shear strain (ε6) exhibit a pronounced nonlinear behavior. These trends lead to significant stress relaxation, such that laminate failure occurs at applied loads or imposed strains substantially higher than those predicted by conventional CLT.

An analytical model is therefore proposed to account for the experimental nonlinear transverse and shear behavior into the existing CLT framework. With this model, the quasi-static response of multidirectional (MD) laminates is predicted based on transverse and shear modulus evolution obtained from experiments conducted on unidirectional (UD) laminates of the same material.

In this way, laminate design can consider material non linearities from early stages, enabling weight savings and fully exploiting the potential of FRP laminates, while simultaneously reducing the number of experiments required for the characterization of MD laminates.

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# Experimental characterization and modelling of radiation transport in UV-reactive matrices for fiber-reinforced composites

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The radiation-induced curing of thermosetting fibre-reinforced plastics (FRP) opens up new perspectives for fast, energy-efficient and tool-free manufacturing processes as an alternative curing method. The use of photoinitiators – matched to the desired wavelength in the ultraviolet spectrum (300 – 400 nm) – triggers chain growth reactions in the matrix, which lead to polymer cross-linking within a few seconds. In addition to the high reaction speed, the advantages of this curing principle include savings in external heat supply and the ease of storage. However, there is currently a lack of in-depth understanding of the fundamental material phenomena involved in the manufacture of thick-walled FRP structures. Radiation transport, reaction kinetics and heat transport are closely linked and, depending on the selected fibre volume content, significantly determine both the curing process and the achievable component quality. A high-resolution characterisation of the process steps is further complicated by the very short reaction times.

The contribution presents modelling approaches for radiation transport in UV-curing matrix systems, taking into account the complex interactions with potential fibre reinforcement. In parallel, novel approaches for the experimental determination of the relevant model parameters are shown and evaluated. The initial radiation input and its duration were varied and the effect on the cross-linking progress in different layer thicknesses was investigated. The contribution discusses the influence of light source radiation intensity, material parameters and absorbed intensity on the achievable material thickness of the resin. These findings provide a fundamental basis for further work on the interaction of radiation transfer with cross-linking progress and process-inherent heat generation in respect of future process simulation in the UV curing of FRP.

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# Tensile–Shear Coupling Behavior of Stretch-Broken Carbon Fiber Woven Reinforcements

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Carbon fibers are widely used in aerospace and other advanced engineering fields due to their excellent mechanical performance. However, continuous carbon fibers have limited formability, which restricts their application in complex-shaped components. Stretch-Broken Carbon Fibers (SBCF) are produced by pre-breaking continuous filaments into short segments with controlled lengths. This process significantly improves the formability of the reinforcement while keeping a high level of mechanical performance, with only a moderate loss in strength. Nevertheless, SBCF behave fundamentally differently from continuous fibers. Their mechanical response is dominated by short-fiber characteristics, especially in tensile deformation. Continuous fibers can often be treated as inextensible during forming, but SBCF show noticeable tensile deformation. This deformation couples with shear, bending, and other modes, making the forming process more complex and influencing defect formation. This study focuses on experimentally characterizing the tensile–shear coupling behavior of SBCF woven fabrics. Prior to shear loading, the fabrics are subjected to different pre-tensioning conditions, including biaxial tension, uniaxial tension along either the warp or weft direction, and combined tension with different magnitudes in the two directions. These conditions introduce a range of initial tensile states that are expected to influence the subsequent shear response during in-plane deformation. Frame-shear experiments are then conducted on the pre-tensioned specimens to examine how initial tensile deformation affects the evolution of shear angle, force response, and deformation pattern. Particular attention is given to identifying the interaction between tensile and shear mechanisms under large deformation. The findings are expected to contribute to a more comprehensive understanding of coupled deformation mechanisms and to support the improvement of forming processes for complex thermoformed composite components.

Keywords: Textile reinforcement, Stretch-Broken Carbon Fiber (SBCF); Tensile–shear coupling; Frame-shear test; Forming; Deformation mechanism

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# Process–Structure insights for FE modeling of braided tape geometries in the Press-Through Process

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Lightweight, high-performance applications demand thermoplastic composites with well-controlled structural integrity and processing reliability. Pressing offers a robust method for infiltrating a thermoplastic bulk polypropylene (PP) matrix through a braided glass fiber/polypropylene (GF/PP) tape preform. The resulting composite properties are strongly influenced by the permeability and structural characteristics of the braid, which govern infiltration efficiency, consolidation quality and post-flow fiber orientation. Understanding and predicting these process–structure interactions is therefore essential for tailoring performance while reducing costly experimental iterations.

To address this challenge, a multi-subsystem computational workflow was developed combining analytical equations, process mapping in MATLAB/Simulink and finite element (FE) modeling in Abaqus. Sequential Simulink subsystems were developed for the braiding, cutting and stacking stages to predict key preform descriptors such as braid angle, thickness, coverage and porosity. The IR heating and transport subsystems were used to determine the temperature and corresponding viscosity evolution within the oven and during transport. Stacked braid outputs are then reconstructed in TexGen to generate representative textile geometries, which are imported into Abaqus to simulate infiltration and compaction during the pressing process.

The integrated framework enables offline linkage of machine and process parameters to resulting braid architecture and thermoplastic flow behavior. Combining Simulink, TexGen, and Abaqus captures both geometric evolution and material consolidation, forming a predictive process–structure bridge. This digital environment supports early-stage design decisions by enabling controlled, virtual exploration of different manufacturing scenarios. It also clarifies how specific processing choices influence local preform deformation and matrix flow, offering guidance for refining process settings and assessing the sensitivity of the braided architecture to key input parameters.

Keywords: braiding, tapes, thermoplastic composites, pressing process

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# Dynamic Mechanical Characterization of Mycelium-Wood Particle Composite for Temperature Sweeps with Finite Element Analysis Support

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Materials for circular economy are developed based on synthetic and natural raw materials at an increasing pace. Wood particulates can form various composites where the particle size, tree species, and wood treatments can be varied. In a composite, the particles need to be bound by suitable matrix phase. Instead of plastics and other processed polymers, fungi can form suitable matrix. Mycelium has recently been studied as candidate fungus in wood particle composites. The wood particles can be recycled, thus, play a role in circular economy. This study focuses on characterization of Mycelium-wood composites. Dynamic mechanical (DMA) characterization is applied over a temperature sweep (50-152 °C). Thermogravimetric analysis (TGA) is supplied to follow stability of the sample material up to full degradation in oxidative environment, i.e. burning. Due to the uneven growth of Mycelium, finite element analysis (FEA) is performed to study load transfer between wood particles and Mycelium in terms homogenized, composite stress used by DMA. FEA involves sample's Mycelium film and wood particles surveyed in tensile loading over ranges of load (displacement) and material properties (stiffness). The film-particle interface is estimated by so-called tie-constraint with averaging contact algorithm. The test results indicate that storage and loss modulus for the composite remain essentially constant up to 125-135 °C. TGA results show that the Mycelium part starts to degrade at 150-170 °C, which is before the wood particles. FEA indicates that the DMA results are highly dominated by the continuous Mycelium film – the effect of wood particles attached is negligible.

#703

# Contrasting Durability Mechanisms in Flax Laminates and Bamboo Fiber Composites with MA-g-PP Modification

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The demand for sustainable yet high-performance materials in the automotive sector has intensified interest in natural fiber–reinforced composites (NFRCs), although their long-term reliability under thermal and hygrothermal loading continues to restrict industrial uptake. This study addresses this limitation through a mechanism-driven durability methodology applied to two technologically relevant NFRC architectures: consolidated long-flax/PP laminates and short-bamboo-fiber (SBF)/PP injection-molded composites. The experimental workflow (Figure 1) integrates hygrothermal aging (50 °C, 95% RH, 400 h) and thermal aging (80 °C, 400 h for flax; 140 °C, 600 h for SBF) with tensile and impact testing, DSC, and DMA to quantify stiffness evolution, viscoelastic transitions, crystallinity changes, and aging-induced damage.

Both untreated and maleic-anhydride-grafted PP matrices were investigated, with 0.2 wt% MA incorporated to strengthen fiber–matrix interactions. The treated long-flax laminates exhibited increased tensile strength and enhanced impact performance, reflecting improved interfacial adhesion. Similarly, the SBF/PP system benefited from compatibilization, indicating that optimized interface chemistry can improve baseline properties even in discontinuous short-fiber composites. Building on this improved performance, the study evaluates how MA-g-PP influences durability during aging and enables differentiation of the dominant degradation pathways. Flax/PP laminates primarily experience matrix plasticization and moderate stiffness reduction under thermal or hygrothermal exposure, whereas SBF/PP composites undergo thermally induced matrix softening accompanied by partial fiber embrittlement [1–3].

Integrating mechanical, thermal, and viscoelastic analyses provides a consistent basis for quantifying durability losses and for evaluating the extent to which improved interfacial chemistry can mitigate them. This work provides a unified framework that links manufacturing architecture, interfacial chemistry, and aging-driven degradation to establish how thermal and hygrothermal conditions govern the long-term mechanical stability of both continuous flax-fiber laminates and discontinuous bamboo-fiber composites. The resulting insights support the development of next-generation automotive composite components where long-term stability and interface integrity are critical for reliable service performance.

#704

# Experimental study on cryogenic bending properties and failure mechanisms of carbon fibre reinforced polymer down to 30K

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Achieving Net Zero emissions in aviation demands innovative solutions for lightweight, high-performance hydrogen storage. Composite Overwrapped Pressure Vessels (COPVs) have emerged as a leading candidate, offering exceptional strength-to-weight ratios for storing liquid hydrogen. However, a key challenge remains; understanding the mechanical behaviour of composite structures under cryogenic conditions as low as 20 K some only a few facilities worldwide are capable of investigating.

At the University of Bath, a bespoke mechanical testing cryostat has been designed and built to enable precise mechanical testing at cryogenic temperatures under vacuum. In this work, we will present a three-point bending test as a demonstrator to characterise Carbon Fibre Reinforced Polymer (CFRP) materials under these extreme conditions.

This study investigates pure resin epoxy 8552, IM7/8552 unidirectional (0_2) composite laminates, and cross-ply (0_2/90_4/0_2) composite laminates, combined with Digital Image Correlation (DIC) analysis to study the material behaviour and failure mechanisms. Tests provide in-situ visualisation of failure modes at cryogenic temperatures, revealing how material performance and fracture behaviour differ from room-temperature conditions.

At cryogenic temperature, the resin becomes more brittle and doubles in stiffness compared to room temperature. This leads to the strengthening of the composite laminates owing to suppression of compressive failure on the compression surface with failure on the tension surface occurring instead. The fractography of the tested samples at different temperature will be investigated in order to identify the mode of failure and brittleness of the material. The moduli of the samples will also be determined as a function of temperature.

These characterised material properties at cryogenic temperature can be used as input parameters for finite element analysis to develop and design a COPV to store liquid hydrogen for the next generation of aircraft.

#706

# Induction heating treatment of wind turbine blade glass-fiber-reinforced epoxy resin as an alternative recycling method

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The accumulation of end-of-service-life wind turbine blades has become an increasingly significant environmental issue. These structures are mainly constituted by glass and carbon-fiber reinforced thermoset polymers (GFRP and CFRP), for which there is a lack of efficient recycling treatments. Mechanical grinding is currently the most common method to recover materials from wind blades, producing fillers for new composites. However, this process severely degrades the glass fibers and does not allow them to recover for reuse, moreover the resulting fillers often are low-quality products. Chemical treatments have been widely studied on a laboratory scale, using various solvents and reactions, but scale-up remains too costly and time-consuming. Thermal recycling is considered the most promising approach when used with polymeric materials, since it allows to recover part of their energy content. Nevertheless, only 20% of wind blade composite material is organic. For this reason, this work presents an alternative thermal process, to better preserve the integrity of glass fibers. Induction heating has been brought into focus, due to its high thermal efficiency, aiming to develop a faster process that consequently minimizes direct heating of the fibers. It is hypothesized that shorter processing times could also reduce the structural damage typically observed in conventional thermal treatments. Results are promising compared to standard pyrolysis, showing a significant reduction in processing time and the recovery of fibers with less structural damage and a homogeneous layer of carbonaceous residue on their surface. This residue can potentially be used as compatibilizer for the creation of new composites. Moreover, this process appears potentially scalable, uses recyclable conductor materials and reduces the overall costs associated with thermal recycling.

#707

# Influences on the fiber volume content during filament winding of thick-walled carbon fiber reinforced composite components with thermosetting matrix

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Filament winding is employed in the manufacture of rotationally and non-rotationally symmetrical hollow structures composed of fiber-reinforced plastics. This technology is selected for its various applications of small to medium series sized components, which include pipes, pressure vessels, and load-bearing elements in wind turbines.

The manufacturing process for thick-walled rotationally symmetrical components represents a substantial challenge, due to the increasing internal stresses that arise as component thickness increases. In this context to ensure the fulfilment of the specific requirements for the respective application, it is necessary and important to be able to set and ensure a consistent fiber volume content. A multitude of process parameters are available for this purpose in the manufacturing process of these thick-walled structures, which have a direct influence on the fiber volume content. These include the thread tension with increasing component thickness, the winding speed, the amount of resin applied to be taken up by the fibers in the resin bath, and the reproducible spreading of the fiber rovings when deposited on the winding mandrel.

The investigations examine the extent to which the aforementioned process parameters affect the fiber volume content and the way in which specific properties, for example mechanical properties like 3 point-bending or tension tests with reference to flat samples, of the fiber composite components are influenced. The present analysis focuses on carbon fiber-reinforced flat and thick-walled components with an epoxy resin matrix.

The objective of this study is to consider a range of fiber volume contents and ascertain the associated specific properties mentioned above. This will facilitate the conclusions regarding the impact on the fiber volume content of the manufactured components.

#708

# Smart thermoplastic composite laminates with self-healing capability

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Self-healing capability is a fundamental feature of biological systems and has increasingly inspired research in the field of materials science. In this context, self-healing composites represent an emerging class of materials able to autonomously restore their mechanical properties after damage. This functionality makes it possible to reduce maintenance interventions, extend the service life of components, and improve both environmental and economic sustainability. This study examines the intrinsic self-repair mechanisms occurring in thermoplastic composites, with a specific focus on the recovery of microcracks or localized damage that may develop during service. Such processes are typically activated by external stimuli, primarily temperature or voltage, which increase the mobility of polymer chains and promote the reformation of physical bonds and chain entanglements across the fractured surfaces. The main objective of the research is the design of self-healing thermoplastic matrices, mainly based on polyamide 6 (PA6), a material extensively used in thermoplastic composite manufacturing thanks to its excellent mechanical and thermal properties. Given the limited number of systematic studies in this area, various combinations of PA6 with thermoplastic healing agents and compatibilizers were investigated to identify the most effective formulations. The optimized matrices were then employed to produce long carbon fiber reinforced laminates. Experimental results showed that the resulting composites were able to fully recover their original mechanical strength and fracture toughness, confirming the effectiveness of the self-healing mechanism. Owing to their high tensile performance and remarkable self-repair capability, these materials exhibit strong potential for advanced structural applications where extended durability and minimal maintenance requirements are essential.

#709

# Lightweight Double Curvature Sandwich Panels with improved Fire Reaction for Façade Panels

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Double-curvature façades offer strong architectural appeal but are costly and complex to manufacture using conventional molds. Reconfigurable multipoint molding tools provide a promising alternative, enabling rapid shape changes through adjustable pin arrays and thereby reducing tooling time, cost, and storage needs. This project aims at solving two cumulative technological challenges concerning the materials for the development of lightweight sandwich FRP composites suitable for this forming approach: (1) fire-resistant materials compliant with A2,s1,d0 or B,s1,d0 classifications of EN 13501; and (2) with adequate processability, i.e. the fiber fabrics must have sufficient drapability to conform to double curvatures and polymeric matrix materials must be compatible with processing temperatures below 200 °C. Furthermore, candidate cores must be thermoformable.

This work evaluates several sandwich composite configurations for producing curved façade panels, comparing fully thermoplastic systems, using fire-retardant polypropylene (PP) and polyethylene (PE) matrices, with thermoset systems using naturally fire-resistant furan and fire-retardant epoxy resin. Basalt and glass fiber fabrics were selected as reinforcements, and all sandwiches incorporated a thermoformable foam core. Thermoset panels were manufactured by vacuum assisted resin infusion VARI, while thermoplastic panels were produced via a two-step compression-molding route.

After reaction-to-fire testing (ISO 11925-1) and UV-exposure conditioning screening conducted on flat specimens, the most promising candidates were subsequently subjected to the Single Burning Item test (EN 13823). The study identifies viable material combinations capable of meeting fire-performance demands while remaining compatible with reconfigurable multipoint molding to enable the industrialization of lightweight double-curvature composite façade panels.

#710

# Turning Up the Heat: A Novel Xenon Flash Lamp Based Active Thermography Method for Revealing Composite Defects

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Non-destructive testing (NDT) is an increasingly important research topic for composites as new materials and processes mature, and their use in safety-critical applications grows. A popular method of composite NDT is active IR-thermography, an established inspection technique that uses external heat sources to induce a thermal response and reveal subsurface defects. This study investigates a new active thermography technique that uses a powerful and highly controllable heat source, a xenon flash lamp, combined with a novel processing method, Restricted Heat (RH), to enhance damage detection. The controllable heat source allows for different variations of sample heating and exposure times to detect defects, and the combined method has the capacity to study how different heating conditions will affect damage detection.

In this first study, the project uses a “humm3” xenon flash lamp (from Excelitas Noblelight Ltd.) to impart high energy, broadband heating pulses onto composite panels and an infrared (IR) camera with a 48° field of view (FOV) lens to measure the thermal response. Several composite samples are assessed that include defects of known in-plane dimensions and depth. Predetermined delamination damage is produced using pillow inserts during manufacture. Additionally, a set of panels subjected to low-velocity impacts is evaluated, using a drop-tower rig to generate Barely-Visible-Impact-Damage (BVID) of unknown in-plane dimensions and depth within the laminate. The RH algorithm is applied to the thermographs collected by the camera using a MATLAB script.

The method developed in this study is able to detect pillow insert defects up to four plies deep within the panel with a signal to noise ratio (SNR) of 5.96 and detect BVID from 5 J impacts with an SNR of 3.77. Results indicate improved performance over traditional inspection methods, with halogen-based thermography (2x 600 J halogen lamps) unable to demonstrate the same sensitivity and reliability when detecting defects.

#711

# Modelling the effect of out-of-plane waviness defects on damage and failure of thermoset laminates

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The growing geometric complexity of composite aircraft components creates considerable manufacturing challenges. In particular, a manufacturing defect that may occur in laminated composite structures is the out-of-plane (OoP) waviness of the plies, which can have major effects on the mechanical performance of thermoset laminates, especially on tensile and compressive strength, but also on the damage scenario and failure of the composite structure. This study presents a robust method for the automated generation of digital twins to investigate the behaviour of unnotched and notched carbon-fiber/epoxy resin laminates with OoP waviness defects subjected to tensile and compressive loads. The finite element models are generated from parametrised waviness defects extracted from cross-sectional optical images of the specimens. Multiple Gaussian amplitude modulations in the three spatial directions are employed to capture the complex out-of-plane waviness geometry. This approach enables the description of a wide range of defect morphologies, including both uniform and graded waviness, whether they appear as embedded humps, indentations, or other configurations. The whole laminate is then rebuilt by explicitly embedding the waviness into the ply-by-ply mesh, thereby faithfully reproducing the original image. The behavior of the plies is modeled using the progressive damage and failure model (OPFM) developed by ONERA. Simulations are carried out in the commercial software Abaqus/Explicit . The numerical results show that the developed finite element approach is robust and efficient for accurately simulating the effect of out-of-plane waviness defects on specimen strength and damage scenario up to failure.

#712

# Kinetic Modelling of Early-Stage Thermal Degradation in Carbon-Fibre-Reinforced Thermoplastic Composites During Processing

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Early-stage thermal degradation during processing can significantly influence the crystallization behavior and structural performance of high-performance thermoplastic composites. Understanding this degradation regime is essential for defining robust processing windows and ensuring reliable part performance, particularly for advanced systems such as carbon-fibre-reinforced low-melt polyaryletherketone (C/LMPAEK) and carbon-fibre-reinforced polyphenylene sulfide (C/PPS). This work presents a kinetic modeling framework designed to quantify the onset and progression of early thermal degradation under processing-relevant conditions.

The approach is grounded in the principles of solid-state reaction kinetics, where the degradation rate depends on temperature, exposure time, and the evolving extent of chemical transformation. The framework remains compatible with kinetic descriptions commonly used in polymer degradation studies, including Avrami–Erofeev-type formulations that capture non-linear time dependence, saturation behavior, and sensitivity to thermal history. Such models are well-suited for representing the coupled thermo-chemical phenomena occurring in semi-crystalline thermoplastics at sub-pyrolytic temperatures.

Experimentally, specimens were subjected to controlled isothermal treatments using thermogravimetric analysis (TGA) to simulate the high-temperature exposure typically encountered during composite processing, from 5 to 60 minutes in either air or nitrogen. Following thermal treatment, the specimens were analyzed using differential scanning calorimetry (DSC) to quantify degradation-induced changes in crystallization temperature and degree of crystallinity, providing the dataset required for fitting and validating the kinetic parameters.

A predictive model was developed by combining crystallization kinetics (e.g., Nakamura-type descriptions) with the general solid-state reaction law in which the temperature-dependent rate constant follows an Arrhenius relation. The resulting model predicts the onset and progression of early degradation under realistic thermal histories, showing consistency with experimentally measured shifts in crystallization behavior. Overall, the methodology enables an evaluation of how thermal exposure, crystallization changes, and degradation kinetics interact during manufacturing and how they may influence the consolidation quality, thereby helping to define a reliable process window.

#713

# Experimental and numerical investigations on the bending and inter-layer shearing behavior of glass-fabric rubber composites

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Fabric rubber composite seals have been widely used to close gaps, reduce leakage, and optimize clearances in various parts of aircraft. These seals are usually composed of several fabric reinforcements in a rubber matrix, which can provide stiffness, abrasion resistance, or fire-resistance to the seal based on its functional properties. Considering conventional seal cross-sections, most seals are subjected to bending and internal pressure as a result of counterpart movements and differential pressure, respectively. These loads have a direct relationship with reaction forces acting on the counterparts and sealing efficiency. Stiff fabric-soft matrix composites are usually modeled in an oversimplified way in the literature, and this study aims to fill this gap. First, coupon tests were conducted to characterize the hyperelastic behavior of pure rubber and composite with a layer of fabric. The test results enabled the evaluation of various constitutive models and the identification of the corresponding material parameters. The coupon tests were then simulated in Abaqus software, validating the developed material models against experimental results. Next, composites with multiple layers of reinforcement, oriented identically, were subjected to three-point bending to examine complex multi-axial deformation state through thickness and reinforced layers with full-field measurements. In addition, inflation tests on rubber and composite enriched the understanding of complex structural behavior by replicating pressure loads. Consequently, the same structural tests were virtually performed by explicitly modeling pure rubber and thin reinforced layers in Abaqus software, evaluating their capability to reproduce bending behavior, pressure response, and out of plane shearing behavior between rubber and fabric layers. Finally, the developed modeling strategy led to a parametric study that examined the effect of different fabric orientation combinations, the number of fabric layers, overall thickness on bending and interlayer shearing behavior.

#714

# A Computationally Efficient HSL-FE Approach for Predicting Fibre Breakage in Composite Structures

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High-performance structural components are increasingly manufactured from fibre-reinforced polymers. Under longitudinal tension these materials accumulate damage in the form of fibre and cluster breaks, which can be captured with detailed microscale models; however, such models are either restricted to uniform loading, or they are prohibitively expensive for component-scale analyses. This research proposes a multiscale framework that couples a computationally efficient hierarchical scaling law (HSL) with finite element (FE) models to predict damage accumulation and failure in complex-shaped components with multi-directional lay-ups. The FE models use three-dimensional continuum or shell elements to represent the composite layup and incorporate cohesive elements to represent non-catastrophic damage mechanisms (e.g. splitting, cracking, delaminations), allowing the evolving stress state along the specimen to be resolved. Ply-wise stress histories are then passed to the microscale HSL, which predicts the statistics of fibre and cluster breaks for every element in only a few seconds, and maps the predicted damage and failure probability fields back to the full component. This framework is validated against synchrotron radiation computed tomography (SRCT) experiments on cross-ply composite specimens with a waisted geometry. The model reproduces both the spatial distribution and magnitude of the observed damage with strong agreement, thereby validating the combined HSL–FE approach. This offers a viable route to fast prediction of fibre breakage in full-scale industrial components (e.g. wind turbine blades) and enables damage mapping to be integrated into design and assessment workflows.

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#715

# Strain Distribution Around Damage in CNT Yarn in a Polymer Matrix Using Synchrotron Radiation X-ray CT (with DVC) and Raman Spectroscopy

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Recent advances in enhancing the material properties of carbon nanotube (CNT) yarns—structures composed of twisted nanoscale CNTs—have broadened their potential application as reinforcing elements in composite materials. In this study, the strain distribution around damage in CNT yarns embedded in a polymer matrix under tensile loading was examined using synchrotron radiation (SR) X-ray computed tomography (CT) combined with digital volume correlation (DVC) and Raman spectroscopy. Single-yarn fragmentation specimens, consisting of a continuous CNT yarn embedded within a $SiO_2$ particle-filled epoxy polymer matrix, were fabricated to characterize the strain distribution in the damaged regions of the CNT yarns. Analysis of the SR X-ray CT data coupled with DVC demonstrated that damage developed within the CNT yarn embedded in the epoxy matrix, which subsequently induced load redistribution and deformation in the surrounding matrix. In segments of the CNT yarn that remained intact, localized variations in strain—both increases and decreases—were identified. Consistent behavior was also observed in the Raman spectroscopy analysis. Such responses arise because tensile loading triggers inter-CNT slippage within the yarn, thereby reducing the efficiency of load transfer between neighboring CNTs. These findings provide valuable insights for the composite materials community and are expected to advance the development of strength prediction models that incorporate the actual failure mechanisms of CNT yarns within polymer matrices.

#716

# Influence of the out-of-plane stress on compressive strength in the fiber direction: application to ply waviness defects and bolted joints

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A widely used theory to explain the mechanism of fiber kinking in a unidirectional (UD) ply in a composite laminate under compressive load in fiber direction is to suppose that an initial fiber misalignment causes local shear stresses and that the kink band forms due to an instability related to the nonlinear shear behavior of the ply (Budiansky and Fleck, J. Mech. Phys. Solids 41(1) (1993), 183-211). In a laminate, this instability is influenced by structural effects such as the ply thickness and the presence of adjacent plies (Grandidier et al. Compos. Struct. 94 (2012) 3799-3806). We use a semi-analytical approach based on these assumptions to analyze the influence of transverse compressive and axial shear stress on the compressive strength of a UD ply in a laminate. The shear instability is supposed to occur when the ply in the misaligned zone fails in matrix mode (inter-fiber failure). The combined transverse and shear damage criterion for the matrix mode of the ONERA Progressive Failure Model (OPFM) (e.g., Laurin et al., Compos. Part A 38 (2007) 198-209) is used to predict the shear failure. The nonlinear behavior of the ply under transverse and shear loading before failure is also taken into account. Based on this analysis, an improved criterion for compressive failure of the plies in fiber direction is proposed, which accounts for the reduction of compressive strength under superimposed out-of-plane shear stress and the increase of compressive stress under out-of-plane compression. The criterion is implemented in OPFM and applied to the simulation of compressive failure of composite laminates with out-of-plane ply waviness defects (which cause out-of-plane shear stresses under in-plane compressive loads) and damage under bearing in bolted joints (where out-of-plane compressive stress is induced by the bolt head and nut inhibiting the Poisson effect).

#717

# Conceptual Design of Boats Using Finite Element Analysis and Homogenization of Stiffened 3D Printed Structure of Wood-Plastic Composite

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Transitioning from traditional wooden boats to the circular use of recyclable polymer-wood composites is an important topic. This technological shift is a good way for decarbonizing small-vessel manufacturing, while also significantly reducing production time through large-scale additive manufacturing. This work presents a method to conceptualize a boat design for a 10-meter fishing boat meant for coastal and inland waters. These boats are targeted to be produced using large-scale fused-granulate fabrication (FGF).

In this work, the boat has the following design requirements: suitable stiffness of the hull, battery storage for propulsion, and seating places. Abaqus (Simulia) standard (2023) is used for the finite element analysis (FEA). The geometry of a hull with single-shell structure is produced using SolidWorks 2025- and imported to Abaqus. The real walls are planned to be stiffened using suitable stringers and a double-skin concept. Therefore, a method developed by Romanoff, J. et al. is used to homogenize the stiffener-skin structure into single wall (shell) with similar orthotropic stiffness. The material model is estimated for 3D printed wood-plastic composite (WPC). 3D printing introduces strong directionality to material properties. Therefore, appropriate engineering decision is needed to apply real composite behavior with the homogenization method in a practical way. Finally, load conditions of slamming and operational pressures estimated using ISO 12215-5 are applied and the global deformation is evaluated. Also, tensile testing is performed to implement realistic stiffness related to the actual FGF manufacture.

The results indicate that the homogenization method is efficient to use and allows for fast analysis to survey different stiffener configurations, materials, and deformation of the full-scale vessel structure.

#718

# Off-axis cracking in carbon and glass fibre-reinforced composites: in situ inspection of the influence of stacking sequences on damage patterns

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Off-axis cracks are usually the earliest form of damage that occurs in fibre-reinforced polymer composites during mechanical loading. They result from fibres separating from the matrix, creating debonds that subsequently coalesce into a crack extending through the ply thickness. The current study analyses off-axis cracks using a replica system that casts a negative of the surface, yielding a micrograph of the specimen. By combining the replica with in situ loading, the evolution of damage patterns can be inspected with an optical microscope.

The replica system allows overcoming several hurdles in the experimental characterisation of off-axis cracks. First, the specimen is kept under load during the casting of the replica, avoiding crack closure and relaxation artefacts, as often observed in post-mortem characterisation studies. Secondly, the replica covers a large area (5×1 cm²) with a high resolution (~1 µm), allowing imaging of submicrometre debonds that eventually coalesce into macroscopic damage. Finally, the fact that this technique only allows edge observation is not deemed problematic, as off-axis cracks mainly initiate at the edge before tunnelling through the composite parts.

Three lay-ups (cross-ply, quasi-isotropic, and [0/±60/0/±30/0]s angle-ply laminate) were tested for two materials (carbon- and glass-epoxy). Experiments revealed that in a cross-ply laminate, debonding in the transverse plies occurred when the stress level in that ply reached the transverse ply strength. Whether or not these debonds coalesced into a fully developed transverse crack depends on the fibre properties, the ply thickness and the relative thickness ratio with other plies. Inclined debonds and cracks were imaged in the transverse ply of the quasi-isotropic laminate due to neighbouring angled plies.

In conclusion, in situ tensile loading combined with a replica system enabled us to examine the relationship between damage onset and stacking sequences.

#719

# Identification and modeling of pore formation conditions during reactive acrylic resin polymerization

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Reactive thermoplastic systems are emerging as innovative solutions for composite manufacturing, offering a route to overcome the processing limitations of conventional high-viscosity thermoplastics. Mainly composed of low-viscosity monomers, these systems promote efficient reinforcement impregnation thus enabling in-situ polymerization of thick structural composite parts. One of the key challenges in the reactive pultrusion of Elium® resin-based composite structures lies in limiting pore formation during processing. Indeed, because of the low pressure involved in this process, the combined effects of the highly exothermic reaction, monomer volatility and chemical shrinkage enhance pore nucleation and growth during polymerization within the die. This study therefore focuses on understanding these complex mechanisms in the unreinforced resin system initiated by three peroxides and on modeling the critical conditions leading to pore nucleation.

An experimental setup enabling direct observation of pore formation while polymerizing Elium® C195E resin in a confined environment was therefore designed, with controlled temperature and pressure. Tests conducted over [90–110] °C and [1–4] bar highlighted the key role of polymerization kinetics on pore formation. In particular, accelerated reaction rates combined with chemical shrinkage and thermal gradients generate local depressions that promote nucleation.

Complementary studies on polymerization kinetics, monomer evaporation, rheology and chemical shrinkage were carried out to provide data for the numerical model. A numerical simulation was then implemented in COMSOL Multiphysics® to reproduce the resin behavior within the observation cavity. The model captures the effects of chemical shrinkage and local exothermy within the glass tube, allowing the identification of critical values of local pressure, conversion and temperature that lead to pore nucleation. These results thus provide a basis for optimizing pultrusion parameters to produce defect-free composite parts.

This work is part of the INFRAlight project funded by France 2030 and operated by the French Agency for the environmental and energy transition (ADEME).

#720

# Dynamic Post-Fatigue Response of Composite Materials: A Multi-Scale Damage Analysis

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Automotive structures are usually designed using mechanical data obtained from unstressed virgin materials. However, since most components undergo fatigue loading during operation prior to any crash event, it is essential to evaluate the residual behaviour of materials that have already experienced pre-damage under subsequent dynamic loading. This study investigates how fatigue-type preloading influences the dynamic tensile response of discontinuous-fibre-reinforced composites, with a specific focus on Advanced Sheet Molding Compounds (A-SMCs). To quantify the effects of pre-fatigue damage, tension–tension fatigue tests were conducted at 30 Hz across varying stress amplitudes, followed by tensile testing at multiple strain rates ($10^{-3}$ $s^{-1}$, 1 $s^{-1}$ and 100 $s^{-1}$). The post-fatigue dynamic responses were then systematically compared with those of the corresponding virgin material. The results show that both quasi-static and high-strain-rate behaviours depend strongly on the number of fatigue cycles experienced prior to loading. Additionally, strain rate significantly modulates the effect of pre-fatigue damage: the stress and strain thresholds for damage increase with strain rate, whereas for a fixed strain rate, they decrease with increasing fatigue cycles. These findings provide fundamental insight into the mechanisms of damage evolution in discontinuous composites under combined cyclic and dynamic loading, and lay the groundwork for the development of advanced predictive models and design tools for automotive structures subjected to realistic service conditions.

#721

# On the failure mechanisms in discontinuous fiber composites obtained from recycled prepreg scraps.

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This study investigates the failure mechanisms of discontinuous fiber composites manufactured from prepreg scraps still in good conditions. Typically, after cutting prepreg sheets into the desired shapes, the irregular remaining portions are discarded, leading to the disposal of up to 35% of the raw material. This practice results in economic losses and environmental impact. To mitigate this issue, the proposed method collects the scraps, cuts them into smaller, regular patches, and assembles them according to ordered architectures to form recycled sheets and rolls suitable for standard lamination. Mechanical testing demonstrates retention of approximately 90% of the stiffness and 50% of the strength compared to the reference continuous material, demonstrating load-carrying capability and suitability for less demanding applications.

Given the discontinuous nature of the recycled material (fiber interruptions, resin-rich regions, voids, and partial overlaps) a detailed fracture analysis is essential. Specimens with different in-plane joint geometries between patches are designed, manufactured, tested under tensile loads, and analyzed from a failure perspective. As expected, in-situ monitoring with a digital microscope reveals that fractures initiate in resin-rich regions at patch interfaces, the weakest zones, and then propagate through interlayer delaminations followed by fiber breakage. In addition, Digital Image Correlation is employed to monitor fracture behaviour and strain evolution on specimen surfaces. Higher strain levels consistently appear around joints between patches, which are the first to fail, with fractures originating at specimen edges and progressing toward the centre across the width. Changes in length and inclination of the joint interface lead to differentiated fracture morphologies, delayed delamination and breakage phenomena, and a slight improvement in the mechanical performance. Similar results are obtained from FEM numerical models reproducing the tests. Finally, ex-situ stereomicroscope observations at multiple magnification levels provide a detailed visualization of fracture surfaces and broken fibers, offering deeper insight into fracture patterns.

#722

# Mapping the Vulnerabilities in the Carbon Fiber Supply Chain

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Carbon fibers are a strategically important material underpinning the energy and mobility transitions. In commercial aircraft, they reduce weight while maintaining structural integrity, improving fuel economy and lowering emissions. In wind turbines, their superior stiffness-to-weight ratio enables longer blades and higher energy yields. Because alternative materials cannot match these combined properties, carbon fibers have few viable substitutes making their availability increasingly important as global decarbonization efforts accelerate. Despite this importance, scientific literature provides little insights on current industrial-scale carbon-fiber manufacturing process as details remain proprietary. This lack of accessible information, combined with the complexity, cost of production and the dominance of a small number of manufacturers, heightens concerns about supply risks.

This research aims to investigate how geographical factors shape the supply chains of carbon fibers, with the goal of identifying major supply related risks and potential pathways for mitigation. A techno-economic assessment maps the leading global producers, evaluates the degree of geographic concentration, and compares present and projected production capacity against anticipated growth in aerospace and renewable energy applications. The methodology provides a structured overview of the manufacturing process from precursor synthesis through to finishing. This process mapping is examined specifically through the lens of supply chain vulnerability, focusing on dependencies that constrain both established producers and potential new entrants.

The results show that high energy requirements, dependence on specialized precursors, and proprietary process technologies significantly restrict rapid capacity expansion and raise barriers to market entry. The findings aim to provide an understanding of the supply-chain dynamics governing carbon fibers and to show which geographical concentrations patterns most strongly influence their overall supply risks. By clarifying the conditions under which carbon fiber supplies may become constrained, this research supports more informed policy interventions, industrial strategy, and long-term planning for sectors relying on this material.

#723

# Shape-Stabilized Phase Change Material Nanocomposites with Enhanced Thermal Effusivity via Aligned Carbon Nanotube Reinforcement

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Thermal energy storage (TES) and management systems require materials that combine high energy density with shape stability. This work focuses on the development of shape-stabilized organic phase change material (PCM) nanocomposites reinforced with horizontally aligned carbon nanotube (HACNT) architectures. In this way, the exceptional CNT properties for efficient heat and load transport are exploited, simultaneously addressing the two main issues of organic PCMs, i.e., leakage above the melting point and low thermal conductivity.

Vertically aligned CNT arrays (~1 vol%) were synthesized via chemical vapor deposition and mechanically knocked down. Two superimposed HACNT layers were melt-impregnated under vacuum with various PCMs including alkanes (octadecane, docosane, hexacosane) and fatty acids (decanoic, dodecanoic, tetradecanoic acids) with phase change temperatures in the range 28-57 °C. Vacuum-assisted infiltration ensured complete PCM integration, while excess PCM removal via tissue paper absorption produced shape-stabilized nanocomposites that exhibited no leakage above the PCM's melting temperature.

The resulting composites achieve substantial heat storage capabilities with melting enthalpies of 150-250 J/g and final CNT volume fractions of 2-6 vol%, depending on the PCM's chemistry and molecular weight. Scanning electron microscopy of cryofractured surfaces confirms complete infiltration without evident porosity while preserving CNT alignment. Dynamic mechanical analysis reveals mechanical integrity throughout phase transitions and superior shape stabilization: storage moduli ~1.5 GPa below melting temperatures (scaling with CNT concentration) and maintained structural integrity (MPa-range moduli) above melting points. Although the melting enthalpy decreases with an increase in the CNT concentration, the thermal conductivity along the CNT direction shows the opposite trend, reaching ~1.7 W·(m·K)-1. This leads to an increase in thermal effusivity up to ~11.3 J·cm-3/2(m·s·K)-1/2.

Moreover, these HACNT-PCM nanocomposites exhibit solar- and electro-to-thermal energy conversion capabilities. Therefore, the developed nanocomposites are promising candidates for next-generation thermal management applications requiring rapid, reversible thermal response with high energy density and mechanical robustness.

#724

# The effect of mismatch angle of double-double composite laminates under quasi-static and fatigue loading conditions

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In the design of composite structures for practical applications, multi-directional (MD) laminates are commonly employed. In fact, these laminates are vulnerable to delamination at several interface locations, stressing the need to characterize how interlaminar fracture toughness varies with the angle between adjacent plies. Although Mode I, Mode II, and Mixed-Mode I/II fracture tests are well established and widely used, they are limited to 0º//0º interfaces. In the absence of more appropriate testing methodologies, the resulting fracture toughness values are commonly assumed to be representative of interfaces with differing ply-angle mismatches, despite the potential limitations of this assumption. Following a numerical study [1] to investigate the suitability of using Double-Double (DD) laminates as a design principle for interlaminar fracture samples with midplane misaligned interfaces, in this work, we investigate a specific DD stacking sequence - defined by two fiber angles, Φ and Ψ, arranged in [-Φ/ Ψ/ Φ/ -Ψ]n // [Φ/ -Ψ/ -Φ/ Ψ]n, ranging from 0° to 45° (with a step of 15°) and repeated n=10 times through the thickness. Owing to its potential for homogenization and quasi-uncoupled behavior, the main objective is to evaluate whether DD can be used as a tool for interlaminar fracture testing of MD samples. The MD interfaces were tested under quasi-static loading conditions (mode I, II, and I/II) and fatigue loading conditions (mode I and II). These experiments established a relationship between the mismatch angle and interlaminar fracture toughness (static tests) and the crack propagation rates.

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[1] P. Pereira et al. Numerical investigation of the potential of double–double laminates to measure the interlaminar fracture toughness of multidirectional interfaces. Composite Structures, 2025

#725

# Finite element modelling of electromagnetic induction welding of carbon fibre reinforced thermoplastic composites

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Many of the advanced composites use thermosetting matrices, however, once cross-linked, they are non-reversible, posing environmental and sustainability issues, and limit the possibility of creating a multi-functional structure. On the other hand, in theory, the physics of thermoplastic-based composites offer favourable characteristics such as repairs, self-healing and fastener-free joining processes by melting the thermoplastics above their melting temperature; hence, they are attracting rising attention in advanced applications such as aerospace. There are several techniques available to melt the thermoplastics, and subsequent cooling allows the consolidation and bonding. A few examples include conduction, friction, ultrasonic, laser and electromagnetic induction welding. Among these, electromagnetic induction welding is one of the contactless, fast-welding techniques suitable for automation and is widely used for the thermoplastic-based carbon fibre reinforced composites. Being a multiphysics phenomenon, parameters pertaining to electromagnetic, thermal and mechanical demand careful selection to melt the localised small volume of thermoplastics, avoiding matrix degradation in zones away from the bond line. Finite element modelling (FEM) of the multiphysics electromagnetic induction welding can provide an optimum processing window, which ultimately reducing the experimental efforts and hence cost. In this work, a 3D FEM for the electromagnetic induction welding was developed. Fully coupled electromagnetics Maxwell's formulations with the transient heat diffusion governing equations were employed. Time-harmonic AC current was provided to a Double-D shaped coil, inducing Eddy currents in the carbon fibre thermoplastic laminates. Some interesting findings of the induction welding, such as the selection of appropriate current, frequency, optimal coil parameters, and coupling distance, are discussed to obtain the required temperature of the weld pool at the single lap shear (SLS) joint of the carbon fibre reinforced thermoplastics composites.

Keywords: Modelling, joining, multiphysics, induction welding, carbon fibre, thermoplastics.

#726

# Manufacturing and Applications of Soft-rigid Multi-Matrix Fiber-Reinforced Plastics

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Multi-matrix fiber-reinforced plastics (MM-FRPs) expand the design possibilities of polymer composites by impregnating fiber reinforcements with multiple resin systems rather than one. Ideally, the employed matrices differ markedly in mechanical and/or functional performance, enabling locally tailored properties such as stiffness, toughness, and damping, as well as thermal or electrical conductivity. For thermoset composites, several manufacturing approaches are currently being explored to realize such local matrix variations. One promising route is the Tailored Matrix Placement (TMP) process recently proposed by IPF, which deposits resin droplets locally onto the textile preform prior to consolidation. In this approach, polyurethane (PU) is selectively applied and subsequently complemented by vacuum infusion with epoxy (EP). Using a soft PU state (above its glass transition temperature) enables the production of composites featuring distinct soft and rigid zones with locally adjustable matrix stiffness.

With this work, the TMP manufacturing process will be introduced and its key advantages and limitations will be discussed. In addition, several application examples of soft–rigid MM-FRPs will be presented.

Soft hinges can be realized by introducing PU between rigid EP regions, thereby creating locally compliant laminate zones within an otherwise stiff composite. The achievable flexibility can be tailored through PU hardness as well as the thickness and length of the PU hinge zone, and it can be further influenced by the local fiber architecture. Proof-of-concept demonstrators from soft robotics and orthopedic applications will be shown.

Beyond stiffness tailoring, combining matrices with different storage and loss moduli enables composite structures with highly adjustable damping behavior. After identifying the dominant eigenmodes of vibrating plates by means of numerical simulation, various PU pattern layouts were applied and evaluated experimentally, including single-mode patterns as well as superimposed patterns addressing multiple modes simultaneously.

The presentation will conclude with an outlook on alternative MM-FRP manufacturing approaches and future material concepts

#727

# Image-based parameter quantification of End-of-Life composite components using semantic segmentation

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The management of End-of-Life (EoL) fibre-reinforced polymer (FRP) wind turbine blades (WTBs) poses a growing challenge due to the absence of an integrated circular value chain currently available on the market. Repurposing structural WTB components as beams or sandwich elements offers a viable strategy to address this emerging material stream, retaining material value in second-life applications. The present study focuses on WTB spar cap beams, with the objective of identifying their geometric and structural parameters, deriving their EoL material properties in an automated, fast, and reliable process.

The developed method utilizes an image-based machine learning approach for the detection of distinct fibre layers within spar cap beams. This allows for quantifying geometrical parameters and deriving material properties, thereby enabling an efficient material characterization. A computer vision pipeline for semantic segmentation of different spar cap cross sections was built using the PyTorch-based “segmentation models” Python framework. The semantic segmentation of image data is achieved through the implementation of a convolutional neural network (CNN), employing an U-Net architecture with EfficientNet encoders. The applied network architectures are tailored to ensure their applicability in EoL composite repurposing, aiming for optimal performance and efficiency. They are trained using labeled and augmented image data, containing a range of spar cap beam cross sections of various WTB types. The developed models are compared and evaluated according to their reliability and computational efficiency.

The results demonstrate that the developed semantic segmentation models reliably determine the key geometric and structural parameters required to characterize the material properties of EoL composite components.

#728

# Digital Twins for In-Line Monitoring of Press Processes for Composites with 3D grading: a Concept Paper

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The adoption of lightweight construction methodologies holds considerable potential in promoting climate protection within the mobility sector because it involves a reduction in the weight of parts, thereby enhancing resource efficiency during the production process. The realization of complex lightweight construction geometries can be achieved through the combination of long fiber-reinforced and continuous fiber-reinforced thermoplastics. However, high gradients in physical properties emerge in the transition zone between the two materials, which can significantly impair the behavior of the parts during use. A promising solution to achieve continuous transitions in physical properties is to develop new manufacturing processes that introduce targeted 3D grading into the transition zone. For example, this can be accomplished by adapting fiber orientation or fiber volume content. In-line process monitoring is imperative for the development and adjustment of the new manufacturing processes, which encompass an expanding number of semi-finished product properties and process parameters. Digital twins have been demonstrated to be a suitable solution for this purpose. This research presents a concept for developing a digital twin for a compression molding process in which the bulk material is pressed through tape-braided preforms with holes to create the transition zone. A component of the digital twin is the simulation of compression molding. In order to accomplish this objective, an examination of the requirements for the simulation environment is necessary. Furthermore, the paper presents a series of concepts aimed at measuring process parameters and fluctuations in semi-finished product properties and taking them into account in the simulation. This paper also examines machine learning architectures capable of displaying the results of the simulations in real time, enabling in-line process monitoring.

#729

# Development of a method for inline fiber tension monitoring and component measurement in the wet winding process of hydrogen pressure vessels

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Filament winding is a key process to manufacture type IV hydrogen vessels with a high gravimetric storage density. Based on previous investigations, the winding process parameter fibre tension plays an important role to achieve high mechanical strength of the laminate in fibre direction.

The study introduces a method of continuously measuring and documenting fibre tension close to the thread eye, enabling the relevant fibre tension to be observed in close proximity to the deposition point. A LabVIEW based program has been developed to realise wireless transmission of data from the fibre tension sensors directly to a laboratory computer for visualisation and documentation of measurement signals in real time.

The fibre tension measurement method has been extended to include a concept for the optical laser measurement of wound parts up to 3.5 m length during manufacture. This allows layer thickening to be documented, especially in turning zones. The collected data is transferred to the LabVIEW programme, where it is used to create a new mandrel file that can be imported into CADWIND automatically. Using the gathered information, it is possible to generate the subsequent layer's winding programme based on real measurement data. While CADWIND allows the virtual update of the winding mandrel using simulated layer data, the newly developed method allows for more accurate winding paths based on the actual part geometry, thereby reducing the risk of fibre slippage during the manufacture of staggered ply layups.

The combination of high-quality laminate and an optimised and manufacturable ply layup that maximises material usage appears to enable the gravimetric storage density targets for hydrogen vessels set by the US Department of Energy (DOE) to be achieved.

#731

# Mechanical Performance of Hybrid CFRP/BFRP Filament-Wound Tubular components

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Fiber-reinforced composite materials are widely used due to their high specific strength and the ability to tailor properties through controlled combinations of fibers and matrices. Carbon fibers provide exceptional stiffness and low weight but suffer from intrinsic brittleness and limited damage tolerance, which reduce their effectiveness under impact or off-axis loading. Basalt fibers, offering higher toughness, improved thermal stability, and greater sustainability, represent a valuable alternative. Their integration in hybrid configurations with carbon fiber can enhance fracture resistance and overall durability, making them promising for advanced structural applications.

This study investigates the manufacturing and mechanical performance of hybrid composite tubes produced by filament winding using a laboratory-scale machine. Carbon-fiber-reinforced polymer (CFRP) and basalt-fiber-reinforced polymer (BFRP) layers were combined in different stacking configurations. This aimed at evaluating the effects of materials hybridization in terms of stiffness, toughness and cost effectiveness, potentially combining the advantages of each constituent material. After curing, the tubes were cut to obtain standardized specimens for mechanical characterization. Tensile strength was evaluated on ring specimens according to ASTM D2290, while radial compressive behavior was assessed following ASTM D2412.

The study aimed at evaluating whether hybridization can improve the overall mechanical response of filament-wound structural tubes and to identify optimal combinations of CFRP and BFRP for specific loading conditions. Results show that the introduction of basalt fibers can mitigate brittle failure modes typically associated with CFRP components, while maintaining good tensile and radial compressive performance..

Overall, the findings demonstrate that hybridization of CFRP and BFRP in filament-wound tubular structures offers a promising route for lightweight, cost-effective damage-tolerant components in engineering applications.

#732

# Mechanical performance of polymer composites produced by additive manufacturing with continuous and short carbon fibres

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Additive manufacturing (AM) is increasingly used for on-demand spare parts and small series of end-use parts. AM processes have many advantages, such as enabling innovative designs with short lead times. AM technologies, including process monitoring systems, are developing at a fast pace.

This study deals with material-extrusion AM with continuous-fibre reinforcement in a thermoplastic polymer matrix (CFAM). Parts produced by CFAM are typically composed of two phases: one phase dominated by continuous fibres and one only reinforced with short fibres. Consequently, the study also assesses the short fibre phase and the interfaces between phases.

A key challenge regarding CFAM processes is to understand their capabilities and limitations compared to conventional composite manufacturing processes, including process-specific defects and failure modes, such as delamination. To predict the mechanical performance of parts made by CFAM, there is a need for material models and data for numerical simulations. For rapid on-demand production of critical parts there is no time for trial and error and design iterations.

An R&D project in our lab aims to establish a comprehensive framework, combining experiments and modelling, in order to predict and optimize CFAM part performance. Options for material recycling are also studied. Some results from this work will be presented.

The presentation will focus on quasi-static loading of the two material phases (short and continuous fiber-reinforced thermoplastics) and their interfaces, and the calibration and verification of material models. The continuous fibre phase was tested assumed transverse isotropy to determine the material parameters for tension, compression and shear. A second set of experiments determined the interlaminar shear properties for the laminate response. Testing the short fibre phase captured the nonlinear material behaviour to failure in tension, compression and shear. A final set of experiments captured mode-I traction-separation data for the inter- and intralaminar interfaces of the continuous fibre phase.

#733

# Introducing fiber steering in a stacking sequence table for improved performance matching in a bi-level composite optimization

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The increased design freedom offered by composite laminates requires special attention for design and optimization methods. Having many variables remains a challenge for efficient strategies and avoid local minima. So-called bi-level optimization strategies have therefore been employed. These consist in representing layups by means of a continuous homogenized stiffness distribution in the first step, often with Lamination Parameters. A second layup retrieval step is however required. Such a step, called performance matching, aims to obtain layups close to the first level stiffness distribution, and that satisfy the optimization constraint [1].

One layup representation for this second step consists in using a Stacking Sequence Table (SST) [2], which integrates design rules and ensures ply continuity between regions of different thickness. The SST identification problem is solved by means of a genetic algorithm, where most SST strategies are limited to straight fibers. This research aims to introduce curved fibers in a SST to improve the results in a performance matching approach, and match closer the first level solution. By allowing fiber steering within a single continuous ply, the second optimization step allows increased spatial stiffness variation for a given laminate thickness. The ply steering is achieved by introducing an additional genetic reproduction operation. The improvement of performance matching with curved fibers over the use of straight fibers is highlighted on different industrial size structural test cases. The work is funded by R&T department of Airbus Atlantic.

[1] Y. Meddaikar, F.-X. Irisarri and M. Abdalla, Laminate optimization of blended composite structures using a modified Shepard’s method and stacking sequence tables, Structural and Multidisciplinary Optimization, 535-546, 2017.

[2] F.-X. Irisarri, A. Lasseigne, F.-H. Leroy and R. Le Riche, Optimal design of laminated composite structures with ply drops using stacking sequence tables, Composite Structures, 107, 559–569, 2014.

#734

# Numerical Mechanical Characterization of 3D Interlock Reinforcements Using a Virtual Fiber Approach

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## 1. Background

Thick composite reinforcements with 3D architectures have attracted growing attention across various engineering fields due to their superior resistance to delamination and cracking during Resin Transfer Molding (RTM) process compared with conventional 2D layered reinforcements. To reduce reliance on time-consuming trial-and-error procedures in the design and optimization of such complex textile architectures, numerical tools have become indispensable. However, the intricate geometry and multi-scale interactions of 3D interlock reinforcements pose significant challenges for developing robust and efficient simulation approaches. Most existing studies rely on homogenized macroscopic models that treat the fibrous reinforcement as a continuum and therefore fail to capture the yarn-level geometry and local deformation mechanisms. Mesoscopic numerical investigations on the mechanical behavior of 3D interlock reinforcements still remain limited in the literature, especially regarding in-plane shear and bending behavior, which strongly influence drapability and the overall forming performance.

## 2. Procedure

This study proposes a meso-scale finite element virtual fiber approach for 3D layer to layer angle interlock composite reinforcements and conducts virtual material characterizations to have a comprehensive understanding of their mechanical behavior. The method incorporates a detailed geometric modeling strategy in which each yarn path is described by a Fourier-series representation derived from X-ray tomography measurements, and each yarn is represented by dozens of discrete virtual fibers modeled using a hybrid truss-beam formulation. A pseudo-thermal pretension step is then applied to consolidate the internal architecture and generate the final geometrically consistent yarn-scale model. The model is validated against in-plane shear and out-of-plane bending responses, showing good agreement with experimental results and confirming its ability to reproduce the characteristic deformation modes of interlock reinforcements. This model is also applied to characterize the in-plane bending stiffness, highlighting its potential for calibrating mesoscopic constitutive behavior that can serve as inputs for macroscopic simulations.

#735

# (Elasto)capillary Effects in the Slurry Impregnation Method in for Manufacturing Unidirectional Thin Ply Thermoplastic Tapes

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Unidirectional carbon fibre-reinforced polymers are strong, stiff and lightweight. This makes them attractive to a variety of industries, including aerospace, marine and automotive. In manufacturing of unidirectional tapes, the high viscosity of the thermoplastic polymer makes direct melt impregnation challenging, especially at high fibre volume fractions. One way to address this, is to impregnate the dense fibre bundles with a water-based polymer slurry rather than molten polymer: polymer-based particles are suspended in water as transfer liquid which spontaneously penetrates fibre bundles due to its low viscosity and strong capillary action, followed by water removal, and melt consolidation. To evenly distribute the polymeric particles between the carbon fibres, the underlying transport phenomena need to be well understood. Here, we focus on understanding this transport phenomena in regimes dominated by capillary forces. In this scope, we have performed wicking experiments analogous to the Wilhelmy method, using a microbalance to measure in real time the penetrating water amount with T700 and T800 carbon fibre tows, observing the capillary effects of different fibre sizing, porosities, and slurry compositions (water, polymer particles, surfactants and rheological modifiers). Experiments show the strong correlation of these parameters on the wicking dynamics, and that the amount of penetrating water can drop up to 25-30% due to changes porosity, surfactants and rheological modifiers, which is in line with the governing principles of the Washburn equation. Moreover, the width of the bundle shrinks by up to 70% due to a strong elasto-capillary coalescence effect. This causes the porosity, thereby permeability, of the tows to change, which affects the subsequent saturation stage of the bundle and demonstrates the importance of the fibre pretensioning to control the fluid structure interactions. Ultimately, this study supports our efforts in the TU Delft TapeLab to develop the next generation thin ply thermoplastic composites.

#736

# VVUQ applied to composite damage models

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As advanced modelling and simulation (M&S) become an essential tool for supporting decision-making processes (process qualification, optimisation of experimental campaigns, technology trade-offs, sizing, optimisation, up to certification by analysis supported by tests), processes for asseissing the credibility should be standardised and deployed in industrial practices. In particular, composite damage models are key capabilities to assess the performance and integrity of composite structures of aerospace products. In this presentation, we aim at presenting our effort to derive a proper VV&UQ (Verification, Validation and Uncertainty Quantification) framework and tools to support credibility assessment of such M&S capabilities. We will showcase development and application of methdologies that aim to take into account the constraints associated to composite damage model themselves as well as composite testing needed to calibrate, validate and quantify real world uncertainties. Special focus will be put also on the need for a software integration to guaranty correct usage, traceability and extensibility of the models and analyses.

#737

# Innovative Carbonisation-Pyrolysis Process: Set-up of the reclamation line and CFRP recycling functionality assessment

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End of life thermoset composites usually end up in solid-waste streams, where they are burned or landfilled. Recycling technologies exist to valorise these materials, and one of the most established methods for CFRPs is pyrolysis. This thermal recycling process requires a continuous supply of inert gas and substantial energy to reach high temperatures (>500-800°C), along with long operating times to separate carbon fibres from the polymer matrix. The most energy intensive step is the heating of the pyrolysis furnace. Overall energy demands vary from 2.8 to 30 MJ per kg of CFRP waste recycling, prompting efforts to optimise the process, reduce gas and energy consumption, while reclaiming processable reinforcing fibres.

In this work, the combination of two energy intensive processes in one was investigated to provide a lower-impact industrial recycling process of CFRP. Hot gases produced by carbonization can be exploited to pyrolyze CFRPs and therefore reduce the energy needed to reach the required temperatures, as well as eliminate the extra vector gas needed for inert atmosphere.

The study focuses on the line design, considering the energy transfer to reach required temperature for the pyrolysis of the CFRPs, the installation and investigation of key process parameters. The experimental investigation targets the identification of critical parameters for successful fibre reclamation such as gas flow rates, desired temperature reached, etc. and respective fibres characterisation (Optical inspection, morphology through SEM and mechanical properties through single fibre tensile testing). In parallel, an energy simulation model based on the development of Modelica components was developed to assess the energy gain from hot gases transferred from one process to the other.

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#738

# A physics-guided surrogate model for speed-controlled morphing in fff-printed thermoplastics: Towards inverse design of fibre-reinforced 4D composite structures

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The integration of time-dependent functionality into additively manufactured materials, known as 4D printing, offers a transformative pathway for creating adaptive, lightweight structures in aerospace applications. This study explores the potential of discontinuous carbon and glass fibre-reinforced polylactic acid (PLA) composites to enable sustainable, cost-effective fabrication of morphing components such as small-scale, drone-sized wing and fuselage sections.

Unlike traditional composite manufacturing, which relies on complex lay-up and curing cycles, this approach simplifies the process by using fused filament fabrication (FFF) combined with controlled thermal activation. This enables programmable deformation and internal stress alignment during printing. By adjusting process parameters, local stiffness and shape-changing capabilities can be built directly into the part, removing the need for molds or autoclaves and significantly cutting material waste and energy use.

Tests show that fibre reinforcement improves both mechanical strength and thermal stability, while the thermoplastic matrix adds reusability and repairability, key factors for sustainable aerospace production. Carbon fibres help speed up cooling and maintain internal stresses, which support shape transformation. Glass fibres, on the other hand, increase stiffness but limit the ability to morph.

This work establishes 4D printing of fibre-reinforced thermoplastics as a promising alternative to traditional composite processing for small, unmanned aerial vehicle (UAV) components, enabling scalable, intelligent, and environmentally responsible fabrication of next-generation lightweight aerospace structures.

#739

# Towards sustainable, lightweight, high-performance and cost effective carbon fibers

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Reducing the mass of composite structures in the aerospace and automotive sectors is a critical industrial challenge, driving the accelerating demand for low-density carbon fibers. Currently, the industry remains heavily dependent on Polyacrylonitrile (PAN), a petro-sourced polymer which is used as the standard precursor for yielding high-performance fibers. To address this dependency while enhancing sustainability and reducing weight, this research focuses on the development of Hollow Carbon Fibers (HCFs), which offer superior specific mechanical properties through their unique geometry.

The fabrication process begins with the critical selection of sustainable solvents and precursors. Wood-derived biopolymers, specifically cellulose and lignin, are utilized as effective alternatives to PAN. Prior to spinning, the resulting "dopes" undergo rigorous characterization: DSC and TGA to determine the physicochemical properties of the solvent-polymer system, while rheological analysis is crucial to ensure optimal viscosity, preventing spinneret overpressure and breakage. To achieve the hollow architecture, a bi-component spinning method is employed, ensuring the structural integrity of the fiber during thermal treatment. The subsequent carbonization phase is the most critical step; although energy-intensive and costly, it is essential for establishing the carbon network that grants the HCFs their mechanical strength. The final fibers are analyzed through Scanning Electron Microscope for morphological quality assessments.

In parallel to the experimental work, a numerical modeling approach using the PATO tool has been developed to create a digital twin of the carbonization process of the fiber. Unlike purely predictive models, this simulation relies on experimental results to run, and allow to analyze the internal mechanical stresses generated within the complex geometries of the hollow fibers during thermal processing.

#740

# Improved Flexibility in Robotic Direct Yarn Placement for 3D Textile Reinforcement via Dynamic Height Adjustment of Roving Placement Rack

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Robotic Direct Yarn Placement (RDYP) technology has emerged as a transformative technology for fabricating fiber reinforced plastic (FRP) structures, offering advantages such as high material efficiency, geometric flexibility, and reduced waste. These benefits make RDYP suitable for industries like automotive manufacturing and construction industry. However, a major limitation of current RDYP methods is the reliance on fixed support and winding points to stabilize unconsolidated yarn, which restricts the mobility of the robotic manipulator and limits the fabrication of complex 3D reinforcement structures with hierarchical or branched topologies.

To overcome this, we developed an enhanced RDYP approach that integrates a single robotic manipulator with a dynamic support system, the Roving Placement Rack (RPR). This system enables real-time adjustments in the height of supporting tools during the yarn deposition process, allowing support structures to appear only when necessary. This dynamic adaptability optimizes the manipulator's movement, reducing interference and improving the system's flexibility and precision in fabricating complex 3D textile reinforcements.

The RPR system executes yarn placement procedures tailored to the specific reinforcement topology being fabricated, with the procedure developed based on the planned geometry and yarn trajectory. A programmable logic controller synchronizes the robotic manipulator with the RPR, ensuring seamless communication and real-time adjustments during fabrication. This integration significantly enhances the efficiency of the RDYP process, enabling the production of self-supporting reinforcement structures with complex geometries that were previously difficult to achieve.

By enabling the fabrication of complex topologies, this proposed approach significantly advances RDYP technology and its application to textile reinforcement. It permits the creation of high-performance composite materials with greater flexibility and precision, marking a significant step forward in the manufacturing of complex 3D FRP structures in the construction industry.

#741

# Bond Strength of CF/LM-PAEK Laminates Manufactured Using Flashlamp Automated Fiber Placement (FLAFP)

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Demand for higher-rate, weldable, and recyclable structures is driving the increased use of thermoplastic composites in Automated Fiber Placement (AFP). Laser-assisted AFP is widely used, yet it presents safety concerns, and the need for a laser-safety enclosure adds considerably to the overall cost. HUMM3, a broadband flashlamp heat source, has been introduced as an alternative heating method for AFP. Despite its rapid broadband heating capabilities, its use in AFP remains limited, with only a few studies available.

This study investigates how placement velocity and visible nip-point temperature in Flashlamp Automated Fiber Placement (FLAFP) affect the bond strength of CF/LM-PAEK laminates (Figure 1). A full factorial Design of Experiments with four replications was conducted, varying placement velocity (25, 35, and 45 mm/s) and visible nip-point temperature (325 °C, 355 °C, and 385 °C). Bond strength was quantified through single-lap shear (SLS) testing, and cross-sectional micrographs were used to evaluate consolidation quality. A response surface model was developed to estimate SLS values across the investigated parameter space.

This study provides novel insights into the bond strength achievable with flashlamp AFP. Higher SLS values were obtained compared to reported literature results for laminates produced using flashlamp AFP on a heated mold. The results also indicate that flashlamp AFP can achieve bond strengths comparable with laser-assisted AFP. Cross-sectional micrography confirmed that full intimate contact and effective void removal are achievable under the tested conditions. These findings highlight flashlamp heating as a promising alternative for Laser-assisted AFP.

#742

# Fatigue of Additively Manufactured PLA – interpreting or avoiding split populations

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Nominally identical parts produced by additive manufacturing – within a single print – can vary greatly in fatigue life. Tests can superficially appear to have two or more completely separate groups. Quasi-static test results may provide some warning, but typically sampling a smaller number of specimens means that this is not guaranteed.

A short study is presented, using miniature tensile specimens of PLA, printed at 100% density, in batches of 36. A commercial FDM printer was used, with recommended process settings, in a conventional "slicing" algorithm. If the requested consistent dimensions are assumed, cyclic testing seems to show two distinct populations with up to an order of magnitude difference in fatigue life. Evaluation of dynamic stiffness (calculated throughout the cyclic loading) showed a strong correlation between the two populations in fatigue life, and two slightly separated bands in stiffness.

In fact, a significant part of the problem is the flawed assumption that the specimens are dimensionally consistent. It is always preferable to use accurately measured dimensions for each specimen, and this might be expected to resolve the problem, but with very small specimens the combination of true printing resolution (and accuracy) and available measurement resolution, result in a problem of imprecise cross-sectional area – with obvious effects on stresses determined.

Using dynamic stiffness measured at the beginning of the fatigue tests, a correction can be applied, assuming that the material modulus was effectively consistent within a single orientation in a single print. The formerly separate populations now become close enough to treat as one, although some bias appears to remain.

#743

# Micro/Nano-structured Polyethylene Composites for Galactic Cosmic Radiation shielding.

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In view of the possibility of establishing a permanent human settlement on the lunar surface, the Italian Aerospace Research Centre has begun developing a functionalized, multilayer composite material designed to reduce radiation exposure while also providing the structural properties required for long-term habitation. Space radiation is considered the primary health hazard for crews on long-duration missions. Beyond Earth's magnetic field, two main types of radiation are of concern: Solar Particle Events (SPEs), emitted by the Sun, and Galactic Cosmic Rays (GCRs), which originate and are accelerated within the galaxy and are significantly more energetic.

The effectiveness of a material as a GCR shield generally increases as its atomic number decreases and its charge-to-mass ratio increases. Consequently, hydrogen offers the most effective shielding. However, since a shield composed of pure hydrogen is not practical, hydrogen-rich materials are the most suitable candidates for GCR protection. Polyethylene (PE), with the molecular formula $(C_2H_4)_n$, has therefore attracted considerable attention for potential use in space structures.

To ensure that PE retains its functional properties in the lunar environment, where temperatures can reach up to 120 °C, Ultrahigh-Molecular-Weight Polyethylene (UHMWPE) fabrics have been employed as the polymer matrix. Additionally, to increase the stopping power of PE, suitable fillers such as $Al(OH)_3$ and $H_3N–BH_3$ have been incorporated to enhance shielding against primary GCR. A dedicated manufacturing process has been developed to combine UHMWPE fabrics with Linear-Low-Density Polyethylene (LLDPE) films to produce multilayer composites. The mechanical properties of the samples, particularly their interlaminar shear strength, were evaluated to assess intra-laminar adhesion. Comprehensive thermal and thermo-mechanical characterization, along with preliminary radiation-shielding assessments, has also been carried out.

#744

# Experimental analysis of tape manufacturing with melt impregnation

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Thermoplastic composite parts are typically produced using semi-finished products such as prepregs or unidirectional tapes. The final composite's performance is closely linked to the microstructure of such products. Understanding the thermoplastic tape manufacturing process parameters is essential for advancing thermoplastic composite technologies. At the Delft TapeLab, thermoplastic tapes can be produced using slurry-based systems, melt impregnation, or combinations of these techniques and each process involves multiple interrelated parameters. The melt impregnation process consists of an initial dry fibre spreading step, followed by through-thickness impregnation with a molten film. The homogeneity of fibre distribution is influenced by several interdependent processing parameters that remain not well understood. In this scope, the effects of wrap angle, polymer feed rate, and pulling speed were investigated through a series of experiments, enabling the assessment of both their individual and combined influences. Tape quality was analyzed for each experimental setup through characterization of the internal morphology, focusing on fibre distribution and void content. Fibre volume fraction and void content were determined through density measurements. Surface defects and dimensional consistency in width and thickness were also evaluated. The results indicated that, within the fixed 6-bar spreading setup, optimal dry-fibre spreading was achieved at an average wrap angle range of $\theta$ = 30-40°. This range generated sufficient tow tension (3–6 N) to improve alignment, while avoiding excessive tow compaction observed at the impregnation unit at higher angles. For the impregnation stage, the corresponding optimal processing window was defined by a polymer feed rate range of Q = 2-3 kg/h and a pulling speed range of v = 2-3 m/min. The optimal feed-rate to pulling-speed ratio, ensured uniform through-thickness fibre distribution when kept within ±10%. This work provides a foundation for developing an integrated process model of the impregnation line, enabling the design of microstructures for various fibre–polymer combinations.

#745

# Interfacial Performance of Vitrimers with Glass Fibres: A Comparative Study with Insight into Post-Healing Adhesion Behaviour

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There is growing demand for recyclable fibre-reinforced composite materials for use in higher performance applications. Composite materials already make a critical contribution to sustainability and the circular economy, playing a key role in the structural optimisation and light-weighting required to increase energy efficiency, but constrained by limited end-of-life options due to the polymers used. This challenge is highlighted in aerospace and wind energy sectors. Moving to more sustainable long-term options is of global importance but must be founded on fundamental science. To optimize performance of first-generation high performance recyclable composite materials it is necessary to better understand, and quantify, the micro-mechanical parameters that govern the structure-property relationships within these materials. Composite properties derive from a combination of the material properties of both the reinforcement and the matrix, as well as the ability to transfer stresses across the reinforcement-matrix interface.

Vitrimers are a unique class of polymer, capable of reforming and self-healing when heated above their topology freezing temperature. In this temperature range, covalent adaptable networks undergo simultaneous bond cleavage and regeneration, preserving the overall crosslink density throughout the process. Since this healing is often thermally activated, vitrimers combine the mechanical strength of thermosets with the reprocessability associated with thermoplastics making them an attractive polymer for sustainable manufacture.

This work investigates the interfacial properties with a focus on bonding between vitrimer resin systems and glass fibres, of varying sizing chemistries, with results benchmarked against those of a conventional epoxy polymer by use of the microbond test. Given the vitrimers potential ability to self-heal, the interfacial adhesion will be re-evaluated post-heal to gain a deeper understanding into the materials behaviour and the interactions which take place at the microscale. Analysis of tested samples, both before and after healing will also be conducted, utilising optical and scanning electron microscopy.

#746

# Non-linear compressive response of aligned recycled carbon fibre composites through 4-point bending of sandwich beams

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Recycled carbon fibre (rCF) composites can exhibit higher compressive than tensile strength, in contrast to the typical behaviour of virgin carbon fibre (vCF) composites. This dissimilarity stems from the fibre reclamation process: aggressive resin-removal treatments may damage fibres and reduce tensile strength, yet also produce clean fibres that enable strong fibre-matrix interfaces, thereby promoting compressive strength. Since this tensile-compressive balance is governed by the reclamation parameters, it can serve as a proxy for recycling quality. Furthermore, CF composites display a non-linear longitudinal strain response, and quantifying this behaviour is essential for fully exploiting rCF as a sustainable and economically viable alternative to vCF.

Highly aligned rCF pre-preg (supplied by Lineat Ltd) was cured, sectioned into skins, bonded to PMMA cores, and tested as sandwich beams under 4-point bending (modified ASTM D5467). Compressive and tensile surface strains in the gauge section were measured using standard strain gauges. A data-reduction scheme was developed to extract the strain-dependent Young's modulus for the compressive and tensile skins, assuming a quadratic stress-strain response and pure bending in the gauge section. The scheme was validated against finite-element (FE) simulations and used to derive stress-strain curves from experimental data for both the rCF composite and a vCF control.

This presentation details the experimental setup, data-reduction method, and FE validation before comparing the obtained mechanical properties to results from established test methods. It aims to demonstrate how a single sandwich-bending test can recover the non-linear tensile and compressive response of CF composites. While applicable to both vCF and rCF composites, the approach supports developments in rCF quality control through direct assessment of the tensile-compressive property balance.

#747

# Structural Design of a Biocomposite Monocoque Chassis for a Light Electric Two-Wheeler

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The increasing urbanisation of cities has led to several challenges in mobility, economic, social, and environmental sectors. In this way, the micromobility sector has emerged as a promising solution, offering a fast and affordable way to navigate urban areas. It also provides flexibility in resource access, helping address equity issues, and can replace private car usage for first and last-mile connectivity, thereby reducing traffic emissions.

Similar to other mobility sectors, the electrification of the micromobility sector is a rapidly growing global trend as it contributes to reducing greenhouse gas emissions and lowering energy consumption. However, the EVMs' (electric-powered micro-mobility vehicles) autonomy remains a challenge due to battery constraints, and the lack of charging infrastructure promotes an even more critical challenge.

One way to improve the EVMs' autonomy is by making the chassis lighter. Composite materials, due to their high strength-to-weight ratio, have been widely used in industries where both performance and minimum weight are required, making them an ideal candidate for this application. Additionally, biocomposites are an emerging material class in which at least one component is derived from biological sources, making them a more sustainable option. However, due to a lack of mechanical property information in the literature and their high variability, their structural applications remain compromised.

The present work shows the development of a biocomposite chassis, manufactured by vacuum resin infusion, using a bio-based epoxy resin reinforced with flax fibres. Material characterisation, numerical analysis, and chassis testing were carried out to enhance the vehicle's overall performance. A monocoque design was adopted to minimise the need for internal structural components and thereby reduce chassis mass. The results indicate that biocomposite materials can be effectively employed in this type of application, offering a viable option for sustainable electric two-wheelers.

#748

# Structural Design and Manufacturing Validation of a Fiberglass-Reinforced Composite Bus Chassis Section

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The goal of this investigation is to develop an innovative bus chassis section manufacturable through fiberglass-reinforced composite materials, replacing the conventional steel-based architecture typically employed in commercial bus construction. The motivation of this transition arises from the need to reduce vehicle mass, improve energy efficiency, and enhance corrosion resistance, all while maintaining or exceeding the structural performance standards expected for urban and intercity transportation systems. By exploiting the high strength-to-weight ratio and geometric versatility of fiberglass composites, the proposed design aims to achieve a global weight reduction of approximately 15% relative to an equivalent steel structure, without compromising stiffness, durability, or safety.

A detailed design and production-validation phase is developed, including the definition of composite materials, laminate configurations, and manufacturing processes optimized for large structural components. Special attention is given to ensure that the composite body meets all requirements related to mechanical resistance, rigidity, impact performance, and long-term fatigue behavior. The development process integrates systematic design methodologies and rigorous production testing to guarantee that the full-composite chassis section can sustain operational load cases typically encountered in service, such as torsional stress, passenger occupancy loads, and dynamic road-induced excitations.

A critical aspect of the study involves validating the complete set of fabrication procedures, layup strategies, curing cycles, and quality-control methods. This phase also encompasses the evaluation of component integration, ensuring structural continuity and reliability throughout the composite assembly. The resulting framework demonstrates the feasibility of producing a fiberglass bus chassis section that meets established performance criteria, contributing to the advancement of lighter, more efficient, and more sustainable public transportation solutions.

#750

# Development of Auxetically Inspired Composite Sandwich Structures for Cryogenic and Space Applications

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Auxetic materials, which exhibit a negative Poisson's ratio, expand laterally when stretched rather than contracting. This unusual behaviour can arise both from a materials geometric configuration, and its intrinsic chemical structure, however due to the difficulties in forming chemically auxetic materials, most current research is focused on the geometric configuration of a material, allowing auxeticity to be engineered through structure alone. Auxetic geometries, such as re-entrant, missing rib cut structure, chiral, and rotating unit designs, offer enhanced mechanical performance, including theoretical improved impact resistance, greater energy absorption and better vibration damping compared to that of conventional materials.

These characteristics make them particularly attractive for use in space applications, where there is continual interest in making structures that are lighter yet maintain mechanical integrity when in extreme environments, such as under extreme temperature gradients. In cryogenic environments, typical composites experience matrix shrinkage, interfacial stress and microcracking. Auxetic structures, such as foams and lattices, potentially help mitigate these negative effects through their unique ability to redistribute stresses and accommodate deformations more uniformly.

The present work aims to develop and characterise an auxetic polymer foam for use as the lightweight core in composite sandwich structures designed for cryogenic environments, similar to the conditions expected for materials used in space manufacturing. The auxetic foam geometric structure is formed by triaxially compressing a polymer foam, such as Polyurethane (PU), and then thermally curing it to maintain its auxetic geometry, e.g. a re-entrant geometry. These auxetic foams will be combined with two composite face-sheets, such as Carbon Fibre Reinforced Polymers (CFRP), to form a composite sandwich structure. These structures will be investigated to understand the potential for improved thermal stability, greater energy absorption, and better vibration damping, especially regarding applications in the space industry.

#751

# Automated manufacturing of steered fibre variable stiffness composites

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Automated fibre placement (AFP) composite manufacturing technology offers precise control of fibres to be oriented in customised directions. This capability allows manufacturing of advanced steered fibre composites, where the fibres are aligned along the complex stress paths in the component, thereby varying the stiffness in desired locations. The stiffness variability is advantageous for next generation advanced aerospace and automotive composites where weight reduction and performance optimization are critical. However, steering often introduces challenges such as increased fibre waviness, gaps, overlaps, and poor interfacial adhesion, which can compromise mechanical properties. These issues can be mitigated through a reconsolidation step, involving the application of controlled heat and pressure to restore laminate integrity and reduce defects. This additional step enhances the in-situ consolidation of composites, thereby eliminating the requirement of autoclave or secondary post processing.

In this research, carbon fibre (CF) unidirectional tapes with a low-melt polyaryletherketone (LM-PAEK) thermoplastic matrix were used to manufacture composite panels with steering radii between 300 mm and 600 mm using AFP. An integrated online monitoring system recorded temperature, pressure, and layup speed during fabrication, providing useful manufacturing data during ply layup. The resulting composites were evaluated through single lap shear (SLS) and interlaminar shear strength (ILSS) tests to quantify the influence of fibre steering and reconsolidation. Experimental results show that reconsolidation enhances SLS and ILSS, while enabling a minimum steering radius of 300 mm without significant defects. These improvements, together with the digitally captured data, demonstrate the effectiveness of advanced AFP manufacturing for in-situ consolidated variable stiffness composites.

Keywords: automated fibre placement, steered fibre composites, digital manufacturing

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#752

# The Scaled Half Tank Test

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Hydrogen as an energy carrier is a promising solution for sustainable and CO2-neutral mobility. For aerospace applications, the storage of hydrogen in liquid form (LH2) is an interesting solution due to its high gravimetric energy density. The development of LH2 tank systems made of carbon fiber reinforced polymers (CFRP) requires detailed characterizing thermal and mechanical material properties as well as leakage behaviour. Further, specific tests are carried out to test specific design features such as feedthroughs or joints. Currently, these tests are carried out on simplified coupon level. In order to efficiently capture relevant effects from real tanks, a new bench for testing of a scaled half tank was developed. The objective is to assess new technologies and validate analysis methods at a representative level.

The core of the test bench is the half-tank test specimen, which consists of a tank with an internal diameter of 400 mm that is cut perpendicular to the tank axis. The half-tank is clamped and sealed against the bench cover. The inside of the half-tank can therefore be filled with cryogenic medium (LN2 or LH2) or helium and can be pressurized up to 20 bar. The half tank and cover plate are integrated into a recipient, allowing the surroundings of the half-tank to be evacuated and leakage measurements to be carried out. The tests focus on the thermomechanical behaviour and the leakage behaviour of the tank dome and cylindrical section. Electrical and fibre optic sensors enable to measure temperature and strain on the inside and outside of the tank. Additional windows in the recipient further allow for optical inspection of deformation.

#753

# Computer Graphics–Based Generation of 3D CFRP Micromodels and the Effect of Fiber Misalignment Phase Angle on Compressive Strength

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Carbon fiber–reinforced polymer (CFRP) composites enable lightweight, high-performance structures across aerospace, automotive, and energy applications. To accelerate material development and reduce certification costs, Integrated Computational Materials Engineering (ICME) frameworks increasingly rely on micromechanical modeling to predict lamina-level behavior. However, predicting fiber-direction compressive failure remains a major challenge due to the complex, interacting mechanisms involved and their strong dependence on microstructural features such as initial fiber misalignment. Although Representative Volume Element (RVE) models have advanced understanding of this phenomenon, most assume uniform misalignment, overlooking the inherent stochasticity of real microstructures and limiting predictive fidelity.

High-resolution imaging techniques, such as nanofocus X-ray CT or synchrotron-based CT, can reconstruct realistic three-dimensional fiber architectures with exceptional geometric fidelity. Yet their adoption is constrained by high cost, limited accessibility, and the time-intensive nature of nanoscale CT data processing. As machine-learning-driven materials design workflows increasingly require large, statistically representative datasets, there is a growing need for synthetic and computationally efficient methods to generate realistic fiber microstructures.

This work introduces a computer-graphics-based methodology for generating realistic three-dimensional micromodels of unidirectional CFRPs with spatially varying, stochastic fiber misalignment. Implemented in the open-source software Blender, the framework enables rapid creation of densely packed fiber architectures and automated transfer into segmented finite element micromodels for analysis in Abaqus.

A parametric study evaluating the influence of local misalignment phase angle distributions shows that models with random misalignment exhibit delayed shear localization and, on average, a much higher fiber-direction compressive strength compared to those with uniform misalignment. The proposed framework provides a scalable foundation for synthetic generation of realistic fiber architectures, supporting integration into ICME pipelines and data-driven composite design.

#754

# Further exploration of single fibre gold coating to investigate the contribution of residual stresses to the fibre-matrix interface

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With the optimisation of composite properties being linked to the optimisation of the stress transfer capability of the interface, the ability to characterise the interface is essential. The stress transfer capability of the interface is often simplified down to a discussion of 'adhesion', used to describe the combination of complex chemical and physical interactions. The interfacial shear strength (IFSS) is used to characterise this 'adhesion', and commonly focuses on the effect of chemical influences, such as fibre sizings and matrix chemistry.

Whilst the development of fibre sizings can undoubtedly improve the strength of the interface, awareness of the contribution of physical parameters is also needed. Physical parameters such as thermal and cure shrinkage stresses as well as static friction have been noted as contributing to the stress transfer capability of the fibre-matrix interface. We previously investigated the application of gold coating to glass fibre surface to suppress chemical bonding across the interface, using a bisphenol-A diglycidyl ether (DGEBA) epoxy/triethylenetetramine (TETA) system at the stoichiometric ratio. The work highlighted the contribution of physical parameters to the interface strength [1].

The current work aims to study the contribution of residual stress to interface strength through suppression of chemical bonding via gold coating, and applying microdroplets of the DGEBA/TETA system at off-stoichiometric ratios. It is expected that by altering the matrix chemistry and suppressing chemical bonding across the interface, further insight may be given on the extent to which residual stresses impact interfacial shear strength.

References

[1] Malone B, Lunn R, Payne A, Thomason J L and Minty R F 2025 Investigating the contribution of physical versus chemical adhesion in the measured value of the fibre-matrix interfacial shear strength of glass-epoxy composites IOP Conf Ser Mater Sci Eng 1338 012025

#755

# Rain Erosion Resistance of Laser Perforated Carbon Fibre Composites for Leading Edge Aerospace Applications

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There is an ever increasing demand within the aerospace sector for lightweight solutions to improve fuel efficiency and reduce carbon emissions during flight. This is particularly important for the next generation of aircraft, including electric vertical take-off and landing (eVTOL) taxi aircraft, which not only have strict weight requirements, but require advanced manufacturing techniques to produce the complex geometries present on such aircraft. Composite materials such as carbon fibre reinforced polymers (CFRPs) can satisfy this requirement, owing to their excellent mechanical properties and high strength to weight ratio.

There are many aircraft components and subsystems that could benefit from composite materials. Two such systems are hybrid laminar flow control (HLFC) and TKS ice protection systems. Both consist of a laser micro-perforated leading edge surface, traditionally made from titanium. By replacing these titanium systems with CFRPs, there is great potential for weight savings to be made. Additionally, composites can provide improved formability compared to what is possible with current titanium manufacturing technologies, allowing for the production of complex parts.

One barrier to the implementation of CFRPs in such applications is their rain erosion resistance, which is comparatively lower than that of titanium. The presence of micro-perforations is likely to further degrade rain erosion performance. To develop CFRP materials into suitable candidates to replace titanium, the effect of laser perforation on rain erosion resistance must first be understood.

The current work focuses on the development of a benchtop rain erosion system and subsequent analysis of rain erosion resistance of laser perforated CFRPs. Rain erosion tests were conducted on a custom-built rotating arm apparatus with an impact speed of 250 mph. Cumulative mass loss measurements were compared between perforated and non-perforated specimens, showing that the perforations had an apparent detrimental effect on rain erosion resistance, with sample geometry also having a notable effect.

#757

# Impact of salt-fog ageing on the recyclability of flax fibre-reinforced bio-composites

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Bio-based recyclable epoxy systems offer a promising way toward sustainable composite manufacturing aligned with circular-economy principles. This study evaluates the recyclability and performance retention of flax-fabric reinforced composites manufactured by vacuum infusion using two recyclable bio-epoxy systems: Polar Bear (PB, >28% bio-content) and Green Turtle (GT, >40% bio-content), both cured with Recyclamine™ R101. Composites were subjected to salt-fog ageing (5 wt.% NaCl, 35 °C) for 30, 60, 90, and 150 days, after which their recyclability was assessed through the yield of regenerated thermoplastic (TPs) and recovered flax fabrics. Both composites exhibit a high degree of recyclability. Specifically, PB and GT show a TPs yield of 73.5 and 78.4% for unaged samples, respectively. After 30 days and up to 150 days of ageing, the yield of recovered TPs decreases in both systems, however, the reduction is more pronounced for GT. By 150 days, PB retains 51.2%, whereas GT-R drops to 39.6%. This behaviour is attributed to the higher bio-content in the GT formulation, which accelerates degradation processes during ageing.

Thermogravimetric analysis confirmed that the thermal stability of regenerated TPs is only slightly affected by ageing: the maximum degradation temperature decreased from 381 °C to 375 °C for PB and from 371 °C to 368 °C for GT. FTIR analysis showed that salt-fog exposure did not significantly modify the chemical structure of recovered thermoplastics and flax fabrics, with all characteristic absorption bands remaining present.

New composites were produced by compression molding using the recovered materials. For PB, the recovered composites retained 85–90% of the original tensile strength and 70–75% of the Young's modulus after ageing, while GT showed lower mechanical performance, consistent with its greater degradation. Overall, both systems remained chemically recyclable after up to 150 days of marine-environment ageing, with PB showing higher recovery efficiency.

#758

# Modelling of 3D Interlock Woven Composites by a Semi-Continuous Approach: Formulation and Elastic Domain

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3D woven composites have been in used for more than a decade in parts that require good impact resistance, such as aircraft engine fan blades. The modeling of these structures is currently based on homogenization methods to obtain properties that are then used in continuous FEM models, though this approach has shown difficulties to fully grasp the effect of composite mesostructure on failure mechanisms. Indeed, studies have shown that similar weaving architectures may display different impact behaviors regarding failures which current homogenized modeling methods fail to capture effectively.

This study aims to develop a new modeling approach capable of handling such limiting cases. It relies on a modeling strategy called "semi-continuous" that is being developed since the 2010's in the Institut Clément Ader, and consists in representing the composite at the scale of the weaving pattern. The yarns are modeled by a network of 1D elements (truss or beam) that is being stabilized by 3D elements that represent the matrix. This approach, originally developed for 2D woven composites has shown good capabilities in the prediction of both impact and post-impact behavior, mainly thanks to its ability to account for the weaving geometry. The goal is then here to transpose this approach to 3D woven composites.

A first proof-of-concept model will be presented. It has given good predictions on the elastic modulus of different weaving architectures. Damage modelling is introduced through the use of 3 damage variables to represent matrix cracking, and a fragile failure criterion for the yarns. A sensitivity study has also been realized to understand the key parameters of this modelling strategy. A comprehensive experimental campaign, both under quasi-static and dynamic loads is set to be achieved to fully understand all failure mechanisms, as well as to identify directly or inversely, the parameters of the model.

#759

# Re-exploring the Importance of Residual Stresses to the Stress Transfer Capability of the Fibre-Matrix Interface

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It is well understood that there has been significant growth in the development of fibre-reinforced composite materials for use in high performance applications due to the combination of material properties and lightweight. Coinciding with this there has long been a concerted effort to develop a better understanding of the micro-mechanical parameters that control the structure-property relationships within such composites. It is well known that composite properties result from a combination of the properties of the fibre and the matrix as well as the ability to transfer stresses across the fibre-matrix interface. Although optimising the interface is widely recognized as critical to optimising the performance of a composite, it has long been reduced to a discussion focussed on optimising 'adhesion', a simple term encompassing the multiple complex mechanisms that exist at interface and contribute to its strength.

Discussions about the interface have primarily focussed on the chemistry of the matrix system and fibre surface coating, to ensure the optimum formation of chemical bonds. Extensive work has been placed to better understanding the chemical mechanisms at the interface that potentially govern its ability to transfer stresses, however less focus has been placed on other physical mechanisms that could play an equally important role. One such mechanism would be residual radial compressive stresses at the interface.

The present work looks to explore the author's decade-long journey into the potential contributions of residual stresses at the fibre-matrix interface. The principles of how residual stresses may contribute to the interface will be explored, as well as discussions on why stresses due to cure shrinkage for thermosets may be larger than typically presumed in the wider literature. Strengths and weaknesses of the concept will be discussed, as well as avenues of interest for the future when it comes to this field.

#760

# Experimental and Computational Analysis of Bio-Inspired 3D-Printed Interlocking Interfaces

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Hierarchical biological structures based on brick-and-mortar architecture show that mechanical interlocking between rigid and more ductile phases can be engineered to achieve high stiffness, impact resistance and controlled deformability. In this work, such mechanisms are replicated using 3D-printed interlocking interfaces, with the aim of understanding how friction, interfacial cohesion and interlocking geometry govern the mechanical response of the system and of developing a predictive model to support the design and optimization of bio-inspired interlocking interfaces.

The interfaces were produced using a dual nozzle fused deposition modeling printer, employing chemically incompatible polymers selected to prevent interdiffusion and ensure an initial contact governed purely by friction. They were fabricated in dry conditions, and in a later phase, additional polymer combinations exhibiting different degrees of interdiffusion were introduced to provide a comprehensive dataset of interfacial mechanical responses for model calibration.

The interlocking geometries were generated numerically using a cellular automata-based model, yielding sharp edged configurations, which were then manufactured and tested under tensile and shear loading to identify crack initiation and propagation mechanisms.

On the numerical side, the interfaces were initially modeled in Abaqus using a coarse finite element mesh and purely frictional contact. Fracture was later introduced through damage-evolution laws, whose coefficients were identified and calibrated against experimental data. Once validated, the model could be extended to include increasing levels of interfacial interdiffusion and to explore their effect on the mechanical response of the interface. The resulting experimental-numerical database can then be used to train an artificial intelligence surrogate model, significantly reducing the computational cost of FEM simulations and enabling the efficient optimization of interlocking interfaces for advanced composite materials.

#762

# Use of Recycled Glass Fibres and Manufacturing Waste in the Production of Sustainable Bulk Moulding Compounds.

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The cost-effective and sustainable disposal of end-of-life composites remains one of the most important challenges facing the industry. With composite usage experiencing rapid growth in multiple sectors (notably wind), this contributes to a rapidly growing waste problem. Several composite recycling technologies enabling recovery of fibres, fillers, and/or polymer resin components, with varying levels of technical maturity and industrial implementation, are currently in development or use. Accordingly, there remains a clear and complementary need to reuse these reclaimed materials to manufacture the next generation of composite materials. These second-life materials must be validated for commercial use, assessed for processability, and be able to attain mechanical properties suitable for use in a new application to support their implementation at scale and enable a circular composite economy.

In this paper, recycled glass fibres reclaimed from end-of-life turbine blade material using a fluidised bed recycling process and recycled fillers produced through mechanical recycling of manufacturing waste were used to replace virgin chopped glass and mineral fillers in the production of new bulk moulding compounds (BMC). Recycled glass fibres were used to displace 25-100% of the glass fibre content and recycled fillers were used to displace 10-30% of the filler content. The flexural, impact, and hardness properties of the resulting compounds were then characterised. It was found that BMC products with mechanical properties acceptable for commercial implementation could be achieved with significant replacement of virgin fibres. In this work, we also make some preliminary investigation for a complementary reuse approach wherein materials from several waste streams and composite recycling methods are used in the production of second-life composite materials.

#763

# Development and Testing of Core Material Homogenisation Technique for Large Scale Resin Infusion Simulations

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Large Composites Sandwich panels using foam or honeycomb cores, are important to several industries. These are commonly manufactured through Resin Infusion methods and, as industries push for larger sizes and faster production rates, are subject to challenges due to the unpredictability and variability in the manufacturing process.

A large source of this unknown variability comes from the core material itself, specifically the incorporated grooves and patterns which perturb the resin flow. Resin Infusion simulations struggle to handle these. Models can either use very fine meshes to incorporate the patterns, incurring a high computational cost, or ignore them, keeping computational cost down but reducing the accuracy of the predicted solution.

This work, supported by the NCC, BAE Systems, Vestas, and ESI, tests a methodology to mitigate the additional computational cost of incorporating these features while maintaining accuracy through the use of CFD Homogenisation. A Representative Volume Element (RVE) of the core material pattern is developed which is then modelled in the CFD software (Altair Hyperworks) to determine the pressure differential for a constant velocity flow. This Pressure differential is used to calculate an effective Darcys permeability which is fed into a conventional Resin Infusion Simulation (ESI's PAM-RTM).

Two test cases are used to assess this method for both accuracy and cost effectiveness. The first is an experimental validation for a rectangular panel with an included 3D printed core with a repetitive isotropic groove pattern. The second is a virtual comparison for a more industrially relevant large scale aerofoil geometry. For both test cases, the homogenised method simulation time and resin time of arrival accuracy is compared against both a low-cost low-detail simplified simulation, and a high-cost high-detail simulation.

#764

# Silica-epoxy nanocomposite matrix shear properties and their effect on unidirectional fibre composite compressive strength

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The matrix plays a key role in the compressive performance of unidirectional carbon fibre composites (UD CFRPs). Owing to imperfect alignment, reinforcing fibres experience shear loading during uniaxial compression, with the matrix providing support against buckling. Therefore, by improving matrix shear stability, initiation of composite failure via micro-buckling may be delayed. Previously, addition of pre-dispersed silica nanoparticles to an epoxy resin matrix has more than doubled the ultimate compressive strength (+ 54%) of UD CFRPs at a nanosilica volume fraction (VSiOx) of 5.5 SiOx vol.%. However, at higher nanosilica content (VSiOx = 12 SiOx vol.%) the improvement is diminished (+ 42%). At present, there is no satisfying explanation for this phenomenon. Strengths and moduli of the nanocomposite matrix (both compressive and tensile) improve monotonically with rising VSiOx and no increase in either nanoparticle agglomeration or void content was observed. Under uniaxial compression, the UD CFRP matrix deforms in shear. Therefore, direct measurement of matrix shear properties should provide better insight. While trends in compressive, tensile, and flexural properties are widely reported for silica-epoxy nanocomposites, measurement of shear properties via established lap shear methods are hampered by debonding above very low silica loadings (< 2 SiOx vol.%). Here, we present a systematic study of silica-epoxy nanocomposite shear performance to explain the relationship between matrix nanosilica content and UD CFRP compressive strength. A torsional shear testing method is applied to access high shear strains (> 100%), and an ultra-low viscosity resin facilitates high silica volume fraction (0 SiOx vol.% ≤ VSiOx ≤ 14 SiOx vol.%). Furthermore, closely-spaced VSiOx increments enable identification of the optimal volume fraction for improved matrix shear performance and, therefore, improved unidirectional fibre composite compressive strength. In future, this understanding may aid development of novel nanostructured matrix systems designed specifically for improved UD CFRP compressive performance.

#765

# Digital Twins of Honeycomb Sandwich Panels for Coupled Thermal–Pressure Simulations

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A coupled thermo-pneumatic digital model of a honeycomb sandwich panel is developed to predict the evolution of temperature and trapped-gas pressure within the core during aerospace missions and in related ground-based verification tests. The structural configuration consists of an aluminium honeycomb core with composite face sheets. Each hexagonal cell is represented as an enclosed gas chamber interconnected with adjacent cells through perforations in the cell walls, reproducing vented aerospace honeycomb typically used to equalize pressure during altitude changes.

The pneumatic behaviour of the core is modelled using transient ideal gas dynamics, including compressibility, humidity variation, and leakage through perforations. The thermal response incorporates heat conduction in the aluminium foils and composite skins as well as convection at the aluminium–air interfaces inside the cells. The surrounding environment - ambient temperature, humidity, and external pressure - is defined as a boundary condition to replicate realistic flight phases such as taxi, climb, cruise, descent, and landing.

The model is implemented in Siemens Simcenter Amesim using a multiphysics architecture that integrates thermal and pneumatic submodels. Simulation results provide designers and manufacturers with predictive insight into how cell geometry, perforation diameter, core height, and skin thickness influence pressure equalization times, and internal temperature gradients. The framework supports sizing of honeycomb panels for aircraft and space applications, optimization of manufacturing parameters, and evaluation of operational safety margins.

Furthermore, the digital model can reproduce environmental conditions encountered during engine-bay operation or in thermal-vacuum (TVAC) chambers, enabling virtual testing of materials and structural assemblies. This work also provides a basis for future digital-twin developments aimed at structural monitoring and life-assessment of honeycomb sandwich panels.

#767

# Correlation between the local cristallinity and porosity and the mechanical performance of the welded interface manufactured by laser assisted tape placement of a thermoplastic composite

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Manufacturing of thermoplastic composite materials through laser-assisted tape placement (LATP) process permits to achieve high manufacturing rates. However, reaching in-situ consolidation (i.e. total bonding of the deposited tape with the substrate) while limiting the generated porosities and attaining important crystallinity fraction still needs to be enhanced. While some recent studies proposed to link the global crystallinity and the global porosity level with the mechanical resistance (i.e. the interlaminar shear strength or ILSS and mode I interlaminar fracture toughness or GIC), the relation between these mechanical indicators and the local porosity and crystallinity at the welded interface still need to be understood. The present study proposes to investigate the correlation between these physical and mechanical properties. Laminates of carbon fibre reinforced poly-ether-ether-keton (PEEK) composite were manufactured with different process conditions (i.e. deposition rate, mould temperature and apparent peak temperature), leading to a large variety of porosity and crystallinity levels measured at the laminate scale. ILSS and GIC were also measured, leading to a wide range of values including excellent properties comparable with autoclave manufactured parts (i.e. ILSS = 90 MPa, GIC = 3100 J/m²). The correlations indicate that a high void content leads to lower ILSS but has a lower impact on GIC. On the other hand, a high crystallinity level increases the ILSS but lowers the GIC. This study therefore shows that achieving in-situ consolidation is possible in a LATP process, and that the manufacturing conditions need to be finely tuned. Also, a compromise has to be found between GIC and ILSS properties, based on the local crystallinity level, which is a direct consequence of the local thermal history.

#768

# In situ X-ray tomography investigation into the effect of the load ratio on damage mechanisms in short glass fibre-reinforced thermoplastics.

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In order to address the challenges posed by global warming, there is a need to optimise the energy efficiency of vehicles by making greater use of composite materials with an organic matrix, particularly thermoplastics.

These easily mouldable materials significantly reduce structural weight, while offering good recyclability and high production rates.

Although initially intended for low-stress components, thermoplastic composites, such as PA66GF50, are now well suited to meet the requirements of parts subject to severe stresses and harsh environments.

However, while several studies have examined the influence of humidity, fibre orientation, loading speed, or frequency on the mechanical response of PA66GF systems, almost none have focused on the effect of the R-ratio on the underlying damage mechanisms.

Yet this is necessary for understanding fatigue and predicting the service life of components in order to guarantee user safety.

To the author's knowledge, this work presents the first in-situ 3D observations of the evolution of volumetric damage in short-fiber-reinforced polyamide under variable R-ratio loading, including creep loading.

Fractography and ex-situ tomography observations were conducted in fatigue and creep tests at two humidity levels.

In addition, to identify the sequence of damage events, their spatial distribution, and their kinetics, in-Situ tomography observations were conducted for several R-Ratios for dry samples.

The results show that the increase in R from fatigue to creep, gives rise to the same family of damage mechanisms: degradation initiates with fibre-end debonding, followed by the formation of microcracks perpendicular to the loading direction in the matrix.

These microcracks slowly evolve into localised crazing zones, which progressively grow and merge to form larger cracks.

This sequence was consistently identified through fractography, ex-situ and in-situ observations. This suggests that the failure of PA66GF50 is governed by a common damage pathway, regardless of the R-ratio.

#769

# Effects of waviness on fiber failure in compression of carbon fiber reinforced polymer (CFRP) specimens: failure scenarios, modeling requirements, and predictive capabilities

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CFRP (carbon fiber reinforced polymer) structures are increasingly used in aerostructures due to their superior mechanical properties compared to metallic ones, particularly in terms of stiffness and fatigue behavior. However, manufacturing defects such as fiber waviness can significantly reduce their static and fatigue strength by promoting earlier damage initiation and propagation. These effects arise from out-of-plane phenomena, including waviness-induced secondary bending and out-of-plane shear, which lead to matrix cracking and delamination.

Predicting the residual strength of a specimen containing a waviness flaw is therefore a critical challenge for assessing the robustness and performance of composite aerostructures, especially during manufacturing ramp-up.

In this presentation, we will focus on the compression strength of composite specimens with waviness flaws. We will first describe the failure mechanisms as a function of waviness characteristics and then propose a modeling approach to predict these scenarios, accounting for out-of-plane shear effects on fiber failure in compression. We will investigate various waviness configurations, ranging from simple cases to more complex ones resembling flaws observed in real aerostructures, such as wing panels. Finally, we will discuss the required modeling complexity for such predictions, depending on waviness characteristics and the desired accuracy.

#770

# Image-based method for creating representative volume elements for predicting mechanical properties of recycled composites made from chopped carbon fibre-reinforced thermoplastics

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The constituents of thermoplastic carbon fibre-reinforced composites do not need to be separated during the recycling and reforming process. This makes shredding a cost-effective and energy-efficient alternative to methods such as pyrolysis or chemical decomposition for thermoset composites. The resulting chopped fibre bundles can be pressed into semi-aligned organo-sheets in a hot press. However, material properties can vary greatly depending on the shredding/cutting method and its process parameters. This results in different fibre lengths and bundling distributions, which in turn cause significant variations of material properties. A method for predicting these properties using representative volume elements (RVE) tailored for recycled chopped thermoplastic carbon fibre-reinforced composites has been presented in [Finder et. all. 2025]

This work implements more refined placement strategies by utilizing a preliminary process simulation. The bundles are loosely placed in a virtual container, which is slightly oversized to the RVE, and compressed by a stamp. During this phase, only the relative material properties with a heterogeneous ratio are necessary for approximating the deformation in the hot press. The shapes of the deformed fibre bundles are extracted and the gaps and the remaining voids are filled with matrix. The RVE is cut out of the preliminary model to prevent boundary effects.

Through the additional simulation step, a higher fibre volume can be achieved, as well as the realistic ondulation observed in microscope images. Predictions of material properties dependent on fibre/bundle length distribution and fibre volume content can be used to optimise the shredding process during recycling.

#771

# Realizing Local Coverage Variations in Thermoplastic Tape-Braided Structures

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Overmolding of thermoplastic fiber-reinforced polymer (TFRP) shells with ribs is an established method to increase structural stiffness, but stress accumulations from stiffness changes or residual stresses make the interface the weak point of the hybrid structure. A novel process aims to create a transition zone instead of a discrete interface by pressing the thermoplastic melt through the textile to form ribs rather than overmolding the TFRP. As gap-free organosheets restrict the polymer flow needed for this, braided thermoplastic tapes offer a viable, highly flexible alternative.

The work focuses on the capability of tape braids to form adjustable gaps that facilitate polymer flow through the laminate into the rip cavity. These gaps can be generated through different design strategies, such as modifying the degree of coverage or overbraiding pins. Pin overbraiding is of particular interest because the pins offer the possibility to create local gaps. The inherent stiffness of thermoplastic tapes causes the influence of the pins to propagate into the surrounding region. While the textile behavior of different degrees of coverage has already been understood, the combined effects of varying degrees of coverage and pin insertion on the textile behavior of thermoplastic braids have not been examined. To investigate this behavior, pins of different geometries had been inserted into the braid. Cameras were employed to capture the textile behavior, and a software tool was used to support its subsequent analysis.

The results show that the pin insertion strongly affects the deformation and rearrangement behavior of braided tapes. Distinct process limitations were identified, demonstrating that lower degrees of coverage enable the integration of larger pins, whereas higher degrees of coverage reduce the potential for local fiber adjustment and thus also limit the pin size. These findings provide new insights into tailoring braid architectures for optimized transition zones in hybrid FRP structures.

#772

# Towards Virtual Certification of a composite aircraft moveable by means of damage tolerance assessment

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AdViCe is the DLR internal project aiming at advancing analysis methodologies for virtual certification. Virtual certification is considered a crucial goal to achieve in order reduce development times and costs, however, it requires ensuring the credibility of the modelling and simulation methods. The AdViCe project aims to tackle the challenges resulting from ensuring the credibility in modelling and simulation, by developing comprehensive approaches, addressing verification and validation, as well as including uncertainty quantification for simulation-based certification. The project considers a composite aircraft moveable use-case to demonstrate certification by analysis as means of compliance for multiple requirements across different disciplines.

One of the certification scenarios investigated in the project is damage tolerance of the component, in particular, the evaluation of residual strength after visible or barely visible impact damage. While significant progress has been made in the composite field to tackle the challenges involving the simulation of low velocity impacts and residual strength evaluation, there are issues to evaluate and quantify the accuracy of these strategies. Within AdViCe the uncertainties in material properties resulting from spatial variability, e.g., local variations of ply properties, are incorporated in the modelling methods, employing a non-intrusive stochastic finite element approach. This approach is based on meso-scale finite element model, combining well-established methods of continuum damage mechanics and cohesive zone modelling. Monte Carlo simulations and surrogate models are used to perform a large number of realizations in order to evaluate the effect of material uncertainties on the resulting delamination after low velocity impact. In the future the effect of delamination on the residual strength will be evaluated, and simulation methods further validated from coupon to structural level.

#774

# Linking Carbon Fibre Microstructure to the Intrinsic Compressive Performance of Carbon Fibre Composites

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The compressive strength of unidirectional carbon fibre reinforced polymer composites is lower than in tension, imposing critical design constraints.

Linking compressive behaviour across length scales requires careful characterisation of fibre microstructure and analysis of single fibre compressive failure modes. A transition in failure mechanisms is observed for composites with fibres of different moduli; high modulus fibre composites tend to fail through compressive fragmentation, whereas intermediate modulus filament composites predominantly fail by microbuckling driven by shear instability controlled by the matrix. Consequently, lower modulus fibres typically exhibit higher compressive strengths. This disparity is linked to differences between these fibres' microstructures.

Carbon fibres can be considered composite materials in that they comprise ordered graphitic phases as the 'reinforcing component', and disordered carbon phase as the 'matrix'. Across fibre types and moduli, changes in the relative proportions, domain size, and orientation of these phases leads to variations in mechanical behaviour. Characterising these features is challenging due to nanometre scale domain sizes and radial heterogeneity often observed in PAN-based fibres.

The microstructure of carbon fibres has been characterised and correlated with their compressive failure behaviour in model composites. Focused ion beam scanning electron microscopy enables 3D imaging of features of compressive failure within fibres of varying moduli. These features are imaged in greater detail than before, revealing new fibre fragmentation mechanisms, alongside transitions in failure modes correlated with fibre modulus. To link microstructure to failure mechanisms, Raman spectroscopy has also been used to quantify spatial maps of the graphitic phases within single fibre cross-sections.

Radial microstructural heterogeneities are imaged, particularly the skin–core morphology of PAN-based fibres, and are shown to influence the compressive response and dominant failure modes. An improved understanding of these microstructural features is demonstrated to be essential for enhancing the intrinsic compressive performance of carbon fibres.

#776

# Self-Sensing CFRP Laminates with Electrospun Barium Titanate Nanofibrous Interleaves for Integrated Structural Health Monitoring

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Structural Health Monitoring (SHM) of aerospace carbon-fiber laminates requires integrated sensing solutions capable of detecting barely visible impact damage while preserving structural integrity. Conventional surface-mounted piezoelectric sensors are prone to environmental degradation and debonding, whereas embedded bulk or patch sensors may act as stress raisers, reduce interlaminar strength, and locally alter laminate stiffness. Piezoelectric polymers offer good flexibility but exhibit limited electromechanical performance and reduced operating temperature due to their relatively low Curie temperature. In contrast, piezoceramics provide high piezoelectric coefficients and a wide usable temperature range at the expense of brittleness and poor mechanical compatibility with the surrounding composite.

In recent years, research has focused on piezoelectrically active composites, in which the sensing phase is distributed in the matrix, as filler, or introduced as interleaved veils. In this work, a fully integrated piezoelectric sensor is realized in a CFRP prepreg laminate by interleaving electrospun barium titanate ($BaTiO_3$) nanofibrous veils at the mid-plane. Additional electrospun nylon veils are employed as electrical insulators between CFRP plies, which function directly as the sensor electrodes and eliminate the need for separate metallic foils. The influence of autoclave cure pressure on $BaTiO_3$ nanofiber density and on the resulting piezoelectric response of the laminate is systematically assessed.

The piezoelectric laminates are characterized through polarization-electric field (P-E) loop measurements to elucidate their ferroelectric behaviour as a function of electric field amplitude, excitation frequency, and temperature. Cyclic through-thickness compression tests are then performed to determine the voltage output, sensitivity, and effective piezoelectric coefficient of the embedded sensor.

Overall, the study provides an overview of the processing-structure-property relationships governing this class of $BaTiO_3$ nanofibre-CFRP laminates and highlights the potential of nanofibrous piezoceramic interleaves for reliable SHM of aerospace composite structures.

#777

# Full-Field Strain Analysis of Additively Manufactured Structures Under Compression Using Digital Volume Correlation

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Digital Volume Correlation (DVC) is a powerful full-field measurement technique that quantifies internal deformation within a structure without direct contact. Unlike traditional surface-based methods, DVC allows extraction of three-dimensional strain and displacement fields anywhere inside a component by leveraging X-ray computed tomography. This capability is especially valuable for heterogeneous systems such as composites and additively manufactured (AM) parts, where interfaces, raster geometry, porosity, and deposition-induced defects play a major role in mechanical performance.

In fused-filament fabrication (FFF), the contact conditions and bonding quality between adjacent rasters strongly influence stiffness, strength, and failure mechanisms. Understanding these mesoscale interactions is therefore essential for improving structural design and developing accurate constitutive models. In this study, a PLA mesoscale AM sample containing embedded copper particles was compressed in situ while imaged using high-resolution X-ray nano-computed tomography (nCT). Volumetric scans were captured before and after loading, and DVC was applied to compute the full 3D displacement and strain fields.

This work outlines the experimental workflow required to obtain reliable DVC measurements, including specimen preparation, printing parameters, imaging considerations, and optimization of DVC settings. The resulting strain fields reveal how raster-to-raster interactions evolve during compression and highlight internal deformation localization that cannot be detected from surface observations alone. These full-field insights provide essential mesoscale information that will be used to inform and validate finite element models aimed at improving predictions of mechanical behavior in FFF structures.

Ultimately, the goal of this work is to support the creation of digital twin models for FFF components by integrating DVC-derived internal strain data with simulation frameworks. The results demonstrate the potential of nCT-enabled DVC to bridge microstructural features and material-level properties in AM polymers and establish a foundation for extending this approach to more complex composite systems.

#778

# Capillary pressure estimation in lcm processes: Comparison of different approaches under spontaneous impregnation conditions

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In Liquid Composite Molding (LCM) processes, capillary pressure constitutes an important mechanism that influences liquid transport through porous media. The interactions between resin viscosity, the fiber-liquid surface properties compatibility, the porous media morphology and the process parameters directly influence the resin impregnation, the void formation and, consequently, the final composite quality. It is therefore crucial to understand the validity range of capillary effects during the process, to establish a reliable method to accurately characterize these effects and to incorporate them into numerical simulation models.

This study investigates different methods to estimate a capillary pressure between a liquid and porous medium as close as possible to the one that occurs at the process scale. The porous medium is a quasi-unidirectional of basalt fabric with a fiber volume fraction of 54.8%. Firstly, equivalent capillary pressures were determined by vertical capillary wicking experiments with a force tensiometer. Two shapes of porous media were tested: a roll of fabric in a cylindrical sample holder and a stack of fabric in a rectangular sample holder (mesoscopic scale). Then, a new method is presented to determine an equivalent capillary pressure during the horizontal spontaneous impregnation of a fabric stack directly within the permeability measurement setup (process scale).

The purpose of this study is to compare capillary pressures measured at two scales and through different experimental approaches. As an expected result, this comparison would enable the identification of the methods and models providing the most representative capillary pressure related to its effect during the process.

#779

# Development of a thermoplastic type IV composite pressure tank for hydrogen storage at 700 bar for mobility applications

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Composite overwrapped pressure vessels (COPVs) remain the leading solution for hydrogen storage in mobility applications due to their compactness, rapid fuel accessibility, high strength-to-weight ratio, enhanced safety and improved fuel efficiency. Type IV COPVs are typically manufactured by winding carbon-fibre reinforced thermoset composites over a thermoplastic liner. However, the use of thermoset matrices poses significant challenges for recycling at the end of the product's life cycle. Replacing thermosets with thermoplastic matrices offers improved recyclability and end-of-life management while maintaining structural performance.

This work enconpasses the development of a fully thermoplastic Type IV pressure vessel for hydrogen storage at 700 bar, designed to meet the safety and performance requirements of the United Nations Global Technical Regulation No. 13 (GTR No. 13) and the European Commission Regulation No. 79/2009. The ISO 19881:2018 standard was followed for the material selection, vessel development, manufacturing procedures, and inspection of compressed H2 tanks, ensuring also compliance with the standard SAE J2601 fueling protocol.

The project initially focuses on the selection of materials, filament-winding pattern development, and structural finite-element analysis targeting a burst pressure of 1575 bar. Subsequently, a laser-assisted tape-winding process is optimized through a design-of-experiments study, demonstrating the relationship between consolidation quality and processing speed when using low-power laser for composite-tape heating. This work will culminate in the manufacture and testing of a full-scale prototype for demonstration and validation purposes.

#780

# Experimental Evaluation of Tensile Properties of Composite Laminates and Comparison with Classical Lamination Theory

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This study aims to evaluate the tensile behavior of fiber-reinforced polymer composite laminates and quantitatively compare the results with predictions from Classical Lamination Theory (CLT). Composite plates will be manufactured using carbon/epoxy prepregs according to several laminate designs, and dog-bone or straight-sided coupons will be machined for testing. Uniaxial tensile tests will be conducted in accordance with ASTM D3039, and longitudinal and transverse strains will be recorded using an extensometer or strain gauges to obtain accurate stress–strain responses. From these data, engineering properties such as elastic modulus, Poisson's ratio, and ultimate tensile strength will be determined for each laminate configuration.

Single-ply properties will be used as input for CLT to calculate the in-plane stiffness matrix and corresponding effective engineering constants of the laminates. The experimental results will then be compared with the CLT predictions to assess the correlation between theory and test, with particular attention to the accuracy of stiffness and Poisson's ratio in the linear elastic range. In addition, deviations observed in matrix- and shear-dominated responses will be analyzed in terms of damage initiation, fiber misalignment, and residual stresses, which are not captured by linear elastic CLT.

The outcome of this work is expected to clarify the practical applicability and limitations of CLT for the preliminary design and stiffness evaluation of composite laminates, and to identify the need for extended models incorporating nonlinear matrix behavior and damage evolution for more accurate prediction of tensile responses.

#781

# Comparative Study of Bio-Based and Conventional Epoxy Resins in Unidirectional Filament-Wound Coupons for Sustainable Hydrogen Storage Applications

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This study presents the comparative analysis of performance of a bio-based epoxy resin and a conventional epoxy resin (RIM Epoxy) in unidirectional filament-wound composite coupon samples with focus on mechanical, thermal, rheological, optical & microscopic, and physical properties. The plates were manufactured by filament winding technology with fiber volume fraction (FVF) of 60%. In this work, two different resin systems-bio-based epoxy resin and conventional epoxy resin (RIM Epoxy) were used as matrix material while ITS 65 carbon fibers was used as reinforcing material. Mechanical testing including tensile strength in fiber direction (0o) and transverse direction (90o) and fatigue strength (tension-tension) of unidirectional filament-wound-plate coupon samples as well as ZDT evaluation of the unidirectional filament-wound-pipe coupon samples, demonstrate that the bio-based epoxy exhibited comparable or enhanced performance relative to the standard resin. The thermal properties such as, curing behavior, glass transition temperature were investigated through DSC and DMA for neat resins and TGA for wound samples. The results showed the enhanced thermal stability for the bio-based epoxy. MARS Rheometer was used to investigate the rheological properties of resins. Optical microscopy (OM) was used to investigate the void content present in the composite, while scanning electron microscopy (SEM) was used to investigate the interfacial bonding between the matrix and fibers.

Beyond performance point of view, the bio-based epoxy provides, reduced carbon footprint up to 18%, decreased reliance on non-renewable feedstock, and improved end-of-life environmental compatibility. Overall, the results confirm that the bio-based epoxy resin is not only a technically viable replacement to traditional epoxy but also a more environmentally responsible and sustainable material option for advanced filament-wound composite applications for hydrogen storage.

#783

# Computational Modeling of Recycled Discontinuous Carbon Fiber Composites Using p-Version FEM

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Reused/recycled discontinuous carbon fiber composites are unique in their material makeup and architecture of the final products, due to their highly heterogeneous, chip based structure in this case. The composite being considered is therefore a composite of composites, with recycled composite chips held together by an epoxy matrix.This architecture gives rise to specific damage mechanisms at various scales, one of which corresponds to damage to the epoxy matrix that binds the chips together. This damage is similar to that found in cases of adhesive bonding with adhesive and/or cohesive failures. As in the case of bonding, this is mainly due to differences in mechanical properties between materials.

Thus, accurate mechanical modeling requires the use of computational methods that can handle severe stress gradients in the vicinity of the matrix-chip interfaces. To avoid the use of a very fine mesh, which is difficult to implement, this work uses a customized p-Version Finite Element Method (p-FEM) that can capture the crucial epoxy gap failure, while maintaining a ``coarse'' mesh.

The developed p-FEM formulation, accompanied by specific pre-processing, allows retaining industrial meshes with a reasonable description of the discontinuous carbon fibre composite while also ensuring compatibility with commercial codes to create a new design tool.  The proposed method aims to investigate the significant size effect in thin-plate composites, analyzing the transition from deterministic failure in small parts (modeled directly) to statistical/probabilistic behavior in large parts (modeled via homogenization). This protocol allows for detailed study of property degradation due to process-induced defects, contributing to optimization efforts and industrial benchmarking, such as for wind turbine blade recycling.

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#784

# Effect of Ply Thickness on Transverse Damage Tunnelling in Glass/Epoxy Laminates

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Cross-ply laminates with a low 90°/0° ply-block thickness ratio are especially susceptible to scale effect. Under uniaxial tensile loading, this phenomenon becomes evident through a delayed initiation of transverse damage within the 90° plies as the relative thickness of those plies decreases.

More recently, prompted by the emergence of commercial ultra-thin plies, París et al. [1] offered a physically based interpretation of the scale effect. This explanation was derived from experimentally observed damage mechanisms in composite laminates, with particular emphasis on the early stages of damage within the 90° ply block. The study concluded that reducing the 90° ply-block thickness makes the initial damage less severe and slows its subsequent growth. Similar findings were reported under tensile cyclic loading.

These studies focused on the initiation of transverse damage in the 90° ply block of cross-ply laminate specimens and the subsequent formation of delaminations at the 90°/0° interface. However, they did not address the through-the-width propagation of this damage within the 90° plies—i.e., tunnelling.

In this work, several cross-ply laminates with different 90°/0° ply-block thickness ratios are explored, taking advantage of the fact that through-the-width damage growth can be captured in-situ using glass/epoxy specimens. The specimens are tested under uniaxial tension with the aim of identifying the onset of damage in the 90° plies and tracking its subsequent tunnelling across the specimen width. The analysis of the results elucidates whether any modification in this stage of damage arises as the 90°/0° thickness ratio changes and, in particular, when ultra-thin 90° plies are involved. Moreover, the results show that these ultra-thin plies contribute to inhibiting the tunnelling phenomenon.

[1] París F., Velasco M.L., Correa E. The scale effect in composites: An explanation physically based on the different mechanisms of damage involved in failure, Composite Structures, 257, 2021, 113089.

#785

# On the Natural Frequencies of MM-FRP Components with Polyurethane Soft Phases

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Multi-matrix fiber-reinforced polymers (MM-FRPs) combine stiff and soft matrices within a continuous fiber architecture and enable the design of multi-functional lightweight parts with tailored vibration and damping behaviour. In this work, we summarise experimental studies on MM-FRP demonstrators in which polyurethane (PU) is introduced as a soft, highly damped phase into epoxy-based laminates manufactured by Tailored Fiber Placement (TFP) and Tailored Matrix Placement (TMP). The design variants investigated range from PU-rich core regions to regularly distributed small PU regions within stitched preforms, enabling a direct comparison of practical strategies for routing strain energy through the soft phase.

Structural damping is characterised by low-amplitude impact excitation combined with high-speed imaging and digital image correlation. The measured responses are transformed via Fast Fourier Transform to extract natural frequencies, modal damping ratios and mode shapes. Results from the plate specimens show that the introduction of PU can shift natural frequencies, particularly when the soft phase is aligned with regions of high curvature or strain energy of the targeted mode. Furthermore, the TFP/TMP routes allow the PU to be placed either in a broadband or in a more localised, mode-selective fashion.

Taken together, these experimental results demonstrate that PU-based MM-FRPs provide an enlarged design space for multi-functional components. By tailoring the topology, volume fraction and placement of the PU regions, it becomes possible to tune damping and dynamic response with only moderate penalties in stiffness, supporting the design of vibration- and noise-optimised lightweight structures.

#787

# Carbon nanotube-grafted carbon fibres and their unidirectional reinforced composites

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In fibre reinforced polymer composites the interface and interphase region surrounding the fibres-matrix facilitates the load transfer and stress distribution throughout, directly affecting the composite's strength and toughness. Methods to improve the fibre-matrix bonding, increase interaction volume, and alter the local stiffness of the interphase region have been predicted to improve composite performance by delaying debonding, reducing stress gradients, and providing lateral support to fibres.

The addition of high-performance nanomaterials, such as carbon nanotubes (CNTs), at the fibre-matrix region is proposed to address the inherent interface weaknesses by adding a mechanical interface/keying as well as increasing the effective volume of the interphase (from the corona of nanotubes around the fibre surface) and altering (increasing) the local stiffness. One method to incorporate CNTs to a fibre surface is to catalytically grow them directly in a chemical vapor deposition (CVD) reactor. The challenge has been to produce this hierarchical carbon nanotube-grafted-carbon fibre (CNT-g-CF) material in sufficient quantity and quality to make composite materials. We have previously demonstrated a robust and uniform production of CNT-g-CF synthesized in an open CVD reactor, producing quantities of 12K tow +30 m per day, with CNT ⌀ ~10 nm and corona length of ~1000 nm. These hierarchical fibres have been characterised at the single fibre level showing significant improvements in apparent interfacial shear strength with +68% and +65%, for polypropylene and epoxy resins systems (when post synthesised CNT-g-CF were inhouse-sized) respectively, tested via single fibre pull-out compared to an as-received unsized carbon fibre baseline. Unidirectional epoxy matrix composite rods reinforced with CNT-g-CFs exhibit 30% increase in flexural strength in three-point bending compared to unsized carbon fibre baseline samples. Unidirectional compression CNT-g-CF and baseline samples, according to ISO 14126, using polyaminde-12 matrix have been prepared via a suspension powder pre-preg tape method and results will be presented.

#788

# A numerical modelling approach for incorporating the effect of defects in large composite structures

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Manufacturing defects may arise in composite production due to ply placement limitations, local fibre steering, trimming operations, and out-of-plane distortions formed during consolidation. These imperfections can locally alter stress fields and significantly reduce structural performance. While the geometry of these defects cannot be resolved in simulations of full components or very large structures, implicitly incorporating their effect within damage and failure models is essential for producing accurate and practically relevant predictions in composite structures.

This paper presents newly-developed defect-specific failure and degradation models that enable an implicit (analytical) representation of several manufacturing defects relevant to industrial laminate production. These include gaps (with and without adjacent ply sinking) and undulations (both in-plane and out-of-plane). The implicit representation allows for the effect of defects to be introduced through enhancements of the constitutive laws and as additional failure modes, rather than through explicit geometric modelling.

The failure models were implemented as an additional capability within a failure model previously developed for pristine structural components (based on LaRC05) implemented in the Non-Linear Finite Element solver Abaqus. This modelling approach is particularly advantageous at larger structural scales, where the mesh resolution required to capture small-scale geometry would be computationally prohibitive.

The numerical implementation is validated against a large experimental dataset at coupon level, including tension and compression specimens in which defects of the types described above were deliberately introduced and subsequently tested. To demonstrate scalability, the framework was used on a skin-stringer run out and a full scale wing box finite element model, with the applicability and suitability of the code to be further verified. These studies highlight the robustness and flexibility of the framework and support its use as a basis for future simulation of larger-scale composite assemblies, especially where defect sensitivity is of critical interest.

#789

# Hierarchical nanostructured interphases for high performance carbon fibre-reinforced thermoplastic composites

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Compression properties of carbon fibre-reinforced polymer (CFRP) composites remain a critical limitation, often reaching less than half of their tensile strength, which imposes significant constrains for structural applications. The low compression strength is primarily attributed to fibre micro-buckling and kink band formation under compressive loading, which lead to premature failure of the composite material. A potential approach to enhance the compression properties of CFRP composites is the modification of the fibre-matrix interphase. By introducing a stronger and stiffer hierarchical nanostructured interphase, either by grafting carbon nanotubes to the carbon fibres or by mimicking the “brick-and-mortar” architecture of natural nacre, not only interfacial bonding and load transfer can be improved but also the polymer matrix in the vicinity of the fibres is stiffened which should delay micro-buckling initiation under compression load.

Previous studies employed layer-by-layer deposition of magnesium and aluminium-based nanoparticles to mimic the nacre-inspired hierarchical “brick-and-mortar” structure on carbon fibres. Here, positively charged inorganic nanoplatelets are suspended in an aqueous solution and deposited onto negatively charged carbon fibres under an applied electric field using a method known as electrophoretic deposition. This technique enables scale up from small laboratory samples to composite-relevant scales while maintaining interfacial integrity. The coated carbon fibre tows are subsequently processed into continuous unidirectional thermoplastic composite tapes and laminates using an in-house built powder impregnation line. The resulting composites are evaluated in terms of tensile, short beam shear, fracture toughness, and compression properties of such “hierarchical” composites are assessed to determine the effectiveness of the interphase modification.

#790

# Microplastic Particles Released from Rain-Eroded Wind Turbine Blades Under Accelerated Testing Conditions

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The global expansion of wind energy has raised concerns about the environmental impact of blade surface degradation, particularly the release of microplastic particles produced by rain erosion. Assessing these risks requires understanding the particle-generation rate and the size range of the released debris. However, erosion develops slowly under real operating conditions, and capturing particles for analysis is challenging.

This study applies an accelerated rain-erosion test to replicate the environmental exposure of wind-turbine blades over their service life. The aim is to determine the wear rate of blade surfaces and to characterize the amount and properties of composite fragments eroded from the leading edges.

Tests are performed using a whirling-arm rain-erosion rig under controlled conditions. After each test, water samples are collected, filtered through 0.2 µm membranes, and the mass of retained particles is compared with the measured mass loss of the blade specimens. The collected particles are examined using optical microscopy, and particle-size distribution analysed to quantify concentration, morphology, and size range. If the particle mass exceeds the specimen's recorded mass loss, FTIR microscopy is used to confirm whether all detected particles originate from the blade material. Water passing through the filters is further analyzed using Py-GC-MS to detect microplastics smaller than 0.2 µm.

Results show that rain-induced erosion generates a wide spectrum of microplastic particles. Using measured erosion rates with typical annual rainfall data, the annual material loss from a single turbine, and the corresponding mass of released particles, can be estimated while considering blade materials, coating systems, and operating conditions. These findings may help to evaluate the potential accumulation of microplastics in soils and surface waters near wind-turbine farms.

This study demonstrates the feasibility of an accelerated method to estimate blade erosion and highlights the need for comprehensive environmental risk assessment.

#791

# Decoding Environmental Drivers of Glass Fiber Dissolution in Composites: Insights from Microdroplet Interphase Testing

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Glass fiber–reinforced composites rely on the chemical stability of the fibers and on the integrity of the fiber–matrix interphase. When exposed to water, however, glass fibers gradually dissolve, and this usually slow degradation can influence the long-term performance of composite structures. This study examines how temperature and pH affect the dissolution behavior of glass fiber reinforcement. Dissolution kinetics were measured through high-resolution ICP-MS, which allowed accurate tracking of the release of the main glass constituent elements into water over time.

The results show two distinct stages of dissolution. An initial period is characterized by rapid ion exchange and surface changes, followed by a steady-state regime in which dissolution proceeds at a nearly constant rate. Both temperature and pH had a notable influence on the kinetics. Higher temperatures accelerated the process, while changes in pH shifted the dominant chemical reactions and altered the overall rate of mass loss.

To link chemical changes with mechanical consequences, additional micromechanical tests were carried out on conditioned specimens. Although the detailed mechanisms varied with the environment, dissolution-related hydrolytic crack growth consistently promoted the development of surface flaws and a gradual weakening of the fiber–matrix interphase. These effects were connected to reductions in properties controlled mainly by the fibers.

This work provides a clearer understanding of how environmental conditions drive the dissolution of glass fibers and affect composite durability. The findings support more reliable lifetime predictions and offer guidance for designing composite structures intended for use in challenging aqueous environments.

#793

# FFF-Printed Continuous-Fiber Thermoplastic Composites for Lightweight Aerostructures: A Correlation of Process-induced Defects and Mechanical Properties

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Abstract:

Additively manufactured continuous fiber-reinforced thermoplastic composites (CFRTPCs) offer strong potential for lightweight aerostructures, yet their performance remains limited by process-induced multi-scale defects and poorly quantified links between printing strategy and structural response. Building on a recent review of fused-filament-fabrication (FFF)- induced defects and advanced characterization in fiber-reinforced thermoplastics, this study presents an experimental framework that explicitly couples processing, defect architecture, and mechanical performance for FFF-printed CFRTPCs. A statistically designed parametric study varies fiber content and in-plane fiber placement strategy within aerostructural coupons. Tensile and flexural tests are performed according to standard composite protocols, and the same specimens are examined using multi-tier scanning electron microscopy and high-resolution synchrotron micro-computed tomography to resolve surface-proximal and volumetric defects. The imaging campaign quantifies pore networks, lack-of-fusion regions, fiber waviness, and, critically, the interfacial characteristics between the fiber and matrix, including interfacial micro-voids and incomplete bead coalescence. Preliminary results show that laminates with lower fiber content and more uniformly dispersed in-plane reinforcement develop extended, partially connected lack-of-fusion regions and chains of interfacial pores that align with the principal loading direction, leading to reduced tensile and flexural performance. In contrast, higher fiber content combined with perimeter-dominated reinforcement promotes broader, continuous inter-bead necks, fragmented interfaces, and more isolated pores, which correlate with markedly improved load transfer and stiffness. Across the dataset, variations in defect connectivity and orientation at bead-to-bead and fiber–matrix interfaces govern mechanical behavior more strongly than porosity magnitude alone. The study establishes processing guidelines and microstructure-based quality indicators for FFF-printed CFRTPC aerostructural components, providing a physically grounded basis for the future integration of advanced NDT and data-driven methods for defect assessment and structural health monitoring.

#795

# Development of quasi-static testing and characterization of CF/PEI composite under Liquid Hydrogen immersion

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Amongst thermoplastic composites, carbon-fibre reinforced polyethermide (CF-PEI) composite shows interesting properties for cryogenic applications such as super-conductive cables, namely due to the high toughness and relatively low coefficient of thermal expansion of the matrix. This material has been selected for full characterization at 20 K in Liquid Hydrogen (LH2) immersion, 111 K in cryogenic chamber, and 296 K in laboratory conditions. Previous works have aimed at developing tensile testing in LH2 : along and transverse to the fibre direction, as well as on [+/-45°] for in-plane shear properties. Such work has now been completed with Combined-Loading Compression (CLC), interlaminar shear (ILS) and four-point bending testing, allowing to fully characterize the material under quasi-static conditions. As compression loading is necessary for such tests and given the sealing constraints related to the LH2 cryostat mounted on the tensile machine, specific tools allowing to reverse the tensile displacement have been designed and tested. Simple, yet efficient, modifications of the normalised CLC test tool have also been carried out in order to ensure proper function in liquid hydrogen environment. Instrumentation through strain gages have been added to the testing facilities and shown to proceed successfully. Comparisons carried out on 4-point flexural tests revealed good correlations between the bending displacement calculated through the strain measured on the lower face of the specimens (with small deformation assumption), and the displacement directly measured with extensometer. Regarding material behaviour, temperature-dependency has been observed on matrix-dominated strength and stiffness properties, which tend to increase from RT to 20K (by up to 70% for ILSS), while fibre-dominated material characteristics seem far less impacted when working in deep cryogenic environment.

#797

# Representative Volume Element and Multiscale Simulation for Mechanics of Micro-Channels in Carbon-Fibre Reinforced Composite for Self-Healing Space Structures

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For space exploration and standard orbital applications, repair and maintenance of structures is difficult or impossible. Smart materials, especially multifunctional advanced composites can heal mechanical damage and adjust their deformation in the event of damage or configuration change to comply requirements of sensors and interfaces. This work presents carbon fibre reinforced plastic (CFRP) with micro-channels modelled using two length-scales in the finite element (FE) framework. Representative volume element (RVE) is created and implemented to compute one-step direct solution to feed stiffness matrix for the laminate length-scale. Matrix-rich regions are modelled with capability to (non-linear) plastic deformation, and the fibrous regions, bundles in twill reinforcement, are modelled with Tsai-Hill criterion for failure onset. The results describe the effects of micro-channels as stress concentrations for i) unidirectional ply stack, and ii) 2x2 twill configuration with bundle modelled on a meso-scale. Additionally, functionality of the micro-channels is analysed for the purpose of balancing thermal expansion mismatch in a space environment with extreme temperature difference between laminate outer surfaces. The geometric and mechanical data is adopted to comply physical samples with channels made using a method of filament embedding. According to the results, the twill architecture leads to failure onset at the bundle junction regions – not only for bundles' exterior but also for micro-channels located in the central volume of the bundles. These indications suggest to use lay-up of unidirectional plies with micro-channels over the twill reinforcement.

#798

# Use of Recycled Short Carbon Fibers for Anti-icing Applications in Wind Turbine Blades

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This study investigates the use of carbon-fiber (CF) composites for anti-icing applications in structures such as wind turbine blades, focusing on replacing continuous fibers with short fibers. However, from a stress-transfer perspective, these fibers should not be considered 'short' but rather 'discontinuous'. Therefore, the term 'discontinuous CF' (dCF) is used throughout the rest of the text. Particular attention is given to recycled CF, with the main objective of assessing their electrical and heating performance. A previous study [1] demonstrated that continuous CF (cCF) patches can effectively repair heating layers, though fiber orientation plays a critical role. Therefore, this work evaluates: (1) the performance of dCF compared to cCF, and (2) the difference between virgin and recycled dCF.

Virgin and recycled discontinuous fibers (6–12 mm) were used to manufacture composite plates and repair patches.

To examine robustness under real service conditions, rectangular panels with several cCF laminate layups were tested: $[0_2]$T, $[90_2]$T, $[45_2]$T, [0/90]T, [45/−45]T, [0/45/−45/90]T. Damage scenarios were simulated by introducing rectangular and circular cutouts, which were then repaired using discontinuous-fiber patches produced by vacuum infusion. Heating performance was assessed by applying DC, measuring electrical response, and monitoring temperature distribution.

The influence of fiber type (continuous vs. discontinuous, virgin vs. recycled), fiber distribution (oriented vs. random), fiber orientation in the repaired laminate, and damage geometry was systematically analyzed. Results show that recycled dCF provides heating performance comparable to virgin discontinuous fibers. Although discontinuous fibers generally do not match the effectiveness of continuous fibers for heating-layer repair, randomly oriented recycled-fiber patches performed sufficiently well to be considered for repairing anti-icing layers in wind turbine blades. Overall, the study supports the development of sustainable composite solutions while promoting the reuse of fibers recovered from end-of-life structures.

Reference

[1] Al-Ramahi NJ, Fernberg P, Nilsson G, Joffe R. Materials Today Communications 2025:49 (113772). https://doi.org/10.1016/j.mtcomm.2025.113772.

#799

# Revolutionizing Energy Storage with Coaxial Structural Batteries

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The global shift toward decarbonized and energy-resilient infrastructures has intensified the need for technologies that combine energy storage with structural functionality. Structural batteries represent a promising direction for next-generation multifunctional systems in transportation, aerospace, and smart infrastructure. Among emerging concepts, coaxial all-solid-state batteries based on sodium ferroelectric electrolytes show exceptional potential due to their safety, scalability, and unique electrostatic charge-storage mechanisms, firstly developed by Braga's group. This work investigates the electrochemical and mechanical behavior of coaxial structural cells employing Na-based ferroelectric solid electrolytes and metallic rods as current collectors. The electrolyte exhibits extraordinarily high permittivity and fast Na+ transport, enabling electrodeless operation in which charge is stored through interfacial polarization rather than traditional redox reactions. The coaxial design integrates an inner aluminum rod, a ferroelectric electrolyte layer, a copper outer current collector, and a carbon-fiber-reinforced polymer structural shell. Here, it is examined the influence of aluminum core diameter on the cell's electrochemical response while maintaining constant outer geometry. Electrochemical impedance spectroscopy demonstrates that the 6-mm configuration minimizes interfacial and bulk resistance, leading to improved charge-storage behavior. When charged for only 3 minutes at 1.5 V, the 6-mm coaxial cell sustains a long-duration discharge plateau between 0.85 and 1.1 V for more than 40 days, exhibiting the characteristic self-charging behavior of ferroelectric solid-electrolyte systems. In addition to enhanced electrochemical performance, the coaxial configuration provides inherent mechanical strength. Even after three-point bending deformation, the cells retain electrical functionality and can operate in simple circuits, demonstrating robust electro-mechanical coupling. These results highlight the potential of coaxial all-solid-state structural batteries as safe and sustainable energy-storing structural elements suitable for future multifunctional engineering applications.

#800

# Investigation of compressive failure of novel hybrid boron-carbon fibre reinforced composites observed in-situ by computed tomography

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The use of carbon-fibre-reinforced polymer (CFRPs) composites is critical for the aerospace, defence and sports industries. Under compressive loading, CFRPs typically fail by unstable propagation of fibre micro buckling. Recent investigations by the authors have highlighted that with the hybridisation of CFRPs with boron fibres, the unstable propagation of kink band in carbon fibres can be deflected and diffused. This results in an overall improvement in compressive performance, in terms of an increase in the failure strain and as well as ultimate strength. However, the current understanding of these deflection mechanisms has been realised only by the post-test fractography. To obtain insights to the mechanisms involved during the failure process, the authors have recently conducted in-situ compression testing using synchrotron X-ray computed tomography (CT) for both the conventional CFRP (baseline without boron fibres) and the hybrid specimens containing boron fibres. The laminates were prepared using carbon fibre prepreg MR70/T402 using a bespoke hybridisation process. Small-scale rectangular flat specimens (height = 10 mm, width = 3 mm) containing a notch at one of the long edges were machined from the laminates. The specimens were tested using a Deben CT5000 tension-compression rig fitted with a 5 kN load cell and subjected to a compressive load under constant displacement rate. The loading was interrupted at various stages during the test and CT scans were obtained at each interruption. The results of this work not only enable the understanding of the failure sequence due to hybridization in 3D for the first time but also inform models of the process and help us develop optimised carbon-boron composite hybrids. The findings from these results will guide the designers to develop lighter composite structures in the aerospace, defence and sport sectors by utilizing the potential of this new hybridisation strategy.

#801

# Quantitative Evaluation of Interfacial Degradation in Hydrothermally Aged CFRP Using Cyclic Push-Out Testing

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Efficient characterization of interfacial degradation is crucial for understanding the hydrothermal aging behavior of carbon fiber reinforced polymers (CFRPs). The interface hydrophilicity governs water uptake and interfacial bond stability, yet its quantitative influence on crack initiation and energy dissipation remains poorly understood. In this work, cyclic single-fiber push-out tests were employed to systematically investigate the degradation mechanism of CFRPs with different interface hydrophilicity.

Unlike conventional one-time push-out methods that provide only interfacial shear strength, the cyclic approach enables real-time monitoring of progressive debonding. By decomposing the energy of each cycle into elastic, frictional, and dissipative components, the method directly captures the onset of interfacial cracking and the evolution of fracture energy during stable debonding. This energy-partitioned analysis allows damage evolution to be studied.

Experimental results reveal that the degradation of the interface fracture energy after hydrothermal aging increase significantly with the increasing hydrophilicity. Crack initiation occurs at a lower fibre displacement threshold at the hydrophilic interface compared to the reference sample. Moreover, the resin surrounding aged fibres exhibits markedly reduced viscoelastic recovery, as reflected by limited fibre rebound during unloading, indicating a substantial loss of matrix elasticity and energy dissipation capability. This viscoelastic deterioration is more pronounced in the hydrophilic CFRPs. Together, these findings indicate that increased water adsorption and hydrogen bonding at hydrophilic sites give rise to both epoxy-matrix degradation and weakened interfacial bonding strength.

Overall, the proposed cyclic push-out technique provides a powerful and quantitative means to evaluate CFRPs interface degradation under hydrothermal conditions. This study offers new insights into the relationship between interfacial chemistry, energy dissipation, and fracture behavior, and establishes a foundation for future durability of composite interfaces.

#802

# Enhancing life cycle assessment for multi-cycle recycling carbon fiber reinforced PEEK

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In recent years, the use of carbon fiber reinforced polymer (CFRP) composites has increased in industries such as aeronautics, primarily to reduce weight. While reducing the mass of on board parts can decrease environmental impacts during the operational phase, other stages of CFRP life cycle (e.g. production, manufacturing, end-of-life) has significant environmental impacts. Consequently, to meet legislative requirements and reduce these impacts, industries must explore processes such as recycling and remanufacturing multiple times, supported by relevant environmental assessment methods. This is particularly relevant for thermoplastic matrix composite materials, which can be partially reused, remanufactured or recycled. Life cycle assessment (LCA) is the prevailing methodology for quantifying environmental impacts and evaluating recycling benefits. However, existing approaches often fail to account for the degradation of material quality over successive remanufacturing and recycling cycles. To produce parts that meet the technical requirements for service life, this deterioration in quality must be compensated for by adding material, which should be integrated into the overall environmental assessment.

This study addresses this limitation by examining various calculation methodologies and proposing an adapted model that explicitly incorporates the evolving quality and quantity of the material during recycling and remanufacturing. It is specifically applied to carbon fiber reinforced polyetheretherketone (PEEK-CF) composite, a high-performance material used in demanding aeronautical applications. The economic and ecological implications of its production suggest its viability in multi-cycle processes.

The proposed model is adapted from the Circular Footprint Formula (CFF), developed by the Product Environmental Footprint. It introduces a term representing the amount of virgin material required to compensate for the losses of quantity and quality with each remanufacturing and recycling cycle. This adaptation enables the assessment of the environmental impact of recycling the material multiple times. Furthermore, it is possible to adapt the modified CFF according to the functional unit of a LCA.

#803

# Design and Structural Optimization of Co-Free Ni-Rich Layered Oxides for Lithium-Ion Batteries

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The rapid growth of electric mobility and large-scale energy storage systems has intensified the demand for high-energy and long-life lithium-ion batteries. Among various cathode materials, cobalt-free Ni-rich layered oxides such as NMA have emerged as promising candidates due to their high specific capacities exceeding 200 mAh $g^{-1}$ and operational voltage ranges up to 4.4 V, enabling higher energy density and improved sustainability compared to conventional cobalt-based systems. However, practical deployment remains constrained by insufficient rate capability, intergranular cracking, surface degradation at high voltages, and increased impedance during prolonged cycling. Therefore, strategies that enhance Li-ion transport and reinforce structural stability are essential to achieving durable performance.

In this study, NMA cathode powders with uniform spherical morphology and controlled particle architecture were synthesized through a solution-assisted aerosol processing route. A polymer-based functional additive was incorporated during precursor preparation to regulate particle development and improve interfacial stability. This microstructural tuning enhances particle cohesion and mitigates internal mechanical stress during Li-ion insertion and extraction, enabling reduced polarization and more efficient ion diffusion at high operating rates. As a result, the modified cathode exhibits improved rate capability and enhanced cycling retention relative to the unmodified reference material.

Comprehensive structural and electrochemical analyses, including XRD, TEM, XPS, and EIS, confirm that the optimized NMA cathode maintains a well-ordered layered structure with reduced cation disorder, stabilized surface chemistry, and suppressed charge-transfer resistance growth during extended cycling. These findings highlight the importance of morphology and interface regulation, even without extensive compositional modification, in improving the performance and durability of Co-free Ni-rich layered cathodes. Overall, this work provides insight into advanced design strategies for enhancing NMA cathode performance through processing-driven microstructural optimization and interface engineering, offering a promising direction toward sustainable, high-energy lithium-ion battery technologies.

#804

# Recycling and tailored printing of carbon fiber composites

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3D printing of recycled carbon fiber was demonstrated by the fused filament fabrication technique. A recycled carbon fiber spun yarn was processed into a filament for 3D printing, using polyamide 6 and polyamide 12 as matrices. The fibers were aligned along the filament's axial direction, and the filament followed the print path during 3D printing. Four specimens were prepared from the filament by 3D printing. The effect of the 3D printing process on the tensile properties of the recycled carbon fiber filament was evaluated. The comparison of the four specimens showed that the 3D-printing process adversely affected the tensile properties of the composite by damaging the fibers and dispersing the fiber direction. Multiplying the filament compensated for the variability in the tensile properties and improved the tensile properties of the 3D-printed coupon. The 3D-printed recycled carbon fiber-reinforced polyamide showed intermediate properties between those of 3D-printed continuous and milled carbon fiber composites. 3D printing is an effective molding technique for the use of recycled carbon fibers.

#806

# Machine-Learning-Accelerated Cohesive Zone Model for Fracture Analysis of Composite Materials

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This work presents a set of open-source Abaqus C++ user subroutines and a machine-learning-augmented Cohesive Zone Model (CZM) for fracture analysis of laminated composite materials. Leveraging modern C++ features, the framework adopts an object-oriented hierarchical design and integrates the TensorFlow C++ API to construct and train machine-learning (ML) models.

The workflow begins with a conventional CZM to predict the failure response of composite laminates. During each analysis step, key computational quantities—including field variables, damage evolution metrics, and solution information—are extracted and used to update the ML model through an online learning strategy. Model construction, training, and validation are performed asynchronously, in parallel with the finite element analysis (FEA), utilizing idle CPU cores and available memory to avoid interference with the primary simulation. Once the ML model attains sufficient predictive accuracy, it replaces the standard CZM, significantly reducing the number of nonlinear iterations required to capture fracture progression and thereby lowering the overall computational cost.

Details of the code architecture and implementation are provided, and the proposed ML-CZM framework is validated through benchmark simulations, including double cantilever beam (DCB), end-notched flexure (ENF), and mixed-mode bending (MMB) tests.

#807

# Effect of deviatoric angle on axial compressive strength of fibrous composites

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Axial compressive stress-strain curves of unidirectional carbon fiber reinforced plastics (UD CFRP) were calculated based on the distribution of deviation angle from the axial directions. UD CFRP specimens were prepared by changing the initial fiber misalignment by controlling the tensioning force during 3D printing. The deviation angle of fibers from the axial direction was obtained from X-ray computed tomography imaging by means of structural tensor analysis. Softening in the axial compressive stress-strain curve was noticeable in the analysis when local strain at fiber kinking region was adopted. In contrast, the experimental stress-strain curves could be reproduced by adopting average strain over the strain gauge length, which is the same condition with the experiment. The axial compressive strength was dependent on distribution of initial fiber misalignment, which were well predicted analytically. Estimation of axial compressive strength using deviation angles yields a closer match to the experimental results than using projected angles.

#808

# $SiO_2$-Carbon Composite Microsphere as a 3D Host Material for Stable Lithium Metal Batteries

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Lithium metal anodes (LMAs) are considered promising candidates for next-generation high-energy batteries owing to their high theoretical capacity (3860 mAh/g), low density (0.534 g/cm³), and low redox potential (−3.04 V versus the standard hydrogen electrode). However, practical implementation remains hindered by challenges including dendritic lithium growth, non-uniform Li plating/stripping, and large volume fluctuation during cycling. To address these limitations, three-dimensional (3D) host architecture has gained attention due to their ability to accommodate lithium, reduce local current density, and suppress dendrite formation. Incorporating lithiophilic sites into conductive 3D hosts further improves nucleation behavior while inhibiting the formation of lithium dendrites. In this study, we designed $SiO_2$-embedded carbon microspheres as a 3D host for LMAs, synthesized via spray pyrolysis process.

The resulting structure features a porous morphology with uniformly distributed $SiO_2$ domains covered by carbon structure with interconnected CNT networks. This synergistic architecture optimizes ionic/electronic pathways and promotes dense, dendrite-free lithium that mitigates parasitic reactions. SEM observations further confirm this behavior, revealing highly uniform and densely packed lithium plating without upper-surface accumulation or dendritic features. Consequently, asymmetric cell tests demonstrated highly reversible lithium plating and stripping behavior with excellent electrochemical stability over extended cycling, while maintaining a high Coulombic efficiency during extended cycling. When paired with a commercial cathode, the full cell exhibits excellent capacity retention and rate capability. Ex-situ XPS and in-situ EIS analyses confirm that the synthesized composite forms a stable solid-electrolyte interphase (SEI), which effectively regulates interfacial resistance during repeated lithium deposition and stripping. These results highlight the strong potential of synthesized 3D host as a practical and high-performance 3D host framework for lithium metal batteries.

#809

# Numerical Simulation of Fatigue Damage in CFRP Cross-Ply Laminates Incorporating Frequency-Dependent Internal Heat Generation Using an Entropy-Based Viscoelastic–Plastic Damage Model

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This study aims to develop a numerical model that unifies the mechanisms governing the fatigue life of CFRP, which is significantly affected by frequency, particularly in high-frequency loading conditions where internal heat generation accelerates damage progression. First, a generalized Maxwell model is introduced to replicate the anisotropic viscoelastic response of CFRP, and it is implemented as a viscoelastic-plastic constitutive law using the UMAT subroutine. Next, an "entropy-based damage model" is constructed by combining irreversible damage accumulation based on load modes with strength degradation proportional to the entropy generation, in accordance with the Hashin failure criterion. The material's inherent defect distribution is represented by introducing element-wise strength variations using a Weibull distribution. Additionally, internal heat generation from energy dissipation due to viscoelasticity and plastic deformation, as well as heat conduction from the specimen’s interior to the surface, is modeled. The effect of temperature rise accelerating damage progression is incorporated through the time–temperature superposition principle.

Fatigue analysis of CFRP cross-ply laminates reveals that at low frequencies, transverse cracks originating from the edges dominate due to viscoelastic damage. In contrast, at high frequencies, internal temperatures rise by 15–20 ℃, and damage progresses from within the laminate. The predicted fatigue life aligns with the experimental “bell-shaped” frequency dependence, demonstrating that the proposed model is effective for predicting the durability of CFRP. The model is a versatile analytical tool applicable to arbitrary load histories, stress ratios, variable amplitudes, and thermal cycles. Furthermore, the findings of this study clearly indicate that the fatigue life and damage behavior of CFRP vary significantly with frequency, suggesting that load frequency should be carefully considered when evaluating the durability of CFRP in practical applications.

#810

# Numerical analysis of post-forming shape and thermal residual stress in thermoplastic CFRP

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Thermosetting CFRP is widely used in current aircraft structures; however, to improve manufacturing throughput, the use of thermoplastic CFRP (CFRTP) for selected components is increasingly being considered. During the cooling phase of the CFRTP forming process, characteristic distortions occur, accompanied by the development of thermal residual stresses. In this study, these phenomena are investigated through numerical simulations performed in Abaqus based on the finite element method.

To accurately reproduce the thermo-mechanical behavior of CFRTP in Abaqus, both the viscoelasticity of the resin and the material anisotropy arising from fiber orientation must be considered simultaneously. Direction-dependent material properties were first calculated using a micromechanics-based rule of mixtures. These properties were subsequently incorporated into an anisotropic viscoelastic constitutive model implemented via a user subroutine, in which a generalized Maxwell model was employed to assign direction-specific relaxation behavior. Furthermore, to apply the Arrhenius-type temperature–time equivalence principle, temperature-dependent shift functions were introduced into the dashpots, capturing the transition from pronounced viscoelastic behavior at elevated temperatures to predominantly elastic response at lower temperatures.

Using this modeling framework, cooling simulations were conducted for an L-shaped component. When cooled from 500 K to 300 K, a clear spring-in deformation was observed, and the resulting distribution of thermal residual stresses was quantified. This deformation was attributed to the mismatch between the in-plane and out-of-plane coefficients of thermal expansion. In addition, the magnitude of the residual stresses was found to decrease slightly with longer cooling durations, indicating that the cooling profile has a significant influence on residual stress formation.

The findings of this study highlight the importance of accounting for thermal stresses during the fabrication of structural CFRTP components and demonstrate the potential of the present approach to support improved process design and part quality in thermoplastic composite manufacturing.

#813

# Fatigue Life Estimation of Cross-ply CFRP Composite Laminates: An Experimental & Computational Micromechanical RVE Approach

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Carbon Fiber-reinforced polymer (CFRP) composites are extensively employed in structural applications across the aerospace and defense sectors. These structures are often subjected to extremely high-cycle ($10^8$-$10^9$ cycles) multiaxial fatigue loads throughout their service life. Consequently, laminated composite structures incorporate both longitudinal and off-axis plies to accommodate multiaxial loading and maintain structural integrity. Under tension-tension fatigue loading of the composite laminates, initial damage typically originates in transverse plies as fiber/matrix interface debonding, eventually propagating to matrix cracking and fiber failure in the adjacent longitudinal plies. Following a hierarchical approach for designing robust composite structures, the current research aims to predict for the first time the tension-tension fatigue damage behavior and the corresponding fatigue life (S-N curves) of cross-ply CFRP composite laminates using a physics-based micromechanical Representative Volume Element (RVE) modeling approach. To achieve this objective, the fatigue behavior of the longitudinal fibers is modeled using a phenomenological approach based on a single-fiber S-N behavior. To simulate the fiber/matrix interface fatigue damage behavior and fatigue delamination, the cohesive zone formulation, combined with Paris law-based fracture mechanics principles, is utilized. Additionally, the epoxy matrix fatigue damage is captured using a nonlinear elastic material model combined with a pressure-dependent modified von Mises criterion. These material models are implemented in Abaqus®/Explicit via three independent VUMAT subroutines to predict the fatigue behavior of the composite laminate. Moreover, a cycle-jump strategy is employed to improve the computational efficiency of the proposed RVE modeling framework. Further, for simulating the fiber/matrix interface fatigue damage, the Mode II Paris law constants (CII, mII) are determined from in-house single-fiber fragmentation fatigue experimental testing. Finally, by integrating the fatigue behavior of the fiber, matrix, and interface constituents, the tensile S-N behavior of the cross-ply laminates is predicted, and the proposed methodology is validated both quantitatively and qualitatively through comprehensive fatigue experiments.

#814

# Evaluation of Bonding Strength in Single-Lap Joints Between Nanostructured Aluminum Alloys and Thermoplastic CFRP Laminates

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This study investigates the mechanical performance of single-lap joints composed of an aluminum alloy and a thermoplastic carbon-fiber-reinforced polymer (CFRP) with a polyamide matrix. Improving the reliability of such dissimilar-material joints is essential for lightweight structural applications, particularly in transportation and industrial machinery, where hybrid metal–polymer assemblies are increasingly adopted. To enhance the bonding strength between the aluminum alloy and the thermoplastic composite, nanostructures were fabricated on the aluminum surface through anodizing and subsequent chemical etching. A silane coupling treatment was then applied to introduce additional chemical bonding capability. The treated aluminum substrate was joined to a thermoplastic CFRP laminate through thermal welding using a hot-press process.

The introduction of nanoscale surface features significantly improved the mechanical interlocking at the interface, resulting in a 1.4-fold increase in bonding strength compared with the specimen without nanostructure. While single-lap joint testing is widely employed because of its simplicity and ease of specimen preparation, its results are influenced by bending moments inherent in the asymmetric geometry, yielding only an apparent joint strength rather than a true interfacial property. This limitation becomes more pronounced in dissimilar-material joints, where mismatches in elastic modulus and thermal expansion can generate substantial thermal residual stresses during forming.

To address these challenges, we developed a closed-form analytical expression for the energy release rate associated with interfacial crack propagation. The model incorporates both the bending deformation characteristic of the single-lap configuration and the thermal residual stresses arising from the joining process. By comparing the analytical predictions with experimental measurements, we confirmed that the energy-based evaluation framework provides a more fundamental and physically meaningful assessment of joint strength. The agreement between analysis and experiment demonstrates the effectiveness of the proposed approach for characterizing hybrid metal–thermoplastic composite joints and offers valuable insight into the design of high-performance lightweight structures.

#815

# MXene-based carbon fibre composites for structural energy storage - Towards multifunctional materials combining strength and energy storage capability

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Structural battery composites are an emerging technology with potential for automotive, aerospace, and drone applications that demand load-bearing capability combined with efficient energy storage. While structural batteries dominate current research, their reliance on liquid or gel electrolytes introduces fire risks and limits structural performance.

This work introduces a fully solid-state structural dielectric capacitor concept that integrates a polymer-based nanodielectric with carbon fibre reinforcement, creating a multifunctional composite. Achieving an optimal balance between dielectric performance and mechanical integrity remains a key challenge. To address this, two-dimensional MXene ($Ti_3C_2Tz$) layered particles are incorporated in a polyvinylidene fluoride (PVDF) matrix. MXenes, with high conductivity and large surface area, enhance polarisation and energy storage. 21.4 vol% MXene in PVDF achieved an energy density of 1.6 $Wh \cdot kg^{-1}$ with a breakdown strength of 8–10 $MV \cdot m^{-1}$. Reducing the dielectric thickness from 120 µm to 15 µm resulted in a threefold increase in dielectric breakdown strength. Further optimisation of MXene orientation and dielectric thickness is currently being explored to maximise performance.

Electrical properties were characterised using dielectric spectroscopy and inductance-capacitance-resistance (LCR) analysis, while scanning electron microscopy and X-ray computed tomography confirmed uniform MXene dispersion and in-plane alignment of the layered structures.

By quantifying these relationships, this work establishes design principles for structural capacitor composites that combine mechanical robustness with enhanced energy density, enabling safer, lighter, and more efficient energy storage for electrified mobility systems.

#816

# Fabrication and Evaluation of Polyamide 66 Composites with Recycled Carbon Fiber

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Carbon-fiber-reinforced plastics (CFRP), known for their light weight and high performance, are used widely in automotive and aerospace industries as alternatives to metals and ceramics. However producing carbon fibers requires energy-intensive high-temperature processes, and most end-of-life CFRP waste is still landfilled. As CFRP usage continues to expand, particularly in transportation, the amount of waste is expected to grow, making recycling strategies essential. As a result, research on recycled carbon fibers (rCF) has been gaining attention, especially in Japan, which leads global CF production. Developing effective applications for rCF is crucial for improving the carbon fiber life cycle.

This study focuses on producing PA66/rCF composites through in-situ polymerization to explore new possibilities for rCF utilization. Polyamide 66 (PA66) is an engineering plastic with high mechanical strength, heat resistance, and chemical durability, used in applications ranging from household products to automotive and electronic components. In-situ polymerization enables better dispersion of carbon-based fillers compared with melt mixing, which often leads to filler aggregation.

Optical images and SEM observations confirmed uniform dispersion of rCF within PA66, with no noticeable aggregation. However, fiber pull-out marks and voids were observed in the composites. XRD analysis showed that the crystallinity of PA66 decreased after rCF addition, likely due to physical or chemical disruption of crystallization. Mechanical tests indicated little improvement at very low rCF contents, whereas higher contents led to significant increases in modulus and tensile strength. Thermogravimetric analysis revealed lower thermal stability at low rCF loadings, while composites with high rCF contents showed enhanced stability due to the rigid structure of the fibers. These results suggested weak interfacial adhesion between rCF and PA66. Therefore, to address this issue, we conducted surface oxidation of rCF, and the effect of surface modification on the structure and properties of PA66/rCF composites was investigated.

#817

# On the determination of Fiber/Matrix Interface mode-II Fatigue Parameters: A Concurrent Experimental & Computational Approach

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Owing to advancements in computing power, computational micromechanics has emerged as an indispensable tool for understanding and predicting the initiation and propagation of damage in composite materials subjected to quasi-static loads. For reliable predictions of the mechanical behavior of a UD composite ply under quasi-static loads and extending it to fatigue loads, the micromechanical modelling framework requires accurately characterized properties of its constituents. Among these, the fiber/matrix interface, being vulnerable and weakest link, demands precise evaluation. Moreover, off-axis and longitudinal plies are prone to damage under in-plane shear and longitudinal fatigue, where the interface predominantly experiences mode II fracture. Consequently, the current research focuses on determining the fiber/matrix interface Paris-law parameters under mode-II loading while developing a thoroughly validated Finite Element model. Single-fiber specimens are manufactured by embedding carbon fiber in an epoxy matrix. A tensile test is performed in-situ using an in-house mini-tensile experimental setup under an optical microscope to generate a single fiber break and initiate interface debonding. Subsequently, the specimen is unloaded and reloaded until the existing interface debond propagation, and the corresponding critical load is recorded. Following, each specimen is subjected to tension-tension fatigue at multiple load severities (R = 0.1, 5 Hz), during which the interfacial debond length is monitored as a function of cycle count to extract the Mode-II Paris-law parameters. A representative section of the specimen is modeled in Abaqus. The VUSDFLD is employed to initiate fiber damage utilizing the maximum stress criterion, while the VUMAT is used to simulate the fiber/matrix interface behavior through a cohesive zone formulation. The model simulates fiber breakage and initial debonding under static loading and subsequently applies cyclic loading to capture the interfacial debond growth rate. Collectively, these parameters provide essential inputs for RVE-driven fatigue analyses, improving the accuracy of longitudinal tension-tension and in-plane shear fatigue predictions.

#818

# Fatigue resistance and self-healing of carbon fiber reinforced vitrimers subjected to bending tests

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Carbon fiber–reinforced thermosets are an excellent choice for high-performance sectors due to their high mechanical properties and low weight. However, thermosets are characterised by a crosslinked insoluble network that hinders reprocessing: this prevents a sustainable End-of-Life (EoL) management of composite parts, which are generally landfilled or incinerated. Vitrimers are a recent class of polymers characterised by a covalent adaptable networks and thus capable of bond-exchange reactions: this allows an efficient reprocessing and a self-healing behaviour, which allows new EoL strategies for composites. The fatigue resistance and healing capability of vitrimer-based composites are here investigated. Three carbon fibre composites are compared featuring: a conventional epoxy (DD) as benchmark, a disulfide-exchange vitrimer (DA) and a biobased transesterification vitrimer (PG).

The resins were first synthesised, cured, and characterised chemically and rheologically. All systems exhibited high crosslinking degrees and thermal stability above 300 °C. Rheological measurements confirmed the dynamic behavior of vitrimer networks, with stress relaxation times decreasing significantly above their topological transition freezing temperatures. Unidirectional composites were then fabricated and subjected to static and fatigue three-point bending tests. Fiber content between 48% and 63% in weight were obtained, with PG composites showing the highest content and thus resulting into slightly higher flexural strength.

Three-points bending fatigue tests were first performed to measure the benchmark lifespans of the DA and PG composites. Then, the loading cycles were alternated to healing cycles by heating specimens to 170 °C for durations based on measured relaxation times. This resulted in extended fatigue lives of about 290% and 240% for the DA and the PG composites, respectively. Force–displacement analyses showed cyclic stiffness recovery after each healing step, indicating a partial restoration of the matrix network.

Overall, this work proves how vitrimer-based composites, even considering bio-based precursors, can extend the composites' lifetime through thermally activated healing.

#820

# Uncertainty-aware composite quality monitoring

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Composite materials play a significant role in many industries, such as aerospace engineering, due to their high strength to weight ratios and their design flexibility. Despite their advantageous properties, it is challenging to ensure that certain quality and reliability thresholds are achieved, as even small deviations due to manufacturing or material-chemical processes, like curing, affect their structural performance and strength. This challenge is intensified by the fact that we are not living in a deterministic world, thus all these processes and simulation models have inherently many uncertainties attributed to material heterogeneity, tolerances, measurement noise and drift, model assumptions and more.

To ensure that produced composite materials are robustly meeting all the desired properties threshold, those uncertainties shall be considered and integrated in the overall composite part quality assessment procedures. To this end, the current work entails uncertainty quantification and propagation on a novel industrial dielectric sensing method in manufacturing process monitoring. The main results present the impact assessment of the identified uncertainties throughout the composites' curing process on the final material properties. To do so, first a complete account of identified uncertainties is reported along with their characterization. Then, classic Monte Carlo methods are used to perform the necessary propagation and deliver reference results related to any quantity present in the pipeline, while focus is placed on conductivity, degree of cure, viscosity and glass transition temperature of the curing resin.

The incorporation of uncertainty quantification to the above-mentioned pipeline will provide a better understanding of the overall curing process dynamics, as well as, facilitate high reliability in the monitoring of this process and ultimately obtain uncertainty-aware results, that allow better composite quality control and product qualifications.

#821

# Automatic Ply Instance Analysis for CFRP Micrographs

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We present an automated approach to distinguish between ply instances in semantic segmentation masks of carbon-fiber reinforced polymer micrographs. Interpreting the segmentation mask as a graph with pixels as vertices, enables us to use a shortest-path algorithm yielding the ply-separating paths. We calculate edge costs based on their minimum distance to fiber, to epoxy and - where available - to two different fiber orientations. With our ply-separating path calculation, we bridge the gap between semantic segmentation and ply instance segmentation using global information.

The general approach is broadly applicable and only presumes ply separability based on interleaf layers or fiber orientation angles provided in the segmentation mask. It can handle interrupted or wavy plies and does not require user interaction except of few parameter choices. We successfully applied our approach on high-resolution micrographs featuring a broad range of characteristics like artificially added gaps in single or multiple plies, different stacking sequences and ply traversing cracks. The usage of our in-house trained, machine learning-based segmentation model has advantages, however even a basic, binary segmentation mask based on Otsu's method is sufficient for specimens with interleaf layers.

Assigning each fiber pixel to a ply based on the calculated paths, allows for a comprehensive, quantitative ply analysis with respect to its microstructural properties like the local fiber volume fraction and ply-level properties like ply and interleaf layer thickness. The initiation of transverse cracks is strongly influenced by the individual ply thickness, which varies due to manufacturing effects. Our tool enables a quantitative correlation between these factors. The interleaf layer thickness affects mode-II interlaminar fracture toughness and their as-built distribution can be used for low-velocity impact simulations based on stochastic finite element method. These insights help to reveal manufacturing-induced inhomogeneities, draw conclusions on manufacturing parameters and link mechanical properties to underlying microstructural imperfections.

#824

# Bio-Mediated Longitudinal Reinforcement in Architected Mycelium Composites

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Loosely bonded bio-composites often struggle to achieve the robustness required for their application in load-bearing components. Techniques like hot/cold pressing can significantly improve the strength, typically along the pressing direction; however, they often compromise the design freedom and are mostly limited to simple shapes. Mycelium-based composites (MBCs) have emerged as a promising alternative, where loosely bonded organic substrates are bonded and reinforced by a growing hyphal network. However, the density of the hyphal network often remains non-uniform, resulting in MBCs with inferior and spatially heterogeneous properties, a common challenge in the field of MBCs.

In this work, we present a unified experimental framework demonstrating how biological mycelium growth can actively mediate longitudinal reinforcement in architected scaffolds across multiple architectures and material systems. We study the role of different scaffold materials, like 3D printed bio-ink formulated from agricultural waste and earthen material, and stiff wood-polymer filaments. In scaffold architectures, we studied open architected designs like woodpile structures, sheet and strut-based triply periodic structures. The focus is on the uniform mycelium colonization and improvement in the mechanical performance. Our findings indicate that the material and architecture of the scaffolds directly influence the mycelium colonization, which in turn governs the mechanical robustness. Substrates with higher accessible lignocellulosic components and scaffolds with better gas exchange promote dense and uniform mycelium growth. The presence of dense mycelium network shows a 2-5 fold increase in compressive strength in MBCs as compared to bare scaffolds. Microscopy and deformation analysis show that the mycelium establishes an interconnected fiber-like reinforcement network through hyphal bridging, pore confinement, and strong interfacial adhesion, resulting in uniform load distribution, crack deflection, and non-catastrophic failure. These results highlight bio-mediated material-structure interactions as an effective strategy for engineering robust, architected mycelium-bound composites for load-bearing applications.

#826

# 3D microstructural characterization through micro-ct-based statistical analysis of fiber reinforced thermoplastic polymers

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Predictive performance modelling of recycled fiber-reinforced thermoplastic polymer (FRTP) composites requires accurate characterization of their intricate microstructure. In this study, an X-ray micro-computed tomography scan was performed on a short glass fiber-reinforced polypropylene composite sample representative of low-shear mixed recycled FRTPs. Segmentation and fiber topology analysis methods were subsequently explored for microstructural characterization of the scan data. Four geometric descriptors were extracted for statistical analysis, including fiber volume fraction, length, orientation and curvature. The results showed that descriptors directly obtained from the segmentation data, particularly fiber volume fraction and orientation, can be determined with reasonable consistency. In contrast, topology-related descriptors such as fiber length and curvature remain sensitive to the initial segmentation artefacts, limited spatial resolution, and the robustness of fiber tracking algorithms. The presented scan-segmentation-topology analysis workflow shows potential for microstructural characterization of recycled FRTPs in future research, while highlighting the need for improved fiber topology reconstruction and validation strategies.

#827

# Bicontinuous Electrolytes for Structural Supercapacitors

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Structural supercapacitors (SSCs) require electrolytes that simultaneously support rapid ion transport and mechanical load bearing—a combination that remains challenging to achieve due to the intrinsic trade-off between ionic conductivity and stiffness [1]. Bicontinuous electrolytes have emerged as a promising solution to achieve target values of ionic conductivity (>1 mS $cm^{-1}$) and stiffness (>1 GPa) [1, 2]. This is achieved through the presence of two continuous phase, one responsible for the mechanical performance and another for ion conduction. The properties and microstructure of the resulting electrolytes are affected by number of factors from composition to synthesis conditions.

In this study, epoxy/ionic-liquid electrolytes based on bisphenol A diglycidyl ether (BADGE), isophorone diamine (IPDA), and 1-ethyl-3-methylimidazolium bis(trifluoromethylsulfonyl)imide (EMIM-TFSI) are fabricated via reaction-induced phase separation (RIPS) to produce bicontinuous microstructures. Multi-oxirane ring epoxy additives (1–50 wt%) are incorporated to modify the BADGE/IPDA/EMIM-TFSI curing network, and their effects on morphology, stiffness, and ionic conductivity are examined. Although multi-oxirane ring epoxy additive's blends with BADGE are common in conventional thermosets [3], their application in BADGE/IPDA/EMIM-TFSI electrolytes remains largely unexplored. Additional oxirane groups also enable the formation of cyclic carbonates, which can enhance ionic mobility and provide an additional mechanism to simultaneously tailor ion transport and mechanical performance.

References:

1) E. S. Greenhalgh, S. Nguyen, M. Valkova, N. Shirshova, M. S. Shaffer and A. Kucernak, Compos. Sci. Technol., 2023, 235, 109968.

2) Q. Wendong, J. Dent, V. Arrighi, L. Cavalcanti, M. S. Shaffer and N. Shirshova, Multifunct. Mater., 2021, 4, 035003.

3) D. Budelmann, C. Schmidt and D. Meiners, Polym. Test., 2022, 114, 107709.

#829

# A ‘characteristic length’-free cohesive fatigue damage model for improved crack-front tracking and damage prediction in laminated composites

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Delamination under high-cycle fatigue, is one of the most critical damage mechanisms in laminated composites. In this case, the interfacial crack can steadily grow even at a lower applied load level and reach a critical size leading to unexpected structural failure. Numerical prediction of fatigue delamination typically relies on cohesive zone modelling. However, most existing approaches require the specification of a characteristic length to relate the crack-growth rate obtained from Paris law to a numerical damage growth rate for degrading the interface stiffness of cohesive elements. Proposal for this length varies across the literature, leading to a lack of objectivity. Also, multi-integration point cohesive elements would require characteristic lengths computed locally at each integration point, which complicates the implementation and limits the general applicability of these models.

To address these issues, this work proposes a novel ‘characteristic-length’-free geometric algorithm built on top of an existing cohesive law for delamination under fatigue loading. The algorithm introduces a sweep coordinate and a moving-plane construct that implicitly tracks the evolving crack front within the interface plane. Crack-front orientation is determined using a local growth-direction criterion, while crack advance is represented through the geometric sweep of the front over the element, enabling accurate estimation of the swept area, which acts as the physical measure of fatigue crack extension. This formulation operates naturally at each integration point, making it efficient and compatible with multi gauss point cohesive elements. Numerical results on fatigue delamination growth under pure and mixed mode loading using multi-integration point cohesive elements will be presented showing good agreement with experiments and existing numerical methods.

#830

# Preparation of Plasma-Treated Carbon Nanotube-Reinforced Polysulfone Nanocomposites

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Polysulfone (PSU) is a high-performance polymer with a rigid and chemically stable aromatic backbone. The excellent properties such as high mechanical strength, thermal resistance, and biocompatibility, make it suitable for applications in medical devices, transportation, and electronic materials. However, PSU generally shows poor compatibility with fillers, particularly with non-polar nanocarbons, often leading to aggregation in composites which results in insufficient reinforcement. In terms of fabrication process, conventional melt-mixing and solution-blending methods often cause agglomeration of fillers due to the high viscosity of PSU melt or solutions. In contrast, in-situ polymerization offers the advantage of dispersing fillers in the reaction medium prior to polymer growth, enabling improved dispersion.

In this study, carbon nanotubes (CNTs) were chosen as fillers for PSU nanocomposites. While CNTs possess excellent properties, low surface polarity of CNTs often causes aggregation in polymer matrices. Therefore, we conducted surface-modification of CNTs via plasma-treatment to introduce isocyanate groups. PSU/CNTs nanocomposites were subsequently synthesized via in-situ polymerization and the effect of surface chemistry of CNTs on structure and properties of the nanocomposites were investigated.

FT-IR analysis confirmed that the nanocomposites with plasma-treated CNTs (pCNTs) showed characteristic absorptions bands assigned to isocyanate, urethane, and urea groups, indicating enhanced interfacial reactions. UV–vis measurements demonstrated that all composites maintained high transparency. The PSU/pCNTs nanocomposites exhibited particularly high transmittance, suggesting improved dispersion state. Thermal decomposition temperatures increased with CNTs loading, and the composite containing 0.05 wt% pCNTs showed the highest stability approximately 10 °C higher than neat PSU. Glass transition temperatures also increased, especially in PSU/pCNTs nanocomposites, indicating restricted polymer mobility due to stronger interfacial interactions.

Overall, PSU nanocomposites containing plasma-treated CNTs exhibited excellent transparency and improved thermal properties. These enhancements are attributed to high and homogeneous CNTs dispersion and strong interfacial bonding between PSU and plasma-treated CNTs surfaces.

#831

# Sustainable Dual-Nucleation Engineering for Fast-Crystallizing, High-HDT PLA

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Global concerns over plastic waste, carbon emissions, and increasingly strict environmental regulations are accelerating the demand for sustainable alternatives to petroleum-based plastics. Poly(lactic acid) (PLA), a bio-derived and biodegradable polymer, has emerged as a promising candidate; however, its slow crystallization rate, low thermal stability, and insufficient heat resistance continue to limit its adoption in high-performance applications. Overcoming these limitations is essential for enabling PLA to meet industrial requirements in sectors such as packaging, consumer products, and engineering materials.

To address these challenges, we developed two complementary strategies designed to significantly enhance the crystallization behavior and thermal properties of PLA while preserving its biodegradability.

(1) Physical self-nucleation via cryogenic impact-induced pulverization (CIIP).

PLA pellets were subjected to a cryogenic impact process that reorganizes chain segments and generates intrinsic self-seeds without the use of additives. This method produced up to a 36% increase in crystallinity, an 80% faster crystallization rate, and pronounced improvements in lamellar ordering. The enhanced microstructure increased the heat deflection temperature (HDT) by up to 81%, demonstrating a scalable and additive-free route for developing heat-resistant PLA materials.

(2) External nucleation using stearic-acid-coated cellulose nanofibers (SACNF).

A green, aqueous, and solvent-free coating process was developed to modify cellulose nanofibers with stearic acid, improving dispersion and compatibility within the PLA matrix. SACNF acted as an efficient heterogeneous nucleating agent while also boosting processability due to the lubricating effect of stearic acid. PLA composites containing SACNF showed a 41.7% increase in crystallinity, the HDT of 133.8 °C, and enhanced biodegradability derived from the natural fiber content.

These two strategies establish an integrated framework for producing high-performance, fully biodegradable PLA. This dual-nucleation platform offers practical and scalable pathways for expanding PLA into heat-resistant and fast-cycle industrial applications.

Ref.

ACS Appl. Polym. Mater. 2025, 7, 2761−2772

ACS Sustainable Chem. Eng. 2025, 13, 9859−9868

#832

# Fabrication and Structural Investigations of Flexible Cellulose-Carbon Dot Composite Films for Optoelectronic Applications

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There is growing interest in biodegradable, transparent, and multifunctional films for enhanced protection and optoelectronic applications. In this study, cellulose-based composite films were fabricated via a solution casting approach and subsequently functionalised with boronic-acid carbon dots (BACDs) to impart optical, thermal, mechanical, and electrical functionalities. The effects of BACD inclusion and post-synthesis treatments, including vacuum drying and thermal annealing, were systematically investigated. UV–Visible transmittance studies demonstrated a notable decrease in ultraviolet transmission in BACD-doped films relative to pristine cellulose films, while maintaining high transparency in the visible region. Following heat treatment, the UV-blocking efficiency was further enhanced, indicating improved dispersion of BACDs and stronger interfacial interactions with the cellulose matrix. Surface morphology analysed by scanning electron microscopy (SEM) revealed a dense, compact, and uniform structure, confirming good film formation, while elemental analysis validated the successful incorporation of carbon dots. Thermogravimetric analysis showed that BACD-doped films exhibited improved thermal stability compared to control films, confirming enhanced resistance to thermal degradation. Dynamic mechanical analysis revealed a significant increase in storage modulus, confirming that the embedded carbon dots effectively reinforced the mechanical strength of the films. Electrochemical impedance spectroscopy revealed alterations in charge-transfer characteristics prior to and following thermal and mechanical treatment. This indicates the formation of semi-conductive pathways within the composite structure. Finally, antibacterial evaluation using optical density (OD) measurements demonstrated a significant reduction in bacterial growth in the presence of BACD-doped films, hence confirming the composite films' effective antibacterial properties. The results indicate the feasibility of producing high-performance cellulose/BACD composite films that exhibit enhanced UV protection, mechanical durability, thermal stability, and tunable electrical characteristics. This method is straightforward, scalable, and sustainable.

#833

# Predicting Functional Properties of Soft Magnetic Composites Using Optimized Machine Learning Models

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Soft magnetic composites (SMCs) are essential materials for modern electromagnetic applications, offering a unique combination of magnetic properties and design flexibility. However, the complex non-linear relationships between processing parameters and functional properties challenge traditional optimization methods. This study utilizes the first experimentally obtained dataset, provided by Ref.[1], for SMCs to develop data-driven predictive models. The dataset comprises 282 samples of Fe-MgO composites, with five independent processing parameters: MgO nanoparticle size, compaction pressure, sintering temperature, annealing time, and atmosphere.

We employed four machine learning algorithms—Support Vector Regression (SVR), XGBoost (XGB), Random Forest (RF), and Gradient Boosting Regressor (GBR)—to predict five key properties: density, coercivity, DC permeability, permeability at 3 kHz, and resonant frequency. The dataset was randomly partitioned into 80% training and 20% testing subsets. Hyperparameters for each model were optimized to minimize prediction error.

The results demonstrate that ensemble learning methods (XGB, RF, and GBR) generally outperformed SVR in capturing the complex dependencies within the data. The optimized models achieved exceptional accuracy, particularly for resonant frequency (R2 score > 0.89), and demonstrated strong predictive capability for coercivity and permeability (R2 score > 0.92). These findings confirm that machine learning approaches can effectively model the processing-property relationships in SMCs, providing a powerful tool for accelerating material design and process optimization without extensive trial-and-error experimentation.

[1] R. Bures, V. A. Milyutin, M. Faberov, Z. Bircakov, P. Kollar, J. Fuzer, Scientific Data 12, 8 (2025), https://doi.org/10.1038/s41597-024-04286-w

#834

# Three-Dimensional Nano-Imaging of Interface Crack Growth Along Carbon Fibers Under Cyclic Loading

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This study employed in-situ synchrotron radiation X-ray nano-computed tomography (nano-CT) to visualize the three-dimensional propagation of a crack at the interface between carbon fibers and an epoxy matrix under cyclic loading. Small, dumbbell-shaped specimens containing a transversely embedded bundle of carbon fibers were subjected to cyclic loading at maximum stresses below the yield stress. Crack propagation was captured after specific numbers of cycles using a custom-designed, piezo-actuated fatigue testing system installed at beamline BL20XU of the SPring-8 synchrotron facility in Hyogo, Japan. Reconstructed nano-CT images revealed that interfacial cracks initiated at the ends of the fibers on the sample surface and propagated several micrometers along the interface. The measured crack propagation rate along a single carbon fiber decreased with increasing cycle number, eventually indicating a transition to non-propagating cracks. The corresponding stress intensity factor range calculated at the crack tips was lower than the experimentally determined threshold value for the bulk epoxy matrix, as determined using compact tension specimens. This confirms that the interfacial crack in a single carbon fiber is too small to fracture the surrounding epoxy matrix, suggesting that the fatigue behavior is governed by the local fracture toughness of the epoxy matrix. In contrast, in a sample containing several carbon fibers, the interfacial cracks coalesced and propagated to fracture the surrounding epoxy matrix. These findings provide the first direct three-dimensional visualization of an interfacial crack along a single carbon fiber under elastic cyclic loading and offer new insights into the micro-mechanical origins of fatigue resistance in CFRP materials.

#835

# Hemp-based composites usage for a 12.6 m wind turbine blade

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End-of-life management of wind turbine blades is becoming a central challenge for the composites sector, driving interest in more circular and environmentally responsible material systems. Bio-based composites, particularly those reinforced with hemp fibres, present a promising route toward reducing environmental impact while maintaining adequate structural performance. Hemp offers high specific mechanical properties, full biodegradability, and potential agricultural co-benefits, while recyclable thermoplastic resins such as Elium® further enhance circularity by enabling monomer recovery.

Despite these advantages, natural fibres exhibit lower mechanical properties than conventional glass and carbon reinforcements. Their behaviour is further complicated by variability arising from harvesting, retting, moisture uptake, and porosity development, as well as the bilinear elastic response observed in many hemp-based laminates. These uncertainties necessitate careful structural redesign and the explicit consideration of property variability in blade optimisation.

This work investigates the feasibility of replacing conventional composite materials in a wind turbine blade with hemp-fibre/Elium® laminates while accounting for their natural variability. Unidirectional and bidirectional laminates were manufactured and characterised to obtain key elastic parameters and strength properties. Statistical distributions derived from the experimental data were incorporated into an in-house optimisation framework to refine laminate stacking sequences and shear-web placement. Two blade concepts were developed: a fully bio-based design and a hybrid configuration incorporating carbon pultruded plates in the spar cap to mitigate stiffness limitations.

Both concepts were evaluated in Abaqus through structural analyses and compared with a reference blade produced using conventional materials. The results demonstrate the potential of bio-based solutions for reducing environmental impact while highlighting the remaining challenges in terms of stiffness, property variability, manufacturability, and long-term performance. The study provides a pathway toward more sustainable blade designs and identifies the key considerations required for industrial adoption of natural-fibre composites.

#836

# The History of Composites: an introductory overview

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During ECCM-22, a special session is organised at the occasion of the publishing of the book "The History of Composites. People, science, technology and society".

This book, published by @Elsevier, introduces the reader to key milestones in the discovery and technological development of composite materials, including their processes and applications. The book has two parts: in the first, longer part, a "General History of Composites, a bird's-eye view" is presented, whereas the second part contains 28 shorter contributions from leading international experts, discussing specific topics in detail.

For this presentation, eight "breakthrough innovations" have been selected, illustrating how fundamental discoveries have led to the creation of new composite materials, manufacturing processes and innovative products. The presentation explores the first traces of composites from ancient times to the early 20th century. Then, the crucial inventions of glass fibres and man-made plastics in the 1930s will be discussed, leading to the first applications in aviation and other transport sectors. Next, the revolution of carbon fibres in the 1950's-1960's will be explored, leading to the rapid expansion of composites in many different application domains. By the end of the 20th century and the beginning of the new millennium, composites science and technology seem to have matured, and an enormous diversity of composite products have conquered the markets.

For each of these innovations, their dynamics will be briefly analysed and it will be illustrated how fundamental discoveries have led to the creation of new products or have drastically improved existing ones.

This presentation will serve as a necessary introduction to the special session on "The History of Composites".

#837

# Reclaiming carbon fibers: renewable thermosetting polyester matrices for recyclable carbon fiber-reinforced polymer laminates

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We developed a renewable thermosetting polyester matrix formed through esterification of glycerol, citric acid, and maleic anhydride for producing carbon fiber composites. Apart from the three above-mentioned monomers, no other additive was used. The matrix system cures within 2 h to B-stage (a tack-free, handleable intermediate) and in 2 h to full cure with a glass transition temperature above 100 °C, yielding composites that resist organic solvents, water, and acidic aqueous solutions even under prolonged exposure. It shows compatibility with all common fiber types per pre-tests, especially cellulose-based materials like papers, enabling impregnation, curing, and laminates of varied composition up to 66 vol% fiber fraction for enhanced structural performance. The cured matrix remains translucent below 155 °C but yellows above. Initial melt polycondensation of the mixture at moderate temperatures, followed by subsequent curing stages, lead to polymers being well-suited for laminate production. Issues of composite recyclability are addressed by saponification in basic suspension leading to depolymerization of polymer matrix, thus allowing easy fiber regaining with minimal energy input. Mechanical and thermal properties of produced laminates will be presented, as well as fiber quality before and after recycling. The novelty of our approach lies in the innocence of the monomers for polymerization, a sleek formulation, the strength of obtained laminates, and particularly the simplicity of fiber regaining, all of which promote a sustainable, closed-loop process using readily available, renewable monomers to minimize waste. Given the cost and the energy-intensive production of carbon fibers, reasonably, they should not go to waste. We are working on it!

#838

# Embedded GNP-Epoxy Films: A Route to Multifunctional GFRP Composites

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The frontier of composite material science is increasingly defined by the pursuit of multifunctionality, moving beyond mere structural performance to integrate capabilities like sensing, energy storage, and electromagnetic interference (EMI) shielding. In this evolution, graphene nanoplatelets (GNPs) have held notable positions among various nanomaterials. A major challenge lies in integrating nanoscale features into large composite structures due to dispersion and processing limits. This research introduces a novel approach to overcome these limitations. Instead of dispersing GNPs throughout the resin, we engineered and embedded high-concentration (2 and 5 wt.% %) GNP-modified epoxy films directly into the interlayers of a 3D glass fiber-reinforced polymer (GFRP) composite during a single-step co-curing process. LVI tests were conducted at a significant energy level of 50 J using a 20 mm diameter hemispherical impactor. The results were critically compared with the work of Khan et al., which utilized a conical 12.5 mm impactor and liquid thermoplastic films. This comparison provides crucial insights into how the geometry of the impactor and the physical state of the interlayer material (solid film vs. liquid thermoplastic) influence damage mechanisms and energy absorption, highlighting the superior damage tolerance offered by our solid GNP-epoxy films. The composites were evaluated over the X-band frequency range (8–12.5 GHz). The findings of this research confirm that the strategic embedding of high-loading GNP films creates a multifunctional composite where both high impact resistance and significant EMI shielding are achieved concurrently. This work thus establishes a scalable and efficient manufacturing route for producing advanced multifunctional composites, paving the way for their application in the aerospace field.

#841

# Efficient processing of biobased benzoxazines: A step towards sustainable biocomposite manufacturing through catalysed curing

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Benzoxazines are thermosetting polymers offering inherent fire resistance, low shrinkage, high glass transition temperatures as well as high mechanical properties. Their high molecular flexibility allows for a high biobased content and the incorporation of dynamic covalent linkages. These properties enable self-healing, debonding-on-demand and recyclability. With respect to the growing demand of composite materials and especially carbon fibre reinforced composites as well as the increasing amount of production scraps and end-of-life materials, the combined use of biobased benzoxazines and recycled carbon fibres hold significant relevance fostering a circular economy. In recent years, the availability of biobased benzoxazines has been limited by the feedstock availability, as well as the complex interplay of biobased phenols, aldehydes and amines. As a result, processability has been insufficient, characterised by high viscosity, long energy intensive curing cycles and low thermo-mechanical properties.

This work, investigates and optimises the first commercially available biobased benzoxazine synthesised from cardanol and furfural as biogenic feedstocks. Iron trichloride, boron trifluoride and boron trichloride were used as additives, varying weight fractions from 0.5 to 5 % to catalyse the curing reaction. The goal was to tailor the resin system to an out-of-autoclave compression moulding process. Their influence on processability was evaluated through rheology, curing kinetics and thermal stability. A compression moulding process was established based on boron trichloride. The mechanical and thermo-mechanical properties of the uncatalysed and catalysed system were compared to ensure comparable composite performance during process optimisation. The curing time was reduced from hours to minutes, along with significant reduction in curing temperature. Optimised processing also led to reduced thermal degradation of the matrix system during curing, significantly reducing the composite porosity. This work demonstrates a scalable, energy- and resource-efficient manufacturing route for biobased benzoxazine composites and paves the way for their wider adoption, particularly in the automotive sector.

#843

# Experimental and numerical investigation into magnetic alignment of coated fibres in thermoplastic melts

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Hybrid structures that combine unreinforced and fibre-reinforced polymers (FRPs) offer substantial potential for reducing weight in engineering applications while maintaining high levels of mechanical performance. Despite their advantages, the interface between the dissimilar materials remains a critical weak point. Abrupt changes in stiffness at the transition zone can generate stress states that negatively impact the performance of these structures and may result in critical failure or lower load bearing capacity. Creating a graded transition that mitigates these jumps in stiffness is therefore an essential step toward improving the performance of such hybrid structures.

This study proposes a novel approach to manufacture a graded transition zone by magnetically manipulating functionalized short and long carbon fibres within a polymer melt. When exposed to an external magnetic field, these fibres can be reoriented and repositioned locally, thus enabling control over the fibre architecture. This method provides a promising way for tailoring mechanical properties in the interface.

In order to evaluate the feasibility of this concept in real manufacturing environments like injection or compression moulding, a fundamental understanding of the underlying physical mechanisms is required. For this purpose, a comprehensive simulation model is being developed to analyse the influence of magnetic field strength, fibre geometry and coating properties on the fibre orientation. The simulations aim to identify the key parameters that govern the alignment process.

Using the electrodeposition technique, thin layers of iron-cobalt alloy are deposited on carbon fibres, increasing their magnetic susceptibility. These fibres are then used for complementary experimental investigations, observing how magnetically responsive fibres behave in a controlled environment and validating simulation results.

Combined numerical and experimental investigations provide a fundamental understanding of the process, demonstrating its potential to create mechanically optimized transition zones in FRP/polymer hybrid structures.

#844

# Polyurethane Nanocomposites Reinforced with Nanodiamond

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Polyurethane (PU) is known for its flexibility, abrasion resistance, and mechanical strength, and is used in various fields such as coatings, adhesives, and medical devices. Recently, with the increasing demand for flexible and wearable electronics, f further improvement in material performance has become essential.

Nanocarbon materials have been reported to enhance the properties of polymer nanocomposites even at low loadings. Among them, nanodiamond (ND) has attracted attention due to its high modulus, hardness, and thermal conductivity derived from its diamond core. While conventional nanocarbons such as carbon nanotubes and graphene are generally non-polar, nanodiamond (ND) possesses hydroxyl, carboxyl, and epoxy groups on its surface, giving it high polarity and enabling stronger interactions with polymer matrices. In this study, PU was polymerized in the presence of ND to prepare PU/ND nanocomposites via in-situ polymerization, and their structure and properties were investigated.

Structural analysis showed that PU/ND nanocomposites retained high transparency after ND addition, suggesting that in-situ polymerization effectively suppressed the formation of ND aggregates. However, when the ND content exceeded 1.0 wt%, the reduced interparticle distance facilitated aggregation, leading to a noticeable decrease in transparency. Thermal analysis revealed that the decomposition temperature increased with ND loading, indicating the strong interfacial interaction between PU and ND. In addition, high thermal conductivity of ND can also facilitate heat dissipation and prevent localized heat accumulation. Mechanical testing showed that the elastic modulus increased markedly at low ND loadings due to homogeneous dispersion and strong interfacial interactions. At higher loadings, the modulus plateaued and the tensile strength and elongation at break decreased, indicating aggregation of ND. These results demonstrate that achieving strong interfacial interactions while maintaining ND dispersion is crucial for producing PU/ND nanocomposites with enhanced performances.

#845

# Hybrid Lithium-Ion Thin-Film Batteries for Fast Ion Transport and High Areal Capacity

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Next-generation miniaturized sensors and integrated electronic systems require high energy and fast charging within a limited footprint. This necessitates lithium-ion thin-film microbattery architectures that can simultaneously provide efficient ion transport and high areal capacity. However, conventional thin-film cathodes fabricated by vacuum deposition often suffer from intrinsically low ionic and electronic conductivities of the active material. As a result, it is difficult to achieve sufficiently high areal capacity without sacrificing rate performance.

In this study, we design a hybrid lithium-ion thin-film battery that combines a composite cathode with an ultrathin solid electrolyte layer and systematically investigate the correlation between electrode thickness and electrochemical performance. This hybrid configuration enables both high active-material loading and continuous ion/electron transport pathways across the electrode. The solid electrolyte layer is designed to be as thin as possible while maintaining interfacial and electrochemical stability, thereby effectively reducing the overall ionic resistance of the cell.

The fabricated hybrid thin-film cells are evaluated in terms of areal capacity, rate capability, and interfacial resistance using galvanostatic charge-discharge tests, cyclic voltammetry, and electrochemical impedance spectroscopy. The proposed architecture delivers areal capacities exceeding 50 μAh/cm² at electrode thicknesses of several micrometers, while significantly improving capacity retention under high-rate operation compared to conventional monolithic thin-film cathodes. Cross-sectional and electrochemical analyses further confirm that the interconnected ion- and electron-conducting network within the composite cathode, together with the ultrathin solid electrolyte layer, effectively mitigates transport limitations that typically arise in thicker thin-film electrodes. Overall, this work demonstrates that a carefully engineered hybrid thin-film architecture can relax the trade-off between ion transport kinetics and areal capacity and provides a viable design strategy for lithium-ion microbatteries targeting next-generation miniaturized electronics and IoT devices.

#846

# A new geometry to evaluate the strain rate sensitivity of Mode II Interfacial Shear Strength in CFRPs

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The influence of strain rate on Mode II interfacial shear strength (IFSS) in CFRPs is critical, particularly for applications subjected to dynamic loading conditions. A strong correlation has been observed between the interfacial properties at the microscale and the mechanical performance of composite materials at the macroscale, with the interfacial properties essential for shear and off-axis strength. Several techniques have been developed to evaluate IFSS but the values obtained vary significantly and even results from the same type of test can exhibit considerable scatter. On one hand, tests using specimens with a single fiber embedded in the matrix may not accurately reflect the complex mechanical conditions present in real composite materials. On the other hand, studies at higher strain rates remain limited.

This work presents a novel experimental method to assess Mode II IFSS and its strain-rate sensitivity using a single compression-loaded coupon whose geometry concentrates shear in two narrow bands while minimizing tensile and mixed-mode effects. Coupons were water-jet cut, machined and ground from 3 mm AS4/8552 unidirectional laminates. Fibers were aligned with the loading direction and face flatness/parallelism were controlled. Two loading regimes are considered: (i) quasi-static and (ii) dynamic on a Split Hopkinson Pressure Bar. Full-field strains were measured via 2D-DIC during both tests.

A stress state analysis in the sample is done using the information obtained by DIC, in combination with 2D and 3D finite-element simulations in ABAQUS/Explicit. Even though full symmetric loading in both arms is difficult to achieve in quasi-static conditions, the fracture response of the sample is close to pure shear. Meanwhile, in the dynamic tests non-symmetrical loading seems to be less relevant due to inertial forces acting on the sample. All in all, our geometry reveals itself as a viable option to study the behavior of fiber/matrix interface, especially under dynamic conditions.

#848

# Investigating the effects of fiber surface treatment and recycling on out-of-plane wicking in yarns

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Keywords: Wettability; out-of-plane wicking; capillary wicking; filament winding; recycled fibers; sustainable composites.

Abstract

Environmental and End-of-Life challenges in composite materials have pushed for developing sustainable solutions, including the recycling and remanufacturing of fibers but also matrixes. In this context, a detailed understanding of fiber/matrix interactions and impregnation phenomena is needed to improve the processability of composites when recycled or surface-modified fibers are used. This study investigates yarn-scale impregnation in the direction transverse to fibers, i.e., the through-thickness (out-of-plane) impregnation behavior, with a focus on differences induced by modifying the sizing and by the recycling process in terms of wetting behavior, which is relevant to filament winding of composite components.

Dynamic measurements were carried out with a tensiometer equipped with specific sample holders designed for yarn bundles. The analysis combines the modified Washburn equation and Darcy's law to estimate the equivalent capillary pressure (P_cap) driving spontaneous impregnation. Initially, the geometric product (cr) is determined, where c is a parameter related to the tortuosity of the medium and r represents the mean capillary radius. This parameter is obtained using n-hexane, selected as a totally wetting liquid. Subsequently, water is used to measure the apparent advancing contact angle (θ_a), which reflects the fluid/fiber interactions affected by different sizing treatments and by the recycling process.

This work is part of the European ECOHYDRO project, focused on the development of recyclable hydrogen storage tanks using reactive thermoplastic Elium® resin reinforced with recycled fibers. The results contribute to understanding yarn-scale impregnation behavior, which is a key step for sustainable composite manufacturing.

#851

# Manufacturing and Characterization of Polyamide 6 based Thermoplastic Pultruded Profiles with Carbon and Glass Fibers

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The objective of this study is to evaluate the effects of processing parameters on the consolidation and mechanical behavior of polyamide 6 (PA6) pultruded composites reinforced with carbon and glass fibers. Thermoplastic pultrusion provides continuous production, constant cross section with recyclability and stable structural performance. However, thermoplastic polymers have higher melt viscosity, so the consolidation of PA6 requires precise control of melt temperature, die heating temperature and pulling speed to achieve proper flow and uniform fiber impregnation. In this work, two unidirectional PA6 composite profiles were manufactured to study how processing parameters interact with different fiber reinforcements.

Tapes were manufactured using melting impregnation by extrusion, with both materials processed at a same pulling speed. Each reinforcement was processed within its own temperature range to maintain melt flow and proper impregnation. These processing parameters to ensure suitable viscosity and consistent fiber wetting. After tape production, both materials were consolidated in a heated pultrusion die. Selecting the temperatures of the die and pulling speed optimally was essential for reducing voids and achieving uniform consolidation across the profile.

Flexural testing showed that processing variables had a clear influence on mechanical properties, with each reinforcement type exhibiting its own characteristics under the applied conditions. Elevated-temperature flexural behavior was also considered, since PA6 can change its stiffness and bending response when exposed to heat, which is important for understanding performance in real service environments. Thermal and viscoelastic properties were examined using thermogravimetric analysis, differential scanning calorimetry and dynamic mechanical analysis, providing insight into thermal stability, crystallinity and temperature dependent stiffness. These results explained that performance of PA6 pultruded composites depends strongly on interaction between processing parameters, fiber reinforcement and polymer behavior, also emphasize the importance of considering temperature dependent flexural properties when evaluating the suitability of these materials for structural applications across different service temperatures.

#852

# Adhesive bonding of thin Tow-Based Discontinuous Composites: Damage characterisation and analysis

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A new class of composite materials that has gained significant interest is Tow-Based Discontinuous Composites (TBDCs). These materials are manufactured by chopping thin continuous prepreg tapes and randomly distributing them. Using thin tapes increases the strength and shifts the damage mechanism from longitudinal and transverse tape fracture to tape pull-out at higher strain levels. The authors have reported improved performance under tension, compression, fatigue, and energy dissipation. This effect makes TBDCs an attractive alternative to continuous composites for high-performance applications. Despite their potential, efficient connection methods are currently lacking and the adhesive bonding behaviour of TBDC structures remains unexplored.

The TBDCs developed by the authors inherently combine varied stacking sequences due to random tape placement, along with very thin plies (about 20 μm). However, the influence of random tape orientation on adhesive-joint performance remains unclear. Tape ends are expected to introduce multiple stress concentrations across the joint, helping create a more uniform stress field within the overlap. The wide range of interface ply angles in TBDCs may also promote crack deflection from the adhesive layer into the randomly oriented tows, potentially producing complex fracture behaviour similar to that seen in unidirectional composites with varied stacking-sequence angles.

An experimental campaign was designed to evaluate the fracture toughness of adhesively bonded TBDCs using adhesives with contrasting mechanical properties. Double cantilever beam tests were used to evaluate the fracture toughness, and the analysis highlighted the existence of competing damage mechanisms (such as matrix cracking and fibre/matrix debonding) which were strongly influenced by the micro-architecture of the TBDCs and the nature of the adhesives. The findings were validated using a range of experimental techniques ranging from Acoustic Emission (AE) to fractography.

#853

# Towards more Sustainable Cementitious Composites: Spinning of Bicomponent Micro-Fibers Using Recyled Polypropylene

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Strain-hardening cementitious composites (SHCC) offer great potential for the modern building sector, helping to significantly improve the high-velocity impact resistance of structures. They offer the possibility of reinforcing existing structures or being employed in new construction, providing additional safety against impacts like earthquakes, collisions, or terroristic attacks. However, the mostly used high-performance polymeric fibers like polyvinyl alcohol (PVA) or ultra-high molecular weight polyethylene (UHMW-PE) fibers substantially increase SHCC's costs and environmental footprint. This requires the search for more cost-efficient, less resource-intensive alternatives. Polypropylene (PP) fibers are a viable alternative, providing several advantages: (i) production by melt-spinning requires less energy and no solvents, (ii) is far more economical, (iii) and should allow for the integration of recycled PP. Nevertheless, using recycled materials for fiber production is challenging, due to the frequent presence of impurities and inconsistent quality parameters. However, using recycled PP may also offer a notable advantage: an enhanced wettability of the fibers. Increased thermal oxidation of the material during its extended service life and recycling process results in a greater presence of oxidized functional groups that may interact with the hydrophilic cementitious matrix, hence enhancing fiber-matrix interaction.

This study presents an experimental workflow and meticulous material selection accompanied by extensive raw material analysis to assure optimal spinnability, with the aim of maximizing the proportion of recycled PP in the final fiber. To ensure a stable spinning process while yielding mechanically robust fibers with enhanced wettability, we chose to produce bicomponent fibers, with the fiber shell made of recycled PP and the core consisting of virgin PP. Spinning is initially conducted at a laboratory-scale piston spinning device and subsequently at an industry-scale pilot melt spinning line. The mechanical properties of the fibers and the fiber-matrix interaction are investigated, revealing tensile strength close to virgin PP fibers and increased bond behavior.

#854

# Generative AI Design of Bio-Inspired Interlocking Interfaces for Tailored Mechanical Performances

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Interlocking interfaces are a pervasive strategy in biological materials to reconcile high strength with damage tolerance under impact and cyclic loading. Inspired by systems such as woodpecker and reindeer skulls, engineered interlocks can be used to tune load transfer, energy dissipation and failure mechanisms in layered structures. Previous work by the authors employed cellular automata, based on Conway's Game of Life, to exhaustively enumerate admissible topologies on an N×M grid and to identify patterns with favorable mechanical response. While this approach guarantees full exploration of the design space, its computational cost scales as O(N·M!), which rapidly becomes prohibitive for practically relevant dimensions.

The present contribution introduces a generative AI framework that bypasses exhaustive search and directly proposes interlocking morphologies targeted to prescribed mechanical behaviors, such as bending-dominated or stretching-dominated interfaces. A dataset of interlocking patterns and corresponding mechanical indicators, obtained from cellular-automata-driven enumeration and numerical simulations, is used to train the model. Once trained, the generator maps high-level performance specifications and geometric constraints to candidate interface layouts, which are then verified by a secondary AI to fully assess the interlocking presence and typology.

The proposed workflow retains the physical fidelity of cellular automata and mechanics simulations, but it compresses the algorithm's mechanics in a meaningful and dense latent space that can be explored by powerful algorithms such as Genetic Algorithms or Reinforcement Learning AI to obtain desired configurations and properties. In this way, tailored designs can be obtained without sampling the entire N×M configuration space, enabling fast screening and optimization for large-scale structures. Overall, the study outlines a route for coupling bio-inspired interlocking concepts with data-driven generative design tools to create bio-inspired interfaces that can be systematically tailored while keeping the underlying optimization problem computationally manageable.

#855

# Design and analysis of hybrid radar absorbing structures realized by carbon fiber arrays

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Aiming at endowing aircraft structures with load-bearing and Electromagnetic (EM) wave absorption performances while maintaining a lightweight design, this work proposed several Radar Absorbing Structures (RASs) through the hybrid design of composite sandwich structure. Carbon Fiber Reinforced Plastic (CFRP) possesses high conductivity and its fishbone-shaped configuration can effectively excite Spoof Surface Plasmon Polaritons (SSPPs) mode, forming a local strong E-filed around it. When the strong E-filed is combined with the high relative permittivity and dielectric loss of lossy materials, the absorption band will broaden towards lower frequency and the reflection loss (RL) will significantly reduce, respectively. After genetic algorithm optimization, the average EM wave reflectivity of one of the proposed RASs within the range of 2–18 GHz is reduced by 58.1%, compared to that of an absorbent honeycomb sandwich structure. Furthermore, under out-of-plane compression load, the hybrid design results in a coupling effect between the core members. This coupling effect changes the failure mode of the proposed RAS, improving the buckling threshold value. As a result, the specific compressive strength and specific energy absorption of one of the proposed RASs is improved by 99.3% and 173%, respectively, compared to grid sandwich structure. The comparison between proposed RASs with other RAS and composites sandwich structures demonstrates that the proposed RASs is competitive among them, providing a novel solution for the lightweight, high-efficiency, and multifunctional design of aircraft structures.

#856

# Hierarchical interphase design with metal oxide nanostructures on carbon fibres for improved impact resistance and functionality

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Natural materials such as bone, nacre, and plant fibres exhibit exceptional mechanical performance by organising stiff and compliant phases through hierarchical, highly optimised interphases. Inspired by these biological structures, this study explores a plant-root-biomimetic approach to interphase engineering in fibre reinforced polymer (FRP) composites. The interphase has been increasingly reframed as an active and functional region that meets the required demands by controlling stress transfer and energy dissipation.

Drawing from the micro-to-nanoscale architectures observed in biological composites, a hierarchical interphase design based on the controlled growth of metal oxide nanorods on carbon fibres. The resulting tailored fibres with metal oxide nanostructures was obtained by eco-friendly two-step hydrothermal method, thereby promoting strong mechanical interlocking and improved compatibility with polymer and reinforcement. Mechanical characterisation shows significant improvements in impact energy absorption, meaning that more resistance against to external impact or structural deformation.

Beyond structural reinforcement, the biomimetic interphase also imparts multifunctional thermal capacity for the various industrial applications. The aligned metal oxide nanostructures enhance thermal transport across the interphase, enabling higher heat dissipation. The functionality can be used for anti-icing strategies in aerospace industries and thermal management construction with lightweight structural composites.

In this presentation, we will demonstrate how hierarchical interphase design using metal oxides enhances mechanical performance, provides thermal multifunctionality, and enables additional sensing capability through piezoresistive behaviour. This biomimetic strategy offers new pathways for designing high-performance, multifunctional composite materials inspired by nature’s hierarchical systems.

#859

# Debondable primer for demanufacturing of composite sandwich structures

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The transition towards a wider circular economy for composite sandwich structures requires separating multi-phase material systems at end-of-life to suit disparate recycling streams. Technologies enabling efficient interfacial separation are essential for improved sorting and higher value of recycled composite constituents. Interfacial modifiers must also integrate fully into established manufacturing routes while delivering mechanical performance and durability comparable to conventional sandwich structures.

This work presents a debond-on-demand interfacial solution between CFRP skins and a PMI foam core. A thermally activated primer system has been developed, compatible with the required autoclave cure conditions (130°C, 3.5 bars). Processing windows have been defined to ensure adequate skin-core adhesion during service and low-force disassembly of components at room temperature, when ready to recycle, after a short thermal treatment. The primer, composed of a thin thermoplastic layer containing thermally expandable microspheres, can be integrated into standard lay-ups, via spraying or as a film, without altering the curing workflows or processing steps.

Mechanical characterization, including peeling of sandwich skins, lap-shear tests, flatwise tensile tests, creep and four-points flexural tests with fracture characterization demonstrate that the primer maintains adhesion performance approaching benchmark sandwich structures. In addition, these tests confirm the ease of debonding under stresses below 0.5 MPa driven by the volumetric expansion of polymeric microspheres after thermal activation at 170°C for one minute, thus validating the defined processing windows suitable across diverse industrial applications. Furthermore, aging tests indicate positive results, including preservation of debonding capability after exposure.

Overall, this study introduces a process-ready debondable primer solution enabling structural integrity of the sandwich structure during the part lifecycle together with controlled disassembly, which will facilitate composite constituent reuse in sandwich designs. By facilitating cleaner recycling streams and extending component life cycles, the approach represents a significant step towards scalable circularity in advanced composite design.

#861

# A G-code–based Digital Twin workflow for structural design and analysis of continuous fiber–reinforced 3D printed composite parts

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Additive manufacturing with continuous fiber-reinforcement enables the local tailoring of mechanical properties; however, current design workflows rarely account for the actual fiber deposition paths, which limits predictive accuracy. Recent studies have highlighted the influence of local anisotropy on structural performance; however, practical methods for directly translating manufacturing instructions into simulation models remain scarce. The lack of standardized procedures for incorporating machine-level deposition data into finite-element frameworks continues to pose challenges for the reliable prediction of component behavior.

The presented work introduces a workflow that integrates topology-optimised geometries with G-code–based fiber-orientation mapping, forming a semi-digital twin of the printed architecture. Local fiber orientations are represented directly on the finite-element mesh, providing a consistent framework for material calibration and structural analysis. Material behavior is modeled to represent anisotropy and capture potential failure mechanisms, enabling a more realistic representation of structural response under operational loading conditions. The methodology is demonstrated using a functional component, illustrating the approach's potential to link manufacturing data with predictive simulations and to support a systematic design strategy that can be adapted to different geometries and reinforcement schemes.

The proposed framework emphasizes the significance of locally modeled anisotropy and provides a flexible and transferable basis for reliable structural prediction of continuous fiber-reinforced AM parts by linking deposition-path information with calibrated anisotropic models. By explicitly considering the spatial variation of fiber orientation and integrating it with validated material models, the approach provides a generalizable route for improving simulation fidelity, informing design decisions, and ultimately enabling the more efficient and reliable additive manufacturing of fiber-reinforced components.

#862

# Gradient design of CF prepregs for multifunctional composite laminates with excellent electromagnetic wave absorption and mechanical performances

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Thin composite laminates composed of unidirectional fiber prepregs are extensively utilized in aircraft structures due to their high fiber volume fraction and outstanding designability, which is expected to improve the multifunctional design flexibility in both Electromagnetic (EM) wave absorption and load-bearing performances. By inserting continuous Carbon Fiber (CF) prepregs with gradient widths into Glass Fiber Reinforced Plastic (GFRP) laminates (widely applied in traditional EM wave absorbing structures), a Multifunctional Laminated Structure (MLS) is proposed and studied experimentally and numerically. The Spoof Surface Plasmon Polariton (SSPP) mode is excited by CF strips, endowing MLS with broadband (4.5-18 GHz), multiangle (0-70°) and efficient (average absorptivity > 90%) EM wave absorption performance at thickness of 4.4 mm. Besides, experimental and simulation results show that its specific flexural stiffness and strength is increased by 69% and 87% than that of GFRP laminates, respectively. The enhancement mechanism is revealed that the gradient configuration of CF prepregs enhances the load-bearing efficiency of fiber reinforcement. The novel configuration design provides a low-cost, efficiently fabricated and environmental-friendly process, which shows great potential for mass production of lightweight, high-efficiency and multifunctional composite laminates in aircraft applications.

#864

# An alternative heating-phase control method for continuous ultrasonic welding of thermoplastic composites

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The increasing demands for more sustainable aircraft, reduced costs, and high production rates encourage the fast introduction of thermoplastic composites in aircraft structures. However, to introduce thermoplastic composites in high volumes into the aerospace industry, high-speed joining techniques are required to make their use cost-effective during manufacturing. Continuous ultrasonic welding is such a high-speed joining technique that enables the joining of stiff composite structures made from continuous fibres. In this process, a metallic sonotrode connected to a piezoelectric transducer and a static force–applying press moves along the parts to be welded, applying ultrasonic vibrations. The sonotrode is followed by an actively cooled consolidator that extracts the heat directly after the sonotrode while applying pressure.

For stiff aerospace-grade composites such as unidirectional CF/LMPAEK, it is challenging to obtain welded seams with uniform quality due to the limited control methods available for the heating phase, resulting in regions that are either not fully welded or show signs of degradation. The current state-of-the-art uses either amplitude or power control, both of which have limitations and can lead to non-uniform welds when processing stiff composite materials.

In this research, we introduce an alternative control method for our robotic continuous ultrasonic welding process, in which we combine power and amplitude control to obtain superior weld quality compared to existing methods. We linked non-welded areas and areas with degradation to the power and amplitude data measured from the welding generator, enabling weld-quality control based on live data streams. The new control method was compared to the traditional amplitude and power control methods using real-time thermography, mechanical testing, fractography and NDT.

#865

# Virtual characterization of fiber-reinforced polymers using a micromechanical approach

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Digitalization in engineering has fostered the development of virtual testing strategies aimed at reducing physical testing costs and accelerating material qualification for the transportation industry. Virtual characterization offers a powerful alternative to physical testing by enabling the identification of composite material behavior from manufacturing to operation and under a wide range of operating conditions using a fully digital approach, that is difficult or expensive to reproduce experimentally.

This study presents a hybrid experimental-virtual approach to identify the performance of unidirectional FRP plies under different operating conditions. Mechanical tests are conducted on both the composite and the neat resin to calibrate the material constitutive model. A digital micromechanical model is proposed to analyze the stress evolution within the composite microstructure, obtaining the residual stresses from manufacturing to the operating conditions. Once validated, the micromechanical model is used to estimate the effective composite ply properties, especially those that are not straightforward to obtain from experimental testing.

The proposed methodology shows that, with a reduced number of targeted experiments, it is possible to build a predictive digital model capable of estimating effective ply properties, enabling the complete characterization of the composite material system at any operating condition.

#867

# Evaluation of a novel common reed dust-pla biocomposite for fused granulate fabrication

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Additive manufacturing has rapidly transformed material fabrication, offering exceptional design freedom and efficiency. In particular, Fused Granular Fabrication (FGF), has emerged as a versatile method that enables the fabrication of large-scale components for diverse end-use applications. In parallel, the development of bio-composite materials is driving the advancement of functional, sustainable, and high-performance printed products. Using granular-based printing together with a bio-based thermoplastic composite enables the production of items that can be potentially recycled at the end of their service life. This study investigates the feasibility of utilizing reed flour—a side-stream generated during Common reed (Phragmites australis) pellet production—as a reinforcement in polylactic acid (PLA) bio-composites for FGF-based 3D printing, providing a novel pathway to valorize a local side stream biomass. Prototypes were manufactured using a PIOCREAT G5ULTRA FGF printer with a 0.8 mm nozzle. Default process settings were applied while varying layer height and infill to assess their influence on print quality and processing stability. Preliminary results indicate that PLA reinforced with 20% reed flour can be reliably processed in FGF for prototype fabrication and reed flour has a potential as an environmentally friendly, low-cost reinforcement material in PLA composite. Optimal printing occurred at a nozzle temperature of 205 °C and a bed temperature of 60 °C, ensuring consistent material flow and strong first-layer adhesion. While infill variations showed minimal influence on small prototype geometries, layer height significantly influenced print quality. Layer heights of 0.2 mm and 0.3 mm produced satisfactory results, whereas the 0.1 mm setting caused nozzle clogging. These findings indicate that reed flour–PLA composites are promising, low-cost, sustainable and locally sourced materials for FGF, demonstrating both practical printability and potential for circular material use.

#868

# Process-Structure-Property Relationship in TP-AFP of CF/LM-PAEK Ring Laminates

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In-situ consolidation (ISC) during Automated Fiber Placement (AFP) of thermoplastic (TP) composites offers the potential to eliminate autoclave processing, but the complex interplay among thermal and kinematic parameters remains difficult to control in order to achieve mechanical properties comparable to autoclaved laminates, particularly for high-performance semicrystalline thermoplastics. This work investigates the effect of TP-AFP processing parameters and post-deposition thermal treatments on the interlaminar shear strength (ILSS) and thermomechanical behaviour of rectangular ring-shaped laminates laminated onto a flat plate with chamfered edges. Such architecture enables the extraction of short-beam shear (SBS) coupons with controlled cross-section while maintaining a continuous deposition condition representative of industrial layups.

A comprehensive experimental plan was implemented, manufacturing several 3-mm-thick UD CF/LM-PAEK rings under varied process conditions, including laydown speed, compaction pressure and hot gas torch nozzle temperature. Additional “repass” operations, based on multi-cycle annealing with active heating but no material deposition, were applied to assess the potential of post-consolidation thermal reconditioning to enhance interlaminar bonding.

Mechanical characterization was performed via SBS testing (ASTM D2344), complemented by dynamic mechanical analysis (DMA) to quantify storage modulus, loss factor and α-relaxation transitions, and differential scanning calorimetry (DSC) to evaluate crystallinity evolution as a function of AFP processing history. The thermal and kinematic data collected during deposition were processed through custom routines, enabling correlation analysis and preliminary machine-learning-based identification of dominant features governing ILSS.

Results show a dependence of ILSS on local thermal input - particularly nip-point temperature - as well as interaction effects among tow speed, compaction pressure and HGT settings. Repass annealing yielded improvements in interlaminar performance. The combined SBS-DMA-DSC methodology highlights how crystallinity and interfacial mobility influence weld quality.

Overall, the study proposes a unified framework for data-driven optimization of AFP-ISC processing windows for CF/LM-PAEK, supporting future integration of predictive consolidation models and closed-loop AFP process control.

#870

# Hygromnemic Actuators: Development of a New Multifunctional, 3d Printed and Biocomposite-based Material Actuation Mechanism, and Comparison with Genetic-Algorithm, AI-Designed Hygromorphs

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This work introduces a new class of materials actuators—humidity-programmable composite elements, named hygromnemic, that store shape memory directly within their dry structure through a pre-constraining mechanism [1]. By conditioning actuators at controlled relative humidity levels (typically 12%RH) for selected durations, a tunable hygromnemic response is achieved, enabling deformation amplitudes to be predicted via experimentally established hygromnemic functions. Sinusoidal and graded actuation patterns are created by strategically positioning constraining blocks at varying distances, and the underlying mechanism is linked to humidity-induced reductions in the polymer's glass-transition temperature, enabling humidity shape-memory actuation. Hygromorph actuators can have their stacking senquence optimised via genetic algorithms[2]. Hence, the hygromnemic actuated shapes obtained are compared to genetically optimised hygromorphs. Remarkably, actuated shapes remain stable in dry conditions where the material exhibits 253% higher strength and over an order of magnitude increase in stiffness compared to its wet state, offering robust shape retention and both long- and short-term memory effects relevant for soft robotic and architectural systems.

To rigorously characterise the mechanics of these curved actuators, we introduce the Shape Actuation Modulus (SAM)—a new metric defining effective stiffness as the ratio between stress change and curvature change during loading [3]. Conductive PLA-based shape-memory actuators demonstrate a linear actuation regime between 25–50 mm radius of curvature, with SAM values of 3.8±0.9 MPa at 50 mm. Comparison with bio-composite variants confirms that hygromnemic actuators retain over an order-of-magnitude higher stiffness than hygromorphic ones across 20–100 mm radii of curvature.

[1]:de Kergariou, et al. "Hygromnemics: Programmable Material Memory Matter Actuators via Wet Pre-Constraining," Adv. Mater. Technol., 2025.

[2]:de Kergariou, et al. "Design of 3D&4D printed continuous fibre composites via an evolutionary algorithm and voxel-based Finite Elements: Application to natural fibre hygromorphs" Addit. Manuf. 59, 2022

[3]:de Kergariou, et al. "Effective Material Stiffness in Curved Actuators," Adv. Intell. Syst., p.e202500668, 2025.

#871

# Recycled carbon-fibre and biopolymer composites for structural applications

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The urgent need to mitigate climate change has intensified efforts to reduce the embodied energy of structural materials used in sectors such as aerospace, automotive, and wind energy. Carbon fibre reinforced polymers (CFRPs) have become indispensable in these industries due to their exceptional specific mechanical properties; however, their high embodied energy and limited end-of-life options present substantial environmental challenges. While advances in mechanical recycling and fibre reclamation have enabled recovery of recycled carbon fibres (rCFs), the discontinuous nature of rCFs and the reliance on petroleum-derived polymer matrices continue to restrict both mechanical performance and circularity, respectively.

Nature produces biopolymers such as silk and cellulose under ambient conditions, demonstrating properties competitive with that of synthetic polymers. This has inspired a range of potential applications from softer materials purposed for medical applications to stronger materials relevant for structural applications. We propose that low-embodied energy, high performance composites can be developed through incorporation of rCFs within biopolymer matrices produced by genetically engineered bacteria.

The concept of a rCF-biopolymer composite is particularly unique due to the anisotropic nature of both materials within the composite. While this may lead to a more complex manufacturing process, it also provides the opportunity to generate materials with a unique structural hierarchy and tuneable mechanical properties. We present an experimental study on self-assembly of recombinant silk-like proteins within composites, with the aim of developing hierarchical structures that demonstrate high strength and stiffness. This involves analysis of the formation and orientation of supramolecular structures upon application of different surface coatings to rCFs. Finally, we characterise mechanical properties following this ‘tuning’ process to assess structure-property relationships.

#873

# Detection of Mode II fracture of thin paste adhesive joints

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Thin paste adhesively bonded joints are used in many applications such as energy, marine, automotive, and civil engineering. In such applications complex stress fields develop leading to mixed-mode fracture including Mode I and Mode II fracture components. Although Mode I is relatively well investigated, Mode II of thin paste joints is less studied. Commonly, Mode II End Loaded Split (ELS) is the preferred specimen showing stability of crack growth. Mode II ELS joints, with adhesive thickness of 2-3 mm can exhibit an unstable crack growth and non-horizontal crack path. As the crack propagates into the substrate of a ductile adhesive, there are questions regarding the validity of using linear elastic fracture mechanics for fracture energy calculation.

In this work, a semi-automated framework is developed for monitoring crack propagation using full field Digital Image Correlation (DIC) data obtained from DIC images of the specimen's surface. This framework is based on analyzing shear strains around the crack tip. The procedure begins with the visual identification of a reference crack length, to set the initiation point and therefore the estimation, based on DIC data of a shear strain threshold $\varepsilon_{thxy}$ at this crack tip position. This threshold is used as a benchmark for crack advancement detection in subsequent images. The algorithm also computes vertical position of the crack tip enabling crack trajectory identification. This strain localization technique is crucial for Mode II ELS testing as methods based on horizontal displacement thresholding are not suitable due to displacement induced from beam deflection altering the threshold value.

In addition, an automated J-integral method is developed with a positioning of the contour integral which considers the clamping and the fracture process zone that might affect the accuracy. Results from both methods are compared herein.

#874

# A Parametric Approach for Intraply Hybridization of Carbon Fiber and Natural Fiber Textiles

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The growing demand for sustainability considerations in the composite industry has led to a surge in hybrid composites that utilize natural fibers (NFs) and carbon fibers (CFs), aiming to strike a balance between carbon emissions and mechanical efficiency. For interply hybridization, natural fibers turned out to be not only good at absorbing impact energy, but the high permeability compared to carbon fibers makes them functional by reducing the usage of external flow accelerators. This work is an attempt to increase the scope of functional integration of natural fibers further by investigating their textile architecture, paving the way for intraply hybridization. Experimental studies suggest that textile weave architecture has a direct impact on permeability. Particle flow simulation assisted by a parametric loom algorithm enables visualization of the ease of particle flow through different textile architectures within the design domain. To evaluate the structural impact of different weaves, a parametric finite element (FE) solver was introduced within the design domain. The results were further validated qualitatively with benchmark permeability tests and mechanical testing. These results can be used to create a workflow for generative design of intraply CF-NF textile architecture based on evolutionary programming. As a proof of concept, only plain weave unidirectional and bidirectional hybridization was considered in this work. Lab-scale prototypes were prepared by modifying a weaving loom. The samples were then infused with epoxy resin in a transparent mold, and a dual-camera system was used to capture different frames of the infusion process from top and bottom to quantify the infusion time and document the flow front. The Visual-RTM program was used to mimic the process to iteratively determine the actual permeability of the hybrid laminates. Finally, the mechanical and physical properties of the composites were compared with commercially available alternatives to realize the viability of the approach.

#875

# Towards Optimal Fabrication of Composite Hydrogen Pressure Vessels: Coupling Design and Manufacturing through WoundSim-Based Surrogate Optimization

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Composite overwrapped pressure vessels (COPVs) are widely used for high-pressure hydrogen storage owing to their favorable strength to weight ratio. The most prevalent automated manufacturing processes are filament winding and automated fiber placement (AFP). However, current software tools still lack a seamless link between design and manufacturing.

This work introduces a unified design to manufacture framework based on a "simulator in the loop" optimization applied to laminate definition for COPVs. Deposition paths are obtained by integrating geodesic and semi geodesic equations and then converted into manufacturable patterns. These patterns are parameterized by the number of circuits, skip index, and correction terms. These variables introduce controlled, small deviations from the nominal winding angles.

The objective is to minimize mass while satisfying mechanical performance requirements. The optimization couples a pattern generator with a genetic algorithm that explores a discrete angle space, while WoundSim provides high-fidelity analytical evaluations of mass and fiber-direction stress S11. A surrogate model, trained on simulated samples, predicts the mass of each layup and its variants, enabling early filtering and prioritization of the most promising candidates. Throughout the optimization, stress constraints are systematically checked using WoundSim's analytical design module.

In an initial proof of concept on a pilot study, the method reduced mass by approximately 3% (from 84.67 kg to 82.38 kg) while meeting the prescribed limits on the fiber-direction S11 stress. These preliminary results support the feasibility of the approach and its potential to lower computational costs by reducing the number of required high fidelity analytical evaluations in WoundSim.

Keywords: Composite overwrapped pressure vessels, Filament winding, Geodesic and semi-geodesic deposition paths, Pattern parameterization, Simulator in the loop optimization, WoundSim.

#876

# Examination and demonstration of innovative welding technologies for continuous fiber-reinforced thermoplastic hollow profiles in high-performance applications.

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The rising demand for highly functionalized and lightweight composites is driving the need for robust, efficient, and application-oriented joining technologies. Compared to thermoset-based composites, thermoplastic composites (TPC) offer advantages in terms of subsequent processing, recyclability, and functionalization, particularly in the context of highly specialized, high-performance applications. Within this context, welding represents a crucial technology, enabling the economic and ecological utilization of such materials for highly functional structures. While exploiting its full material potential, it allows fast and repeatable joining without the need for additional adhesives or mechanical fasteners.

Whereas extensive research has been conducted on the welding of TPC shell structures, welding of high-performance TPC hollow structures remains less understood but is necessary to achieve reproducible joint quality and meet industrial performance expectations. In particular, the transfer to high-performance thermoplastics, which are essential for high-performance applications, substantially increases the complexity of process development.

This paper evaluates application-driven welding technologies to achieve media-tight tube-to-tube joints for high-performance TPC. An initial systematic assessment enabled targeted identification of welding technologies that meet the mechanical, thermal, and geometric constraints for a tube-to-tube joint. This analysis yielded two preferred variants, which were subsequently implemented for process validation.

The demonstrated local co-consolidation approach achieves highest weld quality and bond strength without additional material, making it well-suited for in-production use. In parallel, a resistance-based welding process was developed for on-site assembly, characterized in particular by its robustness and short welding time. Process parameters were optimized with industrial requirements in mind. Both mechanical integrity and media tightness of the joints were verified through experimental validation, including pressure testing.

By focusing on industrial process requirements and adapting the technology to actual application conditions, the welding technologies described enable the potential of high-performance TPC to be maximized and its range of applications to be expanded.

#877

# Effect of thermo-oxidative ageing on the dynamic properties of disulfide-based epoxy vitrimers

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Equipping native thermosets with dynamic covalent bonds provides exceptional features like malleability and self-healing characteristics - previously reserved for thermoplastics. This emerging class of materials, coined vitrimers, therefore offers a sustainable alternative to conventional epoxy resins, enabling full recyclability and extended service life through self-healing properties. Still, research into their applications remains in its early stages. In particular, practical application of these materials require a detailed understanding of their behaviour under harsh conditions, including the effect of thermo-oxidative ageing during elevated temperature dwellings representing a prerequisite to trigger dynamic bond-exchange that enable the vitrimer's self-healing and malleability features.

Therefore, the present contribution elucidates the impact of thermo-oxidative ageing on thermomechanical and vitrimeric behaviour. First, model-free kinetics are applied to extract a kinetic description of the thermos-oxidative degradation process. Based on that, temperature programs are derived for specimens with tailored thermo-oxidative aged states. Dynamic mechanical analysis and thermomechanical analysis of the specimens with tailored thermo-oxidative aged states is carried out to gain insights into glass transition shift, stress relaxation behaviour, and the onset of macroscopic flow, quantified by the topology freezing temperature T_v. This approach enables us to directly link the apparent thermo-oxidative degradation state to changes in macroscopic properties and reveals valuable implications for the interactions with the vitrimer's self-healing and malleability capabilities in thermo-oxidative environment. Temporarily, selective degradation of the disulfide crosslinks seems desirable as a profound measure to decrease crosslinking density, facilitating accelerated stress relaxation and is accompanied by lower activation energies of the dynamic bond exchange. Still in the long run, the dynamics of the network decay indicating detrimental consequences on the healing and recycling capabilities of these materials.

#878

# Fiber-influenced crystallization in high-performance semi-crystalline thermoplastic composites: Implications for processing optimization

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High-performance semi-crystalline thermoplastics, particularly members of the polyaryletherketone family such as PEEK and PEAK, have gained substantial attention as matrix materials for advanced structural composites. Their combination of excellent thermal stability, high mechanical strength, intrinsic chemical resistance, and recyclability make them good candidates for next-generation aerospace, automotive, and energy applications. Unlike thermoset matrices, these thermoplastics can be repeatedly melted and solidified, enabling faster processing, improved damage tolerance, and enhanced long-term durability. However, their semi-crystalline nature introduces additional complexity, since the degree and rate of crystallization that occurs during manufacturing strongly influence the final morphology and, in turn, the mechanical, thermal, and environmental performance of the composite.

Crystallization can evolve significantly during heating, cooling, consolidation, and post-processing, and is sensitive to factors such as temperature history, pressure, and the local thermal environment generated by the reinforcing phase. While numerous studies have investigated the crystallization kinetics of PAEK polymers in bulk or neat-polymer form, these studies often neglect the presence of fibers, despite the fact that reinforcement can substantially modify nucleation mechanisms, accelerate or hinder crystal growth, and alter the overall crystallinity achievable under realistic processing conditions. Fiber surfaces may act as heterogeneous nucleation sites and constrain polymer chain mobility, all of which contribute to deviations from neat-polymer kinetic behavior.

In this study, we investigate the crystallization behavior of selected polyaryletherketone thermoplastics in the presence of reinforcing fibers, with the aim of quantifying fiber-induced effects on crystal growth kinetics, final morphology, and mechanical properties. By integrating kinetic analysis with processing-relevant thermal histories, this work seeks to establish guidelines for optimizing processing conditions, minimizing shrinkage-related defects, and improving the performance and structural reliability of thermoplastic based composites.

#879

# Investigation of sandwich plates with hexagonal auxetic structure using the R-functions theory

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Auxetic cellular materials are modern materials which have some unique and superior mechanical properties. As a consequence of the structural deformation of their internal cellular structure they exhibit a negative Poisson's ratio, i.e. they significantly increase in volume if stretched and vice versa. Auxetic materials are attracting increasing interest due to their many unusual new properties and several potential applications of auxetic materials in medical, defense, sports, automobile, etc.

Honeycomb auxetic material is one of the modern materials used for the manufacture of core. With the increasing number of applications of sandwich structures with honeycomb core, the number of publications devoted to the study of the static and dynamic behavior of auxetic plates and shells is increasing also. Today, design and modeling of novel auxetic materials and structures is one of the important problems. The paper describes one of the models for vibration analysis of sandwich plates with conventional hexagonal auxetic structure. The plate consists of three layers: the core is an auxetic honeycomb, top and bottom layers are made of functionally graded material (FGM). The proposed approach combining the R-functions theory and the variational Ritz method is numerical analytical one. It allows to construct a system of basic functions satisfying exactly the given boundary conditions for practically an arbitrary geometric shape of the plates considered. Mathematical statement of problem is carried out in framework of the first order shear deformation theory of the shell (FSDT). The effect of the geometrical and mechanical parameters of the plates and cells, type of FGMs, ratio thickness of the face-sheets and core on the natural frequencies of sandwich auxetic honeycomb plates is analysed.

#880

# Smart Digital Twins for Composite Manufacturing

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Resin Transfer Moulding (RTM) is an established out-of-autoclave technique for producing high-performance composite parts, yet achieving consistent and defect-free impregnation remains difficult. Variations in resin viscosity, changes in reinforcement permeability, and other process disturbances alter the flow behaviour, making robust and adaptive control essential. In this work, we propose a physics-informed Reinforcement Learning (RL) strategy for real-time regulation of injection pressure in RTM, specifically aimed at improving manufacturing resilience under uncertain and time-dependent operating conditions.

The method couples a Level-Set/Darcy flow simulator with a Deep Q-Network (DQN) agent trained to adjust inlet pressure so that a target resin-front velocity is maintained. Unlike previous approaches that rely on continuous visual monitoring, the controller uses only readings from four pressure sensors embedded in the mould, increasing its suitability for industrial environments. In addition, the framework is extended conceptually to multi-gate injection scenarios, illustrating the potential of RL to coordinate pressure distribution across multiple inlets to mitigate race-tracking and improve flow uniformity in large or complex geometries.

Training is performed in silico using stochastic permeability fields and temperature-dependent viscosity models, exposing the agent to both gradual and abrupt variations in flow resistance. This enables the development of control policies capable of compensating for evolving material behaviour and unmodelled disturbances.

The learned policy is experimentally validated on a laboratory-scale RTM setup. Results show that the RL controller successfully maintains the desired filling velocity, adapts to unanticipated changes in viscosity and permeability, and reproduces the intended impregnation pattern with high accuracy.

Overall, this work demonstrates the potential of RL-based closed-loop pressure control to enhance robustness and adaptability in RTM processes, while opening pathways toward future multi-gate flow coordination and more autonomous composite manufacturing workflows.

#881

# Evaluation on Ultrasonic Welding Behavior and Joining Strength of CF/Epoxy Laminates and CF/PEEK Thermal Pultruded Rods Using Spread CF/PEI Semipreg Layer

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This study aims to reveal the welding behavior and joint strength of CF/Epoxy laminates and thermally pultruded CF/PEEK rods during ultrasonic welding. For welding of CF/Epoxy and CF/PEEK, PEI based polymer coupling layer is required. However, achieving a uniform and effective coupling layer is not straightforward. Furthermore, it is difficult to obtain high joining strength using only polymer coupling layer. Therefore, in this study, spread-CF/PEI semipreg was inserted at the interface between CF/Epoxy laminates and CF/PEEK rods to achieve both the polymer based coupling effect of PEI and the reinforcement of the weld layer by the spread carbon fibers. The ultrasonic welding system consisted of a servo press unit that provides highly precise control of load and displacement and 20 kHz ultrasonic heating unit. In this study, static spot welding was performed and continuous welding of the rib–skin structure was carried out by moving the ultrasonic horn with an actuator. The ultrasonic welding parameters such as welding pressure, ultrasonic oscillation time and horn travel speed for welding the square rods to the laminates were investigated and optimized. To evaluate the ultrasonic welding behavior, CF/Epoxy laminates and CF/PEEK laminates were first welded to optimize the welding parameters and observe the welded interface. The insights and results obtained from these laminate-laminate welded parts were then applied to perform ultrasonic welding between the CF/Epoxy laminates and CF/PEEK pultruded rods. In order to evaluate the welded interface of CF/Epoxy and CF/PEEK, the interface was etched with NMP solvent and observed using SEM. The joining strength was evaluated using single lap tensile shear test to confirm the effectiveness of the spread-CF/PEI semipreg layer. The experimental results of this study revealed the effectiveness of the spread-CF/PEI semipreg layer for ultrasonic welding of CF/Epoxy and CF/PEEK.

#882

# Automated Winding Technique to Generate Functional Free-Form Composites Inspired by Nature

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In this work, a novel approach to rationalizing free-form shapes via custom winding to create lightweight composite structures was explored. The idea was to take inspiration from biological forms, generate geometric definitions via evolutionary programming and then translate them into fiber paths to create functional shapes. For this purpose, FlexiCAM, an in-house automated winding tool coupled with a multiaxial winding set-up was used. The multiaxial winding technology provides the advantage over conventional winding techniques in such a way that the paths generated in the parametric domain can be exactly replicated on the winding surface because for multiple degrees of freedom providing better realization of the structure and enhanced structural consistency. Moreover, FlexiCAM facilitates the user to adapt geometric definitions directly into material constraints, without converting them into standard G-code, thus reducing information loss during information transfer. It also allows for finding the constraints of the generated paths based on different materials, thus creating a feedback loop. For this work, inspiration was taken from the coocon nest shape, a custom sand-printed mold was prepared and mounted on the winding mandrel, and fiber tapes were wound around the core using the automated process. Later, the core was dissolved, and the finished structure was extracted for testing. CT scan was performed to check for delamination and air gaps in the finished product, while load tests were conducted to evaluate the failure modes of the finished product. Once established, the method can further be optimized to adapt to other non-symmetric free-form shapes, and the rationality of machine learning integration in the design process can be explored.

#883

# Assessing the Performance of Recycled Carbon Fibre in Composite T-Joints

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The increasing demand for lightweight aerospace structures, combined with growing environmental pressures, has increased the need for sustainable composite technologies. While recycled carbon fibre (rCF) has been demonstrated to be a promising solution, there remains a knowledge gap between coupon-level performance and its behaviour in structural applications. This work investigates the use of rCF in a representative aerospace sub-component, a composite T-joint, and evaluates both its feasibility and performance. Carbon fibre tows were reclaimed from cured carbon-epoxy composites that were thermally recycled in air through a programmed isothermal exposure (500°C for 1-2.5 hours) to remove the epoxy matrix and recover the rCF. The reclaimed carbon fibres were subsequently used in the composite manufacturing chain as “noodle” reinforcements for T-joint stiffener specimens. A stiffener pull-off test was employed to characterise the structural performance of rCF noodles. Digital image correlation (DIC) analysis was conducted to map strain evolution in the specimens and to identify the damage sequence. A fibre-characterisation study employing single-fibre tensile testing, interfacial shear strength, thermogravimetric analysis, and scanning electron microscopy were conducted to help link fibre-scale degradation during the recycling process to macro-scale structural performance. To complement the experimental programme, a finite element model was developed in ABAQUS to capture ply-level stress states and simulate delamination events.

Initial results from baseline specimens demonstrated a consistent delamination event in the web radius, followed by a crack propagating through the noodle region, providing a benchmark for comparison against rCF variants. Early modelling outputs show good agreement in strain distribution trends, though further refinement is ongoing to match absolute stiffness and failure initiation loads. This study offers new insights into the structural viability of rCF in aerospace-style joints, supporting a pathway toward recyclable, remanufacturable composites within a circular economy for high-performance structures.

#884

# Study of the Impact behaviour of Double-Double Laminate

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Impact is one of the most common and detrimental sources of damage in composite structures. Typical impact-induced damages include intralaminar matrix cracking, delamination, and fiber breakage. The mechanisms governing the initiation and propagation of these damages are strongly influenced by the composite architecture. Matrix cracking generally occurs first and subsequently triggers delamination, which significantly reduces the compressive strength of the laminates.

The Double-Double method developed by Stephen W. Tsai, & al is an innovative concept of lamination. It consists of a stack of structures called “building blocks” comprising 4 angles $[\pm\varphi/\pm\psi]$. These angles are defined according to the desired mechanical properties and can be between 0° and 90°. Double-Double laminates differ from traditional laminates in several aspects (number of interfaces, mismatch angles homogenization...). Due to these distinctive features, their impact and post-impact compression behaviour may deviate from that of conventional laminates, potentially challenging established impact sizing principles.

This work is based on experimental and numerical studies. Low velocity drop-weight impact tests (LVI) and quasi static indentation are carried out to detect and quantify the key damage mechanisms in these structures. To highlight the failure mechanisms, post-mortem analyses using X-ray tomography are carried out. Additional instrumentation may be implemented depending on the tests . Furthermore, compression-after-impact (CAI) tests are performed to assess the residual strength of the laminates.

Some preliminary LVI and CAI results , shows interesting findings regarding the behaviour of Double-Double laminates.

At the same time, finite element modelling based on a semi-continuous approach is used to understand the key mechanisms and the potential difference between double-double and traditional laminates.

#885

# Experimental Characterization of the Relationship Between Crack Network Parameters and Permeability of Composite Coupons after Cryogenic Thermal Cycling

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The characterization and modelling of composite materials in cryogenic environments have become critical research topics driven by their relevance to emerging technologies in aerospace, advanced transportation systems, and the growing demand for reliable liquid hydrogen storage. At cryogenic temperatures, composite materials exhibit mechanical responses that significantly differ from their well-documented behaviour under ambient conditions. These differences arise from a complex interplay of factors, such as constituent properties, thermally-induced residual stresses, and mismatches in termal contraction, leading to microcracking.

After repeated exposure to cryogenic environments, microcracks propagate and coalesce, creating tortuous, interconnected percolation paths that increase cryogen transport and laminate permeability, a major challenge for type V linerless hydrogen tanks. While the existing literature provides insight into the fundamental physical mechanisms governing these phenomena, a comprehensive understanding of how they collectively influence mechanical performance remains limited.

In this work, a broad experimental investigation was conducted to examine the evolving transport characteristics of materials subjected to varying thermal and mechanical histories. Permeability testing was carried out on both pristine and thermally-cycled specimens. The influence of these thermal fluctuations on the internal architecture of the test coupons was examined using advanced imaging techniques (micro-CT), allowing qualitative and quantitative characterization of microstructural alterations. Microcrack networks were identified and automatically segmented for the assessment of damage and tunneling metrics. These descriptors were then compared with measured permeability responses to explore potential correlations between internal degradation processes and gas transport. The outcomes offer an in-depth perspective on the interplay between repeated exposure to cryogenic temperatures, microstructural damage evolution, and through-thickness gas transport properties, serving as a basis for future, more detailed investigations.

#886

# Structural Supercapacitors with Graphene-Modified High-Surface-Area Carbon Electrodes and Gel-Polymer Electrolyte Separators

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The development of lightweight, multifunctional energy-storage materials is essential for achieving carbon-neutral transportation and reducing reliance on conventional batteries. Structural supercapacitors (SSCs), capable of simultaneously carrying mechanical load and storing electrical energy, offer a promising route toward this goal. However, progress has been limited by the trade-off between mechanical robustness, interlaminar integrity, and electrochemical performance, as well as the absence of scalable manufacturing approaches. In this work, we present scalable structural supercapacitors incorporating graphene-modified carbon fibre electrodes and a gel-polymer electrolyte (GPE) that acts simultaneously as the ionic conductor and separator. A simple brush-coating technique was developed to deposit graphene nanoplatelets with a binder and conductive paint, producing uniform, high-surface-area electrodes (~231 $m^2 \cdot g^{-1}$), surpassing typical carbon-based structural electrodes. The use of a GPE containing 60 wt% Li-salt eliminated the need for liquid electrolyte infusion and yielded the highest ionic conductivity among the formulations studied.

Two cell architectures were evaluated - SSCs using a standalone GPE separator, and SSCs incorporating glass fabric (GF)-reinforced GPE to enhance the fibre–fibre interface. While the GF interleaf introduced slightly higher resistance and lower capacitance, it improved the flexural modulus by ~22% and enhanced interlaminar stability without compromising mechanical strength. All fabricated devices demonstrated a favourable balance between stiffness and capacitance, with multifunctional performance comparable to or exceeding previously reported SSCs. A proof-of-concept demonstration showed that GPE-based cells retained charge longer than those employing GF separators and were capable of powering a red LED. These findings highlight a viable pathway toward scalable SSC manufacturing and provide key insights into tuning electrolyte composition and interfacial design. The demonstrated approach supports the advancement of durable, lightweight, and integrated energy-storage systems for aerospace, automotive, robotic, and wearable applications.

#891

# Bio-based PA11 Composites incorporating space-derived lunar regolith simulant

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The growing interest of space agencies in long-duration missions to the Moon and Mars is accelerating the development of advanced materials and manufacturing technologies capable of exploiting local resources and ensuring high operational autonomy. In this context, the use of regolith as a raw material or functional filler for composite fabrication represents a crucial step toward reducing dependency on Earth-based supplies and enabling the in-situ production of structural elements, functional components, and replacement parts. Incorporating mineral resources available on extraterrestrial surfaces makes it possible to obtain materials with suitable mechanical and thermal properties, contributing to the sustainability and safety of future space infrastructures.

This study investigates the development of innovative composite materials based on polyamide 11 (PA11) reinforced with a lunar regolith simulant. The PA11 Rilsan® grade from Arkema® used in this work is a biobased thermoplastic produced from a renewable and sustainable source (castor oil). PA11 combines thermal stability, high strength, flexibility, chemical resistance, and ease of processing. These characteristics make PA11 a potentially suitable matrix for aerospace applications and support versatile manufacturing strategies with potential uses in both terrestrial and extraterrestrial environments.

The engineering-grade Lunar Highlands simulant (LHS-1E) was first characterized through laser diffraction granulometry, microstructural analysis (SEM), and XRD investigation. The filler was then incorporated into the polymer matrix at loadings of 10 wt.% and 20 wt.% to assess the influence of its content on material performance. The resulting composites underwent an extensive experimental campaign, including mechanical testing (flexural, tensile, creep, and impact), thermal analyses (DMA, DSC, TGA, and VICAT), and rheological characterization.

This multi-level characterization strategy was aimed at identifying the critical properties that will guide the assessment of the material's suitability for practical use, including lightweight structural applications and in-situ fabrication within future space infrastructures based on local resource utilization.

#893

# Poly(butylene succinate-co-adipate) (PBSA) biocomposites reinforced with microalgal biomass derived from wastewater treatment

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The transition towards sustainable material technologies increasingly relies on integrated processes capable of addressing environmental challenges while generating value-added products. Microalgae-based wastewater treatment represents a promising approach, as microalgae can effectively remove organic pollutants and nutrients while simultaneously producing a biomass rich in functional compounds. However, when grown on wastewater, this biomass cannot be exploited in high-value sectors, making its valorization within circular material systems particularly attractive.

In this work, an autochthonous microalga of the genus Chlorella was cultivated in a synthetic wastewater rich in organic contaminants, with the dual objective of evaluating effluent treatment efficiency and valorizing the resulting biomass as a bio-filler for biodegradable polymer composites. Microalgae cultivation was carried out in closed photobioreactors under semicontinuous conditions, yielding stable biomass growth and high removal of organic carbon and inorganic nutrients, confirming the effectiveness of the system for treating wastewater. The recovered biomass was freeze-dried, mechanically milled and incorporated into poly(butylene succinate-co-adipate) (PBSA) at 10 and 20 wt% through melt compounding to develop sustainable microalgae-filled biocomposites.

The materials were characterized through rheological, mechanical, thermal, and surface analyses to evaluate the influence of biomass incorporation on PBSA properties. Mechanical testing showed that the biocomposites exhibit a simultaneous increase in elastic modulus and elongation at break while maintaining comparable tensile strength, suggesting that the biomass confers both stiffness and ductility, an uncommon combination for particulate-filled systems. Importantly, biodegradation tests performed under controlled composting conditions demonstrated that the presence of microalgal biomass accelerates the degradation of PBSA, confirming both the environmental relevance and the circular potential of the developed materials.

Overall, this study highlights an integrated strategy in which wastewater treatment and biocomposite production are combined to create functional, sustainable materials derived from a biologically generated waste resource.

#896

# Overcoming the valley of death: FIB3R, a successful story of research to innovation in the field of carbon fiber recycling

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Carbon Fiber Reinforced Polymers (CFRP), are more and more spreading towards mass-oriented applications, resulting in an expanding waste stream in the incoming years: this scenario allows for a unusual position to set up a cradle-to-cradle value chain dealing with the composite waste further than its end-of-life and up to its correct disposal and re-use before CFRPs waste stream stat accumulating. Indeed, besides a mere energy recovery approach, the attempt at recycling and re-use of CFRPs is economically viable when the reinforcing fraction is gathered, since CFs production is highly energy-requiring. This work, hence, reports the winning case of a recently started-up carbon fibers (CF) re-cycling plant (FIB3R, designed by HERAmbiente @Imola – BO - Italy, from a joined UniBo and Curti Costruzioni Meccaniche patent), starting from basic research which paved the way for the industrial plant, FIB3R, dealing with 160ton/year which started up in Imola (BO) - Italy last November (about to double by June 2026), and offers a perspective on ReCF upcycled reuse.

The plant makes use of a sequenced pyro-gassification approach, the first if its kind in Europe, to produce up to 320tonn/year Recycled CF with performances, in terms of mechanical properties, as high as 90% of their pristine reference values. Tailoring and optimizing the specific recycling process to boost the final ReCF properties, as well as the re-impregnation strategies to optimize composites production are at the basis of a successful result for upcycling. In a preliminary pilot plant-based Life Cycle Assessment (LCA) this process attested to a reduction of 40 $kgCO_2$ eq per kg of recycled CFs, compared to virgin CFs, which, upon industrial scale-up (presently under evaluation on the FIB3R plant) envisages an estimated reduction of the carbon footprint up to 90%.

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#897

# Capturing Localised Electro-Thermal Effects by Incorporating Spatially Varying Property Fields in the Simulation of Lightning Strike on Composite Structures

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Composite aerostructures are increasingly exposed to critical lightning strike events, where localised high-temperature and electrical discharge phenomena can induce severe structural degradation. Experimental evaluation of the performance of the composite structures against lighting strike is very complex, expensive and requires specialised safety infrastructure. Alternatively, the performance can be evaluated through numerical simulations through a multi-physics approach involving electro-thermo-mechanical analysis. However, in these simulations, the material properties are assumed to be uniform across the whole computational domain. This assumption is unrealistic and oversimplified for heterogeneous and anisotropic composites, where local fibre architecture and matrix distribution generate spatially varying properties. Experimental observations indicate that heat and current preferentially propagate along locally conductive paths, particularly in woven architectures such as twill weaves.

In this work, we propose a modelling approach where the material properties are assigned as field variables which not only vary based on the spatial coordinates but also are dependent on the temperature at that given location. We extracted these property fields from high resolution images of the dry fabrics and implemented in the multi-physics simulation package by using user-defined interpolation function. The objective of this study is to resolve the detailed behaviour of localised current and heat transport within the twill weave fabric during electro-thermal loading. Preliminary thermal analysis on a twill weave fabric demonstrate that this approach captures localised temperature gradients and heat-flux pathways more realistically than simulations that use uniform properties. The primary limitation of this approach arises from mesh-resolution requirements i.e. sufficiently fine meshes are necessary to represent the property fields, increasing computational cost. Quantifying this trade-off forms an essential component of the ongoing study.

#898

# An innovative multi-layer bonding interface to improve the perfor-mance of concrete-FRP hybrid structures

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Abstract und introduction:

In recent decades, as research into fibre-reinforced composites (FRP) has advanced, the integration of FRP with concrete has also demonstrated excellent application potential. The primary challenge encountered in this application is the reliable bonding between FRP profiles and concrete. Conventional solutions generally depend on mechanical connectors, surface roughening, or epoxy adhesives. However, their performance is frequently con-strained by debonding, which is limited when applied to dry–to–wet interfaces.

The study proposes a novel multi-layer bonding interface system, which builds upon traditional dry-to-wet connection methods. The structure consists of glass fibre-reinforced polymer (GFRP) profiles, an intermediate bonding membrane layer, and freshly poured concrete. The concept builds upon the Waterproof Bonding Membrane for fresh concrete PT Proofflex FBV, whose textured surface enables mechanical interlocking with concrete, while its polymeric backing requires tailored bonding treatments to achieve reliable adhesion to GFRP substrates.

Experimental investigations:

This study thoroughly investigates the mechanical interface behaviour of this multi-layer system. A range of strategies for surface en-hancement is proposed, including the embedding of coarse aggregates, fibre fabrics, and surface-activated bonding primers. The objective of these measures is to enhance shear transfer efficiency and delay interface slippage while maintaining the flexural strength of the concrete-FRP hybrid structure.

Shear tests and three-point/four-point bending tests, cross-validated with numerical simulations in COMSOL Multiphysics, enable further evaluation of stress transfer mechanisms and potential failure modes.

Conclusion and outlook:

The innovation of a bonded interface has been introduced to address the significant challenge posed by the extremely low natural adhesion between concrete and FRP in the context of dry-to-wet bonding. Consequently, while maintaining the mechanical properties of traditional connection methods, it significantly improves the durability of composite structures. This advancement has the potential to engender a plethora of prospects for both academic research and engineering practice.

#899

# Magnetic Nanoparticles for Self-regulated Magnetic Heating in Thermoplastic Composite Welding

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The aerospace sector is accelerating its shift toward sustainable manufacturing through lightweight, recyclable thermoplastic nanocomposites. As advanced polymer matrices become central to high-performance structures, joining technologies must evolve to support high rate production and future strategies for repair, disassembly, recycling, and remanufacturing. Induction welding is a promising non-contact method for bonding thermoplastic composites, but it traditionally relies on electrically conductive fibres to generate heat via eddy currents.

Embedding magnetic nanoparticles (MNPs) within non-conductive polymer matrices provides an alternative route by enabling localized heating through magnetic hysteresis losses. By tuning the Curie temperature of ferromagnetic nanoparticles, heating can be intrinsically self-regulated at the polymer's processing temperature, effectively shifting the process control into the smart material. This principle supports welding as well as reversible joining and autonomous repair concepts needed for a circular aerospace economy.

In this study, magnetite ($Fe_3O_4$) was first dispersed in silicone oil to evaluate baseline heating behaviour. Temperature evolution was monitored using an optical fibre sensor during exposure to varying magnetic field amplitudes and frequencies. These colloidal tests showed a strong dependence of heating rate on particle concentration up to 0.4 vol%, followed by a non-monotonic drop at higher concentrations.

The same nanoparticles were then compounded with LM-PAEK in a twin-screw extruder, and the heating behaviour of the resulting extrudates was characterized via thermography. Heating rates up to 60 °C/s were achieved, with full LM-PAEK melting in under 10 s. Unlike the liquid medium, heating in the polymer increased monotonically with particle loading, suggesting improved magnetic coupling and dispersion from melt processing.

Overall, the magnetothermal response of embedded nanoparticles depends not only on concentration but also on dispersion quality. Such nanocomposites could enable efficient magnetic welding and next-generation capabilities including repair-on-demand, reversible disassembly, recycling, and self-healing interfaces.

#900

# Manufacturing and numerical simulation of induction heating in a novel additively manufactured carbon fibre thermoplastic

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Additive manufacturing of continuous carbon fibre offers new design flexibility during the manufacture of carbon fibre components. While traditional automated manufacturing offers some design flexibility through fibre steering, new additive manufacturing methods offer bespoke placement and alignment of individual tows. This capability has been used to design structures for mechanical loading, but to date comparatively little work has been done in the electrical domain. In the current work, a continuous carbon fibre composite, is manufactured using a Markforged Mark Two printer. Individual tows are laid down in a continuous pattern around the edge of the part to vary the electrically conductivity locally. The pattern is designed to enable induction heating around the edge of the part so that significant heating occurs away from the coil. The part is subject to an alternating electromagnetic field which induces eddy currents and heat in the conductive areas of the part and the heat is measured using a thermal camera. Following the experimentation the heating behavior of the composite part is modelled using COMSOL. Finally, several novel layups are modelled to investigate the influence of layup on induction properties.

#901

# Tailored interface by growing ZnO nanoflakes on CF surface using microwave radiation for CF/PEI laminates

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Carbon fiber-reinforced thermoplastic (CFRTP) laminates are gaining rapid attention as sustainable, high-performance alternatives to conventional thermoset composites. Among these, CF/PEI systems offer excellent recyclability, thermal stability, and mechanical robustness. However, their widespread adoption in demanding structural and multifunctional applications requires further enhancement of fiber–matrix interfacial bonding and the integration of additional functional properties. In this work, we introduce a rapid, facile microwave-assisted strategy for the direct growth of uniform zinc oxide (ZnO) nanoflakes on carbon fibers, enabling substantial performance improvements within an exceptionally short processing time. The optimized ZnO–CF/PEI laminate is fabricated via the in-situ growth of ZnO nanostructures through a microwave treatment of only 3 minutes, leading to a markedly improved interfacial architecture. Mechanical characterization reveals simultaneous and significant enhancements across key properties: a 21% increase in interlaminar shear strength, a 17% improvement in flexural strength, and a 22% rise in storage modulus. These gains stem from the strengthened interphase created by the conformal ZnO nanoflake network, which promotes superior stress transfer and mechanical interlocking. Beyond structural reinforcement, the integrated ZnO nanolayer imparts outstanding electromagnetic interference shielding effectiveness (EMI SE) of −48 dB. This enhanced shielding arises from increased reflection, absorption, and multi-scattering induced by the hierarchical ZnO–CF surface. The combined mechanical and EMI-shielding performance underscores the multifunctionality achieved through this simple surface-engineering route. Overall, this study demonstrates a powerful and scalable approach to simultaneously enhance the structural and functional capabilities of thermoplastic composites. The ultrafast microwave-assisted ZnO growth process provides a promising pathway for advancing CFRTP laminates toward next-generation aerospace, automotive, and industrial applications requiring lightweight, recyclable, and multifunctional materials.

#902

# Optimisation of fibre-reinforced polymer extrusion with numerical simulation and AI

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The use of composites has become widespread in recent years. In aeronautics, for example, composite parts are often used for large components (such as fuselage parts). These parts are manufactured from long-fiber prepregs to ensure good mechanical strength. Today, some of these parts are reaching the end of their service life, raising the question of how to recycle them.

The main recycling processes include chemical recycling, where the matrix is dissolved using chemicals, and mechanical recycling, which involves grinding the material, extruding it into a new polymer matrix, and then remanufacturing composites from these pellets. This step is usually carried out using a twin-screw extrusion process. During this recycling stage, it is important to optimize the process in order to estimate the size of the fibers in the reformed pellets at the outlet.

This process can be optimized using the Ludovic® software, which accurately simulates the twin-screw extrusion process, and provides an in-deep understanding of what happens throughout the screw profile in the extruder. By calculating the material history (temperature, pressure, viscosity, filling rates, and shear rates along the screw), we can predict the evolution of fiber breakage along the profile and then optimize the screw profile. This task can now also be performed by the AIGEN-TSE module. This module tests different combinations and suggests the best screw profiles and process conditions to achieve the ideal compound.

#903

# Challenges and strategies for particle dispersion and process-induced microstructural design in functional particulate composites

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Recently, particulate composites containing micro- and nanoparticles have been widely studied for a range of functional applications, such as smart sensors, high-performance electronics, and energy storage. To fully exploit their (nanoscale) properties, optimised particle deagglomeration and dispersion in the polymer matrix are generally essential but have been commonly overlooked in the literature to date. Moreover, classical dispersion methods, such as shear mixing, have proven insufficient; therefore, high-power (ultra)sonication has attracted increasing interest from both industry and academia. Despite the promising potential of ultrasonication, a well-described framework for effectively tailoring the processing and, hence, final microstructure of particulate composites is generally lacking.

Therefore, we performed multiple studies on thermoplastic and thermoset particulate polymer systems to reveal relationships between the processing-induced microstructure and functional performance. We developed a framework to optimise ultrasonication parameters and identified a threshold of 100 J/ml for the energy density and a high power density of 0.3 W/ml to achieve effective solvent- or resin-based 3D particle dispersion. However, low-power bath sonication (10 J/ml and 0.01 W/ml) was sufficient to disperse hydrophilic 2D particles in polar solvents. Hence, the energy density was identified as a successful universal scaling parameter, and enabled benchmarking of the effect of ultrasonication on the functional performance of different polymer-filler systems. We studied three particles for three different applications: 3D barium titanate for nanoscale 3D strain mapping, 2D MXene for energy storage and EMI shielding, and 1D short carbon fibres for acoustic shielding. Specifically for shielding, a lower degree of deagglomeration resulted in an enhanced functional performance by a factor up to 7, for which shear mixing offers an effective strategy to retain agglomerates as local scattering ‘defects’. Therefore, this benchmarking study demonstrated the crucial need for a combined microstructural and functional characterisation to achieve a truly optimised filler dispersion procedure for particulate composites.

#904

# SMC goes full circle: From characterization and numerical simulation of compression moulding to end of life recycling

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The compression moulding of SMC materials is an intricate thermomechanical process. During compression, the SMC undergoes complex flow and heat exchanges, while curing reaction progresses. As a fibre suspension material, SMC exhibits non-Newtonian behaviour that depends on temperature and time, due to curing reaction and viscosity variation. And, in addition to process temperature, the exothermic curing reaction is also a heat source. Despite its complexity, numerical simulation is a powerful tool for optimizing the compression moulding of SMCs and predict, among others, weld lines, cavity filling, fibre orientation and later distortions, minimizing waste by decreasing trail-and-error experiments and defected products. Also, as a non-recyclable material, SMC products face limitations on the use of landfills to be discarded due to environmental concerns, and its heterogeneous composition requires complex methods of separation. Thus, the reuse of SMC in new products is viewed as a viable solution.

In this work, the methodology followed for the SMC properties characterization, particularly, curing kinetics and viscosity, are described. Both properties are validated, through experimental compression tests and numerical simulation, which are correlated by image analysis. The validated properties are then used as inputs in the numerical simulation of SMC compression moulding. The optimization of the production process of a case study, an electrical junction box, is performed to minimize product defects and waste. To complete the circle, this project worked on the incorporation of industrial SMC waste into thermoplastic matrices for the injection moulding process, enabling the reintroduction and reuse of an otherwise landfilled material as components of electrical junction boxes. Various formulations were manufactured and tested, with incorporations of 30 – 50 % of SMC waste and different compatibilizers. The processibility of the developed formulations was assessed, as well as their mechanical properties (tensile, flexure and Charpy impact).

#905

# A Stripe Pattern approach to generate a semi-realistic models of Variable Stiffness Composite laminates obtained through AFP

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The generation of semi-realistic models of variable stiffness composites (VSCs) is an important challenge to better identify the gap between idealised numerical models issued from design strategies and real manufactured parts. VSCs are promising materials because they allow the fibre reinforcement to be placed along optimized curved trajectories, improving local mechanical performance where it is most needed. However, the mechanical behaviour of VSCs is strongly influenced by the manufacturing process as well, which introduces defects, singularities, and local variations of stiffness that are difficult to predict. Automated Fibre Placement (AFP) is an advanced manufacturing process wherein multiple narrow tows of fibre-reinforced tape are deposited onto a mould surface by a robotic head. This technique allows precise control of fibre orientation and enables the production of complex, high-quality composite laminates. In the present work, to generate semi-realistic models of the AFP-manufactured composite, the stripe-pattern method [1] is used to generate spaced trajectories that naturally follow an input angular field. The curves extracted from the stripe-patterns are subsequently used to define the narrow fibre tows as two-dimensional elements using a B-spline formulation.

The narrow fibres tows are later imported into Ansys through PYACP to model the composite structure in Python environment and to provide access to the main features of Ansys Composite PrepPost (ACP) The main results of the mechanical simulations on the numerical model have been compared to experimental data to validate and calibrate the mechanical properties of the characterised material within the semi-realistic numerical model. [1] K. Crane, Stripe Patterns on Surfaces, Carnegie Mellon University, 2015. Available at: https://www.cs.cmu.edu/~kmcrane/Projects/StripePatterns/

#907

# Predicting size effect on compressive failure in blunt notched multidirectional laminates with a semi-discrete progressive damage model

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The current work investigates size effects on compressive failure in sharp-notched (centre-notch) and blunt-notched (open-hole) multidirectional fibre-reinforced composite laminates, with emphasis on how specimen geometry influences strength and failure mechanisms. Although small-scale specimens are widely adopted for characterisation, neglecting geometric scaling parameters such as notch size and laminate thickness can lead to non-conservative strength predictions. To address this issue, a high-fidelity finite element framework is developed that integrates key damage mechanisms including fibre kinking, matrix cracking, and delamination. A kinematically enriched two-scale constitutive law for fibre kinking is used, wherein localised kink-band deformation is distinguished from the surrounding bulk response using a dedicated kinematic enrichment. This is combined with a mesh-independent semi-discrete crack formulation for matrix cracking, while an automated failure mode-selection criterion determines whether fibre kinking or matrix cracking initiates based on the evolving stress state. Using this methodology, the compressive failure response is simulated for both sharp- and blunt-notched laminates, revealing distinct scaling effects associated with different laminate architectures. Sublaminate-scaled laminates predominantly exhibit brittle behaviour with minimal delamination, whereas ply-block-scaled laminates exhibit significant delamination and fibre push-out due to strong interlaminar interactions. Increasing laminate thickness improves compressive strength by enhancing buckling resistance, particularly in ply-block configurations containing multiple central 0° plies, while sublaminate-scaled configurations show negligible thickness influence. In-plane scaling demonstrates the opposite trend, where increasing in-plane dimensions reduces compressive strength; however, ply-block laminates remain comparatively stronger due to delayed kink-band evolution and improved energy dissipation. In centre-notched laminates, highly localised notch-tip deformation introduces a notch-blunting effect driven by matrix cracking, which delays fibre kinking and results in higher compressive strength than open-hole configurations. Overall, the proposed modelling framework successfully captures the experimentally observed scaling effects influenced by the complex interaction of damage with specimen size.

#908

# Impact localization by P(VDF-TrFE) piezoelectric nanofibers scaled up from coupons to real components

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Composite materials, renowned for their high stiffness to weight ratio, offer significant mass reductions. However, their laminar architecture makes them vulnerable to barely visible impact damage, such as delamination and matrix cracking, which can drastically degrade fatigue performance and trigger unexpected failure. Consequently, designers often rely on conservative safety factors, limiting the potential for weight savings. Structural Health Monitoring (SHM) techniques enable real-time assessment of structural integrity, permitting the design of components with lower safety factors without compromising reliability. Nevertheless, the embedding of discrete sensors, a key component of the SHM chain, introduces material discontinuities that can reduce the mechanical properties of the host laminate.

To address these challenges, this work proposes a nanostructured piezoelectric sensor fabricated from P(VDF-TrFE) nanofibers with carbon fibre prepreg electrodes, designed to minimize the mechanical impact on the host component. The sensors are co-laminated into recycled carbon fibre prepreg components and are capable of capturing elastic waves propagating within the material, enabling the detection and localization of impact events. Impact source localization is achieved by combining a Time Difference of Arrival approach with Gaussian Process regression, producing a probability map that identifies the most likely impact location.

To evaluate localization performance, sensors were co-laminated onto a composite battery pack casing. Preliminary tests were also conducted on a coupon plate and a module subcomponent to assess the scalability of the proposed solution. Furthermore, the mechanical impact of sensor integration was compared to that of commercially available PZT disks and virgin samples. This analysis demonstrates the scalability of the methodology, showing that the proposed sensor effectively transforms complex real-world components into smart structures capable of self-monitoring, while causing minimal impact to the mechanical properties of the virgin laminate.

#911

# Electrospun PA12 nanofibrous membranes as interleaves in CFRP laminates

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The replacement of metals with carbon fibre reinforced polymers (CFRPs) has become increasingly common in lightweight structural components. Nevertheless, delamination remains one of the major limitations, and it adversely affects the performance and reliability of these materials in structural applications. Interleaving electrospun nanofibrous membranes between plies is a promising strategy to improve interlaminar properties. Most available research on electrospun nanofibrous interleaves has focused on polyamide 6 and 66, while polyamide 12 (PA12) has been investigated only in a limited number of studies, and its role in controlling delamination behavior in CFRP laminates has not yet been clarified.

In this work, PA12 nanofibrous membranes are produced via electrospinning technique from solutions with different polymer concentrations, and electrospinning parameters are varied with a focus on controlling humidity during processing. The solvent system was also optimized to obtain the best compromise between polymer dissolution, processability and solution stability. The influence of solution and electrospinning parameters on fibre morphology is investigated by scanning electron microscopy (SEM), which is used to evaluate fibre diameter, surface appearance and mat structure. Variations in concentration and humidity result in significant changes in fibre diameter and surface morphology.

The PA12 nanofibrous membranes are interleaved within epoxy-based CFRP laminates during the lamination step, which are designed to undergo delamination tests to assess their effect on interlaminar fracture toughness. By correlating solution parameters, electrospun morphology and delamination resistance, this study aims to clarify the specific role of PA12 nanofibrous mats when interleaved into epoxy-based CFRP laminates, thus evaluating their potential ability for hindering delamination.

#912

# Manufacturing of carbon-fiber-reinforced boss elements for energy storage in space applications

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Pressure vessels in the space sector serve a broad range of critical functions, including the storage of fuels and oxidizers, the provision of pressurized gas, and the operation of reaction control systems. Current research efforts increasingly focus on the development of Type V pressure vessels to enhance both volumetric and gravimetric efficiency. Boss elements represent essential components of all pressure vessels, as they interface with valves, sensors, and other system hardware. Conventionally, these elements are manufactured from metallic materials through machining processes.

This study investigates the manufacturability of composite boss elements, thereby supporting the development of novel Type V pressure vessel configuration composed entirely of carbon-fiber-reinforced polymers (CFRP), in order to further increase storage efficiency. To manufacture these boss elements, Sheet Molding Compound (SMC) and pre-impregnated material were selected and processed using compression molding in a hot-press setup. In this context, hybrid boss concepts that combine different material systems were examined.

Depending on the material combinations, manufacturing parameters, and component thickness distribution, key characteristics such as void content and resin distribution were identified and analyzed. The findings provide insights into the feasibility, manufacturability and performance potential of CFRP boss elements for next-generation pressure vessel systems in space applications.

#916

# Effects of manufacturing on the microstructure and mechanical performance of hybrid composites

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The implementation of structural composite materials in the aerospace sector has enabled only modest weight savings. The complex phenomena observed in these materials and the limitations of the current analysis methods lead to the adoption of conservative configurations, resulting in a highly restricted conventional design space. Additionally, recent manufacturing technologies (fibre placement, fibre co-mingling) provide additional flexibility in structural design, which can only be fully exploited if the links between processing parameters and structural performance are well known.

In this context, hybrid composite materials – where different types of carbon fibres reinforce a polymeric matrix – have emerged as a promising non-conventional option, with the potential to enhance the behaviour of composite structures. However, this is currently hindered by the lack of a well-established formal relation between the hybrid architecture (interlayer, interyarn and intrayarn) and the corresponding manufacturing process with material properties and structural performance.

This work presents a study of the effects of two hybridisation techniques – interlayer and intrayarn – and of two manufacturing processes – hand lay-up and automated fibre placement – on the microstructure and mechanical behaviour of hybrid composites. HR40 and T800 fibres embedded in TP402 epoxy resin are used as the baseline thin-ply materials. Computed X-Ray Microscopy with micrometre-level resolution is used in combination with Artificial Intelligence-based segmentation to identify the main features of the microstructure, in particular fibre dispersion and damage precursors. Mechanical tests performed in representative coupons highlight the main differences in the properties resulting from the different hybridisation and manufacturing techniques employed.

Findings provide a solid foundation for a methodology that will link the scales of composite materials and enable the credible implementation of non-conventional configurations, supported primarily by numerical models.

#917

# Yarn-Level Contact Morphology and Frictional Response under Pretension in Flax/PA12 Woven Fabrics

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Inter-yarn friction critically governs deformability, defect formation, and load-transfer pathways in textile composite preforms. However, its mechanistic origin remains poorly resolved in natural fiber systems, where irregular, morphology-driven contact conditions deviate significantly from classical circular or Hertzian assumptions. In hybrid flax/PA12 woven fabrics, the staple structure and intrinsic surface variability of flax yarns generate non-axisymmetric, spatially evolving contact interfaces that challenge conventional friction models. This study develops a geometry-resolved contact formulation that quantitatively links pretension, yarn morphology, and frictional response across different weave architectures. High-resolution SEM imaging was employed to reconstruct interlacing regions, enabling the derivation of a saddle-shaped contact surface that captures the inherent warp–weft interaction geometry. The model describes pretension-mediated evolution of real contact area and shear resistance, revealing a competition between yarn straightening and friction. Validation against yarn pullout experiments demonstrates strong predictive capability for macroscopic friction forces and architecture-dependent stick–slip characteristics, with plain weave exhibiting the most stable frictional regime. The proposed framework offers a physics-grounded interpretation of friction mechanisms in natural-fiber textiles and establishes a quantitative pathway for optimizing the forming behavior of sustainable composite preforms.

#918

# Transverse mechanical behavior of unidirectional composites under extreme low-temperature conditions

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Carbon-fiber/epoxy (CFRP) laminates are ideal for the design of structures operating at cryogenic temperatures due to their mechanical properties–to–weight ratio. Transverse stiffness, strength, and damage evolution govern the structural response and long-term reliability. As a result, composite materials used in extremely low-temperature environments—such as cryogenic systems and aerospace applications—are of particular interest. However, the design data available for unidirectional (UD) laminates at low temperatures are largely derived from laminate-level tests, limiting the ability to assess the influence of constituent properties and fiber–matrix interfaces.

Quasi-static transverse tensile tests were performed on unidirectional AS4/8552 specimens, machined at 90° and ground from 3-mm AS4/8552 panels into a “dog-bone” geometry, to evaluate their transverse response. The specimens were tested at room temperature, −70 °C, and −150 °C using a climatic chamber capable of combining dry ice and liquid hydrogen in a controlled manner to achieve stable thermal conditioning. Strains were measured using HBK-C Series Strain Gauges bonded with M-BOND-610-1 adhesive, both designed for cryogenic environments. Two thermocouples-one attached to the specimen, and another placed inside the chamber—were connected to a portable datalogger to continuously record the temperature and verify that the target conditions were maintained throughout testing. The experimental results show a dependence of transverse tensile strength on temperature, as well as noticeable changes in transverse stiffness across the different temperature levels tested.

The experimental results are complemented by finite element models based on computational micromechanics in ABAQUS/Standard, enabling the evaluation of constituent-level parameters and their impact on the macroscopic behavior. The proposed framework offers a systematic approach to connect the temperature-dependent micromechanical response with the overall performance of the material. Ongoing work focuses on refining the numerical models and validating them against the experimental data to establish a robust methodology for the low-temperature design of CFRP components.

#919

# Development and implementation of topology optimization techniques for unidirectional composite materials

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Topology optimization has emerged as a computational design tool for optimizing material distribution within a given design space to improve structural performance and reduce weight for any type of geometric configuration. However, the principal developments in the field of topology optimization have always focused on conventional materials, which can be easily approximated as isotropic materials. Meanwhile, composite materials have been increasingly introduced in aerospace applications due to their inherent advantages for lightweight applications, such as their high specific stiffness and strength, but their complex anisotropic behavior presents unique challenges for conventional optimization methods, because not only can the material distribution be optimized, but the fiber orientation can also be optimized in order to enable the full potentiality of the unidirectional composite materials.

This work focuses on developing and implementing a topology optimization formulation specifically tailored for unidirectional composite materials, using Abaqus® FEM software to support the base structural analyses. The optimization approach was developed for the purpose of enabling both topology and fiber orientation optimization of each element of a structure. The results show that using the strain energy as the objective function, with total mass and/or maximum failure criteria acting as constraints, it is possible to obtain design solutions with better material distributions compared to a pure conventional isotropic approach. The composite material utilized throughout the study is the continuous carbon fiber reinforced Onyx® used with the Markforged® Mark Two 3D printer; however, the proposed optimization framework is not limited to additive manufacturing only.

#920

# Light-driven pnipam/gold nanoparticle hydrogel nanocomposites for biomedical applications

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Significant efforts have been devoted to develop light-driven hydrogel nanocomposite actuators for biomedical applications, as light stimuli offer a safe, non-contact, rapid, and spatially precise control mechanism suitable for in vivo environments [1]. However, these systems still face key limitations, including shallow light penetration and slow response times. Herein, we present a single-material 4D-printing strategy implemented via stereolithography (SLA) using gold-nanoparticle-doped P(N-isopropylacrylamide) (PNIPAM), a temperature-responsive hydrogel that undergoes a volume phase transition near its LCST (≈32 °C) in aqueous media [2,3]. Gold nanoparticles (AuNPs) synthesized via the inverse Turkevich method were accordingly incorporated within 3D-printed PNIPAM cylinders (solid and porous) to endow light absorption around 532 nm and efficiently convert the absorbed light into heat, allowing rapid light-triggered volume change. While the solid cylinder endows a temperature increase from 22.8 °C to 70.9 °C within 12 s of illumination (532 nm, 0.5 W) and returns to ambient conditions within 12 s after the laser is switched off, a pronounced photo-induced shrinkage is recorded, achieving a shrinking ratio of 0.246 ± 0.18 . In contrast, pure PNIPAM solid cylinders without AuNPs doping exhibit no light-induced shrinkage, and their temperature increases by less than 2 °C within 1 min of illumination, confirming the essential role of photothermal doping. The porous structures further enhance light responsiveness by improving light penetration depth and internal heat propagation, resulting in more efficient volume shrinkage. Overall, this light-responsive hydrogel nanocomposite demonstrates strong potential as a versatile soft actuator platform, particularly for supporting miniaturized imaging devices navigating endoscopic pathways.

#922

# Polydopamine-Coated $BaTiO_3$ Nanoparticles and Annealing Effects on the Piezoelectric Response of Composite Nanofibers at High-Frequency

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As the demand for high-performance materials in energy-harvesting applications grows, the transition to polyfluoroalkyl substance (PFAS)-free piezoelectric materials has become increasingly important. Despite the excellent piezoelectric performance of PVDF (polyvinylidene fluoride) and its widespread use in renewable energy systems, environmental concerns have been raised due to its classification as a per- and PFAS. These “forever chemicals” pose significant environmental hazards, prompting a shift toward more sustainable polymer alternatives.

This study investigates the piezoelectric response of PFAS-free composite nanofibers in high-frequency by integrating polydopamine (PDA)–coated Barium titanate ($BaTiO_3$, BT) nanoparticles into a polymer matrix and applying annealing treatments at various temperatures (80, 100, 120, and 140 °C) for 90 min. The composite nanofibers were fabricated using electrospinning, with PDA-coated BT nanoparticles dispersed in poly(3-hydroxybutyric acid-co-3-hydroxyvaleric acid) (PHBV) as a biodegradable and biocompatible piezoelectric polymer.

The effects of nanoparticle coating and annealing on the crystallinity, morphology and electromechanical properties of the composite nanofibers were systematically examined using X-ray diffraction (XRD), differential scanning calorimetry (DSC), Fourier-transform infrared spectroscopy (FTIR), and scanning electron microscopy (SEM). After annealing at 100 °C for 90 min, under compression test, the piezoelectric output increased by 50%, reaching approximately 30 mV while tensile strength enhanced 113%. The PDA coating improved nanoparticle dispersion, while annealing promoted crystallinity, collectively enhancing the piezoelectric response.

The core–shell nanofiber composed of a piezoelectric polymer (PDA-coated BT@PHBV) as a shell with Rhodamine B (simulated drug) as the core was fabricated to evaluate on-demand drug release. Under a vibration frequency of 33 kHz, the release rate constant (k) reached to a higher value of 0.02 $min^{-1}$ and demonstrated reduced drug leakage compared with the core–shell nanofiber without PDA coating and the annealing process. These findings highlight the potential of PHBV composite nanofibers for sustainable and high-performance piezoelectric polymers for drug-delivery applications.

#923

# Numerical modelling of plant fibre-based insulating walls: integrating X-ray tomography and finite element method for thermo-mechanical behaviour prediction

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Keywords: sustainable bio composite construction, plant fibre-based insulating wall, thermo-mechanical behaviour, 3-phases numerical modelling, decision support tool.

The construction industry is responsible of nearly 37% of CO2 global emissions. The use of bio-derived materials as concrete gains a lot of interest in the research field as they offer long-term sustainability to buildings while maintaining optimum thermo-mechanical performance as an insulating wall. However, a numerical model where each phase of biobased concretes – fibres, binder and pores – is represented with its actual geometrical features remains renowned to the best of our knowledge.

The particularity of this study is precisely to develop and enable an original numerical protocol to predict the behaviour of plant fibre-based insulating walls. The most accurate representation of the complex shapes of each phase and its properties is carefully considered.

First, lime-hemp concretes formulated with Tradical Thermo® (lime) and Technichanvre C020® (hemp shiv) were implemented.

Then, X-ray tomography on a sample was performed to obtain the biobased concrete's real three-dimensional structure.

Finally, the three-dimensional structure of the biobased concrete considering the three phases – fibres, binder and pores - was meshed (element types: C3D4 and DC3D4). A finite element method was conducted using Abaqus® software to simulate and predict the thermo-mechanical response under compression and heat flux of the bio-derived composite.

Meanwhile, the developed numerical model was fed with thermo-mechanical characteristics data of each constituent – fibres, binder and pores. Thermal and mechanical experiments were performed and compared with numerical results of the bio-derived composite.

The obtained results will enable the development of a decision support tool for the buildings professionals who use the bio-derived and sustainable composites.

#924

# Rapid Inspection of GFRP Composites leveraging Digital Tomosynthesis: A Comparative Performance Study with X-ray CT

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Glass-fibre reinforced polymer (GFRP) composites are widely adopted in wind-energy, aerospace, automotive, and civil-engineering for safety-critical components due to their high strength-to-weight ratio, durability under severe environments, and tailorability. Use of mock-fibre (spread-tow) in GFRP-pultrusion ensures strong fibre-matrix interface through uniform wet-out (resin-impregnation) around individual filaments thereby reducing defects. Nevertheless, ensuring structural-integrity demands comprehensive defect detection. Conventional NDT techniques have drawbacks: ultrasonic-scanning suffers from poor penetration, shadowing, and inter-ply signal loss, while high-resolution X-ray computed tomography (XCT), though effective in flaw characterization, remains costly and time-consuming, restricting its use for industrial inspection.

Digital Tomosynthesis (DT), an emerging X-ray technique, offers a cost-effective solution for near real-time volumetric inspection, addressing many limitations of XCT. Currently, there is a gap in systematic studies comparing XCT and DT across a spectrum of GFRP-geometries—e.g., solid/hollow profiles with square and circular cross-sections, dog-bone shape—despite their prevalence in critical applications e.g., turbine-blades and its root-assembly. This study assesses the effectiveness of DT for GFRP inspection by analysing spatial resolution, signal-to-noise and contrast-to-noise ratio, scan-time, and computational demands by comparing images of identical slice-positions from both XCT and DT across varied real-world samples having flaws e.g., crack, void, crease, resin-deficient regions etc.

Despite a moderate loss of Z-direction resolution and out-of-plane blur in DT, reliable flaw-detection in a range of profile-geometries is demonstrated within 3–5 minutes. Analysis included detection-sensitivity (true/false positives), morphology, and geometry-dependence of artifacts. Moreover, a virtual DT-model is developed leveraging the open-source Tomosipo and ASTRA-toolbox to accelerate meshless-reconstruction and identify the origin of the artifacts. Optimization strategies are proposed to minimize artifacts and align DT-acquisition with practical considerations: X-ray path-length vis-a-vis sample aspect-ratio, GFRP's inherent image-contrast, limited-angle acquisition, and industrial throughput constraints. For high-quality GFRP manufacturing, speed, and adaptability of DT position it as the fit-for-purpose NDT-contender for inline integration, despite the image-quality trade-offs.

#925

# Fatigue performance of stepped lap composite joints reinforced with metal Z-pins

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Due to the high peel and shear stresses arising at the joint edges and the inherent low transverse strength of laminated composites, composite joints are highly prone to delamination failure. To improve their strength and fracture toughness, various toughening strategies have been proposed. Among these, z-pinning, which involves inserting thin metallic or fibrous pins through the thickness of an uncured laminate, has proven effective in enhancing the static strength of various composite joint configurations. However, less effort has been devoted to assessing the effect of z-pinning on the fatigue response of lap joints, especially when unconventional pin shapes are considered. Moreover, most of the investigated reinforcing patterns consist of comprehensive pinning across the overlap region. The resulting high pin densities may reduce the composite tensile strength.

This study examines the fatigue performance and the damage progression of stepped lap composite joints selectively reinforced with conventional and staple-shaped metal z-pins. The joints were manufactured with a cross-ply layup and bonded with an overlap length of 40 mm. Before curing, some panels were selectively reinforced with stainless-steel z-pins. The pins, cut from a continuous stainless-steel wire of 0.5 mm diameter and then staple-shaped by plastic deformation, were inserted into pre-punched holes aligned in four rows straddling the joint line and located at 5 mm from the joint edges. Experimental results indicate that the debonding, which starts at the joint edges and propagates along the joint interface up to complete adherends separation, governs the ultimate failure of both unpinned and pinned joints. Pinned joints, particularly those reinforced with staple-shaped pins, exhibited fatigue lives that were significantly longer than those of unpinned joints. Thus, the selective insertion of Z-pins near the edges of the joint is capable of effectively slowing down the growth of the debonding crack that ultimately leads to final failure.

#926

# Bio-inspired 3D-printed wearables for shock absorption

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A major challenge in sports injury prevention is creating textiles that provide protection against impact, but do not restrict movement and stay breathable, ensuring that athletes will wear them even during low-intensity training. In this work, shock-absorbing patches inspired from heavy fruits, such as jackfruit (Artocarpus heterophyllus), durian (Durio zibethinus), soursop (Annona muricata) and sugar apples (Annona squamosa), are developed. The hierarchical structure of these natural systems, and particularly their protective skin, is studied using synchrotron X-ray imaging. Based on macro- and microstructural knowledge gained from these natural systems, several spike-inspired geometries with and without porosity are 3D-printed via PolyJet with Vero acrylic resin directly onto cotton woven textile. The absorption capability of these patches is measured and benchmarked against commercial counterparts made of polyurethane/polyborodimethylsiloxane on knitted polyamide/elasthane at 25 J and 50 J of impact, according to the cognate ISO 1621-1 standard for motorcycle wearables. Our results indicate that at 25 J, the non-porous designs with the highest spike-base width-to-height aspect ratio exhibited the best performance, minimising the force transmitted to the anvil by 42% compared to commercial samples. As a limit case of this trend, an impact test on a flat square pattern resulted in a 71% decrease in performance, underscoring the critical role of the spike geometry. The contribution of material viscoelasticity and architecture in the impact performance is further investigated by replicating the commercial design, composed of a thin hollow diamond pattern, using the 3D-printed matrix. Although the initial impact performance was comparable, the 3D-printed matrix fractured at a diamond edge on the second strike. This suggests that the spike pattern is more effective at redistributing forces from the tip to the base, thereby reducing stress concentrations. Such a bio-inspired structural approach presents a promising route toward lightweight, flexible, durable, and athlete-friendly natural-fibre protective textiles.

#927

# RTM Co-Infiltration of Continuous Fiber Composites Using Two Epoxy Matrix Systems: Process Control and Interphase Analysis

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This study examines RTM proces two thermosetting epoxy matrices that are co-infiltrated into a continuous fiber-reinforced architecture to generate property-specific zones within a single structural component. The focus lies on hydrogen-electric propulsion systems for aviation in which radial-flow motors exhibit strong thermal gradients. Warm regions near coil packages and cold regions influenced by hydrogen-based cooling impose conflicting requirements on one composite part. The work investigates whether processing with two matrix systems is feasible and controllable and how this affects mechanical and structural behavior.

The investigation establishes methods for controlled co-infiltration. A substructure with contrasting thermal and mechanical demands is selected and transferred to a planar RTM specimen geometry. Preliminary tests examine phase transition behavior between the two resins and define boundary conditions for subsequent process development. An adapted RTM tool with a glass window enables direct observation of flow fronts and interphase formation. Zoned heating adjusts local resin viscosities to steer infiltration. Post-process optical monitoring and microscopy characterize interphase morphology and curing interactions. Tensile tests quantify interphase strength and support correlations between process parameters and local mechanical response.

The study builds on concepts from Krollmann's hybrid matrix processing and extends process control through broader material characterization. The research program covers resin system evaluation, definition and execution of a co-infiltration test setup, manufacturing trials, and structural assessment. The results identify potentials and limits of simultaneous infiltration of contrasting matrices, determine parameters governing stable interphase formation, and derive recommendations for aviation-grade multi-matrix components with spatially resolved functional requirements.

#928

# Experimental investigation of the vibrational characteristics of 3D printed biocomposite sandwich beams with periodic cores

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Abstract

In this work, the possibility of leveraging 3D printing to manufacture PLA-Flax short fiber sandwich beams with periodic cores is explored. The main objective behind the implementation of such structures is to reduce vibrations through band gaps. Several samples, defined by periodic PLA-Flax cores incorporating patches of a different material and covering the entire beam width, were made using the additive manufacturing process in 3D printing by wire deposition (Fused Deposition Modeling or FDM). Three distinct material assemblies were studied. The first assembly's core was made solely of PLA-Flax patches with empty spaces between them, while the other two each incorporated patches made from a different elastomer material. The printed samples underwent a vibration test using an impact hammer in the fixed-free (cantilever) configuration. Two sets of sandwich beams were printed and tested. In the first set, the samples had three different combinations of materials but shared the same periodic core configuration while in the second set, the beams were made of the same material assembly but featured varying periodic core configurations. Two other samples, one fully made of PLA-Flax fiber and another with an entirely viscoelastic core, were also printed and tested to serve as a reference. Comparative analysis of the frequency responses of the printed beams has shown the presence of band gaps, where vibration velocities are significantly reduced. The results have also revealed changes in band gap characteristics depending on the properties of the patch material and the periodic core configuration, thus demonstrating potential for fine-tuning such structures to suit the targeted application. This research could possibly help pave the way for more thorough parametric studies.

Keywords: Biocomposite, 3D printing, vibrational behavior, sandwich structure, periodic core

#930

# Statistically Equivalent Microstructure Reconstruction of As-Manufactured 3D Unidirectional CFRP: From High-resolution X-Ray Micro-Computed Tomography to High-fidelity Fiber Network Architectures

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Understanding and accurately representing the realistic three-dimensional (3D) microstructural architecture of carbon-fibre-reinforced polymer (CFRP) composites is essential for predictive modelling of their structural behavior, damage evolution prediction, and optimizing manufacturing parameters. Recent imaging developments offer unprecedented insight into microstructural details such as in-/out-of-plane waviness and fiber curvature. Nevertheless, a comprehensive workflow that transforms such high-resolution data into simulation-ready 3D microstructural models is still absent, limiting predictive capabilities in composite design.

Consequently, this work proposes a complete pipeline for processing, modelling, and generating synthetic fiber microstructures consistent with X-µCT observations. Firstly, an analytical slice-segmental ellipse-intersection method is developed providing an extensive per-slice/per-fiber database of in-/out-of-plane misalignment profiles. Secondly, a stochastic probabilistic modelling phase is introduced to capture the per-slice orientation statistics and their evolution along the fiber depth direction. Per-slice angle marginal probability distributions are represented non-parametrically via empirical CDFs, ensuring the dependence of local directional misalignments with defined in-plane copula correlations. A latent autoregressive (AR) process along the fiber direction imposing smooth evolution of out-of-plane orientations, alongside rare high-misalignment motifs extracted and re-introduced during generation to mimic extreme misalignment events. Model hyperparameters are optimized using Bayesian search to match the original statistics with less than 5% error. Finally, using the calibrated modelling parameters, synthetic fibers are generated along the prescribed depth grid considering actual misalignments. In which, a non-overlapping placement scheme via Delaunay triangulation combined with random sequential adsorption, dynamic generation, and distance-based rejection is used. This enforces a statistical equivalence to as-manufactured cross sectional spatial packing and 3D fiber misalignment profiles.

Overall, the current framework models more than 2000 synthetic fibers across ~1 mm depth with RMSE values typically in the 5–10% range, demonstrating strong statistical fidelity to the original X-µCT data.

#931

# Plasma-enhanced interfacial bonding in FRP composites: Effects on fiber–matrix adhesion and dynamic mechanical response

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Fiber Reinforced Polymer (FRP) composites are effectively replacing traditional materials in various applications and remain a focus of intensive research. This paper explores the study of plasma-enhanced fiber-matrix interfacial bonding for three common reinforcing fibers: flax, glass, and aramid. Our plasma sources are developed and specifically designed to meet the rigorous demands of large-scale and rapid industrial production in the composite materials field. The generated plasma is of high density, allowing very fast and effective surface functionalization, even during extremely short exposure times - often a few seconds. Additionally, plasma generated in ambient atmosphere and at atmospheric pressure is a cost-effective and environmentally friendly method, comparable to traditional chemical surface treatment methods.

Plasma treatment was carried out using a Diffuse Coplanar Surface Barrier Discharge (DCSBD) system. Exposure to this type of plasma introduces functional groups onto the fiber surface, leading to a substantial enhances the fibers wettability, and the penetration of epoxy. Consequently, both chemical interactions and mechanical interlocking at the fiber–matrix interface are strengthened. These effects have been confirmed through contact angle measurements, chemical characterization, interfacial adhesion tests, and computed tomography.

This significant improvement may not lead to a noticeable increase in ultimate bending or tensile strength. Bending and tensile tests of laminates are generally not sensitive to fine changes at the interface; they are more influenced by macroscopic factors such as geometry, moisture content, and fiber orientation. However, the improvement was evident in the higher stiffness and mechanical stability of the material during cyclic deformation. Plasma treatment resulted in a substantial increase in the storage modulus (E’), indicating enhanced stiffness and load-bearing capability of the composites.

The plasma treatment of reinforcing fibers improved interfacial adhesion between the fibers and the matrix, allowing for more efficient stress transfer and reducing the extent of viscoelastic deformation under dynamic loading.

#932

# Recycling of carbon fibers employing debonding on demand approach in composite structures

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Carbon fiber reinforced epoxy composites are utilized in various industrial applications due to their promising characteristics such as high strength, low density, chemical and thermal resistance, and so on. However, the increased utilization of composites and their limited lifetime result in a significant number of end-of-life composites and leftovers. In the current study, a debonding-on-demand method using flame-retardant particles as a debonding agent is employed to recycle carbon fibers from their thermoset epoxy matrix in structural composites. The debonding agent particles (flame retardants) are incorporated into an epoxy matrix, which is then used to produce carbon fiber-reinforced composites through the vacuum-assisted compression molding technique. Under normal usage conditions, the flame retardants remain inert, ensuring that the debonding agent modified composites retain their structural integrity and mechanical performance. When the composites are subjected to heat, the debonding agents are activated, releasing inert gases and causing physical changes in the composite matrix. This process allows for the effective separation and recovery of carbon fibers at lower temperatures compared to non-modified reference composites. After the debonding step, the recovered carbon fiber layers undergo acetic acid-based mild chemical cleaning to remove epoxy residues from their surfaces, resulting in fully reusable recycled carbon fiber fabrics. These recycled carbon fiber fabrics are then used to produce a recycled composite. To assess the performance characteristics of the reference, modified, and recycled composites, flexural and dynamic mechanical analysis (DMA) tests are conducted. Modification of composites by the debonding agent proves its efficiency for structural applications by maintaining their mechanical performance under usage conditions, while recycled composites show that the recycling method does not have a negative effect on the structural properties of carbon fibers.

#933

# Recycled Poly(butylene succinate) (PBS)–Cellulose Fibre Biocomposites: Processing Optimisation for Fused Granulate Fabrication (FGF)

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The transition toward low-carbon materials is driving strong interest in bio-based and recyclable alternatives to conventional composites. Within this context, this work, developed under the Italian National CellBioReComp project, investigates recycled poly(butylene succinate) (PBS) biocomposites reinforced with short cellulosic fibres for large-scale Fused Granulate Fabrication (FGF). The aim is to provide a low-footprint, recyclable alternative to current solutions, while improving mechanical performance and dimensional stability.

PBS, after undergoing intensive reprocessing to simulate thermomechanical recycling, was compounded with 5–15 wt.% cellulosic fibres (aspect ratio ≈10) using a semi-industrial twin-screw extruder. The resulting pellets were directly processed via FGF, thus avoiding filament fabrication and associated issues such as diameter instability and increased production costs. Processing parameters were optimized to mitigate PBS shrinkage, inherently high due to its rapid crystallization rate. The addition of cellulosic fibres partially reduced shrinkage, although a brim and adhesive coating were required to ensure proper bed adhesion. Mechanical, morphological and thermal characterizations were performed to assess stiffness, strength, impact resistance, porosity and interlayer adhesion. Tensile and flexural moduli increased with fibre addition, confirming the reinforcing effect of cellulosic fibres; however, similar flexural stiffness was observed for 10 and 15 wt.% composites due to the significant increase in porosity (from 2.77% at 5 wt.% to ~6%). Impact properties decreased with fibre content because of stress concentration around the fibres, though PBS with 5 wt.% cellulosic fibres retained higher impact resistance than typical PLA grades used in FGF. SEM analyses revealed homogeneous fibre dispersion and excellent interlayer adhesion across all formulations. The incorporation of cellulosic fibres enhanced thermal and dimensional stability, demonstrating their effectiveness as a bio-derived filler.

Overall, these recycled PBS/cellulosic fibre biocomposites represent a promising class of sustainable materials for additive manufacturing, combining biodegradability, improved stiffness, and tunable properties aligned with circular-economy principles.

#934

# Natural Material WrapToR Trusses For Civil Engineering Applications.

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The Wrapped Tow Reinforced (WrapToR) truss manufacturing process is a simple, scalable method for producing lightweight truss beams from composite materials. By winding a wetted tow around longitudinal members mounted on a rotating mandrel, WrapToR creates co-bonded truss beams without the need for assembly of many separate parts. The structural performance of WrapToR trusses has been investigated within the context of lightweight, high performance aerospace structures using advanced composite materials. This work considers the use of this efficient geometry and simple manufacturing process in the context of making natural material trusses for civil engineering applications. In this way, the performance added by the truss geometry can partially offset the lower mechanical properties typical of natural materials.

Bamboo is a composite-like material, taking the form of slender tubes comprised of tightly packed longitudinal fibres, providing high mechanical performance per unit weight. Bamboo also has potential sustainability, and affordability benefits due to its exceptionally fast growth rate, allowing for quick replenishment of supply. If paired with an appropriate natural fibre composite tow, fully natural material WrapToR trusses can be produced.

While WrapToR trusses have many potential applications as single truss beams, the technology will be more generally useful if multiple beams can be assembled to form a ‘truss of trusses’, or hierarchical space frame. These structures could be tailored to a variety of applications, potentially utilising a modular design approach. A simple portal frame has been designed to act as a ‘proof of concept’ for a multiple truss assembly. It consists of four WrapToR bamboo trusses joined using ‘chord to chord’ connectors at 90 and 180 degrees. This structure is then subject to mechanical testing, providing insight into the effectiveness of joining WrapToR bamboo trusses into larger assemblies, and to validate developed design and analysis methods for this type of structure.

#935

# The latest developments in grid structures for space applications

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In recent years, the composite grid structures have proven to be an excellent solution for developing highly efficient components capable of withstanding very high loads in the aerospace industry.

Their unique combination of high specific stiffness, load-carrying capability and excellent mass efficiency make them ideal candidates for spacecraft primary structures, satellite platforms, launch-vehicle and high-performance payload support.

The Grid structure consists of a regular and dense system of interlaced hoop and helical ribs (unidirectional carbon fiber reinforcement) that take advantage of the axi-symmetric shape to provide the required structural stiffness and strength, but with a much lower fiber volumetric fraction (except at the nodal intersections) and lower structural mass than for conventional applications of composite material.

Examples of flying grid structures are found in the Russian Proton, the Indian Geosychronous Satellite Launch Vehicle and the more recent European Interstage 2/3 of VEGA-C launcher, developed by CIRA in partnership with Avio.

In the last years, CIRA has developed design methods and manufacturing processes (patented) to realize these kinds of structures, based on automated parallel winding of dry carbon fiber tows and resin infusion. Thanks to these methods, in addition to the interstage of VEGA C, CIRA has also developed prototypes of space structures validated at high TRL, such as cone adapters for payloads, central tubes for satellites and boom segments for deployable antennas.

This paper presents the last developments on grid structures, showing the implemented design method and the innovative manufacturing approach to realize a 12-meter segment boom for a large deployable antenna and a long Central tube with a 0.8m diameter. These kinds of prototypes pose several challenges in terms of design and manufacturing issues since the stiffness-to-weight ratio and stiffness vs. thermal stability are taken to the extreme and the use of fragile ultra-high modulus carbon fiber is necessary.

#936

# A Bayesian approach to evaluate compliance-induced variability in single-fibre tensile tests

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Recycling of carbon fibre reinforced polymers has gained significant attention due to environmental concerns and the high cost of virgin carbon fibres. Among the various recycling methods, pyrolysis and chemical solvolysis are widely used for fibre reclamation, although alternative techniques are also under development. To optimize these processes, it is crucial to accurately characterize the properties of the recycled carbon fibres, typically at the monofilament scale, where fibres measure only a few micrometres in diameter. Tensile properties are an effective indicator of fibre performance. However, due to the small size of the fibres, obtaining reliable measurements is challenging. This is further complicated by epistemic uncertainties in the characterization procedure and the variability inherent to fibres, which is especially prominent in recycled fibres. It is therefore essential to reduce these epistemic uncertainties, which requires a clear understanding of their underlying sources.

This work focuses on a critical stage in mechanical tensile characterization – the evaluation of fibre elongation. Due to the small cross-sectional area of the fibres, elongation is typically inferred from the crosshead displacement during testing. To isolate the true fibre elongation, the parasitic elongation of the loading system, known as system compliance, must be reduced from the total measured elongation. While a few studies have addressed this issue, this work employs Bayesian statistical approaches to shed new light on the associated uncertainties. In particular, Bayesian bootstrapping makes it possible to construct credibility intervals, which offer a more informative representation of uncertainty than confidence intervals. The findings highlight the importance of accurate compliance measurement, as it significantly influences the final results and conclusions. Consequently, rigorous and appropriate procedures are essential.

#938

# High–Aspect–Ratio Discontinuous Galerkin Finite Elements for Efficient 3D Stress Analysis of Laminated Composites

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In the analysis of composite structures, one of the most severe modelling challenges arises at ply interfaces and free edges, where interlaminar stresses can drive delamination. Accurately resolving these three-dimensional stress concentrations with conventional solid finite element models rapidly becomes prohibitively expensive for routine industrial use. Thin plies extending over structural-scale spans force conventional low–aspect-ratio meshes into millions of degrees of freedom, so high-fidelity laminate analysis is often reserved for a few critical coupons rather than integrated into everyday design and optimisation.

This work investigates whether the full three-dimensional physics of laminated composites can be retained while paying only for resolution in the regions where stresses demand it. We develop a three-dimensional symmetric interior penalty discontinuous Galerkin finite element method (DG-FEM) tailored to orthotropic laminates on highly stretched hexahedral meshes. Refinement is aligned with laminate interfaces and free-edge regions, while the mesh remains deliberately coarse in parts of the structure governed by smoother global behaviour, thereby reducing the overall number of elements and unknowns.

The capability of the method is demonstrated in stages. An isotropic cantilever beam confirms optimal L2-norm convergence of the displacement field on elements with aspect ratios up to 22. Manufactured solutions with isotropic and orthotropic materials then show that tractions are transmitted correctly across layers with contrasting stiffnesses. Finally, a classical cross-ply free-edge laminate benchmark demonstrates that the DG-FEM reproduces established interlaminar stress distributions in excellent agreement with hierarchical conforming finite elements. This accuracy is achieved while using highly stretched elements with aspect ratios up to 40, leading to roughly an order of magnitude fewer degrees of freedom. Together, these results position high–aspect-ratio DG-FEM as an advanced computational tool that can bring mechanism-faithful 3D laminate stress analysis much closer to practical design workflows for industrial composite applications.

#940

# Effect of microcrystalline cellulose inclusion on a plasticized PVOH–PBAT blend system for packaging

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Poly(vinyl alcohol) (PVOH) is widely recognized for its biodegradability and film-forming properties yet is hindered by poor thermal processability. In previous work this limitation was mitigated by incorporating biodegradable plasticizers and blending PVOH with poly(butylene adipate-co-terephthalate) (PBAT), yielding a PVOH-rich composite exhibiting an ultimate tensile strength of approximately 29 MPa and a modulus near 1.1 GPa. To further enhance mechanical, thermal and barrier performance, microcrystalline cellulose (MCC) was introduced at 5, 10 and 20 wt%. MCC is a renewable filler derived from wood or cotton that is characterized by high stiffness and the ability to form hydrogen bonds with polymeric matrices. Comparable studies on PVA-starch and PBAT/TPS systems have shown that 5–6 wt% MCC increases tensile strength by 30–120 % and raises the tensile modulus by improving stress transfer from the matrix to the filler. In the present PVOH-PBAT system, the formulation containing 10 wt% MCC delivered the most favorable performance. Tensile testing indicated that the Young's modulus increased to around 1.67 GPa and the ultimate tensile strength to around 34 MPa. Flexural modulus and flexural strength approached 1.21 GPa and 36 MPa, respectively, meeting typical requirements for rigid packaging. These improvements are attributed to hydrogen bonding between MCC and polymer chains and to heterogeneous nucleation that promotes crystallinity. High PVOH content maintains gas-barrier properties, PBAT imparts toughness and biodegradable plasticizers facilitate melt flow. Incorporation of 5 wt% MCC provided only marginal gains, whereas 20 wt% resulted in brittleness and an ultimate tensile strength near 20.9 MPa, consistent with literature reports that excessive MCC leads to agglomeration, restricted chain mobility and reduced ductility. Optimizing MCC content in combination with biodegradable plasticizers yields PVOH-rich PBAT composites with a balance of processability, mechanical performance and biodegradability, making them suitable for sustainable packaging applications

#944

# A Study of Structural Safety of Korean Hyperloop Bogie Frame Structure

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In this study, a bogie frame structure of the Korean Hyperloop (HTX) was designed and analyzed. It uses superconducting magnetic levitation technology to propel and levitate. Therefore, lightweight technology is essential. To achieve this goal, carbon fiber composites and aluminum alloys were applied. Carbon fiber composites were used for the main load-bearing parts, and aluminum 6061 was used for the connections between composite components. The HTX's bogie frame must support the weight of the vehicle body and the superconducting electromagnets, as well as generate propulsion and levitation. To achieve this, Toray's T800 unidirectional carbon fiber with a [0/90] laminated structure was used.

To analyze the structural safety of the carbon fiber composite bogie frame, eight operating load conditions specified in the EN-13749 standard were applied during operation. Furthermore, support conditions were imposed during levitation using data on levitation and guidance stiffness generated by the superconducting electromagnets and the propulsion and levitation coils.

Structural safety analysis was performed to determine the Von-Mises stress in the aluminum parts and the Tsai-Wu index of the carbon fiber composite parts. Under driving conditions, the analysis results showed that the maximum Von-Mises stress in the aluminum components was 101.6 MPa, occurring at the wheel support. The maximum Tsai-Wu index in the carbon fiber composite components occurred at the bracket where the wheel is installed, and was 0.116, indicating a safe value.

Even under levitation conditions, both the aluminum and composite parts remained within the safety range.

Furthermore, fatigue strength was evaluated using the stress values obtained from the analysis and the Goodman diagram. This analysis showed that the aluminum and carbon fiber composite components remained within the fatigue durability curves.

#945

# Interfacial Behaviour of Unidirectional GF/PA6 under Solid-State Stamp Forming Conditions

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Solid-state stamp forming offers a cost-effective route for processing unidirectional fibre-reinforced thermoplastics (UD FRTPs) due to its short cycle time and low energy demand. Accurate characterisation of the interfacial behaviour, governed by debonding and inter-ply friction, is required to describe the deformation of UD FRTPs under solid-state stamp forming conditions. However, existing interfacial data are obtained using non-standardised test methods, and the debonding and inter-ply friction results reported in the literature come from different rigs and testing conditions. These inconsistencies prevent the direct use of available data as modelling inputs. This study investigates the debonding and inter-ply friction properties of unidirectional glass fibre reinforced polyamide 6 (UD GF/PA6) under solid-state stamp forming conditions. To accomplish this, a unified test rig was developed to characterise both mechanisms under controlled thermo-mechanical conditions. Identical definitions of temperature, normal pressure, loading rate and ply orientation were applied in both test modes to minimise rig-related variations and improve repeatability. The tests were conducted within a controlled window of 180–210 °C, 0.03–0.12 MPa and 5–500 mm/min. Debonding tests show that the interlaminar shear strength and crack initiation energy decrease with increasing temperature and pressure but increase with loading rate. Friction tests show that the static and kinetic friction coefficients decrease with temperature and pressure, remain nearly unchanged at moderate loading rates, and rise at high rates. Plies with aligned fibre directions give higher friction coefficients than orthogonal plies under the same conditions. This work provides a standard and repeatable method for characterising debonding and inter-ply friction in UD GF/PA6 under solid-state stamp forming conditions. The results supply the data required for subsequent constitutive modelling and process simulation research.

#946

# Influence of z-pin length on the synergistic mode I delamination behaviour of multi-scale toughened carbon fibre composites.

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Existing engineered composites, such as carbon-fibre reinforced plastics, contain one single dominant reinforcement, namely the fibres. By contrast, natural composites, such as wood, bamboo, and nacre, are multi-scale toughened. The aim of the present work is to investigate the effect of the length of aligned macro-scale carbon fibre/BMI z-pins, embedded through-the-thickness, and/or carbon nanofibers (CNFs) dispersed through the matrix, on the mode I delamination toughness of carbon fibre epoxy composites. Experimental testing and analytical modelling revealed that the mode I steady-state interlaminar fracture toughness of z-pinned specimens (z-pins at 0.5 vol.%) can be increased by ~75% and ~160% at an embedded length of 4 mm and 6 mm, respectively, when compared against a standard specimen with no toughening. The interlaminar fracture toughness increased with z-pin length due to the increased bridging traction response and loads generated by elastic stretching, debonding and shear-induced frictional pull-out of z-pins. Toughening the epoxy with a low 0.73 vol.% CNF content can yield a dual-scale synergistic mode I interlaminar toughening effect of 136% at an embedded z-pin length of 4 mm. Firstly, this is due to a combination of (a) intrinsic toughening mechanisms by the nano-scale reinforcements at the crack tip and (b) the large-scale extrinsic toughening from macro-scale z-pin pullout along the delamination crack path, as revealed in high magnification scanning electron microscopy. Secondly, the nanofibres increase the traction loads generated by the z-pins and interfacial frictional shear stress generated by strengthening the interface between the z-pin and the composite. However, at a longer embedded z-pin length of 6 mm with CNFs, the synergistic toughening efficacy decreases as the z-pins fracture rather than pull-out along the crack path. Thereby, interfacial shear friction stress decreases between the z-pin composite interface reduces the effective pull-out length of the pins as dictated from the analytical modelling framework.

#947

# Research on the Ablation Response Prediction Method for C/SiC Ceramic Matrix Composites

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Hypersonic vehicles flying in the atmosphere are exposed to extreme aerothermal loads. C/SiC composites, with excellent high-temperature strength and oxidation resistance, are widely used as ablative thermal protection materials. This work develops a three-dimensional numerical simulation method for aerothermal ablation on hypersonic configurations, with emphasis on the coupling among surface aerothermal loads, internal heat conduction, and the transition between reactive and inert oxidation of C/SiC. The surface input to the solid is expressed as an equivalent net heat flux obtained by combining cold-wall heat flux, boundary-layer recovery enthalpy, gas enthalpy at the actual wall temperature, mass-loss related enthalpy terms, and radiative exchange at the interface. This non-uniform net heat flux is mapped onto the structure surface using the ABAQUS Mapped Field capability. For material oxidation, reactive oxidation is described by an ablation model based on mass conservation and surface thermochemical equilibrium, yielding a dimensionless mass ablation rate that is converted into surface recession. Inert oxidation is controlled by oxygen diffusion through the protective oxide layer; a gas-transport model is used to compute the oxygen molar flux and the corresponding consumption of the carbon and SiC phases. The stability of the oxide film provides lower and upper bounds of oxygen partial pressure, which are used to distinguish reactive oxidation, inert oxidation, and their transition. On this basis, a fully coupled aerothermal–conduction–ablation procedure is implemented in ABAQUS: along a prescribed flight trajectory, aerothermal loads, transient heat conduction, oxidation-dependent surface recession, and mesh motion via UMESHMOTION are iterated to update geometry and temperature fields consistently. Validation against SiC ground ablation tests and hypersonic cone flight in the atmosphere shows good agreement in stagnation temperature, ablation depth, and ablation rate, demonstrating that the proposed platform is an effective numerical tool for the design and performance assessment of hypersonic thermal protection structures.

#948

# Multiscale Computational Design of Mycelium-Based Hierarchical Composites

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Designing next-generation aerospace materials requires approaches that integrate sustainability with performance across multiple length scales. Conventional 3D sandwich structures used in modern aerospace interiors deliver excellent strength-to-weight ratios but require large amounts of energy to produce, are difficult to recycle, and offer little functional grading for optimized designs. This motivates the exploration of alternative material systems that can be designed and optimized using multiscale computational mechanics. Engineered living materials (ELMs), composed of living cells, present a promising opportunity in this context. Fungal mycelium–based ELMs, in particular, exhibit hierarchical filamentous networks that enable high strength-to-weight ratios, resilience, and adaptivity. Their multiscale architecture makes them compelling candidates for computational modeling and design. In this work, we investigate fungal ELMs as sustainable alternatives to aircraft composite materials, with a focus on bio-based 3D sandwich cores. Starting at the microscale, we develop cellular automata–based models to capture fungal growth dynamics. These are upscaled to mesoscale behavior through a density-based hyperelastic composite model. Finally, we link the mesoscale description to a grain-size–based macroscale design framework, in which structural performance is maximized while minimizing weight. Together, these computational models inform the development of functionally graded granular fungal composites. By advancing both modeling methodologies and material concepts, this research demonstrates how multiscale computational mechanics can accelerate the integration of living materials into high-performance applications. More broadly, it presents a framework for bridging biological complexity with engineering requirements, enabling the systematic design of renewable and recyclable material systems for aerospace applications.

#949

# Probabilistic strength analysis of randomly arranged unidirectional fiber-reinforced composite plate under transverse tensile load with random field modeling of local apparent quantities considering uncertainties in matrix and interface strength

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Multiscale probabilistic strength analysis of random composites becomes an important topic for quantitative strength estimation and reliability design of composite structures. For this purpose, in addition to a conventional stochastic homogenization analysis, several reports on multiscale probabilistic analysis considering random spatial distribution of local apparent mechanical properties can be found in recent literature. For this analysis, probabilistic analysis of local apparent mechanical properties, such as the elastic modulus and strength, plays an important role in the randomness modeling.

For this purpose, a strength analysis with the random field modeling referring to an actual SEM image of a specimen was attempted, and the effectiveness of the approach for probabilistic strength evaluation of composites was discussed. In those reports, the random arrangement of fibers is considered as a random input, and the detailed influence of the other random factors such as material properties has not been investigated.

For this background, in this report, microscopic material properties such as the microscopic fracture criterion of resin and interface are also considered as random inputs, and probabilistic strength analysis of a randomly arranged unidirectional fiber reinforced composite plate under a transverse tensile loading with random field modeling of local apparent elastic property and strength is attempted. An experimental observation-based microscopic fracture criterion is employed in the analysis, and the random variation of the observed quantity is considered for the analysis. The influence of not only the degree of random variation but also of the assumption of probabilistic distribution on the estimated probabilistic properties of the composite plate is investigated.

From the numerical results, the influence of the microscopic uncertainty in those properties on the probabilistic properties of the apparent strength of the random composite is investigated, and their importance for the probabilistic strength analysis of composite structures will be discussed.

#953

# Compressive strength of self-healing vitrimer composites: Effect of the resin ductility and repairability

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In recent years, carbon fiber reinforced plastic (CFRP) employing vitrimers as the matrix has attracted considerable attention from the viewpoint of improving material circularity of composite structures. Vitrimers are a class of thermosetting polymers that contain dynamic covalent bonds within their crosslinked polymer network. Owing to the bond-exchange reactions associated with these dynamic covalent linkages, vitrimers exhibit self-healing capabilities like those of thermoplastics, while maintaining mechanical properties comparable to conventional thermosetting resins. However, the healing behavior depends not only on the healing conditions but also strongly on the damage scale and damage history, and its underlying mechanisms remain complex. On the other hand, CFRPs exhibit a significant reduction in strength under longitudinal compressive loading and show highly complex damage evolution, which often limits their applicability to structural components. A representative failure mode under longitudinal compressive loading is kink-band formation, a highly nonlinear process involving the interaction of multiple mechanisms such as the development of localized shear stress fields induced by fiber rotation, matrix yielding, matrix cracking, interfacial debonding, and ultimately fiber buckling. These phenomena indicate that damage progression is governed not only by fiber-dominated behavior but also by matrix-dominated mechanisms. Nevertheless, the effects of vitrimer matrices on the compressive properties of CFRPs, as well as on the evolution and healing of such damage modes, remain largely unexplored. In this study, the compressive mechanical response of an epoxy-based vitrimer containing dynamic disulfide bonds, whose bond-exchange reactions are activated by heating, is investigated. Previous studies have shown that incorporating disulfide linkages improves the ductility of the matrix, indicating the potential for enhanced compressive strength. In addition, healing process is applied before the specimen reaches the failure strain, and the influence of healing on the subsequent mechanical properties is evaluated.

#954

# Representative Volume Element Generation for Discontinuous Fiber Composites

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This research presents a method for the computational modeling of discontinuous fiber composites (DFC), materials made by randomly arranging fiber bundles in a polymer matrix. A common method of analysis uses reference volume elements (RVE), the smallest volume elements that can capture the macroscale behavior of the material. The most conventional approach is to use random sequential absorption (RSA), an algorithm in which a bundle position is chosen at random and the chip is checked against the preexisting bundles for intersections; if there are none, the chip is inserted, the process repeats until a stopping criterion is met. While a common approach in composites, RSA often encounters “jamming,” when chips are too loosely packed to achieve the volume fraction while additional bundles are unable to be placed without intersections.

This research uses a modified RSA algorithm to increase the volume fraction of the RVE. The bundles are initially generated as a 2D model where overlaps are allowed, but the number of overlaps are counted towards the total height of the RVE; the point with the most overlaps determines the maximal thickness of the RVE. The main generation of chips works similarly to standard RSA, except that instead of chips being entirely randomly placed, a batch of “potential” chips is created and the one that maximizes the packing efficiency is chosen and the rest are discarded. Excess chips are generated during the modified RSA algorithm; after, the set of chips is trimmed to meet the desired maximum thickness of the RVE. This 2D model is then inputted into the ABAQUS CAE finite element software; the chips are spread in the Z-direction to remove intersection, then are compressed to create the final RVE. This method leads to a significantly higher volume fraction without incurring jamming.

#955

# Sustainable Ni-plated S-glass/Vitrimer composites for electric vehicle battery housings with electromagnetic interference (EMI) shielding and enhanced flame retardancy

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Fiber-reinforced composites are increasingly replacing metals owing to their low density, high strength and stiffness, and excellent fatigue and corrosion resistance. However, most thermoset composites are non-recyclable and are typically discarded, making recycling essential under current environmental regulations. Thermoset recycling methods include mechanical, thermal, and chemical routes. Among them, thermal recycling through pyrolysis is most common but causes an 80–95% reduction in glass-fiber strength. Vitrimer resins, which contain dynamic covalent bonds, combine the advantages of thermosets and thermoplastics, enabling fiber reuse without mechanical damage. Epoxy-based vitrimers therefore offer a promising pathway toward sustainability and a circular composite economy. In electric vehicles, battery housings must ensure safety by providing effective EMI shielding and flame retardancy. In this study, sustainable flame-retardant composites with EMI shielding capability were developed using vitrimer resins reinforced with Ni-plated S-glass fibers and layered ammonium polyphosphate. The composites achieved over 99% EMI shielding efficiency. Flame retardancy was evaluated through limiting oxygen index (LOI), UL-94, and cone calorimeter tests. The electroless plated nickel layer on S-glass fibers acted as a catalyst for char formation, significantly improving fire resistance. Owing to these combined advantages, the layer-by-layer assembled Ni-plated S-glass/vitrimer composites present a promising new class of battery housing materials with EMI shielding and enhanced flame-retardant performance.

#956

# Design and Evaluation of a Sandwich Composite Radome Structure Using Frequency Selective Surfaces

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With the rapid growth of the space industry and the emergence of the New Space era, the importance of low Earth orbit (LEO) satellite constellations has been steadily increasing. However, onboard electronic devices remain highly vulnerable to radiation damage from high-energy protons and electrons, galactic cosmic rays (GCR), solar energetic particles (SEP), and harsh environmental factors such as atomic oxygen (AO), thermal cycling, vacuum, and ultraviolet exposure. This issue is especially critical for small satellites and CubeSats, which often rely on commercial off-the-shelf (COTS) components. While COTS offer advantages in reducing costs and enhancing performance, their low radiation tolerance significantly increases the risk of mission failure.

To address these challenges, this study developed a multifunctional radiation shielding sandwich composite using fused deposition modeling (FDM) of thermoplastic polymers. A gyroid core structure was 3D-printed with polyether ether ketone (PEEK) and then filled with polyethylene (PE) incorporated with high-atomic-number (high-Z) additives. This hybrid material design leverages the high hydrogen content of PE for proton and neutron moderation while utilizing high-Z elements to maximize the attenuation of secondary radiation and neutral particles. Outgassing tests conducted according to ASTM E-595 confirmed excellent vacuum resistance, while LEO environmental simulations replicating atomic oxygen flux, thermal cycling, ultraviolet radiation, and high vacuum showed only a minor (<5%) decrease in mechanical strength. Radiation shielding performance was evaluated using proton beams at the KAERI TR102 facility, neutron transmission tests, and numerical analysis with the SRIM program. Results indicated that adding high-Z materials to the PE filler significantly improved shielding performance, effectively mitigating damage from both charged particles and neutrons. Moreover, all polymer-based composites outperformed aluminum in shielding efficiency at the same areal density. These findings demonstrate that PEEK/PE gyroid composites are promising lightweight materials with excellent additive manufacturing capabilities and environmental stability for protecting LEO electronics.

#957

# Experimental Study of Quasi-Static Indentation and Compression after Indentation on Variable-angle tow Composites

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Tailored fiber placement (TFP) technology enables the design of preforms by aligning fibers in specific directions to enhance structural stiffness and strength. Variable angle tow (VAT) composites made with TFP have a number of benefits over traditional composites, but they also pose difficulties in comprehending the mechanical behavior of VAT laminates, which necessitate further research. Behavior of VAT laminates made with the TFP technique under quasi-static indentation loading is examined in this experimental study. Carbon fiber preforms with two different VAT layups are stitched using Tajima TFP machine with optimal stitching parameters and then resin is infused by vacuum-assisted resin transfer molding (VARTM) process and cured. Specimens are prepared with the dimensions of 100 mm×150 mm. A 100 kN MTS Universal testing machine is used to perform quasi-static indentation test with a fixture as per ASTM D7136 standard. To understand deformation behavior 3D-Digital image correlation (DIC) technique is used, where images are captured using two cameras through a mirror and processed to obtain deformation and strain information. Non-destructive ultrasonic scanning is performed on indented specimens to evaluate the damage caused. Indented specimens are tested under compression to obtain the residual compressive strength of laminates as per ASTM D7137 standard. DIC technique is used to understand damage behavior of laminates under compressive loading. Ultrasonic scanning is performed post compression for the assessment of damage growth. Mechanical response and damage behavior of composite laminates are investigated in relation to different layups. The ultimate goal of this study is to enhance the understanding the behavior of VAT laminates under transverse loading scenario and improve damage tolerance of composite structures by tailoring fiber orientation.

#958

# Rational Design of Continuous Thermal Networks using Novel HCN-Assisted AlN Fibers for High-Performance Thermal Management Composites

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As electronic devices continue to scale down while increasing in power density, effective thermal management has become a critical engineering challenge for ensuring long-term reliability and stable operation. Aluminum nitride (AlN) is a highly promising material due to its intrinsically high thermal conductivity and excellent electrical insulation properties. While most current thermal interface materials utilize particulate AlN fillers, their discrete geometry fundamentally limits performance by generating discontinuous heat transfer pathways and significant interfacial thermal resistance. Consequently, high-aspect-ratio AlN fibers are attracting increasing interest as a means to construct continuous, percolating thermal networks at relatively low filler concentrations. However, the fabrication of high-quality AlN fibers remains technically challenging. The conventional carbothermal reduction and nitridation (CRN) process requires temperatures above 1600 °C and high intrinsic carbon content for complete conversion, which subsequently compromises the spinnability of polymer precursors and degrades resulting fiber quality.

In this study, we introduce an innovative HCN-assisted reduction–nitridation strategy for the stable synthesis of AlN fibers under an $N_2$–$H_2$ atmosphere. This approach utilizes an external carbon black source to induce in-situ HCN formation, thereby activating a more thermodynamically favorable reaction pathway compared to traditional CRN. This novel mechanism successfully achieves complete AlN conversion at significantly lower temperatures, circumventing the inherent requirement for high intrinsic carbon content in the precursor. The resulting AlN fibers exhibit uniform morphology and high crystallinity, confirming the efficiency of the HCN-assisted process. To validate the engineering application, the synthesized AlN fibers were incorporated into polymer composites. With controlled dispersion and alignment, the high-aspect-ratio fibers formed a continuous three-dimensional heat-conduction network. The composites exhibited a low thermal percolation threshold and markedly improved through-plane conductivity even at low loadings, outperforming particulate-based systems. These findings highlight a scalable, energy-efficient route to high-quality AlN fibers and their strong potential for next-generation thermal management composites.

#959

# A Physics-Informed Neural Network for Fatigue Life Estimation in Fiber Reinforced Polymer Composites

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Lightweight fiber-reinforced polymer composite components are frequently exposed to cyclic loading throughout their lifetime. They may experience mechanical performance degradation, namely 'fatigue', which can lead to unexpected, catastrophic failure. In recent decades, considerable effort has been devoted to investigating the fatigue behavior of composites, with a focus on experimental measurements and observations, as well as predictive modeling [1].

Experimental investigations are indispensable for understanding fatigue life and assessing the accuracy of models. However, collecting fatigue data is time-consuming for any material and cannot cover all load conditions. Therefore, approaches that reduce experimental time and effort while still providing important information on fatigue life for design purposes are mandatory.

In this context, this work represents an initial step toward addressing this gap by developing a physics-informed neural network (PINN) for fatigue life estimation based on the fatigue life curve (S–N) data. The proposed framework combines a Basquin/Walker-type fatigue law with a shallow residual artificial neural network (ANN), which learns systematic deviations from the nominal analytical model. The governing fatigue relations are embedded in the training objective through a set of physics-motivated constraints: monotonic fatigue life reduction with increasing stress range, a consistent mean-stress (R-ratio) effect, and a weak smoothness constraint on frequency dependence. Additionally, run-out tests are treated as right-censored observations via a survival-type loss, and Gaussian priors are imposed on the Basquin/Walker parameters to regularize learning under data scarcity. A multi-stage training strategy is adopted to first calibrate the physics parameters and then gradually introduce the data-driven residual while tightening the physics constraints. The resulting model retains the interpretability of classical S–N formulations while achieving improved robustness and generalization compared to purely data-driven baselines, particularly in sparsely sampled regions of the loading space, using only two fatigue tests.

[1] Fatigue in Composites, 2nd Edition. Editor: M. Quaresimin, Woodhead Publishing (2025).

#962

# Angle-Dependent Specific Cutting Forces During Micro-Milling of MACM Fabricated Hemp Fiber/bio-PBS Sustainable Composites

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Sustainable composite materials are high in demand for lightweight, biodegradable components, especially in small-scale engineering and green product design. Present study focuses on, hemp fiber reinforced bio-PBS composites fabricated using microwave assisted compression moulding (MACM) technique. It is an energy-efficient fabrication technique that ensures rapid heating,uniform fusion and good fiber–matrix bonding. While such bio-composites show great promise, their application in functional miniaturized components requires precise micro-machining. Micro-milling becomes essential not only for manufacturing detailed features but also for understanding how these anisotropic materials respond to material removal at very small scales.This study investigates the micro-milling behaviour of the MACM fabricated composite by examining how cutting direction relative to fiber orientation affects machining forces and chip formation. Experiments were performed at cutting directions of 0°,30°,45°,60°,90°,120°,135°,150°,180° and 270° and the resulting force components were used to calculate specific cutting forces, thereby offering a direct measure of the material's inherent cutting resistance unaffected by variations in tool engagement. The results show a strong directional influence. Cutting parallel to fibers (0°, 180°) produced the lowest specific cutting

forces and smoother shearing, whereas cutting perpendicular (90°, 270°) generated significantly higher forces due to fiber breakage, matrix cracking and interfacial debonding. The intermediate orientations (45° and 135°) resulted in mixed chip shapes and unstable force fluctuations, reflecting combined shearing and tearing mechanisms. SEM analysis of machined surfaces and chips confirmed these trends, revealing clean shear at favorable angles and fiber pull out, fracture and surface roughening at adverse angles. Overall, this work provides direction dependent micro-

milling assessment of an MACM fabricated biodegradable composite, offering valuable insights for machining optimization and wider adoption of sustainable materials in precision engineering.

#965

# How to determine the influence of gaps in automated fibre placement?

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Over the last years, gaps and overlaps occurring in automated fibre placement have been investigated in many works. The causes of this can be fibre steering to change the fibre angle over the structure, or laying down on doubly curved surfaces, where having a constant fibre angle also leads to fibre steering. Approaches to take the gaps and overlaps into account range from micro-mechanical modelling, over macro-mechanical smeared approaches, to experimental work. However, one question that remains unanswered is: what is a representative test sample to determine the influence of gaps or overlaps? This work will only focus on gaps, but a similar reasoning can be made for overlaps.

To find a representative sample, two aspects need to be considered: the size and the layout. In terms of size, we aim to find a sample that is as small as possible but still representative of a gap within a large structure. Hence, ideally, a coupon-sized specimen would be sufficient; however, the size may need to be increased. In terms of layout, we need to decide whether to steer the fibres or not. When 'simply' dropping tows, we are often left with a gap that spans the entire width or length of the specimen, which is not representative of real life. When we steer the fibres, the manufacturing complexity is increased, but this approach is closer to real-life use cases.

This work will discuss these two questions by combining analytical and experimental work. Two designs will be discussed: a design with straight fibres where the gaps do not span the entire length/width of the specimen, and a design with fibre steering. By combining the results, novel insights and pathways forward about determining the influence of gaps will be provided.

#966

# Graphene-Integrated Chitosan/Sodium Alginate Nanocomposite Hydrogel for Enhanced Mechanical and Strain-Sensing Performance

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Abstract

Driven by the increasing need for skin-interfaced and wearable electronics, structurally engineered sensors with enhanced performance, including robust sensing capabilities, flexibility, stretchability, biocompatibility, self-adhesiveness, and self-healing properties, have become essential. Inspired by the natural sensing ability of human skin, flexible and stretchable materials such as hydrogels have emerged as key platforms for wearable electronics. This work is focused on developing a chitosan/esterified polyethylene glycol/graphene (Cs./Es.PEG/G) nanocomposite hydrogel as a flexible and multifunctional platform for dual strain-temperature sensing. The double-network design combines the mechanical strength of chitosan, the elasticity of Es-PEG, and the conductivity of graphene. By leveraging the balanced mechanical properties of the two polymers within the double-network hydrogel and the exceptional electrical conductivity of graphene, this strain sensor exhibits strong mechanical resilience and robust conductivity over a wide strain range, reaching up to 350%. It effectively enables tracking of various body movements with a GF of 13.78 and a tensile strength exceeding 3.2 MPa for the 0.15 wt.% graphene sample, maintaining cyclic electromechanical stability over 100 stretching cycles. Additionally, the chitosan polymer exhibits self-adhesion properties due to its terminal hydroxyl and amino groups, which facilitate hydrogen bonding with various surfaces, including plastic, rubber, glass, metal, and human tissues. Most importantly, the hydrogel sensor integrated into wrist, finger, or knee motion produced stable $\Delta R/R_o$ dynamic pulses and detected fever-range temperature changes within 37.5-40°C in real time, showing a linear temperature sensitivity (TCR = -5.62% $°C^{-1}$). These findings show the capability of the hydrogel nanocomposite as a high-performance dual strain-temperature tactile sensor for wearable healthcare monitoring devices and the next generation of electronics.

#967

# Data-Driven Microstructure Extraction and FE Model Reconstruction for CFRTP-NWF

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## 1. Introduction

In recent years, the growing demand for recycled carbon fibers has led to the emergence of various intermediate products manufactured from reclaimed fibers. Among them, NW-CFRTP (non-woven carbon fiber reinforced thermoplastics) exhibit highly disordered and complex microstructures. It may have structural patterns, but are difficult to statistically characterize, which makes the extraction of meaningful features and subsequent modeling extremely challenging. This study aims to extract internal microstructural information from NW-CFRTP and to construct representative datasets that enable reliable microstructure modeling. The effectiveness of the proposed method is evaluated through representative volume element (RVE) simulations.

## 2. Experiment and method

Due to the complex internal structure of NW-CFRTP, we assume that fiber bundles—not single fibers—govern the material behavior, simplifying the model. A small initial data set is constructed by manually labeling a limited number of optical microscopy images to obtain various information, including bundle length and diameter distributions, while X-ray CT scanning is used to extract bundle orientation distribution (BOD). These datasets establish the statistical foundation required for microstructure description. Based on this information, a large number of virtual microstructure samples are generated to enrich data diversity, which are used to train a convolutional neural network (CNN). Once the model achieves sufficient accuracy, it is applied to automatically identify microstructural features from large volumes of microscopy images, producing statistically reliable datasets for subsequent Monte Carlo–based microstructure generation.

## 3. RVE reconstruction

Using the extracted datasets, an RVE model of NW-CFRTP is constructed and its predictive capability is validated through mechanical simulations, demonstrating the effectiveness of the proposed data-driven microstructure reconstruction framework.

#968

# Bio-morphologic printing patterns for 3D/4D fiber-reinforced polymer composites

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Additive manufacturing of fiber-reinforced polymers enables spatially resolved control of fiber orientation, opening new opportunities for lightweight composite design inspired by natural materials such as bone. However, a general framework that links bio-morphologic patterning principles with mechanical performance–driven design remains limited. Here we present a printing-path generation algorithm derived from an anisotropic diffusion–based pattern formation system and integrate it with anisotropic topology optimization to tailor fiber-orientation fields for user-defined objectives. We demonstrate its versatility through examples that maximize structural stiffness and solve inverse problems in 4D printing to achieve prescribed shape transformations. Experimental validation using 3D-printed specimens confirms that the generated printing paths accurately reproduce the optimized anisotropic fields and yield substantial stiffness enhancement. Our approach establishes a biologically inspired, mechanics-informed pathway toward next-generation fiber-reinforced composite architectures.

#969

# Towards Reliable Interfacial Adhesion Testing in Fragile Thin-Film Devices

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Given the increasing use of delicate multilayer structures in emerging technologies, a reliable method to quantify interfacial integrity is essential. Tape peeling is a viable approach for evaluating the adhesion of thin-film devices due to its simplicity and accessibility. However, its application to fragile next-generation thin-film systems, such as perovskite photovoltaic modules, is often hindered by pronounced stick–slip instability. Stick–slip instability in peeling and delamination is a hallmark of dynamic rupture across scales, from adhesive tape to seismic faults. This topic has drawn significant attention in efforts to elucidate the underlying physics. Despite the advances, the manifestation of spatiotemporal instability in fragile multilayer thin-film devices, where competing interfaces and fracture-pathway selection complicate measurements, has remained unexplored. Through comprehensive experimental and theoretical investigations, we demonstrate that stick-slip instability during tape peeling originates from a transition between strength-governed and energy-governed fracture, driven by the viscoelastic dynamics of discrete fibrils formed during adhesive deformation. We further show that systematic tuning of the adhesive/substrate interface properties can trigger this instability even at very low peeling velocities, a regime previously considered stable. By replacing conventional adhesive tapes with thermoplastic thin films, we effectively eliminate stick-slip behavior during peel tests on perovskite photovoltaic modules, providing a practical protocol for reliable adhesion evaluation. By mitigating artifacts like stick-slip instability, this protocol enhances the accuracy and reproducibility of mechanical characterization, providing a valuable tool for both research and quality control in advanced thin-film systems. Furthermore, the insights gained are beneficial for thin-film device, as well as for gaining a better understanding of the mechanisms underlying systems that exhibit crackling noise, such as unstable fractures, stick–slip friction, and earthquake.

#970

# Applying CO2-Curing for Enhancing the Engineering Properties of Alkali-Activated BFS Mortar

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To reduce the use of cement, as it emits a significant amount of carbon dioxide (CO2) during production. This study prepared alkali activation solutions with a water-cement ratio of 0.5 and different modulus ratios ($SiO_2/Na_2O$ = 0.6, 0.7, and 0.8), utilizing blast furnace slag (BFS) to fully replace cement as the primary alkali-activated binder for casting mortar specimens. The alkali-activated BFS mortars were cured for three hours in a high-concentration CO2 environment (0.3%) at a constant temperature of 30°C and a relative humidity of 50%. Then, they were placed in lime-saturated water for further curing until the test ages of 7, 14, and 28 days, to investigate their performance in terms of compressive strength and ultrasonic pulse velocity (UPV). The test results showed that the compressive strength of alkali-activated BFS mortars cured with CO2 was higher than that of mortars cured with only lime-saturated water, and their UPV is also higher, which means their density increased. Specifically, the mortar with a modulus ratio of 0.7 exhibited higher strength and UPV at all ages than mortars with other modulus ratios, and its 28-day strength was more than 10% higher than that of pure cement mortar. This indicates that CO2-curing can enhance the engineering properties of alkali-activated mortar.

#973

# Lamination parameters for hybrid composite laminates

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The increasing demand for lightweight and cost-effective structures in, among others, aerospace and wind energy applications has led to widespread adoption of fibre-reinforced polymers (FRPs). While carbon fibre reinforced polymers (CFRPs) offer excellent stiffness-to-weight ratios, their high cost and poor damage tolerance pose challenges for structural applications such as wind turbine blades. Hybrid laminates combining CFRPs and low-cost, higher failure strain (compared to CFRP) Glass fibre reinforced polymers (GFRPs) present a promising alternative. These hybrid laminates balance competing objectives of cost and stiffness while providing higher damage tolerance.

Most existing optimisation studies of hybrid composite plates treat material selection and ply orientation as decoupled problems, lacking a unified formulation that can capture their interaction holistically. Furthermore, the use of lamination parameters (LP) in structural optimisation has been shown to be effective but is not yet available for hybrid laminates.

This work develops a novel method to enable the use of lamination parameters for hybrid composite laminates. While the material properties of the laminate can be formulated as a function of volume fraction of CFRP/GFRP, the through-thickness material distribution is captured by the novel dispersion parameter (DP). This formulation defines a continuous, convex design region amenable to gradient-based optimisation frameworks. The DPs and feasible region are further explored to create a combinatorics-based and deterministic method to constrain the region, creating a relation between LPs and DPs.

Further, a two-level optimisation strategy is proposed, combining a gradient-based optimisation for LP/DP optimisation and a genetic algorithm to retrieve the stacking sequence. Initial optimisation results indicate that hybrid composite laminates can achieve at least 90% of the buckling load of a full-CFRP laminate with 50% CFRP content, while reducing raw material cost by 40%.

#976

# Transfer Learning-Enhanced Surrogate Modeling for Expanded-Dimension Structural Response Prediction of Vertical-Axis Wind Turbines

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Vertical-axis wind turbines (VAWTs) have attracted increasing attention for offshore power generation due to their superior suitability for floating-platform turbine designs compared to conventional horizontal-axis wind turbines(HAWTs). However, due to the various aerodynamic characteristics and loading conditions of VAWTs, it demands laminate designs that can accommodate their specific operating conditions. The strong coupling among aerodynamic loads, material anisotropy, and geometric parameters further increases the complexity. Conventional finite element analysis(FEA)–based optimization of VAWT blades is computationally intensive and costly. Thus, there is a strong need for a computationally efficient yet sufficiently accurate analysis method for predicting the structural responses of VAWT blades.

In this study, a transfer learning-based multi-layer neural network surrogate model was developed to predict the structural responses of VAWT blades. The model integrates multiple input dimensions—including aerodynamic pressure, material properties, layup configuration, and thickness distribution—to accurately approximate the results of FEA. Through transfer learning, the proposed network facilitates efficient knowledge transfer when incorporating new dimensions, such as material properties, layup configurations, and thickness.

The training results show that the surrogate model can accurately predict blade deformation and strain distribution with randomized external load distributions, achieving an R2 of 0.994. The model's accuracy was further validated using the extreme wind conditions, where the predicted maximum deformation and strain error were less than 1.08%. Moreover, the surrogate model can be successfully extended to additional input dimensions, including material properties, layup configurations, and thickness. Through the transfer learning process, the required sample size for training these expanded-dimensional models can be significantly reduced, thereby lowering the overall computational cost. The developed method provides an effective tool for rapid structural evaluation and optimization of VAWT blades, offering new insights into lightweight and reliable design strategies for next-generation offshore wind turbines.

#978

# Multiscale Modelling of Interlaminated Plain woven metal mesh Composite Structure

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The design of hybrid composites having the combination of metal and conventional varieties of brittle fibers introduces some kind of improved strain due to ductility of metal. This nature of Pseudo-ductility can possibly help in reducing the brittle failure of composites and could be possible to enhance Energy absorption. The present study is focused on a hybrid composite which is having the combination of three constituents, woven fabric, woven metal mesh and polymer matrix calling it as interlaminated metal mesh carbon fiber polymer composite (IMCFRP). Here the Plain-woven metal mesh is stacked in between the layers of carbon fabric laminae with stacking sequence, [(0/90)2 /Al/ (0/90)2]. To understand structural integrity of this kind of hybrid composite, the multiscale approach helps in studying them relating stress variations at microscale level to structural level through meso-scale constitutive relations to the macrostructural level. First the Finite Element Method (FEM) based homogenized properties of fabric yarn are found from micro-scale RVE assuming hexagonally arranged Fibers. The meso-scale geometry of homogenised yarns of fabric and PWM were modelled in Texgen-software and exported as Abaqus voxel mesh Model to Abaqus CAE, and the effective properties were found from applying periodic boundary conditions. To adopt the microstress variationsThe Stress Amplification Factors(SAF's) were calculated at microscale and related to the macroscale through meso-scale constitutive relations.The macro-scale structure of IMCFRP is tested for tensile and shear properties experimentally according to ASTM 3039. The failure criteria and propagation were being evaluated to understand the damage progression in IMCFRP. Since metals and composites and have different failure evolution this study could find useful outcomes for further exploration of any this kind of hybrid composites in design perspective.

Keywords: Plain-woven metal mesh - PWM, Finite element method - FEM, Stress Amplification Factors- SAF's

#981

# Study on Lightweight design of an inboard bogie frame using composite materials

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Globally, demand for rail vehicles that provide eco-friendly high-speed transportation has been increasing, and the miniaturization of the bogie frame and axle is recognized as an important design factor. In this study, a structural integrity evaluation was conducted for an inboard bogie frame using composite materials. Conventional inboard bogie frames are constructed from steel. For lightweight design, part of the side frame was replaced with carbon-fiber-reinforced polymer (CFRP) to achieve weight reduction through material substitution while maintaining high specific stiffness and specific strength. As a result, the bogie mass using composite materials was reduced to 1220 kg, which is 10.36% lower than that of the steel design. For the composite components, the mechanical properties of Toray T800 carbon fiber were used. For the evaluation of structural integrity, the service load cases (SLC) and exceptional load cases (ELC) for the inboard bogie frame were derived, and the boundary conditions were defined according to the safety evaluation regulations for European railway vehicles (EN 13749). For the service load cases, the fatigue strength of the inboard bogie frame was evaluated using the Goodman diagram by distinguishing between the welded and non-welded regions of the bogie structure. For the exceptional load cases, failure of the inboard bogie frame was evaluated using the von Mises criterion for the steel parts and the Tsai–Wu criterion for the composite parts. The analysis results for the SLC were located within the allowable region of the Goodman diagram, indicating that the structure is safe under all service load cases. As a result of the failure evaluation for the ELC, the maximum von Mises stress in the steel parts did not exceed the yield strength of 355 MPa, and the maximum Tsai–Wu index in the composite parts did not exceed 1.0, so the structural integrity was confirmed.

#982

# A predictive unit cell framework for geometric modeling of woven composites using digital element approach

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Digital element approach provides an effective mesoscopic description for woven composites by accurately capturing yarn geometry and interlacing morphology, making it a powerful method for the numerical analysis of both 2D and 3D fabrics. Existing digital element unit cell approaches are generally driven by thermal loads and can reconstruct realistic woven geometries. In such approaches, the as-woven fabric geometry is obtained through a shrinkage using thermal expansion coefficients and temperature fields. However, the termination of this shrinkage procedure is empirically controlled by measured geometry parameters of the actual fabric, which prevents the method from serving as a predictive geometric modeling method for woven composites.

In this work, we propose a novel and universal termination condition for the shrinkage, determined by the yarn tension in real weaving processes. Instead of relying on measured geometric parameters, the evolution of yarn tension represented by the reaction forces in the digital element simulation during the as-woven process is employed as physically meaningful indicators to determine the equilibrium configuration of woven structures. This predictive framework eliminates the need for any prior knowledge of fabric geometries and enables unified predictive unit cell geometric modeling of both 2D and 3D woven composites.

The predicted woven geometries will be quantitatively compared with real 2D (plain and twill) and 3D orthogonal fabrics in terms of geometric characteristics. Furthermore, the method is implemented into an auxiliary geometric modeling tool to enable automated and parametric geometry generation for fabrics, showing strong potential for mechanics analysis and digital material design.

Keywords: Digital element approach, woven composites, geometric modeling

#984

# Evaluation of Structural Integrity for Hypertube Carbody Using Composite Materials

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The hypertube vehicle runs inside an ultra-high-speed evacuated tube and operates at much higher speeds than conventional railway vehicles. Therefore achieving both a lightweight carbody and sufficient strength and stiffness is a key design challenge. To reduce energy consumption, carbody mass should be minimized. Safety under vertical, torsional and bending loads must also be secured.

In Korea, core hyper-tube technologies and ultra-high-speed vehicle structures are being developed under the leadership of the Korea Railroad Research Institute (KRRI), emphasizing the need for validated lightweight carbody design and verification methods. This study evaluates the structural performance of a hyper-tube carbody structure made of extruded aluminum materials and carbon composite materials using finite element analysis.

The analysis was performed using the Altair OptiStruct solver. Extruded sections offer geometric flexibility and enable mass production while providing low weight with high bending stiffness. These sections were modeled in the main transverse and longitudinal members of the carbody structure. Analysis conditions followed domestic structural safety regulations for railway vehicles. Vertical, bending and torsional loads were considered.

For the metallic parts, the maximum Von-Mises equivalent stress remained below the yield stress and for the composite parts, the Tsai-Wu index remained below 1 in all load cases. Also, the modal analysis was also performed for the composite carbody and the first natural frequency was higher than 10 Hz in all cases, indicating sufficient global stiffness and a low risk of resonance under service loads. Therefore, the bogie frame using H2550 composite materials and the aluminum materials was validated as an effective approach for evaluating lightweight carbody structures and can serve as a verification process for future hyper-tube carbodies.

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#985

# Implementation and modelling of vacuum-assisted through-thickness melt impregnation of thermoplastic composites

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Thermoplastic composites offer desirable properties for engineering applications; they have good mechanical properties, do not require a curing cycle, and offer end-of-life re-use/recycling potential. While current processing techniques can produce high-quality thermoplastic composite structures utilising prepreg systems, in-situ impregnation of dry woven/stitched textiles via liquid composite moulding processes (LCM) remains challenging.

Typical transverse melt thermoplastic impregnation methods such as compression moulding often lead to high void content primarily concentrated within the intra-tow pore space. This void content originates from the entrapment of air bubbles due to the multi-scale flow front present during thermoplastic impregnation processes. Addressing this flaw is required to improve the quality of these composites.

This work explores the theory and practical implementation of vacuum assistance as a mechanism that may be used to reduce the void content of melt thermoplastic composites produced in a transverse impregnation process. A novel vacuum-assisted compression LCM die and computational impregnation model has been developed. The experimental die uses a Vario-thermal system to seal create an in-situ air seal during impregnation to maintain a vacuum. It is mounted in a Universal Testing Machine (UTM) for accurate measurement of textile compressibility and deformation.

The presented impregnation model captures the dual scale flow fronts and gas entrapment within the tows seen in woven textiles. The experimental hardware shall be used to validate the computational model. Preliminary experimental and simulation results indicate significant reductions in void content. Early results show void content reducing from the over 10% to less than 1% at typical processing parameters.

This research addresses a critical hurdle in processing high-viscosity thermoplastic composites regarding final void content and quality. In doing so, it expands the range of engineering and high-performance polymers available for advanced applications.

#986

# Evaluation of Structural Integrity of a Composite Bogie Frame for Hypertube Retractable Actuator Using Multibody Dynamic Analysis

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The development of hypertube systems for ultra-high-speed ground transportation is accelerating worldwide, and research on lightweight design and operational efficiency is becoming increasingly important. In this context researchers are investigating the application of carbon-fiber-reinforced polymer (CFRP) composites to the hypertube bogie frame as an effective strategy to reduce structural mass while maintaining load-bearing capacity. Hypertube vehicles require auxiliary wheels for low-speed operation and for emergency running conditions. At high speed the vehicle operates in a magnetically levitated state using electromagnetic actuators, so a retractable wheel system that stows the wheels inside the carbody is essential to reduce aerodynamic drag and to minimize the risk of interference with the guideway. In Korea, research is being conducted on a retractable actuator system as one of the core technologies for the hyper-tube and structural safety evaluation of the composite bogie frame under loads generated during actuator motion is essential. So, the multibody dynamic analysis was used to derive the maximum reaction forces that can occur during the operating motion of the hypertube retractable actuator, and these forces were mapped to a finite element model of the composite bogie frame for of structural analysis. Evaluating of structural integrity was done using the Tsai-Wu failure criterion to assess the design suitability in bogie frame. As a result of the analysis, the Tsai-Wu index in the composite parts of the bogie frame under actuator operating loads during the retracting motion was less than 1, confirming that the designed model is structurally safe. This study proposes a coupled analysis procedure that links multibody dynamic analysis of a hyper-tube bogie frame with a actuator and composite structural failure evaluation. The proposed actuator is expected to improve the running safety of the hypertube and to contribute to the establishment of design criteria for the bogie frame in the future.

#988

# Tailored Interfacial Engineering of Ultra-Thin Hybrid Composites via CNT interleaving for Enhanced Structural and Functional Performance

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Ultra-thin carbon fiber reinforced plastics (CFRPs) are a critical design material for micro-scale and multi-functional structural systems where reduced thickness intensifies interlaminar effects and scale-dependent mechanical behavior. Unlike conventional laminates, the mechanical response of reduced-ply ultra-thin architectures is dominated by few distinct interfaces, making interlaminar modification a paramount design strategy for achieving mechanical integrity. This study investigates a carbon nanotube (CNT)-based nano-reinforcement strategy involving interleaving within ultra-thin hybrid CFRPs, specifically examining the heterogeneous response across polyacrylonitrile (PAN)-based, pitch-based, and PAN/pitch hybrid systems. Using span-specific micro-scale three-point bending tests and SEM fractography analyses, we demonstrate that precise control of CNT loading significantly augments flexural strength, with sub-micron CNT interlayers effectively facilitating load transfer efficiency through enhanced interfacial stress redistribution.

A key finding is that the CNT-mediated toughening effect is intensified with increasing interface density in multi-ply configurations. The magnitude of this nano-reinforcement differs between PAN- and pitch-based laminates, reflecting the influence of their distinct fiber–matrix interactions on CNT load-transfer efficiency. Furthermore, the CNT interleaving successfully mitigates catastrophic brittle failure, a major limitation of thin-ply composites, enabling pseudo-ductile behavior in multi-ply configurations. The PAN/pitch hybrid systems also exhibit complementary flexural properties while maintaining fiber-dependent characteristics of CNT reinforcement.

Overall, this work quantitatively establishes that the mechanical response of ultra-thin CFRP is governed by the synergistic interaction between the chosen fiber architecture and nano-scale interfacial engineering. These results provide fundamental insights for the tailored design and optimization of robust, high-performance ultra-thin hybrid composites, highlighting the importance of nano-reinforcement for advancing damage-tolerant structural materials.

#989

# Effect of ply thickness on interlaminar fracture toughness of thin-ply thermoplastic composites

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Hydrogen has been considered a promising $CO_2$-free alternative to fossil fuels, supporting climate-change mitigation and enabling diverse applications such as transportation, habitation systems, and aerospace. However, storage and transport remain major challenges due to hydrogen's high diffusivity and its tendency to degrade metallic vessels. Current technologies rely on several tank types, with Type IV, CFRP over a polymer liner, being the most widely used. Recently, Type V tanks, made entirely of carbon-fiber composites, have gained attention because they are lighter and avoid liner-related failures such as cavitation or collapse. Yet, their adoption is limited by matrix cracking, high permeation rates, and first-ply failure caused by hydrogen accumulation at interfaces.

This study proposes thin-ply thermoplastic composites as a solution to these challenges. By reducing ply thickness and activating extrinsic energy-dissipation mechanisms such as fiber and ply bridging, both matrix cracking and interfacial weakness can be significantly mitigated. CF/PA6 laminates with 42 µm plies were fabricated in three stacking sequences, 126 µm (thick), 84 µm (intermediate), and 42 µm (thin), each containing cross-ply cores and 0° outer plies for DCB testing. Mode I fracture toughness was measured following ASTM D5528 using Hashemi's compliance method.

Results showed that the thin-layer laminate achieved nearly 50% higher fracture toughness than the thick-layer laminate. Damage analysis revealed that thin laminates promote multiple ply migrations and extensive bridging, increasing crack-surface area and energy dissipation. Although all laminates exhibited fiber bridging, toughness did not scale linearly with the number of bridges. The superior performance of the thin-layer laminate is also linked to its lower crystallinity (28.5%) compared to the thicker laminates (~33.6%), as thinner plies restrict crystal growth due to out-of-plane fiber confinement. Overall, the thin-ply CF/PA6 laminate demonstrated significantly enhanced interface toughness and delayed delamination onset, making it a strong candidate for Type V hydrogen storage tanks.

#990

# Mechanical characterization of carbon fiber-reinforced polymer composites using physics-informed neural networks

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Characterization of the carbon fiber reinforced polymer (CFRP) composites remains a challenging task due to their intrinsic anisotropy. Conventional material identification often requires multiple mechanical tests to resolve the directional elastic properties of the CFRP. To reduce the number of experiments required for characterization, this study integrates the Digital Image Correlation (DIC) technique with a Physics-Informed Neural Network (PINN) framework for efficient and accurate determination of the in-plane elastic properties of CFRP laminates. DIC provides full-field deformation data under applied loads, which serve as training inputs for the PINN. The PINN is constrained by governing physical laws through physics-based loss functions that enforce strain compatibility and equilibrium conditions across the laminate domain. A symmetric quasi-isotropic laminate subjected to uniaxial tensile loading is used as a representative case to evaluate the approach. The DIC data capture global deformation fields, while the PINN simultaneously learns and infers the underlying in-plane elastic constants of the composite material. By embedding physical principles directly into the network optimization, the proposed method reduces dependency on extensive experimental testing while maintaining accuracy in the estimation of the in-plane elastic constants. Results confirm that the DIC-assisted PINN framework can successfully recover the in-plane elastic moduli of CFRP laminates using only tensile test data. This hybrid experimental–computational approach offers a cost-effective and robust pathway for composite material characterization, enabling data-efficient discovery of in-plane elastic constitutive parameters.

#991

# Effect of Processing Pressure on the Interfacial Shear Strength in Hemp/PLA Biocomposites

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Short-fiber thermoplastic biocomposites combine the processing advantages of thermoplastics with the sustainability benefits of bioderived or biodegradable matrices reinforced with natural fibers, yet their mechanical performance is often limited by low fiber–matrix interfacial shear strength (IFSS), critical for effective load transfer. IFSS is typically evaluated via pull-out tests, where fibers are extracted from the matrix at very short embedded lengths to avoid fiber breakage, usually without applied pressure, unlike real processing conditions. This discrepancy results in IFSS values that may not represent true interfacial behavior. In this study, we investigate the effect of processing pressure on the IFSS between hemp bundle fibers and poly(lactic acid) (PLA), finding a significant increase from 5.5 ± 1.1 MPa under pressure-free conditions to 15.7 ± 1.6 MPa at ~43 bar. This improvement is attributed to pressure-enhanced mechanical interlocking due to matrix penetration into fiber surface crevices. Mechanical testing shows that 20 wt.% fiber reinforcement, compared with neat PLA, increases Young's modulus (3.10 to 4.66 GPa) and tensile strength (50.64 to 55.18 MPa) while reducing strain at break (5.17% to 2.33%), indicating embrittlement. Using the Bowyer and Bader micromechanical model, the fiber orientation factor increases from 0.383 at 10 wt.% fiber content, close to the theoretical random in-plane value of 0.375, to 0.515 at 20 wt.%, reflecting fiber crowding and restricted rotation. Importantly, the intrinsic theoretical B–B model IFSS parameter (τbb) remains nearly constant at ~15.2 MPa. This value closely matches the experimental IFSS measured at 43 bar, confirming the model's reliability. These results clarify fiber–matrix adhesion mechanisms and demonstrate that combining natural fiber bundles with realistic processing pressures can produce IFSS values higher than commonly reported, enabling high-performance sustainable biocomposites.

#993

# Investigation of Dorsal Fin Structural Failures in single engine trainer aircraft: Material Degradation, Adhesive Performance, and FEM-Based Repair Optimization

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This study investigates the structural failure of the dorsal fin of a single engine trainer aircraft. Consequently, in-flight dorsal fin failures constitute a matter of significant concern, as they directly affect flight safety and operational reliability. Communication was established with other air forces operating the single engine trainer aircraft in order to assess whether similar incidents had been observed. Their responses confirmed the occurrence of related failures and provided valuable insight into the potential underlying causes. Specifically, they concluded that excessive oscillation of the dorsal fin is likely induced by its detachment from the forward and aft ribs, which are responsible for its structural support, as well as from the aircraft skin. It was further reported that this oscillatory motion allows airflow to enter through the access panel and reach the internal surface of the dorsal fin, thereby imposing additional loads that may lead to structural fracture.

To examine the contributing factors leading to these failures, an experimental investigation was undertaken focusing on the effects of ultraviolet (UV) radiation on specimens manufactured from the same material as the dorsal fin. In parallel, adhesive-bonded specimens were tested to assess the influence of adhesive quantity on structural integrity. Additionally, a finite element method (FEM) analysis was conducted with the objective of optimizing the repair process and improving long-term durability. The combined findings of the material tests, adhesive performance evaluation, and numerical simulations provide a comprehensive understanding of the failure mechanisms and support the development of more robust repair procedures for enhancing flight safety.

#994

# Forming thermoplastic composites with fluid cell press

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The Fluid Cell press enables rapid forming at high pressure (up to 1400 bar) and high temperature, while the material being formed does not come into contact with the pressure medium, but is separated from it by a flexible rubber membrane. Forming, therefore, takes place without issues related to sealing and the forming tool is reduced since only half of the tool is required.

Although forming in Fluid Cell presses is a well-established method for sheet metal forming in the aerospace industry, its use for composite forming has not been extensively explored. In an earlier study on the forming of stacked aerospace-grade thermoset composites, it was found that high forming speeds altered the wrinkling modes and that high pressure had a tendency to displace material in an undesired manner. The latter was due to the low matrix viscosity at forming temperatures. Despite initial difficulties, the process offers benefits that need further exploration.

Thermoplastic composite materials require temperatures above the matrix melting temperature for a short period to enable forming, consolidation, and autohesion between the separate layers in a fluid cell press. Furthermore, since the matrix viscosity is higher than that of the thermoset counterpart, less material movement will occur. The primary challenge lies in heat management, tailoring the process settings to achieve the desired temperatures during the required brief period of forming and compaction.

In the presented work, an experimental series is conducted forming a spar geometry out of stacked, unidirectional carbon fibre/polyamide 6 composite material. In parallel, a modelling framework is developed to predict the instantaneous temperature during forming and the degree of compaction obtained. The study demonstrates that, with effective process control and, in some cases, the use of steel dummies, the fluid cell press enables the rapid production of high-quality formed thermoplastic composite components.

#996

# Enzymatic Surface Treatment to Enhance Interfacial Performance of Hemp Fibers in PLA Biocomposites

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This study investigates how enzymatic surface modification of hemp fibers enhances the interfacial performance and mechanical behavior of poly(lactic acid) (PLA)–based biocomposites. Hemp fibers are composed of cellulose, hemicellulose, pectin, lignin, waxes, and fats, resulting in heterogeneous hydrophilic and hydrophobic surface characteristics. Enzymatic treatment selectively removes amorphous constituents, mainly pectins and hemicellulose, exposing cellulose microfibrils rich in hydroxyl groups while increasing surface roughness and chemical affinity. Contact angle measurements indicate that untreated fibers exhibit predominantly dispersive surface energy (21.6 mN/m) with a low polar contribution (2.9 mN/m), whereas treated fibers show a reduced dispersive component and enhanced polarity, increasing total surface energy from 24.5 to 30.2 mN/m. Single-fiber tensile tests reveal elastic moduli of 24.5 GPa for untreated fibers and 22.1 GPa for treated fibers, attributed to the removal of the stiff lignin phase. Interfacial characterization demonstrates a ~43% increase in apparent interfacial shear strength ($\tau_a$), from 15.7 ± 1.6 MPa to 22.4 ± 1.1 MPa after treatment, ranking among the highest reported values for treated natural fibers in PLA matrices. Micromechanical analysis combining IFSS and debonding energy confirms enhanced load transfer governed by improved frictional and chemical bonding mechanisms. At the composite scale, tensile testing shows that adding 20 wt.% hemp fibers increases the Young's modulus of PLA from 3.10 ± 0.06 GPa (neat PLA) to 4.66 ± 0.08 GPa with untreated fibers and 4.46 ± 0.36 GPa with treated fibers. Tensile strength increases from 50.64 ± 1.50 MPa to 55.18 ± 1.33 MPa and 61.10 ± 1.62 MPa, respectively. Overall, the results clarify the mechanisms responsible for mechanical enhancement in biocomposites reinforced with enzymatically treated lignocellulosic fibers and demonstrate the effectiveness of this approach for developing high-performance, sustainable biocomposites.

#998

# Chemical Corrosion of Glass Fibers in Composites - Mechanisms, Tensile Strength Degradation and Weibull Analysis

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Chemical corrosion of glass fibers remains a critical challenge in the long-term performance of fiber-reinforced polymer and concrete composites. In service environments, where moisture, alkaline media, acids, or salt solutions are present, the glass surface undergoes leaching, ion exchange, and network dissolution. These corrosion mechanisms progressively degrade the silica-based network, creating surface flaws and microcracks that act as stress concentrators. Understanding these mechanisms is therefore essential for predicting durability for service life especially for infrastructure, marine, and energy applications where composites are expected to perform for decades with minimal maintenance. Further, knowledge about these mechanisms is crucial for emerging recycling approaches. Both thermal and chemical recycling processes can induce additional corrosion and surface damage, accelerating flaw growth and causing further reductions in tensile strength. As glass-fiber strength is governed by surface flaw populations, any corrosion—whether from service exposure or recycling—directly affects residual mechanical performance and the feasibility of reusing recovered fibers.

Weibull analysis provides a robust statistical framework to describe these effects. Depending on whether corrosion generates a uniform or heterogeneous distribution of defects, single or mixed Weibull distributions can represent the tensile strength data. The Weibull shape parameter reflects flaw uniformity, while the scale parameter indicates characteristic strength. Monitoring changes in these parameters after chemical exposure enables quantification of degradation kinetics and a deeper understanding of damage evolution.

This work provides an example of how accelerated ageing in different solutions leads to the formation of diverse corrosion phenomena and how tensile-strength testing combined with Weibull analysis can be used to reveal the formation and progression of surface flaws.

#999

# A Critical Damage Growth Model for Notched Fatigue Fracture of CFRP Laminates at Various Stress Ratios

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This paper presents a physically based method that predicts the S-N relationship for composite materials containing notches of arbitrary size under any fatigue stress ratio. The model is built on two damage mechanisms: (1) stable growth of notch-tip damage during cyclic loading, and (2) unstable propagation of an equivalent crack ahead of the notch. For the first mechanism, a fatigue-AS criterion is employed to account for the reduction in unnotched strength due to fatigue. For the second mechanism, a fracture-mechanics criterion is applied to the unstable growth of the equivalent crack, taking into account the change in fracture toughness with increasing fatigue cycles. The fatigue-damage effects that characterize these two constituent criteria are expressed by the author's steady-state fatigue-damage model, which constitutes a vital new component of this versatile formulation. The physically based notched-fatigue model couples the stable and unstable damage-growth criteria, enabling the length of the damaged region at the notch tip to be computed automatically. Unlike a static AS criterion, there is no need to measure the damage-zone size experimentally in this approach. Only the unnotched strength, S-N curve, and fracture toughness of a given composite are required as inputs, enabling efficient prediction of notched S-N curve for any notch size. By combining the model with the author's anisomorphic constant fatigue life diagram method, notched S-N curves can be predicted for any stress ratio as well. Experimental results for notched fatigue of unidirectional-ply and woven-ply CFRP laminates at different stress ratios are compared with predictions to validate the proposed model. A method for estimating residual fatigue strength of notched components is also proposed and verified against test data. Finally, predictions from a phenomenological vanishing-notch-sensitivity model developed previously are compared with those of the present physically based model, highlighting differences and suitable application domains for each approach.

#1000

# Interfacial adhesion performance of theromoplastic-textile composites fabricated by direct material extrusion

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This study investigates the impact of printing speed on the adhesion efficacy of flexible thermoplastic polyurethane (TPU) 3D-printed directly onto plain-weave fabric via fused deposition modeling (FDM). The nozzle temperature was maintained at 220 °C and the heated bed temperature at 60 °C, while the printing speed was adjusted to three levels: 20, 40, and 60 mm/s. The interfacial bond strength was measured using T-peel and impact wedge peel tests in accordance with ASTM-D1876 and ISO-11343 standards. The results indicate a significant inverse link between printing speed and peel resistance. Specimens printed at 20 mm/s exhibited the highest average peel strength, which diminished at 40 mm/s and further declined at 60 mm/s. Reduced speed facilitated cohesive failure within the fabric, whereas faster speeds shifted failure toward the polymer-fabric interface, indicating predominantly adhesive detachment. Scanning electron microscopy (SEM) of exposed surfaces and cross-sections elucidated the fundamental mechanisms. At a speed of 20 mm/s, molten TPU demonstrated enhanced wetting and profound penetration into textile crevices, enveloping individual fibers and establishing strong interlocking. Increased printing rates diminished melt residence time and flowability, leading to superficial contact, limited fiber encapsulation, and smooth detachable surfaces with minimum signs of fiber damage. The results indicate that printing speed is a crucial factor influencing polymer-fabric adhesion in 3D printing. Optimal low-speed conditions markedly improve bonding durability, providing essential process directions for applications in wearable electronics, smart textiles, soft robotics, and functionalized garments that necessitate dependable integration of flexible polymer structures onto fabrics. This study presents a novel approach in isolating printing speed as the sole variable to reveal its strong inverse effect on TPU-fabric peel strength and bonding mechanisms in direct 3D printing on textiles.

#1001

# From Micro- to Meso-Scale: Modelling the Viscous and Anisotropic Behaviour of Aligned Discontinuous Fibre Composites

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Composite laminates are widely used in transportation due to their excellent balance of low weight and high strength. They enable significant mass reduction while maintaining structural integrity, improving fuel efficiency, and reducing emissions. However, complex service loading conditions make them susceptible to damage and failure, requiring a detailed understanding of their behaviour. Since structural performance is closely linked to microstructure, reliable design depends on simulation-based approaches that capture micromechanical mechanisms.

Among advanced composites, aligned discontinuous fibre (ADF) reinforced polymers have emerged as a promising class for high-performance applications. Composed of highly aligned, high aspect ratio fibres, ADF composites can achieve properties comparable to continuous fibre composites while offering greater manufacturing flexibility. During processing, fibres remain solid while the polymer matrix softens, forming a suspension with anisotropic viscous behaviour. This anisotropy arises from microstructural factors such as fibre geometry, orientation, aspect ratio, volume fraction, and matrix properties, all influencing flow and mechanical response. Understanding these multiscale interactions is essential for exploiting ADF composites in complex components.

Micromechanical numerical models explicitly represent fibres and matrix, providing insights into mechanisms governing composite behaviour. Although computationally demanding, these models support homogenization approaches that bridge micro-, meso-, and macro-scales. Such methods enable determination of ply-level properties, development of constitutive models, and creation of homogenized databases for surrogate modelling, guiding material and structural design.

This work further develops a recently purposed computational homogenization framework to compute ply-level viscous properties of ADF composites from micro-scale analysis. The influence of key geometrical parameters - fibre volume fraction, aspect ratio, gap size, and misalignment - on homogenized properties will be assessed. The resulting data will feed into a meso-scale anisotropic viscoelastic model to study ply and laminate behaviour under high-temperature forming conditions. Numerical results will be validated experimentally to enhance predictive forming simulations.

#1002

# Recycling glass fibres from thermoset epoxy composites by a mild catalytic thermo-chemical recycling method

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Recycling glass-fibre-reinforced polymer (GFRP) with a thermoset matrix remains a major barrier to managing end-of-life wind turbine blades. Most proposed technologies, particularly pyrolysis, rely on high temperatures that severely degrade glass fibres, whereas solvolysis can yield cleaner fibres but currently lacks viable valorisation pathways for the resin fraction. There is thus a strong need for economically feasible processes that not only recover 'clean' fibres, but also create real value from the organic mass.

In this research, a two-step catalytic thermochemical recycling route is proposed. The first step involves a mild solvolysis treatment under controlled thermochemical conditions to selectively cleave the epoxy network, release the fibres, and convert the matrix into a liquefied resin phase suitable for downstream upgrading. In the second step, this resin is targeted for catalytic conversion into valuable aromatic functional building blocks. In this work, emphasis is placed on the first step, with an in-depth investigation of the mechanical properties of the recovered fibres.

Under low-temperature solvolysis conditions, both resin liquefaction and fibre recovery exceeded 99 wt%. Most recovered fibres contained only minor residues (0.9–1.5 wt%) and retained >90% of the strength of virgin E-glass, with characteristic strengths of 2.0–2.6 GPa and Weibull moduli of 4.4–8.7. Young's modulus remained unaffected within statistical scatter. A short ultrasonic post-treatment in acetone effectively reduced residues to 0.6 wt% and increased the tensile strength of the most contaminated fibres by up to 117%, yielding recycled fibres with properties comparable to virgin fibres. Therefore, this strategy enables high-quality fibre recovery through a viable open-loop route.

#1003

# Effects of Long-Term Hydrothermal Aging and Secondary Recycling Process on the Interfacial and Mechanical Properties of Recycled Carbon Fibers

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Recycled carbon fibers (rCFs), with significant differences in forms, structure, and properties compared to virgin carbon fibers (vCFs), face challenges in their conversion into high-performance recycled carbon fiber-reinforced thermoplastics (rCFRTPs). In this study, the long-term hydrothermal aging behavior and the effects of secondary recycling on single rCFs were systematically investigated. To simulate harsh service environments, both single rCFs and their PA6-based composites were subjected to accelerated hydrothermal aging in freshwater and seawater environments under elevated temperature. The tensile properties of single rCFs and the interfacial behavior between rCFs and PA6 resin were evaluated at two-month intervals. Surface morphology evolution was characterized by optical microscopy and scanning electron microscopy (SEM), while surface chemical bonding states and O/C ratios were analyzed via X-ray photoelectron spectroscopy (XPS). After six months of artificial aging, the PA6-based rCF composites were subjected to a secondary recycling process through solvolysis, and the resulting re-recycled carbon fibers (rrCFs) were characterized using the same testing procedures. The mechanical properties, interfacial adhesion, and surface characteristics of vCF, rCF, aged rCF, and rrCF were evaluated and compared. Results indicated that recycling processes and long-term hydrothermal exposure led to progressive degradation of rCF properties, particularly in interfacial shear strengths (IFSS), with more severe deterioration observed under seawater conditions. With long-term aging, the fibers exhibited strong light reflections and multicolored streaks on surfaces, indicating progressive surface alteration. Progressive formation of surface deposits was also observed, differing in appearance, size and composition between freshwater and seawater environments, suggesting distinct degradation mechanisms. These findings provide essential insights into the durability of recycled fibers and offer valuable guidance for optimizing recycling processes, surface treatments, and the structure design of rCF-reinforced composites for long-term applications.

#1005

# Engineering biopolymer–nanoparticle aerogels: mechanical properties and microstructural control by freeze-casting

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Freeze-cast biopolymer–nanoparticle aerogels (FBNA) are highly tailorable, anisotropic porous microstructures produced via controlled ice-templating, whose mechanical performance is strongly governed by processing parameters such as pore geometry, freezing temperature, solidification rate, and the concentration of additional constituents. Building upon this framework, the present research focused on unidirectional freeze-casting of an alginate biocomposite with and without the incorporation of carbonaceous nanoparticles (graphene and carbon black). Solidification speed and nanoparticle concentration were systematically varied to assess their influence on the mechanical properties of FBNA. A comprehensive mechanical characterization framework was chosen to elucidate the relationships between freeze-casting process parameters, resulting microstructures, and key mechanical properties, thus optimizing the process for advanced biomedical and structural applications. The research encompasses multiscale mechanical assessments, including uniaxial compression testing to determine compressive strength, elastic modulus, and deformation mechanisms of highly porous aerogel networks. Macroscopic and microscale mechanical analyses were also done to establish process–structure–property correlations that reveal how variations in freeze-casting parameters and nanoparticle incorporation influence anisotropy, pore morphology, and mechanical functionality. These insights inform the rational design and process optimization of biopolymer–nanoparticle aerogels with enhanced stiffness, toughness, and fracture resistance. Ultimately, the outcomes hope to support the advancement of sustainable, high-performance aerogel materials tailored for industrial applications.

#1007

# Intelligent Design Method of Composites Layup Based on Generative Neural Network

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Composite structures possess excellent mechanical properties and design flexibility, making them highly valuable in aerospace and other fields. However, as the number of plies and ply angles increase, the design space for composite layups expands significantly, making it difficult for existing design methods to fully exploit the performance potential of composites and achieve efficient and refined design of composite laminate layups. To address this issue, an efficient layup design method based on a generative neural network is proposed. Leveraging the superior feature extraction and generation capabilities of variational autoencoders, a bidirectional mapping relationship between composite layup information and latent space feature vectors is established. To accurately capture ply angle differences and ply aggregation in composite layups, a multi-scale one-dimensional convolutional neural network is employed to extract local layup features. For performance-oriented layup generation, the latent space feature vectors are divided into layup features and unknown random variables, which are constrained separately through the design of the loss function, thereby solving the one-to-many mapping problem of generating layup schemes from mechanical properties. The established intelligent design method for performance-oriented composite layups can generate 100,000 layup schemes for composite laminates with up to 100 plies within seconds. Comparative studies on stiffened panel layup designs demonstrate the advantages of this method in layup design. The proposed intelligent layup design method enables efficient and smart design of composite layups that meet specific mechanical performance and manufacturing constraints, significantly improving the accuracy and efficiency of composite laminate design. It is also applicable to the layup design of unconventional ply laminates.

#1008

# Refinement of in-situ $Mg_2Si$ in cast magnesium alloys by addition of P and Ca

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Lightweight magnesium alloy castings have begun to be applied to various components due to increasing attention to global environmental issues and energy conservation. However, their application in high-temperature or wear-intensive environments is limited because magnesium alloys exhibit a significant decrease in strength at elevated temperatures. The “fine” dispersion of high-melting point, high-hardness $Mg_2Si$ can effectively improve the high-temperature strength, wear and creep resistance. Among casting techniques, the in-situ formation of finely-dispersed $Mg_2Si$ through the addition of refiners in the Mg-Si alloy melt has been widely used in the previous studies. For example, addition of phosphorus (P) and/or calcium (Ca) as the refiners have been attempted to refine the primary $Mg_2Si$ phase in the alloys. However, the refinement mechanism has not been fully clarified. This study aims to elucidate the mechanism of the refinement based on the crystallization behavior during the solidification process. Mg-9Al-3Si-1Zn alloy was melted with the refiners, and then slowly cooled to facilitate the growth of $Mg_2Si$. Microstructural analysis revealed that the morphology of the primary $Mg_2Si$ phase transformed from dendritic or equiaxed forms to polygonal shapes and refined due to the addition of P. EPMA analysis confirmed the formation of compounds including P as a heterogeneous nucleus near the center of the polygonal $Mg_2Si$, along with the distribution of P within the $Mg_2Si$. These findings suggest that P promotes the refinement of $Mg_2Si$ by the facilitating heterogeneous nucleation and further contributes to refinement by suppressing crystal growth via a poisoning effect. Simultaneous addition of P and Ca also refine the $Mg_2Si$. In this case, CaMgSi was detected from the nucleus and P distribution in the $Mg_2Si$ was also observed, indicating that the Ca-induced heterogeneous nucleation and P-induced poisoning effects contributed for the refinement of $Mg_2Si$.

#1009

# Multiphysics modelling of structural supercapacitors subjected to mechanical damage

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Structural power composites (SPCs) are a class of multifunctional composite materials that can simultaneously store electrical energy whilst withstanding significant mechanical loads. The multifunctionality of SPCs demonstrates their great potential in lightweighting solutions and the adoption of electrification for sustainable transportation. Structural supercapacitor composites (SSCs) are one of the mainstream SPC embodiments alongside structural battery composites, offering high specific power, long cycle life, and good environmental tolerance. The structural abilities of SSCs stem from two key components: carbon fibre-reinforced electrodes with carbon aerogel modification to enhance electrochemical performance, and a structural electrolyte to provide load transfer across the interfaces between the constituents.

To understand the electrochemical behaviour of SSCs subjected to mechanical damage, a multiscale modelling framework is proposed based on a pseudo 4D established electrochemical model for supercapacitors with a hierarchical structure. Three types of damage were considered, including fibre breakage, matrix cracking, and delamination, based on X-ray computed tomography images of a damaged SSC pouch cell under three-point bending. A random global damage map was generated by a Python script, recording the location and damage configuration for each subvolume. The effective degraded properties of the individual subvolumes were solved by a mesoscale representative volume element model through homogenisation. The resolved global effective property maps were then imported into a macroscale full cell model to predict the overall cell performance under galvanostatic charging and discharging. The numerical results were validated by comparing them to the experimental results of SSC pouch cells before and after damage.

Overall, the proposed multiscale damage modelling framework provides a powerful tool for analysing and predicting the effects of global mechanical damage on the electrochemical performance of SPCs, as well as for general energy storage devices.

#1012

# Performance Assessment of Bell–Spigot Joints in GRP Pipelines with Kissing Bond Defects: Experiments and Modelling.

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Kissing bond defects pose a significant challenge to the reliability of bell-spigot joints (BSJs) in glass-reinforced polymer (GRP) pipelines, largely because they are difficult to detect using existing non-destructive testing methods; such defects can severely compromise the load-transfer capacity of the BSJs. This work presents an integrated experimental and numerical study aimed at quantifying the influence of kissing bond defects on the performance of BSJ under representative service loading. Experimental work included hydrostatic pressure tests on real-scale BSJs and tensile tests on flat scarf-joint specimens that mimic the corresponding BSJ bondline section. While in the simulation work, a computationally efficient yet accurate FE framework was developed to simulate real-scale BSJ in GRP pipelines and validated with experiments. The proposed FE model was then used to assess the effect of stochastic and controlled kissing bond defects on the structural performance of BSJ under tensile and hydrostatic pressure loadings. Excellent correlation between the simulations and experiments confirmed the capability of the framework to reliably evaluate the performance of BSJ in the presence of a kissing bond defect. In a controlled kissing bond, defects located near the outer edge of the overlap region produced the most pronounced reductions in tensile strength (up to 28%), whereas defects located away from the edge had minimal impact. While in the stochastic kissing bond defect, the model successfully predicted strength variabilities observed experimentally. Hydrostatic burst tests showed a small reduction in the burst pressure (i.e., 143 bar for pristine joints vs. 138 bar for defective joints), which is attributed to the defect being located slightly away from the outer edge of the joint. The integrated experimental and numerical framework improves insight into defect-sensitive BSJ design and provides recommendations for safeguarding the integrity of GRP pipeline infrastructure.

#1013

# Investigation of moisture influence during manufacturing of artificial bio-based cellulose nanofibril (CNF) fibre/epoxy composites

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Natural fibre reinforced polymers (NFRPs) provide good specific mechanical properties, excellent damping properties at low costs. Despite these advantages, natural fibres have a relatively high degree of variability in their properties and are moisture sensitive. The moisture sensitivity based on the the hydrophilic surface and the presence of lignin and hemicelluloses, which can attract, absorb and bond water.

A new type of artificial bio-based fibre produced by flow-focusing of cellulose nanofibrils (CNFs) has been developed in previous work. With this technique, CNF fibres can be produced with very good specific properties in the range of conventional advanced fibre systems. Compared to conventional natural fibres, these CNF fibres furthermore do not contain hemicellulose and lignin.

The absorption of moisture raises questions about the use of natural fibres in structural applications. Consequently, a lot of studies focus on the moisture influence on mechanical, physical and thermal properties of NFRPs. However, surprisingly only few studies have investigated how moisture during manufacturing influence the composite properties. It is reported that the shear modulus and strength, decreased with increased humidity in the composite manufacturing, particularly at a manufacturing humidity above 70%. Conversely, completely dry manufactured composites do not always show improved properties.

In the present study, CNF fibre and flax fibre reinforced epoxy composites were manufactured at low and high humidity. The moisture content was measured by thermogravimetric analysis (TGA) of the fibres, the pure epoxy polymer as well as on the manufactured composites. Additionally, the influence of humidity during manufacturing on the formation of the fibre-matrix interface was investigated through tensile dynamic mechanical analysis (DMA) measurements. This study will highlight the importance of moisture control during production and suggest pathways for an optimized manufacturing of NFRPs.

#1014

# Mechanical performance versus microstructural inter-filament interface analysis of fdm-printed carbon fibre reinforced PLA composite under static and dynamic loading

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FDM printing has opened up new opportunities of designing and producing complex parts and with more efficiency. This manufacturing process allows for the use of composite materials as well which allows for printed parts with satisfactory mechanical properties.

This paper investigates the static, and the dynamic mechanical properties of a Fused Deposition Modelling (FDM) printed Polylactique acid carbon fibre reinforced composite (PLA-CF) containing 20 wt% carbon fibres (CF) destined to be used for drone structural parts. Unidirectional tensile and three-point flexion tests were performed to characterize the material's static mechanical properties. To cater for the drone dynamic stresses resulting from the motor vibration and the interaction with airflow, dynamic tests using an impact-hammer Vibrometer were also run.

The flexion and tensile tests were repeated to ensure validity of results. The latter showed consistency in the elastic part of the stress/strain curve, satisfactory consistency in the nonlinear part but a significant dispersion in failure level. This dispersion is likely because the composite is FDM-printed, as carbon fibres often presents inter-filament adhesion issues when introduced into PLA. To confirm this hypothesis, an investigation on the microscopic scale is necessary.

Both mesoscopic and microscopic analysis were conducted respectively using an optical microscope and scanning electron microscope (SEM) to quantify and qualify precisely internal damage mechanisms and inter-filament interface conditions.

#1015

# Multimaterial Auxetic Lattice Structures with Optimized Stiffness and Reduced Stress Concentration

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Re-entrant auxetic honeycomb structures offer significant potential for lightweight aerospace components due to their energy absorption capabilities. However, conventional single-material designs suffer from the fundamental limitation of severe stress concentrations around the nodes, resulting in early buckling of struts, creating an inherent trade-off between stiffness and auxeticity. To resolve this specific conflict, this study proposes a hinge-based multi-material strategy. By utilizing high-stiffness PLA/CF (Carbon Fiber) for the struts and high-toughness PLA-ST (Super Tough) for the hinge regions, the multi-material designs aim to mitigate stress accumulation and decouple stiffness from auxetic behavior. However, the introduction of distinct materials comes with the cost of interfacial failure and debonding issues. Alleviating this vulnerability can be achieved through the use of mechanical interlocking which increases the surface area, leading to superior adhesion and attachment between different materials. As a result of the geometric mechanical interlocking the risk of debonding can be minimized and structural integrity under external loads can be maintained.

The proposed work involves a parametric design approach coupled with finite element analysis in which locking parameters including tab length and width will systematically be varied to analyze their effects on the mechanical performance. The lattice structures will be subjected to compression loads until densification takes place, and the energy absorption capabilities as well as stiffness properties will be assessed. In addition, the finite element analyses will be validated by the experimental tests and the results will further be utilized to find a correlation between the mechanical properties and the interlocking parameters. Finally, through the use of machine learning and Random Forest Regression, the importance of each parameter will be quantified. By comparing various mechanically interlocked configurations, this study aims to establish an optimized topology with maximized specific energy absorption.

#1017

# Effects of Residual Stresses on the Load-Bearing Performance of Asymmetric Foam Sandwich Structures

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Cure-induced residual stresses in asymmetric composite foam sandwich structures can significantly affect their load-bearing performance, but have received limited attention compared with symmetric designs. In this work, an asymmetric PMI foam sandwich panel with a carbon fibre-reinforced polymer (CFRP) face sheet on one side and a glass fibre-reinforced face sheet on the other is investigated by means of finite element analysis.

A full cure-cycle model is developed on the ABAQUS platform to simulate the secondary bonding of the face sheets to the PMI core and the subsequent cooling from curing temperature to room temperature. The model captures the curing deformation and residual stress distribution in panels with different core heights, while maintaining the external geometry to represent forced assembly conditions. Based on the obtained residual stress fields, three-point bending and lateral compression analyses are performed. A USDFLD user subroutine is implemented to describe stiffness degradation in the face sheets and core, allowing the interaction between residual stress and progressive damage to be evaluated.

The results show that, within the studied range, varying the core height has little influence on the peak residual stress, which is mainly controlled by the mismatch in coefficients of thermal expansion between the CFRP and glass-fibre face sheets. Increasing core height enhances the maximum bending load but reduces the flexural stiffness, leading to larger deflections at failure. Residual stresses significantly reduce the bending load capacity and cause earlier damage initiation. Furthermore, replacing the pure glass-fibre face sheet with a hybrid aramid/glass-fibre face sheet effectively alleviates curing deformation and lowers residual stress levels, thereby improving the load-bearing performance of the asymmetric foam sandwich structure. These findings provide useful guidance for the design and optimisation of lightweight multifunctional sandwich panels.

#1019

# Efficient Damage Prediction in Composite Pressure Vessels through Representative Modelling

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Carbon-fibre hydrogen pressure vessels are essential for clean energy storage, but accurately predicting their structural performance under uncertainty remains a major challenge. Material imperfections such as fibre misalignment, variable volume fractions, and inconsistent strength introduce spatial variability that affects failure behaviour. Full pressure vessel Finite Element Analysis (FEA) is widely used to predict the vessel's performance, but it becomes computationally infeasible when accounting for spatial variability using non-deterministic models. Non-deterministic models require extremely fine elements to capture local material variations. This requirement makes them impractical for large-scale pressure vessels.

This study presents a computationally efficient representative model focused on the cylindrical region where the fibre tensile damage typically initiates and propagates [1]. The model incorporates spatial variability in fibre strength using random fields and applies a failure criterion to predict fibre tensile failure initiation and progression. By isolating the cylindrical region, the approach significantly reduces the computational cost while preserving the essential stress characteristics of the full vessel. The simulation results show that with a single 4 mm-wide ring, the proposed approach achieves an equivalent stress distribution in the vessel's critical region at 200 times lower computational cost than full-scale pressure vessel modelling. This computational cost efficiency enables us to use ultra-fine mesh elements (approximately 200 µm), which are necessary to accurately represent spatial variability without excessive computational cost.

The proposed method maintains accurate prediction of critical stresses and damage initiation, compared to a full pressure vessel, for large-scale composite pressure vessels subjected to internal pressure. These findings enable improved uncertainty quantification, contributing to safer hydrogen pressure vessels.

Keywords: Finite element analysis (FEA), Composite pressure vessel, Damage initiation, Spatial variability

[1] Ramirez, Juan Pedro Berro, et al. "700 bar type IV high pressure hydrogen storage vessel burst–Simulation and experimental validation." International Journal of Hydrogen Energy 40.38 (2015): 13183-13192.

#1020

# Impact of chemical recycling on the surface roughness and sizing retention of carbon fibre reinforcements recovered from recyclamine epoxy composites

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Carbon fibre-reinforced polymer (CFRP) composites are integral to high-performance sectors, including aerospace, automotive, and renewable energy, due to their superior strength-to-weight ratios. However, the widespread proliferation of CFRPs has precipitated a waste management crisis; traditional thermosets are difficult to break down, making landfilling an unsustainable standard. To address this, sustainable chemical recycling (such as, solvolysis) is essential for establishing a circular economy, as it allows for the recovery of high-quality carbon fibre reinforcements unlike destructive mechanical methods. In this regard, recyclamine epoxy is a promising technology that utilizes cleavable curing agents allowing the thermoset matrix to be chemically de-crosslinked under specific conditions, potentially leading to the recovery of near virgin-quality carbon fibre reinforcements. To investigate this, in this study carbon fibre reinforced recyclamine epoxy composites are chemically recycled using a low-energy sustainable chemical recycling process. The recycling of the composites is achieved by using an aqueous acetic acid solution operating at a temperature of 80 °C. The recycled fabrics are characterised using a combination of different techniques, such as, Thermogravimetric analysis (TGA), Fourier transform infrared spectroscopy (FTIR), Atomic force microscopy (AFM), Optical, and Scanning electron microscopy (SEM). The results from SEM and Optical microscopy demonstrated that the recycled carbon fabrics were able to retain their fabric architecture comparable to the virgin fabrics. AFM results demonstrated approximately 15% increase in the average surface roughness in recycled carbon fabrics as compared to the virgin ones, which can be attributed to the removal of the epoxy film former and lubricant layer. The FTIR and TGA analyses demonstrated that the recycled carbon fabrics were able to retain the chemical functional groups significantly and that the fabrics were free of any chemical residues and impurities. Overall, the surface roughness and sizing components in the recycled carbon fabrics were comparable to the virgin carbon fabrics.

#1021

# Fiber-bridging in carbon-fiber-reinforced epoxy composites

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Carbon fibre reinforced plastics (CFRP) have been extensively researched in recent decades. CFRP are very interesting for complex structures because they offer flexibility in design and can be tailored to specific application requirements. During product development, their thermal and mechanical properties are paramount and determine whether the material meets the performance requirements. Among the mechanical properties, fracture and fatigue behaviour and threshold values are of crucial importance, especially when a 'no crack growth' policy is requested.

To ensure reliable design based on intrinsic properties and to link laboratory coupon-tests to full-scale component performance, it is necessary to identify and reduce sources of data scatter. Certain mechanisms occurring during coupon testing influence results, even though they may not appear in real-life damage due to differences in failure speed or component geometry. One example is the fiber-bridging phenomenon in CFRPs. Fatigue testing standards allow variations in initial crack length, load-ratio, and frequency. However, when results from different parameter sets are compared, large scatter appears. This indicates that the measured behavior is influenced by test conditions rather than reflecting a true intrinsic fracture resistance. One source of this scatter is fiber-bridging, where fibers remain intact across the crack surfaces even after the crack tip has advanced. These fibers store and release energy during each cycle, which is mistakenly attributed to intrinsic toughening mechanisms occurring at the crack tip. As a result, material performance may be overestimated. The extent of fiber bridging depends on parameters such as load-ratio, frequency, geometry, and initial crack length.

The current work shows that through some modifications in data analysis and a more fundamental approach, the effect of these parameters on data scatter can be eliminated to high extent. The experimental approach leads to more reliable data on fatigue crack propagation resistance of carbon fiber reinforced composites.

#1023

# Simulation-Based Target-Surface-Temperature Control for Continuous Induction Welding of CFRP

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As research on aerospace structures increasingly turns to thermoplastic composites, the development of appropriate welding techniques becomes essential. Continuous induction welding of CFRP offers a flexible and efficient method for producing continuous weld interfaces typical for aircraft structures. However, the weld-zone temperature is highly sensitive to material inhomogeneities, leading to fluctuations that can significantly affect joint quality. Conventional monitoring with thermocouples provides precise but only pointwise data and potentially weakens the joint or locally hinders the joining process. A surface-based temperature measurement could reduce or even avoid the need of thermocouples but requires reliable correlations between surface temperature and the temperature distribution in the joining zone. This correlation however is difficult to obtain experimentally due to the complex temperature distribution in the joining partners combined with the limited information provided by thermocouple measurements.

This study applies a numerical simulation approach developed at IVW using ANSYS LS-DYNA® for the transient prediction of the temperature distribution in the welding partners during the welding process. The simulation is used to determine location and value of the surface temperature needed in order to achieve the required joining zone temperatures. A thermal camera (DIAS PYROVIEW 380L) coupled to a CEIA MASTER CONTROLLER V3+ is then used to actively control the surface temperature based on these simulation results.

To validate the approach, simulations with different target surface temperatures were compared with continuous induction welding trials on CF-PPS organo-sheet welding coupons. The weld quality and the predicted weld area were subsequently assessed through NDT.

The results show that the combined simulation and surface-temperature-control approach can reliably predict the temperature distribution and the width of the welded region. This indicates that this technique, supported by numerical simulation, is a promising method for continuous induction welding and may significantly reduce the need for thermocouples in future process setups.

#1024

# Anisotropic Nanocomposite for Sustainable Solar-Thermal Application

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Interfacial solar evaporation is an emerging technology that efficiently convert solar energy to heat for water desalination. To achieve a high evaporation rate and energy efficiency, porous evaporators are developed from photothermal materials for heat localization, fast water transport, and enhanced vapor diffusion.[1] However, conventional evaporators decline in evaporation performance with increasing size, limiting the scalability from laboratory to practical scales.[2] Here, we engineer a hierarchical nanocomposite aerogel using a novel freeze-assisted additive manufacturing technique following a modeling-assisted rational design. We first develop a coupled heat and vapor transport model to reveal the size-dependent boundary layer thickness is the key factor limting the vapor diffusion as size increases. To decouple the boundary layer thickness from overall device size, we devise a freeze-assisted additive manufacturing technique to engineer the macro and microstructure of the aerogel, achieving size-insensitive vapor diffusion and stable evaporation even as its lateral dimensions increase. Unlike conventional evaporators that experience a significant drop in evaporation performance, exceeding 40%, as the size increases, the resulting aerogel exhibits an impressive evaporation rate exceeding 2 kg $m^{-2}$ $h^{-1}$. Moreover, it achieves energy efficiency of over 80%, with a minimal reduction of less than 5%, regardless of its size. Our findings shed new light on the vapor diffusion mechanism in porous evaporators and offer a practical solution for scalable solar-driven desalination.

Reference

[1] H. Zhang, X. Shen*, E. Kim, M. Wang, J.-H. Lee, H. Chen, G. Zhang, J.-K. Kim*. Adv Funct Mater, 2022, 32, 2111794.

[2] X. Zhao, Y. Yang, X. Yin, Z. Luo, K.-Y. Chan, X. Huang, Y. Yang, X. Shen*. ACS Energy Lett, 2025, 10, 3419–3429.

#1026

# Pushing service temperature limits: Unidirectional carbon fibre reinforced polyamideimide composites

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Carbon fibre-reinforced high-performance polymer composites with continuous service temperatures exceeding 150°C are sought after for applications in transportation and the oil and gas sector. Thermoplastic matrices offer several advantages over thermosetting resin systems, including shorter processing times due to the absence of curing reactions, which results in much lower associated safety and toxicity concerns. Additionally, they have “unlimited” shelf lives, lower moisture uptake, can be easily shaped and are potentially recyclable. These traits, along with the greater fracture toughness and longer fatigue life of thermoplastic polymers, render thermoplastic carbon fibre reinforced polymer composites attractive for high-performance, large-scale applications. From the thermoplastic family, poly(ether-ether-ketone) (PEEK) is by far the most extensively investigated polymer matrix for CFRP composites due to its superior mechanical and thermal properties. The high melt viscosity of thermoplastic high-performance polymers can cause manufacturing problems. Amorphous high-performance thermoplastic composite matrices, such as polyethersulfone (glass transition temperature Tg ≃ 225°C, polyetherimide (Tg ≃ 230°C), or polyamideimide (PAI, Tg ≃ 280°C), for production of unidirectional CFRP remain relatively underexplored despite their promising attributes. PAI – commercially available as Torlon – has an attractive property envelope, despite the absence of crystallinity, but has a narrow processing window because of its high Tg and moisture sensitivity, requiring temperatures exceeding 315°C to prevent property degradation. Carbon fibre reinforced Torlon (with a fibre volume fraction (FVF) of ~30 %) is known. We will discuss a continuous aqueous powder suspension impregnation process to produce unidirectional carbon fibre reinforced PAI composites with FVF of 60% avoiding PAI degradation. UD composite tapes will be processed into laminates and mechanical properties of CF/PAI composites, such as short beam shear, tensile and compression properties, besides fibre in matrix distribution, fibre alignment, and void content will be disclosed.

#1027

# Periodic Laminate Unit Cell for Predicting Stiffness, Strength, and Damage in CFRP Laminates.

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Traditional laminate property characterisation relies on costly, time-consuming experiments. Recently, numerical simulation tools have emerged as an efficient alternative, enabling virtual testing and allowing for the exploration of a wider range of configurations. High-fidelity models can accurately reproduce standard tests and predict laminate behaviour under macroscopically homogeneous stress states. However, the finite width of test coupons and the 3D stress state at the edges influence their behaviour through delamination and cracking.

Building on the microscale homogenisation framework, where a unit cell RVE explicitly resolves fibres, matrix, and interfaces, this work introduces a mesoscale unit cell constructed to represent an infinite laminate. By embedding the homogenised ply and interface models into a periodic laminate segment, the unit cell enables the prediction of laminate stiffness, strength, and damage evolution under uniform loading while removing edge effects and reducing the computational time.

The unit cell framework is implemented in an explicit finite element solver, combining continuum damage models, cohesive interfaces, and periodic boundary conditions enforced through user-defined elements to reproduce a uniform far-field stress state. Intralaminar failure mechanisms, such as fibre breakage, pull-out, kinking, and matrix cracking, are represented using a continuum damage model. Delamination is captured through a cohesive zone model.

This approach was applied to unnotched soft, hard, quasi-isotropic, and ±45° CFRP laminates. The homogenised stress–strain responses and failure loads obtained from the unit cell closely matched coupon-level experiments, with predicted strengths falling within the experimental scatter. This agreement confirms that the unit cell reliably captures the overall laminate behaviour, demonstrating its suitability as both a virtual testing tool and a data generator for machine-learning models.

#1028

# Integrated Monitoring Solution for Enhanced Toroidal Propeller Safety

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This work presents the design and integration methodology for the sensing network embedded within toroidal propeller structures developed under the TorPropel project. The complex topology of composite toroidal propellers is anticipated to generate intricate stress distributions and airflow patterns which have not been characterized yet under operational conditions, necessitating real-time monitoring, initially to provide data for validating design assumptions, and subsequently to ensure operational safety while optimising maintenance scheduling. The monitoring system will incorporate two discreet types of sensors: film-based strain gauges distributed over the surface of the composite for continuous strain monitoring, and compact Limmat Scientific airflow sensors for aerodynamic characterisation and validation of computational fluid dynamics (CFD) models. Preliminary computational physics results are used to select sensor locations, with CFD simulations identifying crucial areas for aerodynamic performance and finite element structural analysis providing insights on regions important stress concentrations. Robust, low-profile sensor components and interconnection solutions are selected to facilitate their integration without sacrificing the laminate's structural integrity or the propeller's aerodynamic efficiency. Data acquisition electronics are specified based on their ability to resolve dynamic events during rotation with adequate precision and sampling frequency, while also considering weight constraints and suitability for the environmental conditions of aircraft operation. A wireless communications interface is implemented for real-time transfer of data from the propeller to the aircraft operator, while sensor data is also stored locally for detailed post processing by flight engineers. The power management solution for the monitoring system will focus on energy-efficient operational modes and integrated power generation modules to sustain continuous monitoring throughout extended flight cycles without adding excessive battery mass. All electronic modules are housed within a dedicated compartment integrated into the propeller hub assembly and positioned beneath the nose cone, to provide environmental protection and accessibility for maintenance operations.

#1029

# Compression strength predictions of pultruded carbon fiber profiles for wind turbine blades

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Over the last decade, pultruded carbon fiber profiles have been the dominant building block as the primary load-carrying element in modern large wind turbine blades. Approximately one-quarter of the world's carbon fiber production is utilized in this application. Thus, better control of the mechanical performance of such components can have a substantial influence on the competitiveness of wind turbine blades. In the pultrusion process, it is possible to obtain large fiber volume fractions, typically 65-70%, without the need for secondary oriented fibers, which is the case with non-crimp fabric-based composites. The pultruded carbon fiber profiles are therefore a material with high mechanical performance, exhibiting a high stiffness-to-weight ratio and excellent fatigue resistance. Nevertheless, carbon fiber composites are known for their sensitivity to compressive loadings, where the compression strength is governed not by the fiber strength but by the interaction between the fiber orientation distributions and the shear strength of the matrix material.

In the presented work, 2D microscopy and 3D X-ray-based data, coupled with image analysis tools, are utilized for precise characterizations of fiber orientation distributions. These characterizations are subsequently used in a finite element-based compression prediction model. The challenge of obtaining a sufficiently large field of view using the different fiber orientation acquisition methods is addressed. The actual fiber orientation distributions are used to obtain predictions of the case-specific compression strength of pultruded carbon fiber-reinforced profiles.

#1030

# Effect of Fibre Inclination and Gaps on the Homogenised Stiffness of Variable Angle Tow Composites

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Variable angle tow (VAT) is an emerging high-performance material system in composite applications. While it offers superior mechanical performance, its analysis is highly complex. Besides, the automated fibre placement method used to manufacture VAT laminates often introduces gaps. This defect may affect the effective elastic moduli of the material. This study investigates the influence of tow gaps on the homogenised elastic properties of VAT composites using a combination of representative volume element (RVE) modelling and analytical transformation approaches.

RVE models containing composite prepreg tape and matrix-filled gaps at various ratios were developed in Ansys to determine the effective elastic moduli. First, the fibre orientation was represented using components aligned with the global coordinate system. Homogenised orthotropic properties, which are the baseline moduli, were then transformed to arbitrary fibre orientations using classical transformation formulas, enabling prediction of elastic properties for inclined tows without explicitly modelling the RVE at each angle. Next, to evaluate the accuracy of this transformation-based approach in the presence of manufacturing gaps, novel RVE models were used to simulate inclined fibres and gap patterns that were extracted from a constant curvature fibre path lamina. The homogenised moduli obtained from these RVE simulations were compared against the analytically transformed moduli derived from the baseline RVE.

Results indicate that the inclined-fibre model shows good agreement for Ex and Ey, but exhibits slightly higher Ex and Ey and a lower Gxy compared with the reference transformation model. The results also show a reduction of up to 30% in the normalised moduli when a gap ratio of 0.2 is introduced, which highlights the importance of incorporating gaps and fibre angles effects during VAT laminate modelling. The study demonstrates the potential and limitations of transformation-based homogenisation for modelling VAT materials and structures.

#1031

# Compression moulding with tape trim waste to manufacture structural components

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The use of unidirectional thermoplastic carbon fibre-reinforced tape is steadily increasing, due to advantages in terms of material efficiency, high achievable mechanical performance and suitability of thermoplastic process chains for large-scale production. However, geometric complexity of components is limited because deep-drawing capability is low and the resulting tape wrinkling when depositing curved paths. Slit tapes allow for pseudo-plasticity and are therefore used for more complex structures. But, slitting of UD tapes and processing them generate waste in the form of trim scrap. Slitting alone accounts for 3 % trim loss from master bobbins. Industrially, this waste is chopped and collected for disposal. These chopped tapes offer significant potential as a high-quality, impregnated and mouldable semi-finished product.

This work investigates the mechanical performance and mould filling behaviour of chopped tapes for structural applications. First, plates were produced with different process parameters to determine a favourable processing window. The performance was characterised by microscopy and mechanical tests. In plates made from randomised tapes lengths, a general reduction in average tensile strength with increased variation was observed. With increasing tape length from 6 to 10 mm, the average rises by about 20 %. Further increases are expected with longer fibres, indicating the need for additional research.

Mould filling behaviour was investigated using different tools: two H-profiles with different cross-sectional areas and a complex cleat. Full mould filling could be achieved in all cases. In addition to the cavity cross-section, the processing temperature, pressure and fibre lengths strongly influence mould filling. While mould filling with 6 mm tapes was complete after 15 minutes, mould filling with 10 mm tapes achieved only about 80 % filling. High temperature, pressure, longer time and short tapes improve mould filling, but the mechanical properties decrease by about 20 % when reducing tapes from 10 to 6 mm.

#1032

# Comparison of the Mode I and Mode II fracture toughness of glass fiber- and carbon fiber-epoxy laminates and in-depth analysis of the delamination process using acoustic emission analysis

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Delamination is a dominant failure mode in fiber-reinforced polymer laminates, and accurate interlaminar damage models require a thorough grasp of the microscopic mechanisms that drive delamination initiation and growth. This contribution compares the Mode I and Mode II delamination resistance of a glass fiber-reinforced (GF-) and a carbon fiber-reinforced (CF-) epoxy laminate manufactured with the same epoxy matrix system, thereby isolating the influence of fiber type on interlaminar delamination behavior. To gain deeper insight into the underlying microscopic damage processes, acoustic emission (AE) measurements are performed during the delamination resistance tests.

Mode I toughness is measured using double-cantilever-beam tests. The results indicate that GF-epoxy exhibits a slightly higher initiation toughness than CF-epoxy, although the difference is not statistically significant. In contrast, the propagation toughness of GF-epoxy is notably higher. This increased propagation toughness correlates with more pronounced fiber bridging effects observed in the GF-epoxy system, which enhance delamination resistance during delamination growth.

Mode II toughness is evaluated through end-notched-flexure tests, which capture only initiation toughness due to unstable delamination propagation. In contrast to the Mode I results, where both laminates yield roughly comparable initiation values, the GF-epoxy laminate clearly shows a higher Mode II initiation toughness compared to CF-epoxy.

To probe the microscopic origins of these differences, the AE data collected during testing is subjected to cluster analysis. Scanning electron microscopy images of the fracture surfaces are used to correlate the identified AE clusters to specific damage mechanisms, such as matrix cracking, fiber breakage, and fiber-matrix debonding, thereby providing a link between macroscopic toughness and microscopic failure modes.

Overall, the results demonstrate that the reinforcing fiber material affects both Mode I and Mode II interlaminar fracture toughness.

#1033

# Mycelium-Textile Prepreg Analogues for Fungal Composites

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The rapid growth of fast-fashion has created a large and persistent textile waste problem, yet these fibre-rich materials are readily colonised by fungi and can serve as effective feedstocks for bio-based composites. Here, we present a lamination approach in which textile sheets are pre-colonised individually with Ganoderma lucidum and then consolidated through hot-pressing to form dense mycelium–textile laminates. This strategy overcomes the limited oxygen availability that normally restricts fungal growth in thick substrates: outer plies develop extensive mycelial networks, while inner plies remain sparsely bound. By constructing laminates exclusively from the highly colonised surface plies, we obtained tensile strengths approaching 14 MPa. The resulting materials also showed strong flexural behaviour and adequate shear resistance, positioning them as candidates for lightweight structural panels, interior components, and insulation alternatives. These findings demonstrate that combining textile substrates with a prepreg-inspired assembly method can unlock a new mechanical regime for fungal composites and establish a viable pathway for upcycling low-value textile waste into engineered materials.

#1035

# From constituent to composite: multiscale experiments for enhanced compression performance

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Compression failure along the fibre direction is one of the most complex failure modes in fibre-reinforced polymer composites. In fibre kinking, multiple factors across length scales play critical roles, including fibre misalignment, matrix plasticity and the fibre-matrix interface. Compressive performance can therefore be improved by both enhancing constituent materials and controlling fibre alignment. This also requires advanced experimental techniques capable of resolving behaviour across constituents and length scales. Here, a suite of multiscale experimental methods is introduced to characterise the relevant deformation and failure mechanisms and to quantify the resulting compressive properties.

At the matrix level, matrix yielding in compression, shear, or combined loading can trigger the instability of misaligned fibres and promote fibre micro buckling, ultimately leading to fibre kinking. To investigate this, we developed experimental methods to characterise polymers under compression, shear, and shear/compression. The tests were designed to ensure a high degree of strain uniformity, enabling reliable stress-strain curves up to large deformations. Minimisation of barrelling in compression specimens allowed us to extract key parameters for plasticity models, such as the dilation angle.

At the composite level, to exploit the improved fibre alignment obtained by pultrusion, we developed the “cradle test”, in which compression is introduced via bending of a polymeric beam to which pultruded rods are bonded. This configuration promotes failure within the gauge length, which is typically difficult to achieve with conventional direct compression tests. Inspired by natural hierarchical structures, pultruded rods were also bundled, for which a specialised experimental methodology was established.

The experimental methodologies presented here generate high-quality data sets for calibrating and validating detailed micromechanical models and homogenised mesoscale models for compressive failure.

#1036

# Damage Mitigation in Carbon Fiber Reinforced Polymer Laminates Subjected to Lightning Strikes using Conductive Carbon Black and Retrofitting Technique

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Lightning strike poses a serious threat to the structural integrity of aircraft composite structures. Fiber reinforced composites, despite their light weight and excellent mechanical properties, are poor conductors of electricity, making them susceptible to catastrophic damage in the event of a lightning strike. Aerospace companies traditionally employ metallic meshes to prevent catastrophic damage due to the strikes. However, such meshes have several disadvantages like added weight, adhesion issue, galvanic corrosion, etc. The degree of damage protection also depends on the thickness and hole diameter of the meshes. Alternate means of lightweight Lightning Strike Protection (LSP) are currently being tested at a lab scale.

In this paper, the epoxy resin used as matrix in the laminates were modified using Carbon Black nanofillers to increase the conductivity. CFRP laminates with 6 additional layers of such conductive laminates were prepared. The laminates were subjected to high-current impact strikes. Pristine CFRP samples were also exposed to similar tests for comparison. The damage depth and surface area damage for the samples were observed using 4-D X-ray images. The surface damage area was larger for the conductive samples, but the damage depth was reduced, implying that the conductive layers managed to limit the damage only to the top layers, thus offering protection to the base laminate. The residual strength of the samples was also tested using four-point bending tests. Preliminary results showed that the conductive samples had higher residual strength after strike as compared to the pristine samples. The pristine samples had around 81% residual strength, whereas the protected samples offered a residual strength of around 92%. Additionally, the 6 extra layers offer higher flexural strength than the pristine samples. LSP method using such a technique has the potential to replace the traditional metallic meshes by offering similar protection and added structural strength.

#1038

# Characterizing Mixed-Mode Fracture Behavior in Composite-Metal Joints via Back Face Strain Derived Method

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Characterizing the mixed-mode fracture behavior of composite-metal adhesive joints is essential for the structural design and certification of bi-material aerospace components. However, existing mixed-mode fracture evaluation techniques often encounter intrinsic limitations, including unstable crack propagation, ambiguity in crack-tip identification, and the inability to directly extract the traction-separation relationship (TSR), which is fundamental for cohesive zone model. These challenges restrict the accuracy and reliability of interfacial fracture characterization under combined-mode loading. To address these issues, this study introduces Back Face Strain Derived Method (BFSM) for robust and precise characterization of mixed-mode fracture behavior in composite–metal joints subjected to uneven-moment bending (UMB) test.

Distributed back-face strains were measured along the adherends and used to reconstruct the interfacial stresses and separations based on Euler–Bernoulli beam theory. This approach enables direct extraction of mode-dependent TSR without the need for long-duration crack-tip displacement tracking or optical crack monitoring techniques. The evolution of the fracture process zone (FPZ) and the associated crack-growth behavior were characterized, while the mode-dependent fracture toughness was found to be consistent with the J-integral approach.

Results demonstrate that BFSM provides stable and accurate characterization of mixed-mode fracture behavior across a broad range of mode-mixity conditions. The method effectively resolves interfacial failure mechanisms, capturing the transition from opening-dominated to shear-dominated fracture as well as the pronounced R-curve behavior characteristic of shear-driven regimes. Compared with conventional direct approaches, BFSM demonstrates a superior ability to quantify the evolution of the traction–separation relationship (TSR) throughout crack propagation. The proposed BFSM establishes a rigorous and experimentally accessible framework for quantifying mixed-mode fracture in composite-metal joints.

#1039

# Mad-based identification of transverse crack initiation in carbon fiber reinforced cross-ply laminates

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Composites exhibit inherently anisotropic mechanical behavior, providing high tensile performance along the fiber direction while showing significantly reduced strength under transverse loading. In cross-ply laminates, this often leads to the early initiation of transverse matrix cracks within the 90° plies, followed by crack accumulation and a subsequent transition into interlaminar delamination at the 0°/90° interfaces. The interconnection of crack networks creates continuous leak paths through damage-induced permeation. In hydrogen storage applications, this can result in significant gas leakage and therefore render the storage system inefficient or even unusable. While numerous experimental techniques have been proposed to characterize the damage progression, studies that systematically combine high-resolution strain measurements with acoustic damage monitoring for thermoplastic cross-ply systems remain scarce. This study investigates the damage evolution in carbon-fiber-reinforced polyamide (CF/PA) cross-ply laminates subjected to uniaxial tensile loading until complete failure. Digital Image Correlation (DIC) is employed to analyze the specimen edge to obtain a two-dimensional strain field enabling direct tracking of transverse crack initiation and growth. Complementary Acoustic Emission (AE) monitoring provides a continuous, non-optical assessment of the associated damages, enabling temporal characterization of crack formation and early-stage delamination events. Particular emphasis is placed on identifying the strain level at which the first transverse cracks occur and on evaluating whether both measurement methods detect this onset consistently. By correlating DIC-based crack observations with characteristic AE signal features, the study further examines the capability of AE to distinguish between transverse cracking and subsequent delamination - damage modes that are optically well separable but acoustically more challenging to classify. Conclusively, microstructural analysis of the laminates contextualizes the observed damage mechanisms and the combined insights from DIC and AE reveal distinct differences in crack initiation thresholds and damage progression among the investigated CF/PA systems.

#1041

# Propagation fracture toughness of injection-moulded short-fibre composites under the combined effects of fibre orientation and testing temperature

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Injection-moulded (IM) short-glass fibre reinforced thermoplastics (SFRPs) are lightweight materials suitable for high-volume applications. The injection-moulding process creates a core-shell microstructure with complex fibre orientation states, complicating the characterisation of IM-SFRPs. Although previous studies have characterised the initiation fracture toughness of SFRPs, the propagation fracture toughness of IM-SFRPs has not been thoroughly characterised. The objective of this work is to characterise the combined effect of fibre orientation and testing temperature (from -30℃ to 120℃) on the tensile propagation fracture toughness of injection moulded short-glass fibre reinforced polyamide 6.6.

The propagation toughness was measured using tensile Compact Tension (CT) testing; environmental effects significantly influenced the propagation toughness. For the 0◦ specimens, it increased by 31.6% from room temperature to 120 ℃, and decreased by 44.9% from room temperature to -30℃. Moreover, the propagation toughness was maximum at 0° direction for all testing temperatures, and decreased by 10.3 – 76.0% as the fibre orientation angle increased up to 90°.

The fracture surfaces of CT specimens were observed using scanning electron microscope to characterise the damage mechanisms. Fracture was dominated by fibre tension failure in the 0° coupons, then shifting to matrix shear at 45°, and to matrix transverse tension at 90°. A clear temperature effect was also observed; brittle fracture surfaces at -30 ℃, and ductile fracture surfaces at higher temperatures.

The experimentally measured toughness was used as input for Cohesive Zone Modelling in finite element simulations; these simulations showed excellent agreement with the experimental load-displacement curves in terms of initial stiffness, peak load and post-peak behaviours.

This work first characterised the propagation fracture toughness of IM-SFRPs under the combined effects of fibre orientation and temperature, demonstrating the importance of considering both factors. These results can therefore support industry in designing safer and more efficient damage-tolerant IM-SFRP components.

#1043

# From constituents to composites: the NextCOMP project to enhance compression performance

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The Next Generation Fibre-Reinforced Composites (NextCOMP) project is a collaborative UK Programme grant, focusing on the challenge of improving the absolute performance of fibre reinforced polymer composites in compression. It aims both to address practical limitations of current materials, and to demonstrate the value of quantitative hierarchical materials design. New strategies to control and couple the damage mechanisms operating at each physical lengthscale can improve performance, ideally approaching more closely to the intrinsic compression strength of state-of-the-art fibres. The project takes a holistic approach, exploiting the latest developments in materials, processing, characterisation, and computation, to develop new constituents and architectures, across the engineering length scales. NextCOMP is developing systems that offer improved performance and greater design freedom, enabled by new, fundamental understanding of multiscale materials and hierarchical composite design principles. The talk will introduce the project and examples of promising outcomes, including accelerated modelling of real fibre architectures in compression, CNT-grafted carbon fibres for delayed kink band initiation, and architectured features to deflect kink bands or even arrest propagating translaminar compression cracks.

#1044

# Microscale air permeability characterization of lafp composites using micro-ct imaging: Comparison with pulse-decay measurements

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Vacuum bag only (VBO) as an out-of-autoclave (OoA) processing is increasingly being investigated as a promising alternative for traditional autoclave processing. A critical aspect of ensuring the efficiency of VBO processing is the characterization of air permeability in composite components. By optimizing the process parameters of laser-assisted fiber placement (LAFP), the air permeability of resulting components can be effectively controlled, which in turn dictates the success of subsequent consolidation stages. While traditional techniques like the pulse-decay method are widely used for low air-permeable media such as composites, they are often time-consuming (e.g., 24 hours per sample), invasive (requiring large samples and sealing), and limited in capturing microscale complexity of pore networks that significantly influence permeability behavior.

As a potential alternative, Micro-CT is non-invasive, faster (~2 hours per sample), and provides three-dimensional insights into internal pore morphology, fiber architecture, and the spatial distribution of interconnected versus isolated voids. In this study, a comparative analysis between Micro-CT–derived permeability and pulse-decay measurements highlight the advantages of this high-resolution imaging approach. Micro-CT not only produces permeability estimates consistent with bulk experimental measurements but also provides additional microstructural information such as void connectivity, equivalent pore size, and heterogeneity along the laminate length. These complementary capabilities enable a deeper understanding of how LAFP process parameters govern airflow pathways inside the composite.

The results demonstrate that Micro-CT can serve as a powerful microscale tool for permeability assessment, providing reliable estimates while significantly reducing testing time. Moreover, its ability to directly visualize pore networks offers valuable guidance for optimizing LAFP process windows, particularly for tailoring air permeability in components intended for VBO consolidation.

#1045

# Cryogenic Testing of Pressurised Tubular CFRP Specimens

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Type V hydrogen storage vessels (fully composite structure without a liner) are the most mass-efficient means of storing hydrogen and are therefore highly desired for low-emission future aircraft. However, as hydrogen-powered aircraft require cryogenic hydrogen storage for an acceptable fuel density, the means of qualifying new materials and designs for storage vessels requires testing under the combined thermal and mechanical loads that occur during service. To address this need and allow new vessel concepts to be screened with minimal lead time, a novel cryogenic testing setup using tubular CFRP specimens, representing type V tanks, has been developed and implemented.

The tubular specimens, with an inner diameter of 200 mm and a length of 600 mm, are sealed at their open ends using a specially designed dual-metal flange concept combining Invar and stainless steel with a low permeability adhesive. The different coefficients of thermal expansion between the metals, CFRP and adhesive generate a clamping effect upon cooling and experiments using this setup have demonstrated leak-tightness up to an internal pressurisation of 30 bar while filled with liquid nitrogen (-196°C). Further experimental investigation is foreseen, using liquid hydrogen and extending the temperature range to -253°C.

The specimens are contained within a vacuum recipient, allowing the use of a helium leak detector to observe the gas leakage behaviour of the specimens depending on cryogenic exposure and pressurisation loads. A comprehensive sensor network of strain gauges, distributed fibre-optic sensors, Fibre-Bragg-Grating sensors and temperature diodes records local strains and temperatures along the specimen. This enables correlation of internal pressure, thermal gradients, mechanical response and permeability.

This methodology provides a structurally representative yet experimentally accessible platform that bridges the gap between coupon-level characterisation and full-scale tank testing.

#1046

# Development and Evaluation of Hybrid Sandwich Composites for Enhanced Low-Velocity Impact Resistance

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Sandwich composites are widely used in various sectors including aerospace, offshore renewables, defence, automotive, and civil engineering, due to their excellent properties such as high specific strength, energy absorption capability, specific stiffness, durability, and resistance to impact. Typically, sandwich composites consist of three components: the front and back face sheets (also called skins) and the core material, each responsible for carrying different types of loadings. The face sheets provide high stiffness and resistance to bending, while the low-density core transfers shear forces between the face sheets. This unique morphology allows the structure to withstand impacts through various energy dissipation mechanisms, including crushing, delamination, and localized buckling. The components are either adhesively bonded or integrated using a co-curing process. However, when a single reinforcement material is used for the skin, careful consideration must be given to the material selection, balancing cost-efficiency with high performance and long-term structural integrity.

Fiber hybridization is an effective approach for developing advanced sandwich composites with tailored properties. Numerous researchers have investigated the use of different types of fibres, stacking sequences, fabric structures, and fibre orientations. This approach has led to improvements in several material properties, including impact resistance, interlaminar toughness, and post-impact load-bearing capacity, while also reducing overall cost.

This research presents an investigation of material properties for the design of advanced sandwich composite structures with high resistance to low-velocity impact. It includes the evaluation of various reinforcement fibres, core materials, and adhesives. Optimal materials and lay-ups were selected following extensive experimental testing, including quasi-static mechanical and fracture mechanics methods. A continuous feedback loop between experimental and numerical modelling was maintained to enhance the mechanical performance of the sandwich structures. Non-destructive evaluation techniques were employed during testing for structural health monitoring and to track fracture evolution.

#1047

# Strain rate dependent delamination behavior of hybrid sandwich composites with modified interlaminar interfaces for crash loading scenarios

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Steel-Polymer-Steel (SPS) sandwich composites are introduced as a lightweight alternative to conventional steel sheets, offering an efficient balance between mass and mechanical performance in e.g. automotive industries. For designing and analyzing SPS structures in crash scenarios, strain-rate effects and interlaminar interface properties play a decisive role. They affect deformation and failure characteristics which in turn define the structural integrity and energy absorption capacity. By locally adjusting the interface properties, the global structural response can be tailored to the application of axial crash boxes. High interface properties increase stiffness and crashworthiness, stable deformation and avoid preliminary delamination. In contrast, decreased interface properties provide more energy absorption during crack propagation, enable more pseudo-ductile failure and can serve as trigger mechanism to initiate stable failure propagation.

This contribution examines methods to experimentally determine the Mode I and Mode II interface properties of SPS sandwich composites. Specimen plates are manufactured by bonding warm metal sheets to likewise pre-heated polymer foils in a continuous roll-bonding step using epoxy resin adhesion promoter. After cutting Double-Cantilever Beam and Fixed Ratio Mixed-Mode tests are performed under various strain rates using digital image correlation to measure crack lengths. Additionally, specimens with locally reduced interlaminar contact areas (ICA) are manufactured by modifying the polymer surface via hot stamping. Various patterns are developed to adjust the ICA from 25% of the nominal strength up to 100% for the base specimens. The experimental results are used to identify material model parameters for interface strengths and energy release rates considering their dependence on strain rates and ICA. Therefore, a Finite Element Analysis and metamodel based optimization approach are used to provide cohesive element properties for the adhesion between steel and polymer. Ensuring robust material models is essential for reliable and predictable simulations and efficient crash design studies of SPS sandwich composites.

#1051

# Combined In-Situ CT and Transient Dynamic Analysis of Fibre-Reinforced Composite Joints at Elevated Temperatures

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As the use of fibre-reinforced thermoplastics (FRTPs) continues to grow across industrial applications, the need for effective joining technologies that can accommodate their unique properties becomes increasingly important. While mechanical joining presents a viable solution, the pronounced time- and temperature-dependent mechanical behaviour of FRTPs requires comprehensive experimental investigation under elevated temperature conditions. In-situ computed tomography (CT) has proven highly effective for resolving internal deformation processes, whereas vibration-based transient dynamic analysis (TDA) offers a simple, sensitive and non-destructive means of detecting stiffness changes and damage initiation directly from the specimen's dynamic response. However, the application of both methods is typically limited to room-temperature conditions. To close this gap, the present work combines both measurement techniques under elevated temperatures using a custom-built thermal chamber for in-situ CT applications.

Interpreting TDA signals at elevated temperatures requires a clear understanding of how thermo-mechanical effects influence stiffness, damping and modal behaviour. To address this, temperature-dependent TDA characterisation using a Scanning Laser Doppler Vibrometer is performed to establish reliable reference signatures and to identify dynamic indicators that may correspond to relevant damage phenomena. Once these indicators are known, in-situ CT provides the spatially resolved information to validate and attribute TDA signal changes to specific internal damage phenomena. The combination of both techniques therefore enables a comprehensive interpretation of damage evolution using TDA while simultaneously improving the definition of mechanically relevant load steps for subsequent CT scans.

In this paper, we demonstrate the combined approach using single lap shear tests of self-piercing riveted joints between glass-fibre-reinforced polypropylene and aluminium at elevated temperatures. The results show that the new setup provides unprecedented insight into joint behaviour under realistic thermal conditions and establishes a robust link between TDA-derived signatures and internal damage phenomena captured by in-situ CT.

#1052

# Effects of laminate ply orientations on fibre disruption in branching vascular network composites

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The ramping electrification of aircrafts heralds additional thermal waste that require lightweight solutions. Given the widespread usage of composites in the industry, a multifunctional material in the form of a biomimetic vascular network composite is a possibility that could fulfil both structural and thermal requirements.

A vascular network is usually tailored to its specific use case, but there are often branching points within the composite layup. There is existing literature that has investigated the effects of embedding channels at varying angles, but none that examines said effects relative to a laminate stackup consisting of different ply orientations. The situation is further complicated by branching angles, where optimising for one branch results in the worst-case scenario for the other.

In theory, it should be possible to offset such angle effects by having additional plies in the perpendicular direction, or by optimising the angles such that the detrimental effect is minimised across both branches. To that end, we investigate the structural effects of laminate ply orientations on branching vascular network composites, to test the viability of such an optimisation method. A cost-effective method of vascular network creation is also explored, through 3D-printed polycarbonate (PC) connectors of high thermal stability that enables angle customisation and joining stock straight tubes of different diameters, inspired by Murray's work on branching diameters.

Small scale samples were fabricated using unidirectional prepreg carbon fibre with an out-of-autoclave (OOA) process under vacuum pressure. Thereafter, lubricated diamond wheel cutting was performed both longitudinally and transversely to expose the cross-sections, before cold mounting and observing under optical microscopy. Quantifications are done in the form of resin rich area and fibre waviness angle, which serve as indicators of detrimental structural effects. The results should inform future design work on vascular network composites in terms of branching angle and laminate layup.

#1053

# Toward Reliable Rehabilitation: A Practical NDT Review for Composite Overwrap Damage Assessment

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The use of composite overwrap repair is becoming a preferred solution to restore the integrity of corroded or locally damaged metallic pipes and storage tanks in the water distribution, wastewater utilities, oil and gas, and petrochemical processing industries. The application of composite overwrap repairs is a cold-process method in which repairs are applied in situ without shutdown, reducing the risks of fire and explosion associated with the hot-process welding. For the safe operation and prolonged lifespan of repaired assets, nondestructive testing (NDT) is necessary to monitor corrosion under repair, pipe wall loss under repair, and the integrity of the repair laminate. Most commercially available NDT techniques face challenges due to the unique structural configuration of composite overwrap repairs. The composite overwrap repair itself challenges the assessment of underlying pipe corrosion and wall loss. The heterogeneous nature of its hand-laminated structure leads to significant signal scattering and attenuation, degrading the performance of many conventional NDT techniques. To date, published literature on a systematic critical review of the NDT of composite overwrap repairs is scarce. This study addresses this gap by critically reviewing the NDT techniques for the unique configuration of composite overwrap repair. Drawing on published studies, industry reports, international standards, and expert insights, the study systematically compares the advantages, limitations, and defect-detection capabilities of different NDT techniques, highlighting research gaps and technological challenges in current inspection practices. This pioneering effort is believed to be of significant interest not only to the academic community but also to industry practitioners and operational leaders involved in composite overwrap repairs and their safe and reliable operations.

#1054

# High-fidelity micromechanical modelling of transverse tensile damage in cross-ply composites

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Fibre-reinforced polymers are extensively used in engineering structures owing to their high specific stiffness and strength. However, the first ply failure, particularly matrix damage represented as transverse cracking, significantly limits their potential. Thus, a thorough understanding of this damage phenomenon is essential to advancing the development of composite materials. While experimental approaches provide valuable insights, they prove inadequate for comprehensive parametric analysis. On the other hand, current multiscale embedded-cell modelling techniques that employ homogenised representations of adjacent plies, fail to resolve critical stress gradients accurately.

To address these limitations, this work presents an enhanced micromechanical model based on a multiscale embedded-cell framework. The model incorporates explicit fibre representation not only in the transverse ply but also in adjacent 0° plies to capture interfacial stress gradients, overcoming homogenisation limitations. Additionally, generalised plane-strain boundary conditions are implemented to account for Poisson effects while avoiding artificial constraints on crack propagation under periodic boundary conditions. Gradual increase of interface and matrix properties toward the cell boundaries avoids damage development near the boundaries, enabling physically realistic simulation.

Our high-fidelity model accurately captures the complete process of transverse cracking, from initiation to propagation. The results show that the fibre-matrix interface is the primary site of damage initiation, with subsequent crack growth rapidly linking adjacent debonds to form a through-thickness failure path. An automated crack characterisation algorithm was developed to identify individual cracks by clustering failure points using the DBSCAN algorithm, enabling precise quantification of crack information. This approach provides a robust tool for comparing the model to those with homogenised plies. Parametric studies further quantify the influence of key material parameters, including the matrix, fibre-matrix interfaces, and ply-by-ply interfaces, on the failure process. Therefore, this work provides not only fundamental insights into failure micromechanisms but also a validated computational tool for the design of damage-resistant composites.

#1055

# Numerical and Nondestructive Evaluation of Fiber-Orientation Randomness in Discontinuous Carbon-Fiber-Reinforced Composites

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Discontinuous carbon-fiber-reinforced composites exhibit mechanical properties that are strongly influenced by fiber length and fiber orientation distributions. In particular, when unidirectional thermoplastic prepregs are chopped into small pieces—chopped prepreg tapes—prior to molding, the cutting size and cutting direction are expected to affect the randomness of the resulting fiber-orientation distribution in the final part. However, the quantitative contributions of these cutting parameters to orientation randomness have not been fully elucidated. A clearer understanding of these effects is important for controlling part-to-part variability in practical manufacturing.

In this study, we investigated how the size and cutting angle of chopped prepreg tapes influence global fiber-orientation randomness in discontinuous composites through a combination of numerical simulations and nondestructive evaluation of molded specimens. A simulation framework was developed to randomly place chopped prepreg tapes within a mold under geometric constraints. The global fiber-orientation distribution was computed using orientation tensors and associated randomness indices. Multiple cutting strategies, including unidirectional cutting and mixed-angle cutting, were evaluated to determine how the incorporation of multiple fiber orientations affects randomness for a given number of chopped prepreg tapes.

To validate the simulation predictions, molded composite plates fabricated with different cutting angles and sizes were examined using nondestructive measurement techniques. The extracted fiber-orientation fields were compared with the simulated results to assess the consistency between the virtual model and actual material behavior.

The combined numerical–experimental analysis provides insight into how cutting size and cutting direction affect orientation randomness in discontinuous composites manufactured from chopped prepreg tapes. The findings contribute to establishing design guidelines for optimizing the manufacturing process of chopped prepreg tapes and reducing variability in the mechanical performance of discontinuous fiber-reinforced composite components.

#1057

# Sustainable 3D printing: multicycle reprocessing of post-consumer blends for recycled filament production

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Biodegradable polymers are receiving increasing attention as sustainable alternatives to conventional plastics, thanks to their renewable origin and their ability to decompose under controlled environmental conditions. Currently, they are widely adopted in the production of single-use commercial items for applications in packaging (e.g., cutlery, beverage bottles, plastic bags, coffee capsules), agriculture (films, wraps), consumer goods (casings, circuit boards, data storage components), medicine, automotive industry, construction and others. Polymers like polylactic acid (PLA), polybutylene adipate terephthalate (PBAT) and polybutylene succinate (PBS) are among the most commonly used materials, often specifically designed to be compostable.

Nevertheless, in order to allow for adequate degradation of bioplastics, industrial composting requires specific conditions that are not always achievable, while degradation in natural environments can be significantly slower. This highlights the importance of developing an alternative strategy for the sustainable management of bioplastic products by extending the lifespan of the materials. In this study, mechanical reprocessing was applied to a post-consumer PLA-based polymer blend to evaluate the quality of the recovered product up to five times. Mechanical (tensile, flexural, Charpy impact), thermal (DSC, DMA, TGA, HDT, VST) and rheological (MFI, amplitude and frequency sweep) tests of the recycled polymer were conducted after each extrusion and injection molding cycle. In addition, scanning electron microscopy (SEM) analysis was done to evaluate morphological changes. The results demonstrated a minimal impact on the thermal stability of the polymer blend, whereas mechanical properties remained stable or slightly improved. Specifically, tensile strength and flexural strength increased by 2.6% and 3.7%, respectively, after five reprocessing cycles. Since the blends preserved its thermomechanical and biodegradable properties throughout the reprocessing cycles, this study further investigated its suitability for producing a fully recycled filament for 3D printing, including the incorporation of natural fibers as a reinforcement to improve mechanical performance and overall sustainability.

#1060

# Tape-level deformation of CFRTP-SMC during molding flow investigated by simulation and x-ct tracking

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The carbon fiber reinforced thermoplastic sheet molding compound (CFRTP-SMC) is composed of randomly oriented carbon fiber tapes embedded in a thermoplastic matrix. The discontinuous strands offer high formability and support efficient, high-cycle compression and stamp molding, enabling their widespread use in lightweight industrial components. However, for parts with complex geometries under modern mechanical design, filling the intricate regions of the mold cavity inevitably requires substantial material flow during molding. The flow leads to tape re-orientation and distortion which are observable on the component surface, but its effect on the internal structure, particularly at the level of individual tapes remained insufficiently understood.

This study characterizes the flow-induced behavior of individual CFRTP-SMC tapes during compression molding by combining process simulation with a tape tracking method based on X-CT. The simulation is conducted using the COMPRESSION MOLDING software in conjunction with LS-DYNA, in which each strand is modeled using multiple truss elements while the matrix is represented by solid elements with r-adaptive remeshing. Simulations were performed for both flat plate and component-level hat-shaped structures, and the results reveal distinct tape behaviors depending on their initial orientations, with tapes perpendicular to the flow direction exhibiting the greatest deformation. In parallel, a silver/copper-based conductive paint was applied to individual tapes, and X-CT scanning after molding enabled direct visualization of tape splitting, distortion, and rearrangement induced by the molding flow. The thin metallic paint accurately captured the three-dimensional curvature and edge features of the marked tapes, thus achieving further segmentation and analysis. Taken together, the insights obtained from simulation and X-CT validation provide a consistent multi-scale understanding of tape-level deformation under molding flow, thereby supporting the interpretation of microstructure evolution in both simple and component-level geometries.

#1061

# The First European Benchmark Exercise on Squeeze Flow Testing of High-Performance Carbon Fibre Sheet Moulding Compounds

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High-performance carbon fibre sheet moulding compounds (C-SMCs) are characterised by long carbon fibre reinforcement and high fibre content. C-SMCs can be compression moulded under high pressure to form parts with complex geometries, offering great design flexibility in addition to superior mechanical properties. Understanding the flow behaviour of C-SMCs is key for accurately predicting manufacturing outcomes.

Squeeze flow testing is an experimental method for characterising the rheological and mechanical behaviour of a material utilising a squeeze flow regime. This method has been adopted by several research groups for characterising the flow behaviour of SMCs for several reasons: firstly, squeeze flow testing is particularly advantageous for highly viscous materials experiencing high internal stresses during flow; secondly it allows testing of materials experiencing high level of wall-slippage; last but not least, compression moulding processes are largely dominated by squeeze flows. However, due to the lack of a standardised testing procedure, the reliability and repeatability of this testing method remain low, while the random nature of SMC materials introduces additional challenges in investigating the variabilities caused by the testing procedure. Furthermore, recent studies have demonstrated that the flow behaviour of high-performance C-SMCs differs considerably from that of traditional SMCs with glass fibre reinforcement fibres and low fibre content, which has been well-studied in the past. This highlights the necessity for further investigation into high-performance C-SMCs.

This paper presents a benchmark exercise on the squeeze flow testing of high-performance C-SMCs, jointly delivered by a collection of European research institutes with in-house developed squeeze flow testing facilities. The main objective of the benchmark exercise is to improve the reliability and repeatability of the testing through an understanding of the sources of variabilities in the measured data, and ultimately moving towards the development of a testing standard.

#1062

# Fused Granulate Fabrication as an Enabler for High-Filler Sustainable and Functional Composites

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Additive Manufacturing (AM) of highly filled polymer composites is increasingly attractive for developing sustainable and multifunctional materials. However, conventional Fused Filament Fabrication (FFF) is limited by filament brittleness, nozzle clogging, and poor melt flow when filler contents exceed 30 wt%. These constraints restrict the exploration of composite formulations with improved biodegradability or bioactivity. This work demonstrates the potential of Fused Granulate Fabrication (FGF) to overcome these limitations by directly extruding composite pellets, enabling extrusion of materials too brittle for filament-based processing.

Three application-driven case studies are presented. The first involves leather waste composites, focusing on sustainability and compostability. Leather waste powders were compounded into a thermoplastic starch-based blend at high filler loadings and processed using FGF. While FFF failed above 20 wt% due to filament fracture, FGF enabled the printing of functional parts. A biodegradation demonstration was performed by printing a thin-walled vase, placing it in soil, and visually monitoring its structural degradation over time, highlighting the potential for compostable additively manufactured parts.

The second case study examines bioglass composites with an emphasis on bioactivity. A bioglass-reinforced filament at 50 wt% which was too brittle to be printable via FFF was crushed into pellets which were printed using FGF and analysed by scanning electron microscopy for porosity and microstructural features suitable for biomedical or regenerative applications.

The third case study focuses on porcelain-filled composites. High-porcelain-content composites were printed and subsequently sintered. The resulting ceramic structures were evaluated for shrinkage, densification, and visual quality. These results evaluate the feasibility of using FGF for hybrid processes combining polymer-based additive manufacturing with ceramic post-processing.

Overall, the three studies validate FGF as a robust manufacturing route for sustainable, bioactive, and functional high-filler composites, capable of surpassing the limitations of filament-based additive manufacturing.

#1064

# Design and Evaluation of Magnetoactive Elastomers as Actuators for Soft Biomaterial Mechanical Characterization

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The mechanical characterization of soft gels and biological tissues is essential in biomedical engineering, materials science, tissue engineering, and clinical diagnostics. Investigating their mechanical properties is fundamental to the development of medical devices, therapeutic strategies, skin care products, and biomimetic materials that interact with biological tissues. However, despite significant progress, accurately characterizing hydrogels and soft biological tissues remains a challenging task. The existing methods for this task including rheology, atomic force microscopy (AFM), osmotic compression, micropipette aspiration and capillary micromechanics are currently expensive, slow, sometimes require prolonged fabrication duration and consume large amounts of hydrogel samples. In this work, we fabricate, characterize and compare the properties of various magnetorheological elastomers (MREs) for potential use in hydrogel characterization. MREs are smart, stimuli-responsive composite materials in which magnetic particles are embedded within a soft polymeric elastomer, enabling active control of their mechanical properties and actuation behavior through magnetic field manipulation. Consequently, these magnetoactive composites can dynamically adjust their viscoelastic characteristics, including stiffness and damping. Carbonyl iron particles (CIP) and iron (III) oxide nanoparticles (Fe2O3 NP) were independently incorporated into a soft polymeric matrix (Ecoflex 00-30) to fabricate the magnetoactive composites. A comparison of the magnetization responses of CIP-based and Fe2O3 NP-based MREs highlights the superior performance of CIP-based actuators. Furthermore, morphological and magnetic characterizations of various CIP-based MRE configurations were conducted, revealing higher magnetization in anisotropic MRE samples. The magnetostrictive behavior of a soft, biocompatible, and mechanically compliant isotropic CIP-based cuboidal MRE actuator with a 5 mm × 5 mm cross section and 35 mm depth is also demonstrated, exhibiting a rapid actuation speed of approximately 1 mm/s. Therefore, integrating this actuator with sensing systems offers strong potential for advanced material testing, particularly for characterizing soft materials such as hydrogels and biological cells.

#1065

# Thermoplastic Structural Electrolytes

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Structural power composites are emerging as multifunctional materials capable of carrying load while storing electrical energy. A key bottleneck is the structural electrolyte, which must provide both high ionic conductivity and adequate mechanical performance. Epoxy–ionic liquid (IL) systems have demonstrated proof of concept, but future multifunctional architectures increasingly favour high-performance thermoplastics for their rapid processing, toughness and recyclability. However, thermoplastic structural electrolytes face two major challenges: (i) porosity collapses at the temperatures required for polymer flow, eliminating ionic pathways, and (ii) ILs cannot be safely co-processed with molten polymers due to thermal sensitivity.

This work introduces, for the first time, a thermoplastic structural-electrolyte architecture based on mechanically punching macropores into polyetherimide (PEI) prior to consolidation. Unlike phase-separation or foaming approaches, this deliberately architected pore network is sized to maintain low-tortuosity ion channels that partially survive hot-pressing at high temperatures. The ionic liquid is subsequently backfilled at low temperature, enabling electrolyte introduction without exposing EMIM–TFSI to thermal degradation.

Two processing windows were examined to reveal the inherent electrochemical–mechanical trade-off. Laminates consolidated at 245 °C preserved pore geometry and achieved strong electrochemical retention, with ≈70 % retention of specific capacitance at low current densities relative to a monofunctional baseline, but exhibited poor mechanical performance (E = 17.1 GPa, UTS = 20.2 MPa) due to limited polymer flow and weak interfacial bonding. In contrast, consolidation at 290 °C caused substantial pore shrinkage, reduced specific-capacitance retention to ~50 % of the baseline, and produced a >50 % increase in stiffness, yielding markedly improved mechanical properties (E = 25.7 GPa, UTS = 73.3 MPa).

These results demonstrate that punched-macropore thermoplastics offer a manufacturable and recyclable structural-electrolyte platform, establishing a viable route for thermoplastic structural supercapacitors and identifying pore-geometry optimisation as a key opportunity for improving ionic accessibility while retaining mechanical integrity.

#1066

# Novel aspects from a fatigue database of the fatigue properties of short fibre reinforced polymers

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Thermoplastic polymers are used in numerous applications in the automotive- and the white goods industry. By injection moulding any shape of the product can be implemented in the design in case of lightweight and material savings. For reliable an high quality products, the lifetime must be assessed under application loadings. Mostly general fatigue properties of the materials and interactions from loading, geometry or ambient condition are not available.

This paper presents the results of an evaluation of a fatigue database with more than 10,000 tested specimens and 1,250 S/N-curves. All the fatigue tested specimens and S/N-curves were determined by the Fraunhofer LBF. There are evaluated general parameters of a S/N-curves such as the slope, the scattering and stress amplitude. Based on the evaluated parameter of the S/N-curves, additional parameters such as notch effect, mean stress sensitivity, temperature, fibre orientation, weld lines and variable amplitudes were investigated. These findings were taken into account with morphological properties of the polymer such as the glass transition temperature, fibre orientation or type of polymer. For the notch effect for all technical thermoplastic polymers was found that the notch effect disappears above the glass transition temperature. Below the glass transition temperature, the notch effect is well pronounced. From the evaluated parameter knock down factors were derived. These knock down factors can be used in the early phase of the product development process.

The results give the scientific community an overview of the general fatigue properties and interactions of thermoplastic polymers. A great advantage of the evaluated parameters is to use them to optimize the test matrix and focus on relevant and lifetime influencing parameters.

#1070

# Fatigue prediction of delamination : challenges, characterization, modelling and industrial implementation

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Damage tolerance is a critical sizing criterion for composite structures in aeronautics, requiring proof that the structure can withstand required loads despite various types of damage.

Residual strength depends on damage size, but the lack of efficient computational tools for fatigue damage propagation necessitates a no-growth approach for damage size. Moreover, this approach relies solely on test evidence, leading to extensive testing. Any deviation from test conditions requires additional tests, increasing both development time and costs. As a result, predicting delamination initiation and propagation under fatigue is a major challenge for improving the efficiency of composite structures—both technically and economically.

In this presentation, we propose :

- First, defining industrial requirements for fatigue delamination prediction, focusing on uni-directional carbon fiber-reinforced polymer (UD CFRP) used in primary aerostructures;

- Then reviewing Dassault Aviation’s ongoing work on static and fatigue delamination characterization, including key experimental findings and linking experimental data with modeling efforts for identification and validation;

- Lastly, implementing fatigue prediction in an industrial context assessing the robustness of fatigue delamination predictions, considering experimental variability and industrial damage tolerance requirements.

#1071

# Thermo-mechanical Behaviour of Polyetheretherketon (PEEK) Under Low Temperatures and High Strain Rates

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Fibre-reinforced thermoplastic composites are increasingly considered for extreme-environment applications such as hydrogen storage, aerospace and space exploration. Polyetheretherketone (PEEK) is particularly attractive due to its excellent thermal stability, toughness and repairability. However, its thermo-mechanical behaviour under cryogenic conditions remains insufficiently characterised, owing to experimental challenges such as achieving uniform and stable cryogenic temperatures, obtaining reliable strain measurements under such conditions, and the high associated cost. This lack of data and robust methods limits the confident deployment of PEEK-based and other composites in next-generation lightweight structures for low-temperature applications.

This work presents integrated experimental methodologies to measure the cryogenic thermo-mechanical response of neat PEEK as a foundation for subsequent composite modelling. A cost-effective, strain-gauge-based dilatometry method has been designed to capture the coefficient of thermal expansion (CTE) from elevated to cryogenic temperatures, overcoming accessibility limitations of commercial dilatometers. The quasi-static compressive behaviour is characterised using stereo digital image correlation (DIC) and bespoke low-shadow fixtures to achieve reliable full-field strain measurements, and these experiments will be extended to low and cryogenic temperatures. In addition, high-strain-rate Split-Hopkinson Pressure Bar (SHPB) experiments will be conducted at ambient temperature. A time–temperature superposition (TTS) strategy will then be used to relate strain rate and temperature, enabling prediction of behaviour at low and cryogenic temperatures.

The expected outcome is a predictive framework allowing accurate simulation of PEEK's behaviour across low temperatures. The integration of TTS enables prediction of cryogenic behaviour without requiring extensive low and cryogenic temperature testing, substantially reducing experimental cost, complexity and risks. Ultimately, this framework provides a practical way towards reliable simulation and design of PEEK-based cryogenic composite structures, supporting the development of lighter and safer energy and aerospace applications.

#1072

# Multi-scale Digital Twin of a 3D woven composite technological blade sample

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This study is focused on a 3D woven composite technological testing, directly sampled in a full fan blade part. To enhanced the confidence toward the multi-scale numerical simulations (from macro to meso), we fed the macroscopic Finite Element Model (FEM) with boundary conditions based on the 3D full-field displacement on the 4 upper faces of this technological dovetail sample.

To manage this Digital Twin model on ANSYS Mechanical, we worked both on numerical tools transfer from DIC environment to Ansys WorkBench, as well as a complex multi-camera DIC system of 4 cameras [1] to cover the whole upper faces and 1 monovision camera on the lower area for 2D measurements in the dovetail area. To highlight and compare the load level and the localization of the first damage vs. simulations, we also use others experimental techniques like Acoustic Emission [2] (in-situ) and µ-CT (ex-situ).

Thus, we were able to realize a full loop multi-scale digital twin with a top-down structural zoom using a tool transfer which considers the 3D displacement fields of the macro FEM (ANSYS) which surround the local meso FEM (ABAQUS). This local meso FEM was generated by extractions using a µ-CT software developped in SAFRAN (XtraCT), and these morphological/topological inputs were used in a voxelization FEM tool (REVOXEL [3]). The final meso model image based includes more than 20M dofs.

We conclude on the powerful crosschecking of experimental information (DIC, EA, CT) and multi-scale simulations to describe efficiently the complex behavior of this technological sample under a multi-axial and gradient stress. The prospect will be on the furthers works to carry out this kind of test in fatigue loadings and on other location in other blades.

#1073

# Machining of carbon fibre reinforced thermoplastic (CFRTP) composite: from damage mechanisms to process optimziation

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In recent years, carbon-fibre-reinforced thermoplastic composites (CFRTPs) have drawn substantial attention across multiple sectors—most notably aerospace—owing to their recyclability, repairability, and suitability for rapid manufacturing. Among these materials, carbon-fibre-reinforced polyetherketoneketone (CF/PEKK) has emerged as a particularly promising candidate because of its superior mechanical behaviour and thermal resistance. Nevertheless, producing high-quality fastening holes in CF/PEKK for aircraft structures is still challenging, primarily due to its heterogeneous architecture and sensitivity to heat. Research on the machining response and damage evolution of CFRTPs, especially CF/PEKK, is still limited.

This study presents the first systematic investigation into the hole-forming performance of CF/PEKK. The influence of different machining strategies (traditional drilling versus helical milling) and the roles of key drilling parameters (feed rate and spindle speed) on thrust force generation, thermal response, chip formation, delamination, microstructural damage, and material removal mechanisms were comprehensively analysed and, where appropriate, benchmarked against conventional CF/epoxy laminates. A multi-objective optimisation approach was employed to determine favourable drilling conditions for CF/PEKK. Furthermore, temperature-controlled orthogonal cutting experiments were performed to elucidate the fundamental temperature-dependent cutting behaviour of this thermoplastic composite. This research contributes a substantial body of new insight into the machining characteristics and underlying cutting physics of CFRTPs, offering valuable guidance for achieving efficient, low-damage processing of these advanced composite materials.

#1074

# Fracture analysis of interleaved composites with self-same resin-rich layers using mechanical testing, acoustic emission, and micro-visualization

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The interlaminar toughness of composite materials remains a critical challenge, limiting their broader application in industries requiring high load-bearing capacity and resistance to delamination. This study investigates innovative interleaving methods to enhance the fracture performance of thermoplastic composites.

In this study, the manufacturing process for CF/PEKK thermoplastic composites was modified to create an interlaminar resin-rich layer (RRL) with the same resin. The proposed method allows the primary matrix resin to flow into the interlaminar regions during fabrication. The self-same RRLs maintained fiber volume fraction, preserving in-plane properties and avoiding the weight penalties associated with traditional interleaving methods.

Fracture tests were performed under both Mode-I and Mode-II loading conditions to assess the effectiveness of the resin-rich layer, with results compared to reference samples and pure resin interleaved specimens. Digital Image Correlation (DIC) was employed to monitor crack tip propagation, while acoustic emission data was recorded to analyze strain energy release during crack growth.

The fracture performance improvement of interleaved components was limited. The results further underscores the critical role of strong fiber-matrix bonding and the predominance of fiber bridging during fracture in reference samples under separation forces (Mode-I). These factors contribute to their high GIc values, to the extent that the introduction of an interlaminar resin layer designed to promote increased matrix plastic deformation at the crack tip fails to yield an improvement in GIc values. While, the high volume of interlaminar matrix enables substantial plastic deformation at the crack tip under Mode-II loading, contributing to the elevated GIIc values observed for self-same RRL included samples.

#1076

# Designing for Pseudo-Ductility and Failure in Multidirectional Hybrid Composites

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Hydrogen is increasingly recognized as a key enabler of sustainable aviation and linerless Type V pressure vessels offer an attractive lightweight solution for its storage. However, storing hydrogen under demanding operating conditions raises concerns regarding structural integrity and damage tolerance. Among the strategies proposed, pseudo-ductility has emerged as a promising concept, achieving progressive rather than sudden failure, increasing toughness.

One of the possible approaches to achieve pseudo-ductility is the use of hybrid laminates, in which fibers with distinct stiffness and failure strain characteristics are combined into a material architecture to trigger a sequence of interacting damage mechanisms where low-strain plies fragment gradually transferring load to the high-strain plies. The question is whether this approach can be exploited with thin-ply technology, which suppresses premature interfacial delamination, improves stress redistribution and promotes controlled fragmentation? Futhermore, under operating conditions, such thin-ply hybrid architectures enable the tailoring of laminate permeability, suppressing crack leakage paths.

Within this scope, the present study investigates the uniaxial tensile behavior of multidirectional hybrid laminates composed of glass/carbon fiber plies with thermoset or thermoplastic as a model system. Parametric studies with multiple stacking sequences were performed to explore how different layer arrangements influence the progression of damage and how weak interfaces can be exploited to tailor the failure path. This enhances pseudo-ductility while limiting permeability. An analytical model was implemented to capture key features such as fragmentation of low-strain plies, interlaminar delamination and failure of high-strain plies.

To validate this model, experimental tests were performed on various hybrid laminates. The predictions showed good agreement with the experimental stress–strain curves, confirming that the model was able to predict not only the overall response but also the sequence of predominant damage mechanisms. Ultimately, this methodology explains how to design lightweight hybrid composites with optimal pseudo-ductile response to control failure while limiting permeability.

#1077

# Thermomechanical properties and oxidation resistance of functionally graded, polymer derived SiOC/C matrix carbon fiber reinforced composites

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Carbon fibre reinforced composites with a carbon matrix (C/Cf) have a long history of use as a primary structural material in the aerospace and defence industries. This is due to their attractive combination of high thermal conductivity, strength and creep resistance relative to their density. However, the main disadvantage of this material is its poor resistance to oxidation at high temperatures, which limits its use to low temperatures or inert atmospheres. One solution to this problem is to coat the material with a protective layer or incorporate refractory ceramics into its matrix. However, this alters the material's density and raises questions about the durability of the coating.

An innovative approach is proposed, in which part of the carbon matrix will be replaced with SiOC ceramics. Silicon oxycarbide is an amorphous material often proposed as an alternative to hard SiC ceramics, which offer oxidation resistance coupled with thermophysical parameters similar to those of amorphous carbon. This approach is intended to provide partial protection against oxidation, and thanks to SiOC gradient distribution, the original attractive properties of C/Cf composites are to be preserved. This research hypothesis will be verified through a comprehensive analysis of the material's thermophysical parameters, such as linear thermal expansion, specific heat capacity, and thermal conductivity at temperatures up to 1500°C. Resistance to high-temperature oxidation will be verified on a dedicated ablation test bench (oxy-acetylene torch), with a flame temperature reaching 2000°C.

The research proposed, combined with comprehensive microstructural characterization, will allow Participants to learn about the impact of the material's gradient structure on its selected properties. In addition, this work will provide insight into the latest trends in the technology of synthesizing ceramic matrix composites using polymeric precursors.

#1078

# Capturing the rapid frontal polymerization process: A reaction-kinetics model based on fast scanning calorimetry

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Frontal polymerization (FP) has emerged as a promising strategy to produce high fibre volume fraction composites (Vf > 55 %) with minimal energy input. Research over the modelling possibilities of this technology attempts to extend its applicability closer to industrial use: several approaches have developed and experimentally validated FP models with dicyclopentadiene (DCPD), Diglycidyl Ether of Bisphenol A (BADGE) and 3, 4-Epoxycyclohexylmethyl-3',4'-Epoxycyclohexane Carboxylate (ECC) resin systems, yielding more accurate prediction and control of FP processes. An accurate description of the ongoing reaction kinetics is crucial for this purpose: to this date, Differential Scanning Calorimetry (DSC) has been the preferred technique to identify the constitutive parameters in the models. Nonetheless, the highly exothermic nature of resins and fast reaction kinetics inherent to FP yield temperature gradients in the order of 100 K/s; therefore, the maximum scanning rate of 5 K/s for DSC machines may not suffice to accurately capture the behaviour of any FP process. This work introduces Fast Scanning Calorimetry (FSC) as a viable alternative with scanning rates up to $10^4$ K/s, to simulate the gradients involved in FP. This technique has mostly been employed to assess the influence of fast crystallization on thermoplastic resins, and hardly-ever for thermosets; therefore, the first step of this study validates the use of FSC as a suitable characterization tool. Then, ECC resin systems are tested at varying initiator concentrations to obtain a range of the minimum and maximum temperature gradients involved during curing. These gradients are then measured and used as reference values to determine the scanning rates of the subsequent FSC tests. The results are finally fed to a phenomenological model that can be implemented into future FP numerical studies.

#1079

# Statistical analysis of the effect of long-term deep-sea exposure on the mechanical properties of filament wound composite materials

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Filament-wound composite materials are finding growing use in deep sea structures, including pressure vessels, subsea pipelines and autonomous underwater vehicles. However, extended service in the deep-sea environment can alter their mechanical behaviour through gradual property degradation. Understanding how seawater exposure in combination with high hydrostatic pressure influences their mechanical performance is therefore essential for ensuring reliable and effective structural design.

To achieve this, multiple sets of filament-wound composite specimens, namely rings, arcs, and straight coupons were manufactured and subjected to deep-sea exposure for different durations. A reference batch of unexposed, dry samples was tested first. The composites under study were produced using 12K and 60K carbon fibers and E-glass fibers, all combined with the same epoxy resin system. The specimens were deployed in the sea at about 1000m depth. All specimens were properly mounted on a metallic frame that was lifted every 10 months and the appropriate batch was removed for testing. Each batch was tested according to the standards ASTM D2290 and ASTM D3039 in order to measure the tensile Young's modulus and strength in the fiber direction (E1, σ1) and perpendicular to it (E2, σ2), as well as the shear properties (G12, τ12).

Comparison between the results of a dry reference batch and the immersed specimens was made using the ANOVA statistical analysis, in order to investigate possible differences in material degradation. In short, the comparison showed regarding the CFRP specimens that E1 and G12 were affected, while E2 was not affected. Regarding the GFRP specimens, E1 was not affected significantly, but E1 and G12 were affected. It was also found that the changes in the material properties were different among the different exposure times and that longer exposure times did not necessarily lead to higher degradation.

#1080

# Mechanical performances of PMI foam filled composite sandwich structures with lattice cores

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Sandwich structures with periodic lattice cores, such as corrugated and pyramidal designs, have emerged as primary load-bearing components. However, under compressive loading, these configurations rapidly soften due to core member buckling once the peak stress is reached, significantly diminishing their post-yield load-carrying capacity. In contrast, sandwich panels with foam cores, while exhibiting lower stiffness and strength, possess a pronounced plateau in their stress-strain response, making them excellent for energy absorption in crushing and impact scenarios.

This study investigates a hybrid approach, where lightweight Polymethacrylimide (PMI) foam is inserted into the interstices of a novel channel-type lattice core. The objective is to determine, both experimentally and theoretically, whether this strategy effectively enhances the compressive strength and energy absorption of the sandwich panel under a constant total mass constraint.

A novel all-composite sandwich panel with a channel core was proposed and subjected to quasi-static out-of-plane compression and three-point bending tests. The core was then filled with PMI foam to enhance its performance. The mechanical response and failure modes of the structures were investigated experimentally and via finite element (FE) analysis. Results demonstrate that the proposed empty channel core itself exhibits a progressive crushing mode, outperforming traditional corrugated cores with 209.03% and 718.32% higher compressive strength and specific energy absorption (SEA), respectively. The foam filling further enhanced the performance of the channel core, increasing its compressive strength and SEA by 51.46% and 29.28%. Under bending loads, the foam-filled channel and corrugated cores showed increased specific stiffness by 19.17% and 16.29%, and specific strength by 52.53% and 7.00%, respectively, compared to their empty counterparts. These findings confirm that the proposed foam-filled channel-core sandwich panel offers superior structural efficiency, showing great potential for lightweight load-bearing applications.

#1081

# A Multi-Level ANN-Enhanced Framework for Rapid Progressive Damage Analysis of Aeronautical Composite Laminates

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Composite laminates are widely used in aerospace structures, yet efficient prediction of their progressive damage behavior remains challenging. High-fidelity 3D solid modeling can accurately capture intralaminar failure but becomes computationally prohibitive for large-scale components. To address this limitation, this study develops a multi-level, machine-learning-enhanced modeling framework that couples data-driven surrogate models with nonlinear shell formulations. At the laminar level, 3D unit cell finite element models incorporating a damage model are constructed to generate a dataset of nonlinear responses under multiaxial loading. These data are used to train artificial neural networks (ANNs) that approximate the laminar stress–strain behavior and characterize damage initiation and evolution. The framework is subsequently upscaled to the laminate level, where an analytical formulation of the stiffness matrix for arbitrary stacking sequences is derived. A secondary ANN, structured to shell constitutive laws, is constructed to learn the nonlinear generalized stress–strain relations of the laminate, thereby providing a surrogate constitutive model that bridges the laminar-scale material response and the laminate-scale structural behavior. The resulting surrogate-enhanced constitutive model is implemented in a user-defined nonlinear shell constitutive subroutine (UGENS), featuring an efficient progressive damage analysis. Validation is performed on the analysis of a multi-bay box representative of a Hybrid Wing-Body (HWB) structure. Results demonstrate that the proposed approach retains accuracy comparable to solid-element simulations while achieving a dramatic improvement in computational efficiency. Owing to its speed and predictive capability, the framework is particularly suited for structural sizing, layup optimization, and iterative design of large-scale composite aerostructures,enabling more efficient parametric studies and rapid evaluation of alternative configuration strategies.

#1083

# A Viscoelastic Damping Prediction Method for Unidirectional Composites Based on Multi-Scale Relaxation Simulation

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Predicting the damping of unidirectional fiber composites is essential for vibration control and flutter safety in high-performance structures. In service, composite structures are often subjected to multiaxial loading, and their damping behavior varies significantly with frequency due to the viscoelasticity of the matrix. Existing strain-energy-based damping prediction methods treat the material as a macroscopically homogenized medium, which usually provide only effective damping at discrete frequencies and cannot adequately capture the influence of microstructural features or loading direction.

To address these limitations, this study develops a viscoelastic damping prediction approach that incorporates virtual relaxation simulations within a microscale unit-cell model. By simulating the evolution of the actual fiber–matrix stress field, the time-domain relaxation curve is extracted, from which six frequency-dependent loss factors are obtained using the generalized Maxwell model. These results are further compared with existing theoretical models to evaluate their applicability. In addition, the effects of fiber arrangement and fiber volume fraction on damping are investigated. The results show that different fiber arrangements lead to pronounced differences in damping, indicating that microstructural spatial distribution plays a crucial role in accurate damping prediction. Moreover, increasing fiber volume fraction reduces the overall damping of the composite; when the fibers are non-damping, the matrix fully governs the damping behavior, whereas fiber-intrinsic damping weakens this matrix dominance and mitigates the decreasing trend. Furthermore, based on the correspondence principle, the generalized Maxwell model in the material principal axis is transformed to derive the off-axis complex modulus, enabling the calculation of frequency-dependent damping under arbitrary loading orientations.

#1084

# AI-Powered Vision-Tactile Sensing with an Autonomous Omni-UAV for BVID Detection in Laminated Composites

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The widespread use of laminated composites in safety-critical structures such as aircraft is hindered by the threat of barely visible impact damage (BVID). BVID, often caused by low-energy impacts such as tool drops or bird strikes, can significantly reduce structural strength while remaining extremely difficult to detect. Current visual inspection (VI) methods are time-consuming, operator-dependent, and challenging in areas with limited accessibility. Although automated non-destructive inspection techniques exist, they are often complex, costly, and insufficiently sensitive for reliable sub-millimeter BVID detection.

The AVIATOR project introduces a paradigm shift by developing an autonomous omnidirectional unmanned aerial vehicle (Omni-UAV) equipped with a hybrid vision–tactile sensing system. Mimicking human inspection, the system performs a two-level process: a global visual scan identifies potential damage zones, followed by a local tactile inspection. During contact, a vision-based tactile sensor captures high-resolution 3D surface topography, improving the signal-to-noise ratio and distinguishing fine BVID features from the textured composite background.

The project builds on three scientific pillars: (i) experimentally validated finite element models linking surface deformation to internal damage, (ii) a multi-modal AI platform fusing visual and tactile data for damage detection and uncertainty-quantified diagnosis, and (iii) a morphing Omni-UAV with precise, fully actuated control for stable contact on composite surfaces.

This paper presents recent findings from the AVIATOR project, including the integrated vision–tactile methodology for BVID inspection. Comparative visual and tactile data obtained from controlled drop-weight impact tests demonstrate accurate characterization of impact-induced surface damage across affected regions. The application of a preliminary AI framework for multi-modal data fusion and its predictive capability for damage assessment — for example, predicting internal damage severity from extracted 3D surface features — will be demonstrated. Finally, the design and initial testing of the novel Omni-UAV platform, along with its planned integration toward a fully autonomous inspection workflow, will be outlined.

#1085

# Hydrothermal aging effects on the fatigue life of carbon-fiber reinforced thermoplastic composites

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Hydrothermal aging effects on the fatigue life of carbon-fiber reinforced thermoplastic composites

Thermoplastic polymers and composites offer several advantages such as chemical and impact resistance. They can be used over a temperature range wider than conventional thermosets such as epoxies. The moisture uptake in these materials is very low, resulting in less degradation of mechanical properties under hot/wet conditions. In this study, high performing thermoplastics such as PEEK and PEKK, for aerospace applications are considered.

CF/PEKK and CF/PEEK thermoplastic composites with a matrix content of 34%, and with a quasi-isotropic lamination sequence of unidirectional plies were primarily used for this study. An experimental comparison of the moisture uptake (accelerated aging in a water bath at 70 $^{o}$C) in pure polymer (PEEK/PEKK) and the thermoplastic composite (CF/PEEK and CF/PEKK) is conducted to understand the effect on matrix and interphase in attaining saturation. A microscale modelling to validate the diffusivity of water molecules through pure PEEK polymer and CF/PEEK thermoplastic composites is in the initial stage. Fatigue models are developed from mechanical response (static and fatigue testing) of these materials at different ageing conditions. Also, the impact resistance of these materials is analyzed experimentally for different aging conditions. Constant life diagrams (CLD) for each material tested under each aging/environmental condition are derived to predict the fatigue life of the materials.

The water content at saturation for CF/PEKK and CF/PEEK are 0.27% in weight and 0.18% in weight, respectively. The gravimetric curves are derived and validated with a numerical 2D diffusivity Fickian model. S-N curves and CLD are obtained for each material tested under different aging conditions.

A micro scale modelling of the composite will enable to better understand the diffusion of water molecules through the matrix and interphase. The impact resistance of the materials is to be experimentally tested and analyzed.

#1086

# Efficiency of different compactor types for Joule heating assisted thermoplastic cfrp winding processes

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Meeting the industry demand for fast and efficient production of thermoplastic composites requires new automated manufacturing approaches that overcome the limitations of current processes. A novel production process for thermoplastic composite manufacturing is being investigated, which enables substantially increased deposition speeds in both filament winding and automated fiber placement of carbon-fiber-reinforced thermoplastic tapes by using Continuous Resistance Heating Technology (CoRe HeaT). The method relies on intrinsic heating of the carbon fiber tapes through the Joule effect within the heating zone. By pairing rapid tape layup with an efficient post-consolidation step, the method targets higher productivity without compromising composite quality. Increasing deposition speed can lead to increased preform porosity, as is known from other automated layup technologies with different heating technologies. To achieve high preform quality, it is necessary to minimize void content in the winding process. In this work, we introduce compactors in a CoRe HeaT assisted winding setup to efficiently minimize void content. Conformable silicon rollers, non-conformable metallic rollers and compaction sliders are investigated in their effect on preform quality and usability. Tubes are wound circumferentially on a CoRe HeaT assisted winding machine, using carbon-fiber-reinforced LM-PAEK tapes. Parameter variation includes the compactor type, compaction pressure, winding speed, tape tension and mandrel temperature. Samples are cut, embedded and polished for micrographic inspection. Semantic segmentation is used to analyze microscopic images and quantify void contents. Comparing the three types of compactors, non-conformable rollers lead to the lowest void contents. Moreover, when tape tension and compaction pressure are increased, porosity is being minimized. Mandrel temperature did not significantly influence void contents. The generated results suggest which types of compactors are beneficial for the use in CoRe HeaT assisted winding processes for thermoplastic cfrp structures and support the understanding of achievable preform qualities when using this novel production approach.

#1087

# Adhesive Tests for using in CCLT – a timber sandwich structure with bamboo core

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## Introduction

Cross-laminated timber (CLT) consists of thick, orthogonally layered timber panels that enable large structural dimensions but require considerable raw material and exhibit a density of about 0.45 g/cm³, which can be a limitation in resource-efficient construction. COMBOO, a low-density bamboo honeycomb made from cut Moso bamboo rings, offers distinct mechanical properties at roughly 0.2 g/cm³ and serves as a lightweight core material. Combining both materials yields a sandwich element termed CCLT (COMBOO cross-laminated timber), in which timber faces are bonded to a COMBOO core, aiming at environmentally sustainable, $CO_2$-efficient building systems.

## Materials / Manufacturing

This study presents preliminary investigations on the adhesive bonding between timber and bamboo in CCLT, focusing on the shear strength of the glue line parallel to the timber grain. For this purpose, individual bamboo rings with diameters of 40–45 mm were glued to timber blocks of 50 mm × 50 mm × 9 mm using several adhesive systems, including a natural casein-based formulation. A dedicated mounting apparatus enabled controlled bonding pressures from 0 N/mm² to 1.2 N/mm², allowing comparison of manufacturer-recommended pressures, zero pressure, and intermediate levels.

## Investigations / Results

Shear tests were conducted on a universal testing machine with a maximum load of 50 kN, and the results were evaluated using five-percent quantiles. The most favorable performance was achieved with a biomaterial-based PVAc system, reaching shear strengths between 6.36 MPa at 0 MPa pressure and 4.67 MPa at 1.2 MPa. A PRF adhesive provided values from 5.14 MPa at 0 MPa to 4.40 MPa at 1.0 MPa. EPI, PUR and casein systems showed lower ranges, with EPI between 2.52–3.27 MPa, PUR between 1.98–4.71 MPa and casein between 1.02–4.01 MPa. Overall, the results indicate that PVAc and PRF are promising candidates for the CCLT interface, while natural casein systems may require further optimization.

#1088

# Comparative Life Cycle Assessment of Fossil-based and Bio-based Polymers in Aircraft Interiors

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Thermoplastic polymers such as polyvinyl chloride (PVC)-acrylic are commonly used in aircraft interior applications due to their durability, tensile strength, and mouldability. However, despite heightened focus on sustainability, the life cycle impacts of these materials remain insufficiently assessed. Bio-based alternatives, such as polylactic acid (PLA), have been proposed as substitutes, but their environmental benefits relative to fossil-based materials remain uncertain. This study evaluates the trade-offs between virgin and bio-based polymers using a life cycle assessment (LCA) approach, using OpenLCA software. The LCA modelling is performed in accordance with the ISO 14044 standard, and the system boundary is defined as cradle-to-gate. The calculations are performed using the environmental footprint (EF) 3.1 method and normalisation across all 16 midpoint impact categories is considered. The results indicate that the major impacts for PVC-acrylic include fossil resource use (87.3MJ), climate change (4.4kg$CO_2$ eq.), and water use (6.6m$^3$). The fossil energy demand is more than 90% higher compared with PLA. In addition, water use is identified as a significant hotspot. In contrast, PLA shows a lower climate change impact, with a 2.3% reduction in GHG emissions. It performs better in terms of fossil dependency but presents higher freshwater ecotoxicity. This increase, along with very high land use (104.2pt), is attributed to the agricultural demands of biomass cultivation. Whereas PVC-acrylic relies heavily on non-renewable resources, PLA shifts environmental burdens towards land use and ecotoxicity. In summary, biopolymers can reduce reliance on fossil resources and support the Sustainable Development Goals; however, the use of secondary data limits the robustness of the LCA results and highlights existing data gaps. Future research should address these limitations by using alternative feedstocks and renewable energy to minimise land, eutrophication, and energy impacts.

#1089

# Spatial correlation of fibre distributions in recycled carbon fibre composites using advanced image processing

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The performance of carbon fibre reinforced composites is governed by their hierarchical architecture, typically composed of unidirectional or woven plies consolidated into a laminate. Most recycling routes disrupt this architecture to varying degrees, and the extent of this dissociation strongly influences the mechanical performance of the resulting recycled composite material. To quantitatively asses such morphological changes during reprocessing, the current study presents an image-based method that characterizes fibre-scale structure in a carbon fibre/LM-PAEK laminate size reduction follow by various degree of homogenisation in a twin screw extruder. High-resolution cross-sectional micrographs are analysed to detect and segment individual fibres, which are then parameterized using method of ellipses-based geometric descriptors. The workflow incorporates a novel segmentation features that improves fibre identification in regions of dense packing. From the segmented data, several local and mesoscopic microstructural metrics have been developed as local fibre orientation, diameter, volume fraction, and fibre spacing and neighborhood patterns, enabling quantitative comparison of the material at different states of reprocessing. The method was validated on two datasets of reprocessed LM-PAEK AS4-143-34 having distinct differences in residence time in the extruder. Ultimately, this framework provides a foundation to track the evaluation of microstructural features in recycled composites at different scales and supports future development of structure–property relationships for circular composite processing.

#1090

# Physics-Informed Neural Network for Fracture Mechanics in Composite Structures

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Physics-Informed Neural Networks (PINNs) represent a paradigm shift in solving inverse problems, yet conventional architectures often fail to resolve the singular fields inherent to fracture mechanics due to the breakdown of governing equations across discontinuities. This study introduces a novel, meshless Multi-Region PINN framework designed to resolve the kinematics and kinetics of 2D cracked elastic bodies, with specific applicability to interlaminar delamination in composite structures. By strategically decomposing the domain into distinct continuous sub-regions, the method restores the strict validity of the fundamental constitutive equations within each partition. This modular architecture offers exceptional flexibility, allowing for the seamless modeling of diverse specimen geometries (e.g., DCB, ENF) and heterogeneous properties typical of laminated composites. Critical to this approach is a composite loss function that enforces strict traction and displacement continuity across internal interfaces, ensuring the independent sub-domain networks function as a unified mechanical body. While the current implementation utilizes isotropic constitutive relations, effective for characterizing Unidirectional (UD) fiber laminates, the framework's modularity allows for the straightforward integration of orthotropic stiffness matrices required for general anisotropic composite analysis.

A defining advantage of this approach is its ability to reconstruct full-field internal kinematics using only sparse experimental (or numerical) displacement data from the specimen's external boundaries. This effectively isolates the solution from experimental noise, rendering it highly robust for Digital Image Correlation (DIC) applications where near-tip measurements are often unreliable. Validated against high-fidelity benchmarks, the proposed method accurately captures stress singularities. We further identify a systematic linear drift in the J-integral calculation, attributed to the non-zero divergence of residual stress fields inherent to soft constraint formulations. By implementing a thermodynamic error-compensation strategy anchored to the far-field, we achieve path-independent fracture energy estimates with a relative error of 1.5%, establishing a reliable methodology for hybrid experimental-numerical fracture analysis of composite materials.

#1091

# A Physics-Informed Framework for Modeling As-Manufactured Variability in Automated Fiber Placement

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As demand continues to grow for high-performance composite structures, automated deposition technologies have become firmly established as industry standards. However, there remains a significant gap between the smooth, idealized “as-designed” CAD surfaces and the stochastic reality of the deposited material. In practice, these "as-manufactured" signatures, characterized by variable gaps, overlaps, tow waviness and thickness fluctuations, introduce uncertainty that compromises precise performance prediction.

This work presents a generalized framework for synthesizing high-fidelity virtual layups, applicable to a wide range of automated processes including Automated Fiber Placement (AFP) and Automated Dry Fiber Placement (ADFP). By leveraging in-line metrology data, a Bivariate Gaussian Process is proposed to spatially model stochastic variations in tow architecture. By explicitly coupling tow width and thickness, the model enforces that lateral spreading induces compensatory thinning. This ensures that stochastic representations remain physically admissible.

Although the proposed geometric engine is process-agnostic and suitable for structural or thermal analysis, this work focuses on its application to permeability prediction. A Monte Carlo simulation campaign integrates the stochastic generator with a multi-fidelity flow solver, combining hydraulic circuit approximations with Computational Fluid Dynamics (CFD). The analysis focuses on quantifying how the physical coupling of defects induces systematic flow restrictions within the preform.

This research aims to provide the foundation for "Virtual Qualification" across the manufacturing spectrum. By enabling the derivation of physics-based knock-down factors, this framework allows engineers to replace conservative empirical safety margins with data-driven predictions, ensuring that the impact of process variability is accurately accounted for in the early phases of composite design.

#1092

# PP/Flax Composites: Green Materials for Sustainable Manufacturing

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Thermoplastic composites reinforced with flax fibres are gaining attention as sustainable alternatives for lightweight structural applications. However, the processing behaviour of PP–flax systems is still not fully understood, and different manufacturing routes can strongly influence their final properties.

This contribution presents an investigation on how selected process conditions affect the quality and performance of PP/flax laminates. Particular attention is given to the relationships between manufacturing parameters, microstructural features and resulting mechanical response, with the aim of identifying robust and energy-efficient processing strategies.

The study provides general insights into process–structure interactions in natural-fibre thermoplastics and supports the development of reliable and sustainable manufacturing approaches for PP/flax composites.

#1093

# The experimental characterisation of compressive performance of pultruded carbon fibre/epoxy composites

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Pultruded carbon fibre/epoxy composites possess high fibre alignment. Recently, within the EPSRC-funded NextCOMP programme, circular cross-section, pultruded rod based hierarchical composites have been developed, with overbraiding to laterally support pultruded rods in compression. However, the characterisation of the compressive performance of these materials in axial compression loading is sensitive to factors such as specimen end preparation, loading misalignment and localised non-uniform loading. End fittings have been used to prevent the premature failure of these materials in axial compression test but this results in high complexity of the preparation process. The aim of this work is to develop low-complexity compressive test methodologies for pultruded carbon fibre/epoxy composites.

Commercial pultruded carbon fibre/epoxy composites of 0.7 mm diameter (denoted as 'rod') and 6 mm diameter (denoted as 'strut') were used to validate two test methodologies. The rod specimens were investigated using a modified four-point bending 'cradle' test. Specimens were adhesively bonded onto acrylic cradles featuring a 'T-shape' undercut gauge section. The specimens were failed in compression within the gauge section without rod buckling and debonding, and the measured compressive failure strain and axial modulus was consistent with the manufacturer's datasheet values.

The strut specimens were characterised using an eccentric buckling test. Specimens were bonded with design endcaps which offset the strut centre by 7 mm from the endcap centre to promote bending. Three strain gauges spaced at 120° were bonded at mid-span location to determine axial strain, with one strain gauge at the maximum compressive strain location. The specimens exhibited an initial tensile-side fracture, followed by compression-side failure. The compressive strain at the onset of the tensile-side fracture was higher than literature values, perhaps due to the strain gradient effect. Moreover, a non-linear stress-strain relationship was recorded and is currently under further investigation.

Details of both test methodologies will be presented and discussed.

#1094

# Effects of galactic cosmic radiation on the mechanical performance of thin high-strain PEEK composites for space applications.

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Fibre-reinforced polymer composite materials are highly desirable in space-based applications due to their excellent mass-specific mechanical properties. However, polymeric materials are particularly susceptible to the harsh environment of space (i.e. radiation, thermal cycles, plasma). Polyether ether ketone (PEEK) is a high-performance thermoplastic polymer that is uniquely suited to space applications due to its mixture of strong mechanical and environmental performance.

A series of thin (~0.25 mm) carbon-fibre PEEK composite laminates has been manufactured and exposed to simulated galactic cosmic radiation (1 GeV energy Fe26+ ions at GSI Helmholtzzentrum), representing exposure equivalent to 0-200 years in space. The laminates consist of two sets: A baseline set of continuous fibre composite (Vf ~50%) and a secondary set of aligned discontinuous fibre composite (ADFC) (3mm fibre length, Vf ~30%) manufactured using a novel co-mingling technique being developed at the University of Bristol. This manufacturing technique combines the patented HiPerDiF (High Performance Discontinuous Fibre) alignment process with homogeneous co-mingling, resulting in well-aligned, void-free thermoplastic laminates at moderate Vf.

These laminates will then be mechanically tested using the counterbalanced column bend test (CB-CBT) method, developed by NASA to mechanically characterise thin, high-strain composites, which are often used in deployable space structures. The aim is to demonstrate whether galactic cosmic rays significantly impact mechanical properties over a mission's lifetime (stiffness, strength, curvature at failure). Furthermore, the study aims to quantify the suitability of the ADFC material for high-strain composites in space applications. The long-term goal for introducing ADFCs into space applications is to leverage their inherent advantages in remanufacturing, which may play a critical role in manned deep-space missions and in-orbit manufacturing of large-scale space structures.

#1095

# Influence of Process Parameters on the Slurry Erosion Behaviour of 3D-Printed Polylactic Acid

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In recent years, there has been a growing need in developing lightweight and sustainable materials in applications related to slurry transportation. Slurry erosion is becoming a legitimate concern for engineering polymers and composites used in other emerging applications, such as slurry pumps.

This study examines the slurry erosion characteristics of 3D-printed polylactic acid (PLA) produced by the Fused Deposition Modelling (FDM) method under various 3D printing and slurry erosion test parameters, focusing on the effects of raster orientation, infill density, slurry impact angle, and slurry velocity. PLA samples were manufactured with infill densities of 50%, 75%, and 100%, with X, Y, and diagonal raster orientations, for the slurry erosion tests. The slurry impact angle, ranging from 15° to 90°, and velocities of 20, 25, and 30 m/s, were key parameters to measure the cumulative mass change.

The results show that the 3D-printed sample with 50% infill density experienced a mass increase, attributed to sand particle embedment on the sample surface. Conversely, the samples with 75% and 100% infill densities showed mass loss after the slurry erosion tests. The sample with 100% infill density and diagonal raster orientation demonstrated the greatest slurry erosion resistance, while the X raster orientation sample exhibited the lowest resistance, followed by the Y raster orientation sample. The slurry erosion rates, calculated from mass loss values relative to the mass of erodent sand, indicated that tests performed at a 45° impact angle resulted in the highest erosion rates at each slurry velocity, followed by 30°, 60°, 90°, and 15°. Furthermore, due to increased kinetic energy, the highest erosion rate was observed at 30 m/s slurry velocity, followed by 25 m/s and 20 m/s.

This study provides a robust methodology for investigating 3D-printed polymers and new findings of the process-structure-performance relationship in slurry erosion behaviour.

#1096

# Degradation of semi-structure bell&spigot GFRP pipe joint integrity due to air pocket and kissing bond defects

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Adhesive bonding is now a significant alternative to traditional joining methods across various industries (e.g., automotive, aerospace, electronics) due to its cost-effectiveness and technical benefits, including improved strength-to-weight ratios, uniform stress distribution, and enhanced material compatibility. Despite these advantages, quality control remains challenging, as joint performance is highly dependent on bond-line defects such as air pockets (voids), and kissing bonds. Understanding the impact of these defects is crucial, especially where these joints form essential, load-bearing connections in structural systems. The presence of these flaws is a primary concern, potentially leading to catastrophic failure in load-bearing structures like GFRP pipeline networks, aircraft components, and wind turbine blades.

This study investigated the effect of controlled air pockets and kissing bonds on the Glass Fiber Reinforced Polymer (GFRP) pipe joints integrity (formally known as bell&spigot joint), commonly used across various industries ranging to oil and gas, water and wastewater treatment, power generation and others. Dedicated pipe joints (200 mm internal diameter) were manufactured according to the manufacturer's protocol (FPI Industries), involving strict control over surface preparation (shaving, sanding), environmental conditions (temperature and dew point), and the two-stage curing process (natural cure followed by 125 °C for 1.5 hours) for the two-part FPI WAVISTRONG© adhesive, used to join the pipes. The critical size defects of air pocket, expressed as a fraction of the overlap area, was introduced within the bond line (with a CT-scan image confirming its presence and location), while kissing bond was applied using a mold release agent. The prepared joints were then subjected to pressure test, till failure. The resulting burst pressures obtained for the kissing bond and air pocket defects were 10% and 20% lower, respectively, compared to the pristine case. These values were well within the error envelope of the lap-shear test results, as investigated by authors earlier.

#1097

# Towards enhanced closed-loop recycling of sand-filled glass fibre composites

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Thermoset composite materials offer exceptional strength-to-weight ratio, corrosion resistance and design flexibility. However, their heterogenous structure and crosslinked matrices pose significant challenges for recycling, particularly for sand-filled laminates used in the fabrication of composite pipes. Conventional recycling routes for these materials often result in downcycling, limiting their reuse potential and environmental benefits. This work explores strategies to enhance closed-loop mechanical recycling of sand-filled glass fibre reinforced polymer (GFRP) composite pipes by improving material recovery and reprocessing efficiency. Mechanical recycling combines size reduction, particle classification, and separation to incorporate recyclates as fillers or reinforcement in new laminates. Coupled with surface modification, this approach improves fibre–matrix adhesion and composite performance, extending composites lifespan and reducing virgin material demand.

Manufacturing waste from GFRP pipe production and both shredded end-of-life epoxy and polyester based wind-turbine blades are considered as recyclates. The proposed integrated approach combines optimised shredding and recyclates classification from large flakes to dust, with particle size control, thermal and chemical surface treatments, and formulation adjustments to enable high-value closed-loop recycling. Particle size distribution was characterised using image analysis of microscopy images of individual particles and fibres, while recovered particles underwent thermal and chemical surface treatments to restore interfacial adhesion with new resin systems. Comprehensive characterisation of the recyclates included surface morphology (SEM), chemical functionality (FTIR), composition (TGA, calcination) and evaluation of the effect of recyclates type and content on the mixture's viscosity and processability. Selected and treated recyclates were successfully incorporated into new composite laminates both at laboratory and pilot industrial scale of GFRP pipes, and their mechanical performance assessed, e.g. flexural, pressure tests. The findings from this work contribute to circular economy principles, help reduce landfill waste, and support the development of environmentally responsible end-of-life strategies for complex composite systems.

#1100

# Biocomposites reinforced with cactus pear glochids: Effect of polymer matrix and compatibilization

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The development of biodegradable biocomposites incorporating agricultural residues is essential for advancing circular material strategies. Glochids, microscale spines derived from cactus pear, have already shown promising reinforcing effects in biodegradable polymeric matrices such as PLA. However, despite their potential, limited interfacial adhesion between glochids and biodegradable polymers remains a key challenge, and no systematic investigation on their compatibilization has yet been conducted.

This work presents a study on the compatibilization of glochids with PBAT and PLA matrices using a multifunctional chain extender (Joncryl®). While the mechanical and rheological behaviour of glochids alone has been explored, their interaction with a compatibiliser represents the main innovation of this contribution. A single, fixed concentration of Joncryl® was employed, while two different filler loadings (10 and 20 wt%) of glochids were evaluated to assess the effect of filler content.

The results confirm that glochids increase stiffness in both matrices, but the introduction of Joncryl® induces distinct, matrix-dependent interfacial effects. The compatibiliser increases melt viscosity at low shear rates and enhances shear-thinning behaviour, although the magnitude of these effects differs markedly between PBAT and PLA. These differences suggest that Joncryl® acts through different chain-extension mechanisms, depending on the chemical structure and reactivity of each matrix. In addition, the compatibiliser influences the biodegradation behaviour of the biocomposites, indicating that interfacial chemistry affects not only processability and rheology but also the environmental degradation pathway.

Overall, this study provides the first evidence of compatibilization effects in glochid-filled biodegradable polymers, offering new insights into the design of reinforced biocomposites derived from cactus pear residues and highlighting the crucial role of matrix-filler-compatibiliser interactions in shaping final material performance.

#1102

# Micro-ct characterization of flexural-fatigue damage evolution in CFRTP-SMC

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Carbon Fiber Reinforced Thermal Plastic Sheet Molding Compounds (CFRTP-SMC) show significant advantages in high-speed manufacturing and recyclability, had begun to be applied in the automotive industry. In the actual situation, dynamic loads are more common and more harmful for materials to withstand compared to static loads. For example, flexural fatigue failure, which compromises the entire structure, even if the cyclic load remains below the ultimate flexural strength of the CFRTP-SMC material.

In previous studies, the influence of the tape geometric size on the flexural fatigue performance was investigated. It was found that in addition to the fatigue life parameter being affected, the final failure mode of fatigue also differed. Based on this, this study utilized the Micro-CT to observe the fatigue damage evolution process in SMC flexural fatigue. Due to the different X-rays reflectivity and absorption rates, the void areas, as well as the fiber and matrix areas can be distinguished. Thus, it is possible to observe the details of micro-crack initiation and subsequent development within the specimens at different fatigue stages.

The crack initiation sites in different tape geometric size reflect their structural weaknesses and stress concentration sensitivity, explaining the inevitable variation in fatigue performance. The propagation path and rate of cracks are manifestations of the resistance of different specimens to fatigue loads, and they are helpful in understanding the reasons for the differences in fatigue performance among specimens of different tape geometric size. The results of this paper contribute to the comprehensive understanding of the flexural fatigue process of CFRTP-SMC, providing experimental and theoretical support for future fatigue simulation modeling.

#1103

# In-plane fatigue crack growth of fiber-polymer composites based on a novel specimen design

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Conventional fracture characterization of fibre-polymer composites relies heavily on compact tension (CT) specimens. Although this setup is informative, it often introduces artificial stress concentrations at the load introduction points and typically leads to unstable crack growth. Thus, CT specimens struggle to reproduce the gradual in-plane fracture processes that govern real structural components.

To overcome these limitations, this work introduces a novel in-plane fatigue fracture specimen specifically developed to generate stable, naturally evolving cracks under cyclic tension. The specimen is designed with a long and wide central region, curved lateral boundaries, and full-width clamping at the top and bottom. A small pre-crack is introduced to localise crack initiation, while the geometry avoids the compressive stresses that normally develop on the non-loaded backside of CT specimens. As a result, a more uniform stress field is achieved and out-of-plane bending is suppressed.

Digital Image Correlation is used to quantify crack initiation, growth rate, and local opening. A dedicated post-processing procedure evaluates displacement discontinuities along user-defined lines parallel or perpendicular to the crack path. For each line, the displacement distribution is approximated with a four-parameter bell-shaped function, providing objective measures of crack length and crack width. This enables consistent tracking of primary and secondary crack fronts, as well as their eventual coalescence, without user filtering or manual interpretation.

Three-dimensional finite element simulations incorporating a non-linear orthotropic damage model reproduce the gradual stiffness degradation and crack-path evolution observed experimentally. The comparison between measured and predicted crack lengths demonstrates strong agreement, confirming that the proposed configuration activates the same governing in-plane failure modes captured by the numerical model.

The study demonstrates that this design generates a stable fatigue crack growth in fibre-polymer composites under realistic in-plane loading, offering a practical alternative to CT-based testing for validating progressive damage models and characterising crack-opening behaviour in composite materials.

#1104

# Advanced Composite Cryostat Design for Next-Generation High-Energy Physics Detectors at CERN

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Material-transparency optimisation is a key consideration throughout the layout of a high-energy physics (HEP) experiment, from the innermost tracking detectors to the outer calorimetry. Transparency refers to minimising particle energy loss through materials, which depends on both thickness and atomic composition. Despite considerable efforts to reduce superconducting coils thickness, the cryostat housing these magnets remains a major contributor to the material budget. For liquid argon-based calorimeter technologies, an additional cryostat is required to contain this cryogenic liquid. In specific detector designs, such as ATLAS, a single cryostat accommodates both magnet and calorimeter.

CERN regularly upgrades detector components in its major experiments (ATLAS, ALICE, CMS, LHCb) to enhance hit rates and collision data sensitivity. Replacing the current aluminium alloy cryostat with a fully carbon-fibre reinforced polymer (CFRP) design could yield up to a 60% gain in structural envelope transparency. As part of CERN's R&D for future detectors, this work investigates the design and feasibility of a full CFRP cryostat for the ALLEGRO experiment's electromagnetic calorimeter (ECAL) within the Future Circular Collider (FCC). Building on the proven ATLAS Liquid Argon barrel cryostat concept, the ALLEGRO cryostat will house both the ECAL barrel and a superconducting solenoid magnet. The ECAL features external and internal diameters of 5.5 m and 4 m, respectively, with a length of 6 m, surrounded by a thick solenoid. These dimensions, combined with cryogenic conditions and heavy structural loads, present significant challenges. To reduce tooling waste and cost, a modular multi-section cylindrical design is under study. For scalability and complex geometries, high-performance thermoplastic composites manufactured via automated fibre placement (AFP) have been identified as promising. Several thermoplastic polymers are being evaluated for compatibility with cryogenic and radiation environments.

Such large-scale, high-transparency composite structures are of strong interest for future HEP experiments worldwide and aerospace applications facing extreme conditions.

#1105

# Analysis of the interfacial diffusion coefficient in organic matrix composites based on multi-scale finite element modelling of thermo-oxidation gradients

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Carbon/epoxy composites exhibit risks when subjected to elevated temperatures during long exposure time. Among these, thermo-oxidative aging of the polymer matrix is particularly critical. The formation of a thin oxidized layer (TOL) at the surface induces local material weakening, generating stress and strain gradients, which may ultimately promote damage accumulation and premature failure. In the case of unidirectional composites reinforced with continuous fibres, the degradation scenario depends on the anisotropy of the composite [1]. Moreover, fibre/matrix interface may be expected to play a decisive role in driving TOL evolution. This raises a central question: must a specific behaviour of the fibre/matrix interface, particularly through diffusive phenomena, be accounted for to accurately describe the oxidation gradients of laminated composites?

To address this issue, a numerical model based on the finite element method [2] and the Representative Volume Element approach has been developed to predict thermo-oxidation gradients within unidirectional composites. The model accounts for three key features: (i) the anisotropic diffusion tensor, (ii) the contribution of the fibres to the reactive term, and (iii) the local effect of the fibre/matrix interface on diffusion mechanisms. A test–simulation dialogue is implemented to validate oxidation gradients by comparing the predicted and measured TOL values under controlled experimental conditions. This approach demonstrates the necessity of incorporating the dominant interfacial contribution to the diffusion term and allows to identify the local interfacial diffusion coefficient in order to ensure robust prediction of TOL evolution. This step constitutes a prerequisite for assessing the impact of oxidation gradients on the thermomechanical properties (e.g., glass transition temperature, stiffness) and on the mechanical state (stress and strain fields) of laminated composites, with the broader objective of predicting their long-term durability.

[1] Pochiraju, K.V. et al. Mech. Time-Depend. Mat. 2008, 12, 45–68.

[2] Marquez Costa el al. Polym. Degrad. Stab. 2025, 234, 111194.

#1106

# Closing the loop: full recyclability of composite structures for cabin interior through adapted vitrimeric polymers meeting the application specific requirements

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The CirKle project aims to address the challenge of achieving full recyclability of composite sandwich panels through innovative polymer solutions. Current degradable systems and vitrimer technologies offer promising pathways; however, existing commercial systems often fall short in meeting stringent performance standards and / or recyclability of both fiber and polymeric matrix. This research highlights the necessity for new polymer solutions that can effectively close the recycling loop especially regarding the polymer component of the fibre reinforced polymer (FRP), particularly in demanding applications such as aircraft cabin interiors, where lightweight construction and stringent fire, smoke, and toxicity (FST) requirements are paramount.

To tackle these challenges, our work is based on an established epoxy-based disulfide-crosslinked vitrimer. Disulfide chemistry emerges as a particularly advantageous approach, as the respective exchange reactions can occur at low temperatures and chemical recycling is easily accessible. With the covalent introduction of self-synthesized phosphorous-based flame-retardant additives, mechanical and FST properties are adjusted to meet the mechanical and FST property requirements of aircraft cabin interiors. Our findings demonstrate that these advanced vitrimeric polymers can serve as a matrix in recycled carbon fiber reinforced polymers (rCFRP). Furthermore, we have developed processes and methodologies to ensure closed-loop recycling of both fibers and matrix, thereby advancing the circular economy within the aerospace sector. This research not only paves the way for more sustainable material practices but also aligns with global efforts to enhance environmental responsibility in engineering design. The outcomes of this project hold significant implications for the future of composite materials, providing a framework for the integration of closed-loop recyclability into high-performance applications.

#1111

# In-line High-Frequency Infrared Drying for Glass Fiber Production: Eliminating Sizing Migration and Reducing Downstream Energy Demand

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Drying represents a critical downstream step in glass fiber production, as the applied water-based sizing leaves the fibers with up to 10wt.% moisture after winding. In the established production of direct and assembled rovings, the process chain is discontinuous: fibers are spun, wound into finite packages, and subsequently dried, with assembled rovings requiring an additional rewinding step. This results in long drying durations of 12–24h at 100–120°C, high energy consumption, and extensive installation space, since industrial convection or RF dryers may exceed 30m in length. Drying alone accounts for up to 45% of downstream energy demand.

A fundamental limitation of conventional drying is sizing migration. Centrifugal forces and moisture transport shift the sizing from inner to outer spool layers, creating irregular accumulations, unstable processing behavior, and material losses. As a result, process-related scrap rates may reach 10%, since oversaturated outer layers must often be discarded.

To overcome these issues, an in-line high-frequency infrared drying approach has been developed. The emitter, with a peak wavelength of 1300nm, is integrated directly into the winding zone and selectively heats the fibers and sizing without significantly warming the surrounding air. This promotes uniform drying of the freshly deposited outer fiber layer and effectively suppresses sizing migration. Preliminary trials demonstrated residual moisture levels below 2% at take-off speeds up to 1200m/min, along with uniform sizing morphology and mechanical performance comparable to conventionally dried fibers.

Continued refinement of the drying module and experimental setup now targets residual moisture levels below 0.8% by enclosing the drying zone and enhancing in-line efficiency. This results in a more homogeneous sizing distribution and significantly reduced scrap. In addition to time and energy savings, the in-line concept eliminates the large spatial footprint of conventional dryers. Current projections indicate an energy-reduction potential of up to 30% compared to traditional drying methods.

#1114

# Towards the development of carbon negative advanced composite materials

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Fibre-reinforced polymer composites are increasingly being used for industrial applications where strong, durable and light materials are required. However, there are well-documented environmental concerns with these materials as they are derived from a complex supply chain involving fossil-derived raw materials. Substituting fossil-derived constituents with materials from biogenic carbon feedstocks has been widely explored in literature, yet the potential of these feedstocks to function as long-term atmospheric carbon sinks remains comparatively under-examined. If the biogenic carbon stored in composites is retained over their service life and managed appropriately at end-of-life, such materials could contribute to climate change mitigation.

This project uses a techno-environmental-economic assessment to investigate whether composites manufactured from biogenic feedstocks can achieve net-negative CO2 emissions while maintaining acceptable structural performance and durability. Atmospheric carbon sequestered in both matrix and fibres will be quantified alongside mechanical and durability performances to ensure the materials remain viable for long-term service. End-of-life solutions will also be thoroughly explored.

Several bio-based epoxies were formulated with an amine curative package to achieve resin matrix formulations with a high biogenic carbon content. The cure kinetics, thermomechanical properties, environmental durability and processability of these resins were systematically assessed and benchmarked against an industrial fossil-derived epoxy. Two resin systems were identified as having similar or better thermomechanical performance and environmental durability (compared to the benchmark), while also exhibiting suitable curing and rheological behaviour for composite prepregging. These candidates, along with the benchmark, were successfully filmed with a consistent areal weight and impregnated into carbon, glass and flax woven reinforcements to produce void-free composite laminates via an autoclave cure. Ongoing mechanical characterization of these biogenic composites, integrated with life cycle assessment, will determine the conditions under which they can act as effective, durable carbon sinks and provide guidance as to which applications they would be most suited for.

#1116

# Multifunctional CFRPs Enabled by Roll-to-Roll Laser-Reduced Graphene Oxide

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Graphene-enhanced carbon fiber reinforced polymer (CFRP) laminates exhibit significantly improved electrical conductivity and mechanical performance with through-thickness conductivity increases of 8–120× and an average 23.25% increase in maximum stress before failure. Despite these advantages, the widespread use of graphene nanoplatelets in industrial composite manufacturing remains constrained by high material cost, low production yield, and challenges associated with achieving uniform dispersion within the matrix. To address these constraints, this study investigates a novel approach that integrates laser-reduced graphene oxide (rGO) into CFRP laminates, widely used in aerospace, aviation, and other high-performance applications. Utilizing a single step, eco-friendly, and high-quality novel roll-to-roll (R2R) laser pilot line process, laser-assisted rGO generates uniformly adhered few-layer graphene directly on the composite surface, creating conformal networks that enhance load transfer and accentuate electrical performance. The technique is fully compatible with R2R manufacturing, enabling direct patterning, and providing precise control over graphene reduction parameters, thus delivering an environmentally efficient and flexible one-step approach for high-grade rGO incorporation. The restored $sp^2$ carbon network within rGO improves conductivity, while its textured morphology promotes enhanced fiber–matrix adhesion and strengthens interfacial bonding. The henceforth rGO-doped matrix regions contribute to a multifunctional behavior, leading to modified properties of electrical and mechanical nature. Overall, this study demonstrates a unified composite system that combines rGO-enhanced CFRPs with modified mechanical robustness, advanced electrical functionality, and superior multifunctional performance. The demonstrated scalability and material efficiency position make this approach as a promising and economically viable pathway for next-generation aerospace and high-performance engineering applications.

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#1117

# Influence of Thermoplastic Composite Blades on Structural Damping and Load Reduction in Wind Turbines

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The adoption of thermoplastic composites for wind turbine blades offers a unique combination of recyclability, reduced manufacturing energy, and improved dynamic performance. This study combines experimental validation and numerical simulations to assess the influence of thermoplastic resin systems, specifically Elium® resin, on blade damping and its effect on turbine loads. A 13-m thermoplastic blade was manufactured and structurally validated against an equivalent epoxy blade under static and fatigue loading. Both blades exhibited comparable stiffness and fatigue resistance, confirming the suitability of thermoplastic composites for primary structural applications. However, the thermoplastic blade demonstrated a five- to sevenfold increase in structural damping, a property which is expected to mitigate dynamic responses and reduce operational loads.

Complementary aeroelastic simulations were performed on a 5-MW reference turbine using OpenFAST, considering three damping scenarios: baseline epoxy blade, Elium® blade (×5 damping), and an amplified ×10 damping case. Ultimate loads showed negligible variation except for yaw bearing and rotor shaft bending moments, which decreased by up to 5.6%. In contrast, fatigue loads exhibited substantial reductions: Damage Equivalent Loads (DEL) decreased by up to 19% at the rotor shaft and 17% at the yaw bearing, while composite fatigue life improved by 15–22%. These reductions suggest potential for lighter designs and extended component lifetime without compromising structural integrity.

The combined experimental and numerical evidence confirms that thermoplastic composites not only meet conventional design requirements but also deliver system-level advantages through enhanced damping, contributing to longer component life, improved reliability and reduced lifecycle costs. Combined with recyclability and faster manufacturing cycles, this technology represents a major step toward sustainable and performance-driven wind turbine design. Future work will focus on maximizing the benefits of increased damping while leveraging the recyclability of thermoplastic blades to support a circular economy.

#1118

# Shape Morphing Composites for Aerospace and Space Structures

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Shape-morphing materials provide a uniquely valuable capability for aerospace and space systems: the ability of a structure to deliberately change its geometry in response to thermal or mechanical stimuli. This controlled deformation enables components to remain compact during launch and then reliably deploy or reconfigure in orbit, offering lightweight, low-shock, and low-power actuation compared with conventional motorized mechanisms. Consequently, shape morphing is increasingly investigated for morphing aerodynamic surfaces, variable-geometry propulsion components, vibration isolation devices, and self-deployable structures, such as solar sails and satellite subsystems. Embedding the shape-morphing effect into composite laminates by integrating SMA wires creates multifunctional smart structures with improved structural and adaptive performance. SMA-reinforced composites provide controlled bending suitable for morphing skins and adaptive spacecraft components, while also enhancing toughness and impact resistance relative to conventional laminates. Demonstrated flight applications, including SMA-driven deployment of solar arrays on GEO satellites, further validate their reliability under vibration, shock, and extreme temperature cycling, supporting their use in smart hinges, foldable panels, and other reconfigurable architectures. A complementary approach employs selective Joule heating of embedded conductive fibers, such as carbon fibers, to induce localized thermal gradients. In this multifunctional configuration, the reinforcement fibers act simultaneously as load-bearing elements and distributed internal actuators, reducing system complexity and enabling morphing of thin aerodynamic surfaces or thermally responsive spacecraft structures without dedicated SMA components. This study demonstrates the feasibility and advantages of Shape Morphing Composites for next-generation aerospace structures. Experimental results show controlled and repeatable deformation, improved energy absorption, and customizable thermal–electrical actuation responses, highlighting their potential as a versatile foundation for future adaptive aerospace systems.

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#1119

# Scalable Manufacturing of Electrically Conductive CF/PEEK Thermoplastic Laminates via Multi-Dimensional Carbon Additive Hybridization

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Carbon-fiber-reinforced polyetheretherketone (CF/PEEK) composites are inherently limited by low electrical conductivity due to high interfacial porosity, restricted charge carrier mobility, and fabrication-induced defects that disrupt conductive pathways. This work introduces a multi-dimensional carbon hybridization strategy that integrates 3D graphite and carbon black (CB), 2D graphene nanoplatelets (GNPs), and 1D carbon nanotubes (CNTs) to construct a robust multi-scale percolation network within CF/PEEK laminates. The resulting hierarchical system enables synergistic phonon–electron coupling across interfaces of different dimensionalities, facilitating continuous channels for both electrical and thermal transport.

A comprehensive multi-scale characterization framework—combining Raman spectroscopy, X-ray computed tomography (CT), and high-resolution SEM—was employed to correlate hierarchical interface formation with microstructural ordering, void evolution, and charge transport behavior. These analyses reveal that dimensional hierarchy plays a central role in governing percolation threshold, microstructural compaction, and matrix–fiber interfacial architecture. Furthermore, hybrid carbon architectures promote temperature-dependent interfacial reconstruction within the semi-crystalline PEEK matrix, improving chain mobility, resin infiltration, and load-transfer efficiency.

Among the evaluated systems, CNT-based interlayers provided the most significant conductivity enhancement (66%) while maintaining high mechanical integrity, achieving a tensile strength of 429 MPa. Meanwhile, CB-based films enabled superior microstructural densification, yielding the lowest void content and confirming their strong compaction capability during consolidation. These outcomes demonstrate that conductivity gains can be realized without compromising structural performance when interfacial design strategically couples polymer mobility with hierarchical carbon networks.

Overall, this study proposes a novel materials design approach for multifunctional thermoplastic composites, highlighting how tailored carbon architectures across multiple length scales can modulate interfacial transport phenomena. The demonstrated strategy provides a scalable and tunable pathway for engineering conductive, mechanically robust CF/PEEK systems suitable for aerospace, energy, and high-performance structural applications.

#1121

# Use of Wet Filament Winding Processes for the Manufacture of Non-Oxide Ceramic Matrix Composites

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Hypersonic flight, next-generation gas turbine components and nuclear fusion demand non-oxide ceramic matrix composites (CMCs) but costly manufacturing techniques limit industrial adoption. Filament winding (FW) is an automated manufacturing process ideally suited to the cylindrical geometries common in the fusion and defence sectors. It enables significant cost reductions through high levels of automation and the minimisation of material waste. Wet FW includes a ceramic-slurry bath and infiltration stage with simultaneous lay-up and matrix introduction; the properties of the ceramic slurry must encourage effective retention of the matrix to produce a high ceramic density in the component.

This work presents a comparison between water and solvent based non-oxide ceramic slurries to create green state materials using wet FW. The rheological properties of the slurry systems including tackiness were assessed, alongside sedimentation and green state microstructure. Carbon fibre tows were used for infiltration during FW trials to demonstrate the practicality and effectivity of manufacturing with the slurries. In SEM images the solvent-based system showed a higher density of ceramic particles, despite non-uniform distribution and interlayer microporosity. The water-based system proved to be more stable with a compatible viscosity; however, the formulation would require further development to improve the deposition of ceramic particles. The trials were valuable for assessing the feasibility of FW with non-oxide ceramic slurries, presenting the need for further research into slurry formulation and mandrel demoulding strategies to optimise component quality.

Overall, this study highlights that FW is promising for use with non-oxide CMCs to produce green state preforms with a high density of ceramic particles.

#1122

# A predictive multiscale modelling framework to accelerate the development of novel vitrimers and their composites

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There has been increasing interest in the development and scaling up of vitrimers in recent years with several research groups and projects developing formulations with widely different functional groups. Vitrimers are a class of polymers which when used in fibre-reinforced composites promise improved recyclability and repairability due to their unique reversible cross-linking nature. However, it is time-consuming, costly and often unreasonable to synthesise and test every vitrimer formulation studied and considered. To help speed up the screening and selection process for vitrimers to be used in wind turbine blade manufacturing, the current study, performed as a part of the EOLIAN project, uses a validated multiscale modelling approach to rapidly predict the properties of cured vitrimers with novel chemistries, while minimizing the need for experimentation. The multiscale framework consists of four length scales: molecular (atomistic-level), micro (ply-level), meso (laminate-level), and macro (part-level). The vitrimer chemistry is an input to the molecular scale modelling, and the major outputs from the multiscale model are the laminate and part behaviours when subject to different loads. Other inputs to the models are the processing parameters, laminate geometry, and layup configuration. All scales beyond the molecular scale use finite element models to propagate the properties and behaviour of vitrimer composites at the different scales studied. The results of the model are validated and the model is calibrated using experiments on selected vitrimer and vitrimer composite formulations that have been synthesised. The proposed multiscale framework is a step towards virtual testing of vitrimers being studied by reducing the time taken in developing novel vitrimers and composites with specific desirable properties.

#1123

# Recyclable composites based on thermoreversible resins reinforced with recycled carbon fibers

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Nowadays, the increasing industrial deployment of composite materials has amplified concerns regarding the end-of-life management of Carbon Fiber Reinforced Polymers (CFRPs). Unfortunately, the intrinsic cross-linked architecture and heterogeneous composition of CFRPs severely hinder their recyclability, particularly with respect to polymer-matrix recovery. Consequently, the development of intrinsically recyclable thermosetting systems has emerged as a critical strategy to mitigate waste generation, enable efficient recovery of high-value constituents, and extend service lifetimes through reprocessability and self-healing functionalities.

This study aims to design a fully recyclable composite material comprising a thermoreversible matrix reinforced with recycled carbon fibres. In particular a polyketone was chemically modified through reaction with different amount of furfurylamine to achieve targeted di-carbonyl conversions of 20, 40, and 60%. The functionalised polymers were subsequently cross-linked with a bio-based aliphatic bismaleimide via the Diels–Alder (DA) reaction, employing three distinct furan:maleimide stoichiometric ratios to systematically vary cross-link density and reversibility. Thus, thermoreversible composite materials were produced by incorporating 30 wt% recycled carbon fibres (rCFs) sourced from industrial Carbon Fiber Reinforced Polymers (CFRPs) waste processed through pyro-gasification in the FIB3R plant (Imola, Italy). Mechanical characterisation was performed over successive recycling cycles to assess structural integrity, retention of mechanical performance, and the effectiveness of DA-based reversibility in enabling repeated reprocessing.

This work provides a demonstrative pathway toward fully recyclable developing thermosets with inherent recyclability enables not only a reduction of plastic waste and an easier recovery of valuable composite components, but it can also lead to an extension of the thermoset lifespan through self-healing and restoration of functionalities upon damage.

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#1124

# Monte Carlo simulation of parallelogram tape CFRTP-SMC using a calculus based geometric abstraction supported by tensile tests and ct-scan observations

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We investigate short-fiber CFRTP sheet molding compound (SMC) laminates with random tape orientations and quantify how tensile strength, elastic modulus, and variability evolve with tape angle. Our research follows a simulation–experiment–simulation framework: an initial Monte Carlo model guided testing at 20°, 60°, and 90°, and while high-resolution CT scan results supply and are used to calibrate real overlap widths, interfacial irregularities, and orientation fragmentation.

The improved model introduces a calculus-based geometric abstraction that represents each parallelogram tape as a continuous set of differential rectangular micro-bundles. This provides an analytical description of angle-dependent load-path projection, stiffness contribution, and micro-bundle shear transfer, clarifying why some angles enhance strength or deviate from classical laminate theory.

A voxelized layout generator produces stochastic, non-overlapping tape configurations, while CT scan results supply and are used to calibrate real overlap widths, interfacial irregularities, and orientation fragmentation. Local stresses are computed using orientation-dependent stiffness transformations and equivalent stiffness averaging. Failure is predicted through Monte Carlo evaluation using Weibull statistics with parameters informed by experiments and CT-derived geometry.

The strengthened framework captures the tensile-strength peak near 20°, reproduces modulus and CV trends at 20°, 60°, and 90°, and yields smooth angle–response curves with robust uncertainty envelopes. Overall, the approach unifies CT-informed geometry, differential tape modelling, and Monte Carlo simulation into a mechanistic and reproducible framework for mapping process, structure, and properties in CFRTP-SMC, with applicability to irregular and recycled tapes.

#1125

# On the Relationship between Structural Variability and Lamina Variability through Global Sensitivity Analysis

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The ply properties of composite materials have inherent variability coming from the manufacturing process. This variability of material properties combined with the additional manufacturing and installation processes required, result in the mechanical response of components of higher complexity (be it laminates or structural components) being subject to uncertainty. The current approach to account for uncertainty relies on the statistically based determination of material properties on the lower tails of their probability distribution. This is achieved by testing a statistically significant number of specimens and using the calculated property as a deterministic value in design process. Another emerging approach is the application of Uncertainty Quantification (UQ) to propagate the probability distributions of the lamina-level material properties through the different structural levels, characterizing the final distribution of the mechanical response of interest. As the size of a dataset required to fully characterize the probability distribution of a given mechanical response is large, UQ typically relies on computational simulations.

Both approaches share common ground: 1) a baseline knowledge of the distribution of the material properties is required, implying experimental tests; 2) as the structural complexity increases so does the potential number of input factors. However, it is unlikely that the variability of mechanical response is explained only if the variability of all input factors is considered, being possible to take several as deterministic values without significantly affecting the result (parsimony of effects). In this work, variance based Global Sensitivity Analysis (GSA) is performed on different configurations to establish a reduced set of material properties necessary to be considered as stochastic such that the general variability of mechanical response of composites can be explained. Data-driven surrogate models are trained on high-fidelity finite element simulations and GSA is performed on these surrogates.

#1126

# Inverse Spectral Chebyshev Method for Full-Field Reconstruction Under Restricted Surface Access in Composite Plates

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Surface-based strain measurements are widely used in manufacturing, inspection, and structural evaluation of composite plates. However, prior studies have shown that existing inverse mechanics approaches, particularly inverse finite element methods (iFEM), become ill-posed when strain data are sparse, unevenly distributed, or limited to small regions of the structure. Such measurement constraints frequently arise in practice, where access to composite components is nonuniform and sensor placement is dictated by geometry, operational restrictions, or manufacturing considerations.

This work introduces the Inverse Spectral Chebyshev Method (ISCM), a new PDE-constrained spectral reconstruction framework developed to overcome these limitations in sparse and region-restricted sensing. ISCM represents the mechanical fields using global Chebyshev polynomial expansions and estimates the corresponding expansion coefficients by solving a constrained inverse problem that simultaneously incorporates measurement data and the governing plate equations. By leveraging global spectral smoothness and the strong coupling inherent in the PDE system, ISCM enables full-field reconstruction from highly incomplete surface measurements, without requiring dense sensing grids, through-thickness sensor pairing, or explicit curvature computation.

The method is evaluated under sensing configurations that the literature identifies as challenging or unsolvable for classical inverse formulations, including measurements confined to limited surface regions, highly sparse and irregular sensor distributions, and mixed domains with both accessible and inaccessible surfaces. Across these scenarios, ISCM accurately reconstructs displacement, rotation, and bending-related strain fields, demonstrating robustness to sensor sparsity, nonuniform placement, and limited measurement diversity. These results establish ISCM as a powerful and versatile computational tool for inverse field reconstruction in composite manufacturing and structural health monitoring, enabling reliable full-field estimation even when sensing is severely constrained by practical accessibility or instrumentation limitations.

#1127

# Tailoring Composite Laminates for Auxetic Behavior via Particle Swarm Optimization

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Composite materials, despite being widely used in aerospace due to their high specific strength, fatigue resistance, corrosion durability, and low weight, they remain vulnerable to low-velocity impacts, where barely visible damage can significantly degrade structural performance. To mitigate this, alternative composite architectures have been explored and among these, auxetic metamaterials, characterized by negative Poisson's ratios (NPR), show particular promise, enhancing impact resistance through lateral densification. In fiber reinforced laminated composite structures, auxetic behavior depends on the orientation and sequencing of individual plies. Since the relationship between fiber orientation and auxetic response is highly nonlinear, computational optimization approaches stand out.

This study focuses on optimizing the fiber angles of multi-ply symmetric face sheets using a particle swarm optimization (PSO) framework to maximize both in-plane (IP) and through-thickness (TT) NPR, enabling fully auxetic laminate behavior and offering insights into the design of impact-resistant composite structures. Four architectural cases are considered, representing different distributions of IP- and TT- dominant stacks: [IP/TT]s, [TT/IP]s, fully IP, and fully TT. For each case, the PSO algorithm searches within ±90° for the four independent angles of the eight-ply symmetric layup, performing three separate optimizations in which angles are rounded to the nearest integer, multiple of 5°, and multiple of 10°, to reflect practical manufacturing limitations and assess the effect of discretization on the optimal auxetic response. For each candidate configuration, Classical Lamination Theory will be used to compute the corresponding Poisson's ratios. Constraint handling ensures both in-plane and through-thickness Poisson's ratios remain negative. The optimization identifies laminate configurations that achieve simultaneous NPRs, confirming the critical role of ply sequencing and the advantage of mixed IP/TT architectures. The results are also expected to highlight the effectiveness of PSO in navigating the nonlinear design space and provide insight into the impact of practical angle discretization on achievable auxetic performance.

#1128

# Biaxial testing apparatus and specimen design for fibre polymer composites

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Uniaxial testing remains the most common method of mechanical characterization for fibre polymer composites. However, due to the inherent anisotropy of these materials, their mechanical strength is strongly direction-dependent, and a standard uniaxial test determines the properties along the applied loading direction. Hence, such tests are inadequate for accurately predicting failure in composite structures subjected to complex multiaxial loading conditions. To address this limitation, in-plane biaxial testing is essential for achieving a comprehensive understanding of composite behaviour under multidirectional stresses.

In this study, a novel cruciform specimen geometry and a dedicated biaxial testing apparatus are proposed that can be utilised to investigate the influence of in-plane biaxial stress states and to identify their interaction in terms of a critical stress surface. Quasi-static numerical simulations are performed on both the specimen and the testing apparatus to cover the full range of in-plane stress states, including tension-tension, tension-compression, and compression-compression loading, with the capability of imposing various biaxial stress ratios. The specimen design is optimized with a primary focus on three key aspects: minimizing geometric stress concentrations arising in the cruciform arm corners, achieving a uniform strain field within the central test region, and maintaining relatively low stresses in the clamping zones. Together, this facilitates the initiation of failure within the intended biaxially loaded region. The proposed apparatus employs a single loading system with a configurable linkage mechanism, enabling controlled variation of both the loading type and the imposed biaxiality ratio. This novel design provides a robust framework for experimental characterization of composite materials under in-plane biaxial loading.

KEYWORDS

Fibre-polymer composites, Cruciform specimens, In-plane biaxial test, Linkage loading fixture, Stress concentrations.

#1129

# Continuous Grafting of Carbon Nanotubes on Carbon Fibres: Numerical and Experimental Study

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In carbon fibre-reinforced polymer (CFRP) composites, the interface and interphase regions are critical for facilitating load transfer, thereby governing the composite's strength and toughness, especially when subjected to compressive loading. Unfortunately, the chemically inert and smooth surface of untreated carbon fibres (CFs) limits bonding with polymer matrices. The weak fibre-matrix interaction restricts effective stress distribution, leading to suboptimal compression performance and highlighting the necessity for advanced CF surface modification strategies.

Introducing nanomaterials with high mechanical performance and CF surface compatibility, like carbon nanotubes (CNTs), to the interphase region of CFRPs enhances fibre-matrix interaction. Aside from the mechanical interlocking effect provided by CNTs, their high specific surface area allows further chemical modification processes. Among multiple methodologies of growing CNTs on the CF surface, chemical vapour deposition (CVD) stands out for its controllability and scalability. CNT-grafted CFs (CNT-g-CFs) can be produced homogeneously, at the whole tow scale, via a bespoke open-ended thermal CVD system. A numerical model was built using COMSOL Multiphysics® to simulate different reaction environments under varying reaction gas inputs. Stepwise experiments were conducted to identify if different gas inputs could yield longer CNTs. Novel nickel-based catalyst components and fibre treatment techniques were explored as well, resulting in successful high-quality CNT growth at lower temperatures (520℃). The CNT layer quality can be varied by changing the catalyst bath concentration and refining deposition techniques. At a primary CF loading of 60 vol%, the current CNT-g-CFs introduce around ~3 vol% CNTs overall. Increasing the density and coverage of CNTs on the CF surface is therefore potentially interesting, alongside optimising their length and crystalline quality. Using the continuous tow production system, the combined Ni-catalyst and growth conditions can be applied at a large scale to provide sufficient CNT-f-CFs for further thermoplastic composite manufacturing.

#1131

# Numerical modeling of magnetorheological polymers fabricated with the aid of a magnetic field

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Magnetorheological polymers (MRPs) are those that are filled with magnetic or ferromagnetic particles. MRPs are used as actuators due to them undergoing a reversible deformation by the application of a magnetic field after fabrication. However, if applied during fabrication, the behavior of the MRP may be tailored by controlling the dispersion of the ferromagnetic particles via the magnetic field. Tailoring the behavior of MRPs this way is an area of research that has received little attention. To address this gap, a numerical model is developed to investigate the effects of a magnetic field on the dispersion of ferromagnetic particles during fabrication of MRPs via additive manufacturing. In this model, three-dimensional geometric representations of iron particles dispersed in polylactic acid (PLA) are simulated. Iron particles are approximated as spheres and are generated within a block that represents a single layer of printed PLA. To simulate the effects of the magnetic field, the spherical iron particles are generated inside the PLA forming columns consisting of various number of pillars and in different orientations. These single layers with particles distributed in columns are simulated under tension. Simulations of spherical iron particles randomly dispersed in the PLA are also performed. These simulations correspond to MRPs fabricated without the aid of a magnetic field. Changes in the stress-strain curves, Young's modulus, and ultimate tensile strength resulting from the different distribution of particles are assessed to determine the effect of the magnetic field during the fabrication of MRPs. These results are used to present guidelines for tailoring the mechanical behavior of MRPs with the aid of a magnetic field applied during fabrication via additive manufacturing. Since the distribution of particles also affects their magnetic properties, these results also have applications in tailoring the magnetic response of MRPs.

#1132

# Three-dimensional printing of functional mycelium biohybrids

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Biological materials constantly adapt to their environment, display lower embodied energy, and possess remarkable mechanical properties granted by their hierarchical structures. Adapting these principles to human-made objects promises to disrupt the way we engineer our high-performance critical structures. However, today's engineering materials remain lifeless, and show only limited abilities to adapt and reinforce under load, or to heal and repair in response to damage. Here we harness the livingness of fungal mycelium to reach emerging properties of complex adaptive systems in an engineering context.

To create the material, we 3D print grid-like structures that provide a mechanically robust architecture combining open airways and a nutrient-rich environment for mycelial growth. The grid is printed using a granulated hydrogel ink that consist of a gelled culture medium inoculated with the fungus. Next, we treat the printed object as a living biological scaffold which can be cultivated in functional liquid cultures. By exposing the living scaffold to functional nano- and micro-particles during their growth phase, we promote the absorption and/or adsorption of functional particles to the material structure. Coupled with 3D printing, this method yields customizable composites with tailored properties such as electrical conductivity or magnetism. These materials represent a step toward biofabrication techniques that harness the agency of living systems to produce smart, adaptive structures.

#1133

# Hybrid CFRP Composites for Cryogenic Environments: Effects of Recycled Carbon Fleece on LOX Impact Compatibility

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This scientific study aims to investigate the feasibility of a novel hybrid composite concept for cryogenic applications, in which a conventional continuous fiber prepreg is combined with a recycled carbon fiber fleece to form a hybrid material. The same resin system is used in both cases. The focus of this study is to understand how the fleece architecture, fiber type, weight per unit area, and layer thickness influence the mechanical behavior, manufacturability, and cryogenic properties.

Particular attention is paid to the role of the fleece as a functional intermediate layer to increase hydrogen impermeability and improve the compatibility properties of the material in a liquid oxygen environment under impact loading.

Among other things, the aim here is to determine how the addition of nanoparticles to the fleece material affects the permeation properties. The aim is to extend the permeation paths by adding fillers, thereby improving the properties with the help of the resulting growing tortuosity paths.

Additional thermoplastic components within the nonwoven fabric are evaluated in terms of their effects on the cryogenic compatibility properties in liquid oxygen and the overall permeability of the composite material. Mechanical tests are performed to quantify stiffness, strength, and impact behavior, while helium transport through the hybrid laminate is evaluated in the specially developed permeation test bench.

LOX compatibility is determined using the special LOX test bench at the University of the German Armed Forces in Munich. The test procedure is based on the ASTM G86-17. The results provide detailed insights into the influence of recycled fiber structures and matrix-compatible additives on the compatibility properties of the material. The study demonstrates the potential of tailor-made carbon fleece interlayers to improve LOX impact resistance and reduce gas permeability, thus offering a promising direction for sustainable, high-performance composites in aerospace applications.

#1135

# Sustainable Hybrid Natural Fiber Composites: Mechanical Performance and Life Cycle Assessment Considerations

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The growing demand for sustainable composite solutions has renewed interest in natural fiber–reinforced thermoplastic laminates. However, understanding how internal morphology and processing conditions affect the structural performance of such materials remains a key challenge. In this study, natural fiber reinforced thermoplastic laminates were fabricated under different processing conditions to investigate their mechanical and environmental performance. Bending behavior was evaluated through three-point flexural testing, while X-ray microtomography (XRM) was employed to characterize internal morphology, including void distribution, fiber packing, and polymer infiltration quality. These morphological indicators were correlated with failure mechanisms to establish structure–property relationships. To assess sustainability implications, a life cycle assessment (LCA) was conducted between the natural/thermoplastic laminates and a hybrid laminate system in which one fiber layer was substituted with synthetic fiber cut-offs originating from industrial waste streams. The LCA quantified global warming potential, energy demand, and material circularity benefits associated with integrating recycled synthetic cut-offs into natural fiber thermoplastic composites. The results demonstrate that internal defects such as void clusters and incomplete fiber wet-out strongly influence the bending response of natural composites, while incorporation of recycled synthetic fiber layers can reduce environmental burden without compromising mechanical performance when optimized processing conditions are employed. This combined mechanical, morphological, and environmental evaluation provides new insights for developing high-performance, low-impact natural fiber thermoplastic composites for structural applications.

#1136

# Influence of Laminate Architecture on the Torsional Behaviour and Stability of Filament-Wound CFRP Driveshafts

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Filament wound carbon fiber reinforced polymer (CFRP) driveshafts are increasingly employed in lightweight and high-performance power transmission systems in aviation, automotive and marine industries, yet their torsional response remains strongly dependent on laminate design and manufacturing quality. This work presents an experimental evaluation of two representative lay-ups with 4 plies each: a [(±45)4] configuration designed for high torsional stiffness and a multi-angle configuration [(±85)2/(±15)/(±45)] designed for high buckling resistance. One driveshaft specimen from each lay-up was subjected to static torsion using a dedicated test bench, with deformation monitored through strain gauges (SGs).

The ±45° specimen exhibited significantly higher torsional stiffness. However, it also displayed limited deformation capacity and an abrupt transition into a characteristic third-order circumferential buckling mode at a lower load than the other design. In contrast, the multi-angle specimen showed a more balanced mechanical response: relatively lower stiffness but improved rotation tolerance, and a delayed onset of buckling. The use of SG enabled detailed identification of the evolving strain field, the localization of instability zones, and the circumferential distribution of the buckling pattern.

The results highlight that laminate architecture imposes inherent trade-offs between stiffness, strength and ductility in CFRP driveshafts. For applications prioritizing high torsional rigidity and minimal angular deflection, the ±45° configuration is advantageous. On the other hand, for higher angular deflection tolerance and higher resistance against buckling, the tested multi-angle lay-up is the better choice.

#1137

# Bridging Material- and Structural-Scale Characterization of Self-Healing Polymer Composites

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Self-healing in Covalent Adaptive Networks (CANs), such as vitrimers, has attracted significant attention due to its potential to repair matrix-related damage in composite materials, including delaminations and matrix cracking. By enabling damage reversal through bond-exchange reactions, vitrimers offer promising pathways to enhance the durability, lifetime, and sustainability of structural polymer composites. However, despite the growing interest, the field still lacks standardized procedures both for quantifying the extent of self-healing and for selecting the most appropriate thermal treatment to maximize recovery. In particular, a pronounced gap persists between structural-scale mechanical tests, which assess healing from an applied performance perspective, and material-scale characterization techniques that probe the intrinsic molecular dynamics governing the healing process.

In this work, we address this gap by evaluating self-healing at both the structural and material scales and demonstrating the coherence between the two. The study focuses on a vitrimer system formulated at CIDETEC from commercially available diglycidyl ether of bisphenol A (DGEBA, part A) and an aromatic disulfide–based dynamic hardener. At the structural scale, Double Cantilever Beam (DCB) specimens were used to introduce a controlled crack, apply a healing thermal cycle, and subsequently quantify the degree of recovery through the regained Mode I fracture toughness. At the material scale, complementary rheological techniques were employed to characterize network dynamics and flow activation.

The combined results reveal a consistent correlation between macroscopic healing efficiency and the underlying molecular mobility, offering a unified framework for guiding thermal treatment selection and advancing standardization efforts in self-healing polymer composites.

Our results show that the healing measured in DCB tests follows directly from the molecular mobility revealed by rheology. This link makes the self-healing mechanism easier to interpret and provides a practical way to select suitable thermal treatments for structural elements using simple material-scale measurements.

#1138

# Capacitive Structural Health Monitoring of Hybrid Metal–Composite Joints

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Hybrid metal–composite joints are increasingly used in lightweight structures for automotive and marine applications, yet their reliability is often compromised by interfacial damage such as delamination or adhesive failure. This study presents hybrid metal–GFRP joints embedding an innovative Structural Health Monitoring (SHM) approach based on capacitive sensing. Unlike resistive techniques, the proposed method does not require conductive fillers, making it cost-effective and easier to implement in standard manufacturing processes.

The sensing principle relies on a capacitor-like configuration embedded in the joint: the metal adherend acts as one electrode, while thin metallic foils co-cured on the composite surface form the second. An array of these foils enables localized monitoring by detecting capacitance variations driven by changes in geometry and dielectric properties during damage propagation.

A distinctive feature of this work is the synergistic interaction between the sensing system and additively manufactured lattice structures at the interface. These 3D architectures, fabricated via Laser Powder Bed Fusion (LPBF) directly onto the aluminum substrate and originally designed to enhance mechanical interlocking and joint strength, act as electric field concentrators: their protruding geometry intensifies the field near the interface, thereby increasing sensitivity to early-stage damage and interfacial separation.

The experimental program includes the dielectric characterization of the short-fiber composites, the fabrication of joints with a specific 3D lattice geometry, and the sensing of failure stages of the joint under mechanical loading via continuous capacitance measurements. Mechanical tests were monitored also by Acoustic Emission for comparison.

This capacitive self-sensing technology demonstrates potential for real-time monitoring of hybrid joints, reducing reliance on periodic inspections and improving structural reliability in high-performance applications.

#1139

# Reliable Binder-Stabilised Preform Manufacturing: Binder Distribution and Processing Conditions

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Binder-stabilised preforms have emerged as a promising approach for manufacturing large structural glass-fibre reinforced polymer (GFRP) components, offering improved handling and dimensional stability prior to resin infusion. However, achieving high-quality preforms requires careful control of the manufacturing process to meet critical objectives: the preform must exhibit sufficient rigidity for manipulation, maintain cohesive interfaces that resist delamination, and avoid introducing defects that compromise the subsequent infusion and curing stages. The inherent heterogeneity of preforms, combined with variability in local binder distribution, adds complexity to process optimisation. These factors influence interfacial bonding and ultimately the structural integrity of the final composite part. Despite their importance, the relationship between processing parameters and the resulting interfaces in binder-stabilised preforms remains insufficiently understood. This study investigates how key manufacturing parameters affect the cohesion of interfaces within binder-stabilised glass-fibre preforms. Experimental trials were conducted to evaluate the influence of the thermal processing conditions on interfacial strength and defect formation. The fibre volume fraction is measured with different processing conditions for the preforming to enlighten the influence on resin infusion flow properties. Cohesion was assessed through mechanical testing and microscopy analysis, providing insight into failures and the role of binder distribution in stabilising the preform architecture. The findings highlight critical parameter ranges that promote robust interfacial bonding while minimising defects, offering guidelines for designing reliable preform manufacturing processes. By establishing these correlations, the study contributes to improving the quality and consistency of large GFRP structures produced via binder-stabilised preforms, supporting their broader adoption in high-performance composite applications.

#1141

# Modeling Moisture-Induced Deformation in CFRP Laminates with Aluminum Layers: Understanding Their Barrier Effect

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Carbon fiber reinforced polymer (CFRP) is widely used for dimensionally stable space telescope structures owing to its high specific stiffness and low coefficient of thermal expansion. However, these polymer-based composite structures absorb moisture on the ground during manufacturing, assembly, and testing in ambient atmosphere, and then desorb it in a vacuum during in-orbit operation. This causes moisture-induced deformation that can degrade optical alignment. Therefore, mitigating moisture-induced deformation and establishing reliable predictive models are critical for next-generation space telescopes. Although various coating technologies have been explored to reduce moisture ingress, the coupled diffusion–strain response in coated composites has rarely been modeled quantitatively.

This study develops a high-fidelity model for moisture-induced deformation in epoxy-based CFRP laminates co-cured with aluminum foil layers that act as physical barriers to moisture transport. Unidirectional CFRP specimens were fabricated (i) without foil and (ii) with foil layers placed at different through-thickness positions. Moisture-induced strains in the fiber and transverse directions were measured using embedded fiber Bragg grating (FBG) sensors, while gravimetric analysis was conducted simultaneously to monitor moisture uptake. During 2000 h of absorption, the aluminum barrier reduced total moisture uptake by more than 80% and significantly decreased moisture-induced strains, demonstrating a strong barrier effect.

The results were interpreted using a previously developed two-phase diffusion model, in which absorbed water is characterized as bound water interacting with the epoxy network and free water accumulating in the polymer free volume, each contributing differently to the strain response. Effective diffusion parameters for aluminum-layered laminates were identified by comparison with bare CFRP, thereby quantifying the barrier effect on moisture transport. For the small amount of water permeating through the aluminum layer, the associated strain response was represented with a piecewise-linear function. The proposed model accurately predicts moisture-induced deformation in CFRP laminates with aluminum barriers for stable spaceborne composite structures.

#1142

# Ultrasonic-assisted in-situ Consolidation of Carbon Fiber Thermoplastic Tapes

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One of the advantages of carbon fiber reinforced thermoplastic (CFRTP) is the ability to produce composite components in a single automated process, including the lamination of the tape and its consolidation. This process, known as in-situ consolidation, eliminates the need for a second step of autoclave or hot-press consolidation, which is mandatory for thermoset composites. As a result, in-situ consolidation reduces processing complexity, time, and manufacturing expenses.

During the in-situ consolidation process, CFRTP tapes are automatically placed and rapidly heated above the melting temperature of the thermoplastic matrix. Fast and high-temperature heating techniques such as nitrogen gas torches, high-power lasers, and flash heating lamps are needed to molten and fuse the CFRTP tapes. Despite the numerous advantages of this technology, certain limitations arise due to the physics of the process: low production rates, high-temperature degradation of the tape, porosity, and a reduction in mechanical properties compared to those obtained through autoclave/hot-press consolidation processes, among others (I. Martin, 2020, M.J. Donough, 2022)

To mitigate or overcome these challenges, alternative heating strategies, such as those employed in ultrasonic-assisted in-situ consolidation (U-ISC), are a promising option to reach the consolidation of the material in a single step. (Rizzolo, 2016, Chu, 2018, Dell'Anna, 2018).

In this work, we used our in-house U-ISC system to manufacture CFRTP samples. By analyzing the power and temperature of the process, we have studied how the porosity and crystallinity of the welded sample affect the mechanical performance of the joint and the microstructure of the consolidated sample. The results showed that a welding speed of 1 mm/s resulted in the highest shear strength. Additionally, samples with less than 4% porosity were achieved, indicating that this process can produce high-quality composites in terms of their porosity and mechanical properties.

#1146

# A parametric geometry framework to introduce variability in toroidal propeller designs

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Air transportation is a long-standing key sector affecting societal, financial and environmental aspects. Therefore, it is constantly in the spotlight fostering animated efforts on developing the next generation of air transport vehicles with cleaner, more efficient propulsion platforms. Consistent to this end, “TorPropel” project aims to advance propulsion technology of regional air transports by upscaling toroidal propellers and using advanced composite materials and manufacturing processes.

Toroidal propellers as a close-loop blade concept, offer aerodynamic benefits and reduced acoustic emissions, due to the impact of geometry in the wake formation and the suppression of tip vortices. However, the geometrical modelling of such concepts is significantly more complex than the traditional open-ended propellers. On top of that, more sophisticated design pipelines such design-space exploration and optimization, have become necessary steps in the overall design process. Hence, indicating that robust, parametric geometry frameworks are the basis of any development effort.

The current work focuses on exactly this, the development of a parametric framework for the systematic production of variable toroidal design propellers. The framework is based on the parametrization of the stacking line and chord distribution using Bezier curves, while defining a specific number of airfoil sections across the span of the blade. To transform this discrete number of sections to a continuous, lofted surface interpolation through radial basis functions is used. On top of the pure geometric features, the framework employs a coupling algorithm to define physics-constrained twist distribution of the toroidal propeller designs. The combination of all the above result in a robust and versatile framework that incorporate over forty geometric and operational variables. Finally, within the context of this work the formulation of full design case is examined including the possible constraints imposed by materials, manufacturing, installation and operating limitations.

#1147

# Qualification by Similarity for Composite Pressure Vessels

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The qualification of Composite Pressure Vessels (CPVs) for applications in different sectors such as automotive and aerospace is a time- and cost-efficient process that relies on analytical and numeri-cal approaches as well as extensive experimental campaigns. Due to the continuous improvements in numerical methods predicting the mechanics of composites as well as increased computational efficiency, certification by analysis is gaining attention in various applications.

This study investigates a qualification approach for CPVs based on the Qualification by Similarity (QbS) methodology as described in selected aerospace standards. This method enables the trans-fer of qualification results from a qualified baseline design to derivative vessel configurations that exhibit variations in geometry or material systems. For this approach, a baseline CPV design is de-fined within this study. A numerical analysis framework for this CPV design is established using fi-nite element analysis, including a discussion of the desired failure mode for the qualification by similarity approach. Key parameters such as the CPV geometry and material properties are varied relative to the baseline design, and their impact on the mechanical response is evaluated. The anal-ysis results are critically discussed with respect to the loading conditions of the CPV as well as manu-facturing-induced effects. The findings provide recommendations on defining acceptable variations for CPV designs, thereby supporting broader applicability of QbS in future certification programs.

The results demonstrate that Qualification by Similarity can reduce the need for extensive physical testing when supported by consistent numerical evidence and rigorous manufacturing parameter-tracking. In this way, efficient certification of CPVs can be enabled.

#1149

# Composite laminate modification with elastomeric nanofibers for improved toughness: impact tests on an automotive component

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Carbon Fiber Reinforced Polymers (CFRPs) are the preferred materials for achieving lightness while keeping high mechanical performance. Often, such composites are in the form of laminates, which, unfortunately, display relatively low mechanical properties perpendicular to the laminate plane, making them susceptible to delamination. As a consequence, the service life of the component can be shortened, leading to premature failures and disposal, besides potential safety concerns.

The laminar structure, though being the cause of the issue, can be exploited to carry out localized toughening through the integration of nanofibrous membranes during the lamination step. In particular, elastomeric nanofibers have proven to be highly effective in improving toughness, thus limiting delamination. For this reason, such a modification can also improve the laminate's impact resistance.

In the present work, epoxy CFRP laminates were nanomodified with nitrile butadiene rubber (NBR)-based elastomeric nanofibrous membranes to evaluate the laminate behaviour when subjected to impacts. Low-velocity impact (LVI) tests were carried out on both laminate plates and a component by means of an instrumented drop-weight. In particular, the selected component is a car rear-view mirror cap with interleaved nanofibers between all plies interfaces, plus a modification on the outer surface. The application of the rubbery nanofibrous veil to the carbon fiber prepreg does not significantly alter the original handleability of the prepreg nor its drapability, allowing these nanomodifiers to be used directly during the lamination step without any special precautions. The impacts were carried out at different energy levels compatible with the impact energies associated with hail. The extent of damage was evaluated by observing the impacted areas, both on the material surface and through the laminate section.

#1150

# Effect of Humidity on the Fibre-Matrix Interface During Cryogenic Cycling

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The potential transition to liquid hydrogen ($LH_2$) as a sustainable energy vector necessitates the development of composite materials capable of withstanding extreme cryogenic environments over extended service lives. Pressurised $LH_2$ storage vessels will experience repeated cycling between ambient and cryogenic temperatures, combined with potential variability in humidity. These factors can significantly influence the long-term structural integrity of composite structures. The fibre-matrix interface is critical to the mechanical performance of fibre-reinforced polymers, governing load transfer, energy dissipation and resistance to microstructural degradation. However, the influence of humidity in conjunction with cryogenic cycling remains poorly understood.

This study investigates the effects of controlled relative humidity exposure prior to cryogenic cycling on the interfacial shear strength of carbon and glass fibre composites, building upon previous work on cryogenic cycling alone [1]. The microbond technique [2] was employed to quantify changes in interfacial performance, while surface analysis was utilised to assess the degradation arising from the combined effects of cryogenic cycling and moisture-induced damage. This research identifies mechanisms of interface weakening and evaluates their implications for long-term composite reliability. These findings provide fundamental insight into environmental interactions at the fibre-matrix interface and support the design of composite materials optimised for cryogenic fuel storage in which both moisture and cryogenic temperatures may be encountered.

1. L.W. Kelly, et al. Investigation of the fibre-matrix interface of glass fibre composites exposed to cryogenic temperatures and cryogenic cycling. In SAMPE Europe 25 Conference: The Future of Advanced & Sustainable Composites, 2025.

2. B. Miller, P. Muri, and L. Rebenfeld. A microbond method for determination of the shear strength of a fiber/resin interface. Composites Science and Technology, 28(1):17–32, 1987.

#1151

# Ultrasonic Welding of Wood Using 3D-Printed Lignin Energy Directors for Wet-Durable and Functional Joints

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The development of sustainable joining technologies is essential for bio-based structural composites. Conventional wood adhesives can deliver good strength, but rely on petrochemical formulations. Ultrasonic wood welding offers a fast, adhesive-free alternative, yet current processes produce joints with limited strength and moisture durability. In this work, we exploit lignin, the natural binder in wood, as a 3D-printed energy director to concentrate ultrasonic energy and promote controlled lignin fusion at wood–wood interfaces. Wood veneers are welded, while a lignin-based ink is deposited on the overlap by direct ink writing. Process parameters and ink formulation are systematically optimised. We demonstrate that the lignin content has a significant influence on joint formation. Combining ultrasonic welding with a short hot-pressing step yields lap-shear strengths of up to 3.48 ± 0.54 MPa and a wet strength of 1.13 ± 0.18 MPa after 24 hours of water immersion, comparable to commercial water-based and epoxy adhesives under the same conditions. FTIR, thermal analysis and microscopy reveal enhanced lignin diffusion and cross-linking at the interface, accompanied by reduced thermal degradation. We functionalise the ink into a conductive interlayer, enabling in situ strain sensing during mechanical loading. Finally, we demonstrate robotic continuous ultrasonic welding and a lightweight welded honeycomb structure, highlighting the scalability of the approach for complex geometries. The results position lignin-based energy directors as a fully bio-derived route to fast, robust and multifunctional joints in wood and other lignocellulosic composite structures.

#1152

# Industrial-Scale Development of Nano-Reinforced Composites and Adhesives for Space Applications

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Lightweight materials such as carbon-fiber reinforced polymers (CFRPs) and structural adhesives are widely used in spacecraft due to their high specific strength and design flexibility. However, because these materials are polymer-based, they inherently exhibit poor thermal and electrical conductivity, which can restrict their use in emerging space applications that demand efficient heat management and multifunctional performance. To address these limitations, Adamant Composites has developed a new class of “nano-enabled” materials by incorporating and uniformly dispersing nanoparticles into established epoxy systems. Two key developments include a nano-enabled CFRP laminate with enhanced through- and in-plane thermal transport, and a graphene-enhanced potting adhesive designed to offer both improved thermal conductivity and electrical conductivity. This work describes the industrial-scale manufacturing routes for these materials and their evaluation for space applications. At the material level, the graphene-enabled adhesive demonstrated a significant increase in thermal conductivity while also becoming electrically conductive. The nano-enabled CFRP exhibited measurable improvements in in-plane thermal conductivity with minimal impact on mechanical performance. Furthermore, production stability studies confirmed that both nano-enabled systems can be manufactured repeatably and consistently. Overall, the results show that nano-enabled composites and adhesives can provide meaningful thermal-management benefits at the spacecraft structural level, while maintaining compatibility with the mechanical and environmental conditions of launch and space operation. These developments open new opportunities for integrating advanced materials into next-generation spacecraft, supporting applications such as improved solar array structures, thermally stable optical benches, and enhanced heat dissipation for space electronics.

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#1153

# Water-Barrier Performance of MXene-Coated Fibre-Reinforced Polymer Composites

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The long-term durability of fibre-reinforced polymer composites (FRPC) is strongly influenced by moisture uptake, which can accelerate degradation processes and compromise structural performance. Improving the barrier properties of surface coatings, therefore, remains an important strategy for extending service life, particularly in moist environments. Due to the two-dimensional nature of MXene particles, these materials create a tortuous pathway that significantly restricts the transmission of water molecules.

The aim of the study was to evaluate the water-barrier performance of MXene-coated FRPC. In this work, MXene particles were deposited onto the surface of FRPC plates using an automated spraying system with precisely controlled nanoparticle quantity. Three surface configurations were examined: a neat epoxy coating, a coating containing a defined MXene deposition level, and a coating with a doubled amount of MXene.

Water permeability was assessed using the standard cup method at two relative humidity levels, 75% and 97%, enabling a robust comparison of moisture transport under varying environmental conditions. Additionally, several moisture uptake–drying cycles were performed to observe the stability of the barrier performance over repeated exposure.

#1154

# Quantum-Assisted Stacking Sequence Retrieval and Laminated Composite Design

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As the aerospace industry pursues greater fuel efficiency and carbon neutrality, reducing the weight of load-bearing structures remains crucial for sustainable design. Laminated composites, with their adjustable fiber orientations, offer high specific stiffness and strength while enabling tailored anisotropic responses to complex load cases. A common design strategy, bi-level optimization, first approximates mechanical requirements through lamination parameters and then retrieves a feasible stacking sequence that matches the lamination parameters and satisfies manufacturing constraints. However, identifying an optimal stacking sequence remains computationally intensive, as the exponential configuration space created by discrete ply angles, combined with the constraints, turns the task into a computationally difficult combinatorial optimization problem.

Recent advances in the field of quantum computation have generated interest in applying quantum and quantum-inspired algorithms to combinatorial problems. Building on our previous work, which introduced quantum algorithms for stacking sequence retrieval [1], we present key advances that bring the approach closer to practical applications in laminate design.

We replace the standard variational quantum algorithms used in [1] with the more advanced Filtering Variational Quantum Eigensolver (F-VQE), employing small-scale, fully entangled state-vector simulations for lamination-parameter matching under a full set of manufacturing constraints. Furthermore, we extend our quantum-inspired Density Matrix Renormalization Group (DMRG) approach to the same constraint set and perform lamination-parameter matching for laminates with up to 200 plies per half, directly comparing its performance against the conventional stacking-sequence retrieval algorithm Opti-BLESS. Across F-VQE and DMRG, we further demonstrate additional objectives, including maximizing buckling resistance and explicitly steering the clustering and dispersion of same-angle plies. Finally, we showcase lamination-parameter matching for a linearly arranged multi-panel structure with generalized blending using F-VQE, illustrating how quantum techniques can be extended toward realistic multi-panel laminate design.

[1] Wulff et al. (2024), DOI: 10.1016/j.cma.2024.117380

#1155

# Implications of Dissimilar Resin Systems and Fibre Architectures on Mechanical Performance of Hybrid Composites

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To further improve design of carbon fibre composite components, hybrid fibre architecture using a combination of continuous-discontinuous material is of particular interest. Flowability of sheet moulding compound (SMC) allows for creation of complex geometries and strengthening features while inclusion of continuous reinforcement with SMC provides superior mechanical properties in a single moulding process. A typical resin system of CF-SMC for use in automotive applications is vinyl ester due to its rapid cure time and enhanced processability. Currently, commercial continuous prepregs are not available in vinyl ester meaning a hybrid architecture must implement dissimilar resin systems in components, most often epoxy – vinyl ester. The incompatibility of these systems may result in a lack of chemical bonding at the interface, causing a weaker interface without intimate crosslinking between the systems.

This study is investigating the influence of dissimilar resin composites (DSR composites) on mechanical behaviour, interfacial properties and consider this as an avenue for optimisation of hybrid architecture performance. The initial benchmark study uses a combination of epoxy and vinyl ester to compare the influence of dissimilar resin systems on mechanical properties such as flexural strength, interlaminar shear strength, fracture toughness and impact strength relative to the monolithic systems. A squeeze flow rig apparatus is used to investigate the influence of flow moulding on promoted inter-diffuse of dissimilar systems as well as its effect on hybrid fibre architectures. Dying of the separate matrices prior to moulding with fluorescent markers or pigmentation is used to allow analysis of the interface and any interdiffusion with microscopy. Preliminary tensile results from the benchmark study show that dissimilar resin systems exhibit comparable moduli to neat vinyl ester and 17% lower than epoxy. Tensile strength is 16% lower than vinyl ester and 25% lower than neat epoxy.

#1156

# Spray Printing of Carbon Nanomaterial-Based Strain Sensors onto Composite Structures: A Facile Method for Customizable Smart Structures

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The demand for real-time structural health monitoring (SHM) is paramount in modern aerospace systems, where fiber-reinforced polymer composites are extensively used due to their high strength-to-weight ratio. Conventional SHM solutions often introduce excessive weight and complexity, compromising the very mass benefits offered by composites. To address this, integrating intrinsic sensing capabilities directly into the structure presents a lightweight and efficient alternative, crucial for enhancing fuel efficiency and reducing maintenance costs. In this study, we developed sensitive, cost-effective, and lightweight strain sensors utilizing various carbon nanomaterials. Precisely formulated sensors utilizing carbon nanotubes (CNT), carbon black (CB), and hybrid CNT/CB materials were fabricated via a spray-printing technique, easily adaptable to industrial applications. Spray-printed sensors were directly integrated onto glass fiber-reinforced polymer (GFRP) composites for in-situ measurements through a controlled thickness. This method minimizes waste and provides excellent conformality over the composite surface. The integrated sensors were subjected to systematic mechanical loading tests to evaluate their electromechanical performance, focusing on reliability over repeated usage, sensitivity (gauge factor, GF), and linearity. Notably, the CB-based sensors demonstrated exceptional performance, achieving a high GF of up to 40, significantly outperforming both hybrid (4.5 ± 0.2) and CNT-only (3.5 ± 0.3) formulations. Furthermore, CNT-based networks exhibit highly deterministic drift behavior with outstanding linearity ($R^2 \geq 0.92$), enabling signal correction via simple linear algorithms. The hybrid CNT/CB sensors were also assessed to understand the synergistic effects on sensitivity and durability. Experimental results confirm the feasibility of using these simple, printable carbon nanomaterial inks for precise strain detection within GFRP structures. These findings significantly contribute to the rapid development of lightweight, customizable, and cost-effective SHM solutions, enabling data-driven, condition-based maintenance protocols. This advancement ultimately paves the way for enhanced durability, reliability, and safety of next-generation composite structures in critical aerospace applications.

#1157

# Temperature model for the direct resistance heating of carbon fiber tapes during fiber placement processes or filament winding

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The Continuous Resistance Heating Technology (CoRe HeaT) is an alternative heating method for carbon fiber placement processes like the Automated Fiber Placement (AFP) or filament winding. Basic principle of the technology is using the Joule effect to heat up the carbon fibers directly via their own electrical resistance. Compared to established technologies like laser or other radiation-based methods, the resistance heating technology enables higher heating rates and offers lower response times. Highly intensive volumetric heating with up to 100.000 K/s and more, allows for processing speeds that go far beyond the capabilities of modern manufacturing machines. To predict and control the temperature at such high deposition speeds and to understand all relevant parameters influencing the heating process, the development of a detailed model is crucial.

The scope of the paper is a model that incorporates the electrical and thermal properties of the carbon fiber materials that are used for these processes. The model can be used to estimate maximum process temperatures and analyze the impact of all relevant parameters in detail. For the model validation, both the electrical and thermal properties of the carbon fiber materials have to be determined. Using direct electrical resistance heating and different simple test setups help to easily determine most of the relevant material properties. A test bench for dynamic heating tests is used for a validation of the model. Following that, a model-based analysis of the individual parameters and a discussion of the results show the importance of the different parameters at varying speeds.

#1158

# Polyester-cotton hybrid mycelium composites for semistructural applications

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Textile waste which is mostly made of non-biodegradable synthetic fibres, poses significant environmental challenges including landfill accumulation and microplastic pollution. Current recycling methods are limited by high energy consumption, the complexity of mixed fibre blends and the reduced material quality of recycled materials. Fungi present a promising alternative to traditional, as they are capable of colonizing various materials, including textile waste. The fungal mycelium acts as a natural binder, connecting textile layers or mixed bio-waste into a composite material. The mycelium consumes cellulose-based fibres like cotton and is tolerant of synthetic fibres or other contaminants such as metal zippers and similar, which are incorporated into as inert filler, therefore rendering pre-sorting of polyester-cotton blends unnecessary. This study investigates the potential of fungal mycelium to create composite materials from five textile types (100% cotton, 100% polyester, 65% cotton/35% polyester, 80% polyester/20% cotton and a polyester-cotton interleave). Three fungal species (Pleurotus ostereatus, Ganoderma lucidum, Trametes versicolor) were compared to determine which species is the most suitable for growing mycelium on four-sheet textile piles for composite materials. The mycelium digests natural fibers like cotton while the synthetic fibres remain intact, retaining their woven structure, which provides better mechanical properties in tension. Other aspect of the study indicates that different fungal species show varying effectiveness in bonding textile fibers, with one species proving particularly efficient for larger-scale applications. This research aims to demonstrate the potential of mycelium-based composites as an innovative approach to textile waste recycling, offering economic and environmental benefits by reducing landfill waste and contributing to the circular economy.

#1159

# Evolution of microstructural damage of aligned discontinuous carbon fibre-reinforced composites under in situ Synchrotron Computed Tomography

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Aligned discontinuous carbon fibre-reinforced composites represent a new frontier in the composite world. Their discontinuous nature provides manufacturing flexibility and lower cost, while fibre alignment enables high mechanical performance. Most importantly, these materials offer significant sustainability benefits: they can be produced directly from waste generated in continuous-fibre manufacturing. However, the mechanical performance of these recycled fibre composites remains difficult to predict, largely because the failure mechanisms governing damage progression have not been observed in detail and are, not yet, fully understood. Limited knowledge exists regarding how fibre ends and misaligned fibres, characteristic of this material, influence the behaviour.

To address this gap, this study investigates the tensile behaviour of aligned discontinuous carbon fibre-reinforced composites using in-situ synchrotron holotomography. This high-resolution 3D nanoimaging technique captures microscale damage evolution within a nanoscale field of view. The synchrotron experiment employed an automated tensile-testing rig that enabled remote control of the load steps between scans. This setup reduced overall testing time and improved the precision of load application. These experiments enable the observation of microscale damage events happening under tensile load.

The in-situ synchrotron experiments revealed, for the first time, high-resolution observations of (1) fibre breaks in reused aligned discontinuous fibres, (2) longitudinal debonds of neighbouring fibres at or near fibre ends, and (3) fibre breaks due to nearby fibre ends. The longitudinal debonds, not previously documented in the context of aligned discontinuous fibres, indicate a complex interaction between fibre discontinuity and damage development. To better understand the local damage, digital volume correlation was used to generate full 3D strain maps, providing detailed information on local deformations.

Overall, the results advance the understanding of damage initiation and propagation in aligned discontinuous fibre composites. These findings provide critical insights for optimising manufacturing parameters in remanufacturing processes and for improving predictive models of the structural performance.

#1160

# Flexural and interlaminar shear performance of glass fibre-reinforced benzoxazine vitrimer composite for aircraft cabin interior application

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Vitrimer composites offer an attractive pathway towards lightweight, repairable, and recyclable composite structures for both aeronautic and astronautic applications, due to the combination of high mechanical and environmental performance of thermosets and the recyclability of thermoplastics in a single polymer network. High-temperature epoxy vitrimer composites often require impractically high consolidation pressures for effective damage repair. Polybenzoxazine vitrimers present a promising alternative, due to their ability to self-repair under significantly lower pressures and their characteristically low water absorption, which helps maintain the wet glass transition temperature (Tg) close to the dry Tg. A major limitation of polybenzoxazines – their inherent brittleness – has hindered their adoption as matrices for high-performance composite structures. In this regard, the development of tougher or toughened benzoxazine matrix systems has been a subject of considerable research efforts. This study investigates from a mechanical standpoint a woven glass fibre-reinforced benzoxazine vitrimer composite for aircraft cabin interior application. The composite was manufactured using a vacuum-assisted wet lay-up process. Tensile, flexural, and interlaminar shear strength (ILSS) tests conducted in accordance with ISO 527-4, ISO 178, and ISO 14130 standards, respectively, demonstrate that the mechanical properties of the developed vitrimer composite meet or exceed aerospace industry thresholds. The tensile strength at room temperature surpasses the required 350 MPa, the flexural strength is approximately 3% above the minimum industry requirement, and the ILSS is 175% higher than the typical aerospace threshold. These results represent a significant step forward in the development of composites structures based on unblended benzoxazine matrix systems and establish the proposed polybenzoxazine vitrimer composite as an attractive candidate for use as skin material for aircraft cabin interior sandwich panels.

#1161

# Mechanical performance of thermoplastic composites reinforced with thermally recycled glass fibres

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End-of-life glass fibre reinforced polymers are increasing environmental pressure due to the difficulty of their disposal. As response, several recycling routes have been proposed to recover fibre content. At the University of Strathclyde, the Advanced Composite Group has developed a pilot-scale recycling process for recovering fibres from end-of-life composites. However, the recycled fibres exhibit a fluffy and low-bulk density condition that differs significantly from their virgin counterparts, creating challenges for handling and compounding.

Injection-moulded polypropylene reinforced with chopped glass fibres is widely used across multiple sectors and represents a significant opportunity for recycled glass fibres. Thus, developing a cost-effective and scalable method to re-process recycled fibres into injection moulded composites with good performance is a key to open up opportunities for injection moulding applications.

In this work, an in-house methodology was developed to compound recycled glass fibres into pelletised forms suitable for injection moulding. This route effectively overcomes the feeding limitations reported when introducing recycled fibres into conventional extrusion processes. Polypropylene matrices with 0–10 wt.% maleic-anhydride grafting were compounded with fibre contents ranging from 15 to 60 wt.%, allowing a systematic evaluation of both matrix modification and reinforcement content. Tensile and flexural specimens were produced and tested.

The results showed there is an optimal level of matrix modification at which the mechanical performance (e.g. strength and stiffness) can increase steadily as the fibre content is increased from 15 to 60 wt% Interface characterisation using microbond tests corroborated these findings, demonstrating that matrix grafting significantly enhanced interfacial shear strength. SEM analysis further supported this result, revealing polymer remnants adhered to the fibre surfaces after failure in grafted systems, in contrast with the clean fibre pull-out found in non-grafted matrices.

The methodology presented provides a new lab-scale route for producing polypropylene compounds reinforced with recycled glass fibres with tailorable properties.

#1162

# Development, characterisation and modelling of novel benzoxazine based Vitrimeric polymers for use in composite materials.

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Vitrimers are a re-processable, re-healable and recyclable crosslinked resin, and are of great importance for industries hoping to replace conventional epoxy resins with a more sustainable alternative. These materials are polymer networks, in part consisting of dynamic covalent bonds which are able to participate in associative bond exchange reactions. This associative exchange, where bond density is maintained, allows for topological rearrangement and macro flowability without compromising material properties crucial in aerospace components, like high strength and stiffness. Commercially available vitrimer formulations (predominantly epoxy-based) show good mechanical properties, but poor reprocessability in relation to their reprocessing temperatures, pressure and melt viscosity. A clear gap exists for the development of more easily reprocessed resins that can satisfy both the performance and reprocessability requirements.

Six formulations, based on Benzoxazine chemistry, were prepared using a one-pot, catalyst free, dry synthesis methodology. The synthesis setup was optimised for in-situ by-product removal via reduced pressure fluid separation. Initial confirmation of hypothesised chemical structures was conducted using spectroscopic analysis techniques and materials were characterised for their thermal transitions, cure behaviours, viscosity and viscoelasticity, thermal degradation and solvent resistance. In addition, an investigation into the healing and reprocessability capabilities of the materials was carried out, measured using stress relaxation and scratch/ healing tests. Characterisation of the materials has allowed for the creation of kinetics and healing constitutive models where materials were confirmed to exhibit vitrimeric properties.

One of the materials developed was highlighted as having the highest healing performance, with another showing moderate healing capability but remaining very promising due to a high Tg and manufacturability.

#1163

# Integration of Ceramic UV Laser Vat Photopolymerization (VPP-UVL) and Spark Plasma Sintering (SPS) for the Manufacturing of High-Performance $Cu/Al_2O_3$ Composites

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Ceramic UV Laser Vat Photopolymerization (VPP-UVL/C) has been established as an effective Additive Manufacturing (AM) process for producing complex cellular lattice structures utilizing advanced ceramics, like alumina ($Al_2O_3$). This research introduces a novel, two-stage methodology employing these ceramic lattices as foundational scaffolds for the manufacture of high-performance copper-alumina ($Cu/Al_2O_3$) metal-ceramic composites.

The $Cu/ Al_2O_3$ composites are successfully manufactured through an infiltration-consolidation route. Initially, the 3D-printed $Al_2O_3$ ceramic structures are filled with copper (Cu) powder subsequently consolidated by Spark Plasma Sintering (SPS). The selection of SPS is critical, as its rapid heating and short dwelling times minimize potential interphase reactions and retain fine microstructures, effectively obtaining an Interpenetrating Phase Composite (IPC).

A key focus of this study is to determine the dependency of the final composite's physical and mechanical properties on the initial geometric configuration of the ceramic structure. To systematically investigate this influence, two different lattice configurations were manufactured and analysed: (i) 2D lattice structures (monoliths), which offer directionality, and (ii) 3D lattice structures (strut-based geometries), which provide isotropic mechanical response. The analysis included three cell sizes for each geometric configuration in order to comprehensively map the relationship between structure and properties across different relative densities.

The results highlight that the combined VPP-UVL/C and SPS route is a highly promising and versatile strategy for creating $Cu/Al_2O_3$ IPCs. Furthermore, the ability to adapt the ceramic structure through AM directly enables a robust approach for microstructural engineering, demonstrating that the final composite properties are highly sensitive and adjustable depending on the chosen geometric configuration and cell dimension of the starting lattice structure. This method provides new paths for the design and production of metal-ceramic composites with customised performance characteristics.

#1165

# Failure criteria and damage models for virtual testing and qualification/certification by analysis

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This work presents a study of available failure criteria and constitutive models for ply and laminate level “hot-spot” identification, for intralaminar damage propagation and for interlaminar damage propagation. Damage onset and progression in fibre-reinforced polymers (FRPs) depend on many factors: properties of the constituent materials; fibre orientation; stacking sequence; ply thickness; nature of loading; etc. This study exploits the applicability domain of 2D and 3D progressive damage meso-models and interlaminar damage models based on different cohesive zone model formulations, accounting or not for interlaminar friction. In meso-mechanical models, the laminate layers are taken as the basic homogeneous building blocks and composite intralaminar damage is characterised by different failure modes. Each layer is represented by the orthotropic material properties that can be determined experimentally from characterisation tests at the lamina level, or from micro-mechanical models using the properties of the constituents. For the complete definition of constitutive damage models it is necessary to define appropriate damage activation functions, i.e., the conditions that lead to the onset of inelastic response. It is shown that 3D failure criteria are key to accurately predict damage onset at the mesoscale, and to enhance available composite damage models based on continuum damage mechanics and smeared crack formulations. Simultaneously, these failure criteria can be employed to predict first-ply failure (FPF) in large-scale models. Moreover, to meet the industrial need for fast and practical tools, omni strain failure envelopes for the prediction of last-ply failure (LPF) can be generated from these failure criteria. Failure criteria and constitutive models are here validated on low-velocity impact, compression after edge impact, mechanically-fastened and stringer run-out test cases.

#1166

# Performance Assessment of Piezoelectric Sensors and Encapsulation Techniques in Composite Structures at Cryogenic Temperatures

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Moving toward a damage tolerant design philosophy, it is necessary to incorporate a Structural Health Monitoring (SHM) system to determine when the structure no longer performs in a satisfactory manner, especially in Carbon Fiber Reinforced Polymer (CFRP) structures working in harsh environments, where damage mechanisms can be complex. A common technique to enhance sensing/actuation performance and protect the network from harmful direct environmental exposure is the embedding of sensors into the textile layup of the fiber reinforced composite. An embedded SHM system, tailored to cold environment applications, must be capable of robust data acquisition in low or even cryogenic temperature ranges.

Thus, this study aims to explore the performance of different PZT sensor types for vibration-based SHM systems operating at low and cryogenic temperatures. The temperature dependence of the independent piezoelectric material properties of 2-2 macro fiber composite, 1-3 composite and plate piezoelectric unbonded sensors is experimentally characterized through Electromechanical Impedance (EMI) measurements and resonance methods from room temperature down to 80 K. Three common electrical insulating embedding techniques (i) Kapton film, (ii) glass fiber, and (iii) smart layers are integrated within a cross-ply layup to determine the most suitable method to embed sensors in CFRPs for cryogenic applications. Electromechanical numerical models are developed alongside the experimental work to better understand the effects of temperature and encapsulation of the sensors. Embedded and free sensors are subjected to short but intense thermal cycling to assess the long-term reliability of the sensors and embedding techniques. Through this study, the impact of encapsulation on sensor sensitivity is quantified in the cryogenic temperature range.

#1167

# Elastic-plastic response of a pressurized closed-cell foam under uniaxial loading

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Closed-cell foams are widely used in lightweight structural and energy-absorbing applications. However, the role of internal gas or fluid pressure on their in-plane elastic–plastic response remains insufficiently understood. This work investigates the uniaxial tensile and compressive behavior of an idealized pressurized closed-cell foam, focusing on the combined effects of unit-cell geometry and internal pressure. The foam is represented by a two-dimensional hexagonal lattice and reduced, through symmetry, to a hexagonal quarter-cell model. An elastic–perfectly plastic material law is used for the cell walls, and large deformations are captured through geometrically nonlinear finite-element simulations. Four inclination angles of the hexagonal walls (−20°, 20°, 30°, and 40°) are examined together with seven internal conditions, ranging from an empty cell to compressible gas at pressures from 0.5 to 500 atm and an incompressible fluid. The macroscopic response is evaluated through normalized stress–strain curves and effective stiffness and yield strength metrics.

The results reveal a pronounced coupling between geometry and internal pressure. Except for the regular hexagon (30°), increasing internal pressure markedly stiffens the structure, elevating both the effective Young's modulus and yield strength, and shifting the onset of the final stress-increase region to lower strains. High internal pressure or incompressible filling suppresses classical hinge-based deformation and redistributes von Mises stress from the vertices to the mid-spans of the inclined walls, producing bending-dominated modes not observed in the empty-cell case. Instability regions appear or disappear depending on the combination of geometry, pressure level, and loading mode, with re-entrant and highly skewed cells exhibiting the strongest sensitivity. Tensile and compressive elastic responses remain largely symmetric.

Overall, the findings highlight the importance of jointly selecting cell geometry and internal pressure to tailor stiffness, plateau behavior, and stability in closed-cell foams, with implications for lightweight structural design and energy-absorbing systems.

#1168

# Machine Learning-Accelerated Predictions of Design Allowable of Composite Laminates

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The generation of design allowables for composite laminates is of utmost importance for the design and certification of the composite structures used in the aerospace industry. The determination of these design allowables, usually relies on expensive and time-consuming experimental test campaigns. With the increase of computational power, and the development of high-fidelity numerical models that accurately represent the response of composite materials, alternatives to generate design allowables based on finite element simulations have also been sought out to reduce the certification costs. However, these solutions are still computationally expensive. The recent advances on machine learning techniques opens a new window of possibilities for the faster prediction of the structural response of materials, by allowing the definition of surrogate models that continuously and analytically describe the design space [1].

In this work, a database of open-hole high-fidelity simulations [2,3] is generated using a HPC framework and used to train machine learning algorithms, resulting in surrogate models that are able to predict the notched strength of several materials, layups and notched geometries.

The trained machine learning algorithms are shown to be able to predict the strength of open-hole multidirectional composite coupons with the precision provided by high-fidelity simulation in milliseconds, corresponding to a time-to-prediction speed-up of over 10k times.

[1] Furtado, C. et al (2021). A methodology to generate design allowables of composite laminates using machine learning. International Journal of Solids and Structures

[2] Furtado, C et al. (2019). Simulation of failure in laminated polymer composites: Building-block validation. Composite Structures, 226, 111168.

[2] Maimí, P., et al. (2007). A continuum damage model for composite laminates: Part I–Constitutive model. Mechanics of materials, 39(10), 897-908.

#1171

# Effect of resin infusion on fibre orientation level of aligned discontinuous fibre composites

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Aligned discontinuous fibre reinforced composites offer an attractive balance between manufacturability and mechanical performance, provided that fibre orientation is maintained throughout processing [1, 2]. These composites differ from conventional short-fibre-reinforced materials produced by extrusion, injection, or compression moulding, as they are manufactured from dry preforms of aligned discontinuous fibres followed by resin impregnation. As aligned discontinuous fibre preform technologies are relatively recent, suitable resin infusion methods must be established. Vacuum-Assisted Resin Transfer Moulding (VARTM) is a potential manufacturing route; however, fibre misalignment during infusion has been studied in continuous fibre composites [3], its extent in aligned discontinuous fibre composites remains largely unexplored.

This study investigates the effect of resin infusion on fibre alignment in aligned discontinuous fibre composites. A casting epoxy system and a PMMA-based infusible thermoplastic resin were employed to evaluate the influence of resin type. Fibre orientation before and after infusion was analysed using high-resolution imaging. By infusing two different resin systems into aligned discontinuous fibre preforms of varying thickness, this study aims to clarify the effects of resin type and laminate thickness on fibre alignment and to provide insight into the mechanisms governing microstructural changes during resin infusion.

References:

1. Nguyen, N.Q., et al., Micro-CT measurement of fibre misalignment: Application to carbon/epoxy laminates manufactured in autoclave and by vacuum assisted resin transfer moulding. Composites Part A: Applied Science and Manufacturing, 2018. 104: p. 14-23.

2. Yu, H., K.D. Potter, and M.R. Wisnom. Aligned short fibre composites with high performance. in 19th International Conference on Composite Materials (ICCM19). 2013.

3. Yoshimura, A., et al., X-ray computed tomography used to measure fiber orientation in CFRP laminates. Advanced Composite Materials, 2016. 25(1): p. 19-30.

#1172

# Displacement-Controlled Ultrasonic Welding of Carbon Fiber Reinforced LM PAEK Laminates - Increased Process Reliability and Repeatable Joint Properties

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The growing demand for thermoplastic matrix systems in future aerospace structural components is leading to an increasing relevance of welding. Electrical resistance welding, induction welding and ultrasonic welding are the primary options.

In polymer welding processes, the resin is melted in the joining zone and partially squeezed by the applied pressure. This material flow from the joining zone is called squeeze out. This creates a weld seam with an associated heat-affected zone and a weld bead at the contact zone. The squeeze out promotes the joint properties by stretching and relaxing the long-chain polymer molecules.

The weld path describes the distance the individual components travel relative to each other during the thermal energy input. The joining path considers the entire path after the process, including the cooling path, and is crucial for the resulting geometry. The relative position of the components can be used as a process control variable.

Within the framework of the investigations described here, sequentially controlled ultrasonic welding is being developed, in order to be able to join large-area structural components such as stringers or frames with high process reliability. The process as well as the joining properties were analyzed.

The resulting process parameters, such as welding time and joining path, as well as the mechanical and morphological properties of the connections are investigated and optimized. Potential applications are presented.

#1175

# Elastomer-Interfaced SMA Hybrid Composites: Interface Enhancement, Analytical Modelling, and Manufacturability for Morphing Laminates

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This work presents an experimental–numerical framework for the design of multifunctional shape memory alloy hybrid composites (SMAHCs) with enhanced interface reliability, control-oriented actuation models, and manufacturing-informed laminate design. Previous pull-out experiments (10.1016/j.compositesb.2024.111785) showed that adding a thin elastomeric interlayer around superelastic NiTi wires embedded in an epoxy matrix significantly increases peak debonding force and transforms failure from abrupt to gradual, enabling full martensitic transformation of the wire. Building on that result, the present study investigates the same interface concept in GFRP–elastomer–NiTi systems using shape memory wires that are either in martensitic state at room temperature or thermally activated by Joule heating, including different embedment lengths and pre-strain levels, and supported by cohesive-zone-based finite element simulations. The results confirm that the elastomer interface acts as an effective stress buffer and sustains higher interfacial shear stresses without premature debonding, often leading to wire fracture and thus fully exploiting the transformation strain.

For actuation modelling, the SMAHC laminate is approximated as an equivalent bimetallic beam in which the SMA–elastomer sub-laminate is represented by a temperature-dependent effective thermal expansion coefficient identified from curvature–temperature tests on SMAHC cantilevers. This adaptation of Timoshenko's theory provides explicit formulas for curvature and tip position as functions of temperature and external bending moments and has been validated against experimentally measured deflections and subsequent control-oriented studies on a K-SMAHC actuator. In parallel, laminate architectures are designed and manufactured with a focus on process robustness: different stacking sequences, fibre orientations, and wire layouts are screened considering manufacturability issues such as delamination, wire handling, and autoclave curing stability. The resulting process-optimized laminates demonstrate repeatable actuation and low damage indices, illustrating how interface engineering, simplified analytical modelling, and manufacturing-aware design can be combined to realise durable, controllable SMAHC morphing components.

#1178

# Effect of Moisture Absorption under Impact Toughness Behaviour of Banana Fibre Reinforced Composites

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Abstract:

In recent years, applications involving polymer composites reinforced with natural plant fibres in key industry sectors have increased significantly due to the advantages natural fibre composites such as high specific strength and modulus compared to conventional glass fibre composites and their environmentally friendly nature among others. This study presents the characterisation and initial results of banana fibre-reinforced bio-epoxy composites with areal densities of 500, 700 and 1000 GSM, with a specific focus on their moisture absorption behaviour and its effects on falling weight impact toughness characteristics under the low-velocity impact (LVI) testing. Samples of banana fibre composites were immersed in distilled water for 240 hours before saturation moisture condition was achieved, after which moisture gain was quantified. 1000, 700 and 500 GSM samples showed moisture gain of 20.52%, 8.64%, and 5.91% respectively at saturation point before LVI testing was performed on both dry and wet samples of all GSM to evaluate the moisture gain effects on the energy absorption behaviour of the composites subjected to 3 joules of incident impact energy. Impact test results indicate that water immerged samples exhibited enhanced energy dissipation under impact, a behaviour attributed to the weak fibre-matrix interface, which decreases the stiffness in the material. The 500 gsm laminates showed the most significant change, increasing from 0.60J in the dry condition to 3.20J when wet, representing 433% improvement in toughness. The 700gsm sample demonstrated a marginal increase from 3.20J to 3.35J (4.7%), while the 1000gsm showed moderate rise from 3.00J to 3.30J (10%). Overall, moisture absorption led to an increase in impact energy dissipation, especially in the case of 500 GSM, primarily due to the weakening of fibre-matrix interface.

Keywords: Banana fibres; Moisture absorption behaviour; Impact toughness; Fibre-matrix interface; Energy absorption.

#1179

# Spatial Geometric Uncertainty Quantification in Filament-Wound Composite Pressure Vessels

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Filament winding enables the high-speed manufacturing of composite structures such as pressure vessels, making it a key technology for hydrogen storage applications. Despite its widespread use, the process exhibits substantial inherent variability arising from material properties, process conditions, and geometric characteristics. These uncertainties manifest both within a single pressure vessel and across different products and production batches. Variations in compaction pressure can induce spatial differences in layer thickness and fiber volume fraction, while inaccuracies in delivery-eye motion lead to local deviations in winding angle. Additionally, numerical simulations of filament-wound structures rely on modeling assumptions—such as effective deposited layer thickness or homogenized material behaviour—that themselves carry uncertainty.

Uncertainty quantification (UQ) provides a systematic means of identifying, characterizing, and propagating these uncertainties to assess their influence on structural performance metrics. By moving beyond deterministic “best-guess” predictions and instead delivering probabilistic outputs with confidence intervals, UQ enables engineers to better interpret simulation results and assess the reliability of predicted quantities such as burst pressure.

In this work, the authors propose a comprehensive UQ framework tailored to filament-wound composite pressure vessels. The framework integrates spatial geometric uncertainties—like local winding angles and layer thickness variation—that are typically neglected or simplified in existing literature. We focus our analysis on the (often neglected) dome parts, because this is where the effect of these uncertainties is mostly concentrated. By combining these uncertainty sources within a unified computational workflow, the approach allows for a more realistic representation of the manufacturing process and its impact on vessel performance.

This integrated UQ framework will facilitate more reliable design, improve predictive accuracy, and support the development of robust and optimized hydrogen storage systems capable of meeting future safety and performance requirements.

#1180

# Characterisation at room and low temperature of carbon/epoxy material after long-term cryogenic exposure

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The development of Liquid Hydrogen (LH2) storage systems for the space and aeronautical sectors is a critical research area, with composite materials offering the most promising solution. A cryogenic tank must maintain impeccable structural and barrier integrity to withstand the internal pressures during LH2 filling and long-term storage, while avoiding permeation. This necessity demands an exhaustive understanding of the material's quality after the manufacturing process and a precise grasp of its thermomechanical behaviour under extreme conditions.

This research focuses on the comprehensive thermomechanical characterisation of an ultra-thin carbon/epoxy composite—a key candidate for cryogenic applications. The material is subjected to prolonged exposure to liquid nitrogen (77 K), reaching long-term conditioning periods. The mechanical properties are evaluated comparatively, both at room temperature and at low temperature, to quantify the exact impact of extended exposure on performance. This analysis specifically aims to clarify existing discrepancies in the scientific literature regarding the properties and long-term stability of carbon/epoxy composites in cryogenic environments.

To complement this characterization, a detailed inspection of the material's microstructure is performed using Scanning Electron Microscopy (SEM). The resulting micrographs allow for the observation of potential modifications or morphological changes within the epoxy matrix and at the fiber-matrix interface after cryogenic conditioning and testing.

Ultimately, this study provides an essential and direct correlation between the thermomechanical characterization results and the microstructural observations. Fibre/matrix interface is mainly damaged after long-term cryogenic exposure, leading to changes of the tensile longitudinal and transverse material strengths. Transverse stiffness sheds light on the brittle behaviour of the matrix whereas longitudinal stiffness tends to keep equal. Coefficients of thermal expansion show relevant changes after long-term cryogenic exposure, arising to the stresses increment that may lead to damage fibre-matrix interfaces. The findings are expected to shed light on the long-term durability and reliability of carbon/epoxy composites.

#1181

# Strain-Dependent Mechanical Properties of Hemp Fibre Composites and the Implications for Wind Turbine Blade Design

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The transition towards bio-based composite materials in wind turbine blades necessitates the precise determination of their mechanical properties across the entire range of operational strain levels. Hemp fibre composites exhibit pronounced nonlinear stress-strain curves, which challenge the direct application of standardized analysis procedures developed for synthetic-fibre composites. In conventional coupon-level testing, the key mechanical properties, such as $E_1$, $E_2$, $G_{12}$, and $\nu_{12}$, are typically determined within prescribed strain intervals, e.g., 0.05 – 0.25 % (500–2500 με) for $E_1$, under the assumption of linearity within these ranges. The determined mechanical properties are then used as engineering constants, providing fixed inputs in classical laminate theory (CLT) during the structural design of wind turbine blades.

In the present study of hemp fibre composites, $E_1$ was determined to be 21.3 GPa in the prescribed strain interval of 0.05 – 0.25 %, whereas a higher value for $E_1$ of 24.5 GPa was obtained when using the narrower 0.01–0.10% strain interval. Similarly, the corresponding $G_{12}$ values were 2.3 GPa and 2.6 GPa, respectively. Wind turbine blades operate predominantly in the strain range of 300–3000 με during normal operation, with extreme loads occasionally reaching 6000–8000 με depending on the structural location and design philosophy.

The results indicate that representing hemp-fibre composites with a single, strain-independent set of engineering constants introduces significant inaccuracies. Properties such as $E_1$ and $G_{12}$ vary noticeably even within strain ranges typically assumed to be linear for synthetic-fibre composites. Consequently, using fixed constants in classical laminate theory leads to systematic stiffness errors, particularly in lightly loaded components, where small deviations can significantly affect the structural response and safety factor calibration. Incorporating the strain-dependent mechanical response is therefore essential for improving structural prediction accuracy and enabling the reliable integration of hemp-fibre composites into wind turbine blade designs.

#1183

# The influence of the obliqueness of open-hole notches on woven fabric carbon/epoxy composites damaging behavior

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Characterization of mechanical strength and damage onset of Carbon-Fibre Reinforced Plastic (CFRP) composites is quite critical for their safe implementation in high-performance industries. Regarding to the specific application requirements, composite structures are designed and manufactured with containing discontinuities frequently, such as notches and holes to accommodate fasteners and joints in critical regions. Consequently, investigating the characteristics of composite specimens with notches is crucial for designing safe parts. Thus, open-hole tensile (OHT) strength becomes a primary design driver and OHT testing of composites has an important part for characterization of the damage behavior.

While standard testing and many studies in the literature assumes perfectly perpendicular drilled open hole tensile specimens, drilling tolerances and different designs can lead to holes formed at oblique angles relative to the laminate's normal axis. This study aims to investigate the influence of the oblique angles on the strength characteristics and damage onset of Woven Fabric (WF) carbon-fibre composite laminates. The investigation is conducted numerically using ABAQUS/Explicit software. The intralaminar behavior of the plies is modelled with using the built-in VUMAT subroutine for fabric reinforced composite plies. The interlaminar damage (delamination) behavior is captured using cohesive surface method adopting the stacked-shell approach. The composite laminates are manufactured from plain-weave [0/90] carbon/epoxy prepregs as 6 plies stacked. The numerical simulations are validated against experimental data obtained from unnotched and straight-hole configuration tests before evaluating the deviations caused by oblique-hole formations. Oblique angles from 90° to 60° are designated and investigated on a narrow interval of 5° decrease on the laminates.

#1185

# Effect of Stacking Sequence on Carbon/Glass Hybrid Composites under Impact Loading

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Carbon/glass hybrid fiber-reinforced polymer composites have attracted considerable interest for lightweight structural applications where high specific stiffness must be combined with improved damage tolerance. By exploiting the synergy between the high strength of carbon fibers and the high toughness of glass plies within a single laminate, these hybrids can more effectively delay catastrophic failure and enhance energy absorption than their non-hybrid counterparts. Under low-velocity impact loading, the response of hybrid laminate composites is governed by the combined effects of constituent properties and the stacking sequence, with latter controlling the onset and propagation of damage. In this study, damage sequence of carbon/glass hybrid composites under low velocity impact is investigated. Three inter-ply hybrid composites including 6 layers of glass plies and 4 layer of carbon plies were manufactured using the VARTM (Vacuum Assisted Resin Transfer Molding) method alongside their baseline carbon and glass laminates, C10 and G10, respectively. Layup configurations of hybrid composites were chosen as [C2G3]s, [G3C2]s, and [GCGCG]s to investigate the effect of blocked and dispersed stacking. A drop-weight test setup is utilized for experiments with an impact energy of 9.77 joule. The damage sequence is captured with a high-speed camera and in-situ strain fields are obtained from the digital image correlation method, while a travelling microscope is utilized to observe damage onset at high resolution. The experiments show that placing carbon plies at the outer surfaces [$[C2G3]_s$ leads to smaller surface deflections with more localized fibre-dominated failure, whereas other configurations of ($[G_3C_2]_s$ and $[GCGCG]_s$) promoted larger global deformation and delamination, redistributing the impact energy over a wider damaged area and enhancing damage tolerance.

#1186

# Evaluating Modelling Assumptions for Large-Scale VARI Processes and Insights from a Blade Demonstrator Infusion

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Vacuum-assisted resin infusion (VARI) is widely used for manufacturing large composite structures such as wind turbine blades. Designing a reliable infusion strategy for these parts is challenging due to their scale, geometric complexity, and the variety of materials involved. Modelling of the infusion process can predict resin flow behaviour and help reduce defects, but most past successes have focused on relatively small, monolithic RTM components (<2 m, <10 mm thick), which differ substantially from blade structures.

Blade manufacturing relies on resin flow through millimetre-scale flow-enhancing features, such as flow mesh and channels machined into core materials, before wetting out the tightly packed micro-scale fibres of the fabric reinforcement layers, across parts that can be 10 m wide and 100 m long. Previous studies have demonstrated large-scale modelling concepts using geometric simplifications, or have explored higher fidelity simulations of smaller sandwich structures, but little work has assessed how modelling assumptions influence simulation fidelity at blade scale.

This study evaluates the impact of key modelling decisions, including curvature representation, homogenisation of core channels, and gravitational effects, on infusion predictions using PAM-RTM. Simulation results are compared for a range of representative and realistic large scle cases. Results show that homogenising hundreds of core channels into a single shell layer can well reproduce the overall flow behaviour, but may lead to large differences in predicted filling times under certain inlet conditions. Including curvature and gravity has also been seen to improve agreement with realistic flow patterns.

The findings provide practical guidance for balancing model fidelity and computational efficiency in VARI simulations for large composite structures, supporting more reliable and cost-effective manufacturing strategies.

#1187

# Influence of Compaction on the Electrochemical Performance of Structural Supercapacitors

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Structural power composites are multifunctional materials that combine mechanical load-bearing capability with energy storage, offering significant weight and volume savings for a range of applications, including those in the aerospace and automotive sectors. In performing these dual roles, structural power composites are likely to present a coupling between mechanical and electrochemical phenomena that need to be well understood if these materials are to be adopted in industrial applications. This study examines the effect of through-thickness compaction on the electrochemical performance of structural supercapacitors - an important but underexplored parameter in structural power composite design, characterisation and operation.

Devices comprising carbon fibre fabrics reinforced with carbon aerogel and a biphasic structural electrolyte were subjected to controlled compaction pressures up to 430 kPa, typical of aerospace composite manufacturing processes and in-service conditions. Electrochemical impedance spectroscopy revealed that increasing compaction substantially reduced internal resistance from 365 Ω.cm² to 117 Ω.cm² while having negligible impact on capacitance. Consequently, the specific power increased with compaction pressure. The reduction in resistance was attributed principally to improved interfacial contact between the current collectors and the electrodes, which was verified by characterising the resistances of only electrodes with current collectors under compaction.

Repeated loading cycles caused only minor resistance increases, suggesting robust mechanical integrity under cyclic compaction. Hence, the structural supercapacitors could operate under conditions involving multiple compaction cycles, such as floor panels, without incurring major changes in their electrochemical performance. These findings underscore the importance of measuring, controlling and reporting compaction during electrochemical characterisation when electrochemically characterising structural electrochemical devices that are sensitive to compaction. For such devices, their performance may be maximised by maintaining optimal cell compaction pressures during manufacture, particularly by ensuring intimate contact between electrodes and current collectors.

#1190

# Characterization of recycled carbon fiber composites based on aligned wet-laid nonwovens

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Growing global demand for carbon-fiber-reinforced polymers has led to increasing amounts of production waste and end-of-life components, making the recycling of carbon fibers even more important. Current recovery methods mainly result in short fibers of varying lengths, which are typically processed into compound materials or isotropic nonwovens. Due to their limited packing density and lack of alignment, these materials have rather low properties, which are usually insufficient for structural applications. In contrast, aligned semi-finished products made from discontinuous fibers offer higher mechanical performance and advantages in further processing. Focusing on the alignment is therefore a key factor in enabling recycled carbon fibers to be used in a wider range of applications and returning them to the circular economy.

This study describes the ongoing development of an wet-laid based process invented by the Fraunhofer IGCV, that allows to align discontinuous fibers in production direction at high volume. The tailored method enables the processing of virgin and recycled carbon fibers (rCF) with a length of approx. 6 to 12 mm into oriented nonwoven roll materials. Various fiber and matrix types (PA6, PA66, LM-PAEK) were combined to produce composite materials on panel level. The material were then compared based on tensile, bending and compression properties as well as eddy current, fiber volume and microsections. The results show a clear preferred direction of the fibers and therefore up to six times higher mechanical properties in machine direction. The adapted process technology’s main advantage is high scalability, enabling the Fraunhofer IGCV pilot line to produce a 25 gsm nonwoven with 610 mm width at up to 6 m/min production speed.

The study is part of the funded project Espresso, which deals with the development and processing of highly aligned thermoplastic tapes made from rCF and tape offcuts into 2nd-life structural components for the sports industry.

#1192

# Interlaminar and intralaminar toughness of carbon/epoxy material after long-term cryogenic exposure

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The successful implementation of Liquid Hydrogen (LH2) storage systems is fundamental for advancing aeronautical transportation. Given the extreme conditions, composite materials represent the optimal choice due to their high strength-to-weight ratio. The selection of a good resin is crucial for the development of the composite material to be use as candidate for this application. This necessity imposes stringent requirements on the epoxy matrix, which must maintain its mechanical efficiency after severe cryogenic exposure. A key metric for assessing this resilience is the fracture toughness of the resulting composite material.

This investigation focuses on the comprehensive evaluation of the Mode I fracture toughness GIc for an ultra-thin carbon/epoxy composite after long-term exposure in liquid nitrogen (77 K). The study differentiates between two critical toughness values: the interlaminar and the intralaminar ones. This property is evaluated comparatively at both room temperature and at low temperature to accurately quantify the precise impact of long-term cryogenic exposure on the material's structural performance.

To further understand the material degradation mechanisms, a detailed inspection of the material's fracture surfaces is performed using microscopy techniques. These surface inspections allow for the observation of changes within the fracture surface resulting from cryogenic conditioning and subsequent mechanical testing.

In summary, this research provides quantitative data on the interlaminar and intralaminar fracture toughness of ultra-thin carbon/epoxy composites subjected to cryogenic conditions. This knowledge is indispensable for establishing robust structural integrity margins. Critically, understanding how the cryogenic environment affects GIc is fundamental to ensuring that the epoxy matrix in combination with the carbon fibre maintains its intended performance and damage tolerance capabilities after prolonged use at cryogenic temperatures.

#1193

# Influence of Stitching Pattern on the Fibre Misalignment and Static and Fatigue Compression Behaviour of Non-Crimp Fabric Composite Materials

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Non-Crimp Fabric composite materials are a class of textile composite constructed from layers of oriented fibre tows, held in place by thin stitching yarns. This design allows the fabrics to exhibit the good drapability and handling stability of other textiles, while minimising the fibre crimp inherent to woven fabrics. However, Non-Crimp Fabrics generally do still have fibre misalignment or waviness which can, in part, be attributed to the presence and geometry of the stitching thread. Fibre misalignment is a critical metric in the determination of composite compression strength. This work considers the influence of stitching pattern on the fibre misalignment and static and fatigue compression behaviour of [0/90] glass-fibre Non-Crimp Fabric composites with three common stitching patterns: the Chain, Tricot, and Mixed Chain-Tricot.

Measurements were first taken of the fibre misalignment on the front and rear face of each pattern from low-magnification backlit photographs of the fabrics using a modified Fourier-Transform Misalignment Analysis algorithm. These measurements are compared to fibre misalignments predicted numerically in idealised models using a Digital Element approach. These fabrics are then used to manufacture glass/epoxy composites, which are tested both statically in uniaxial compression and cyclically in compression-compression fatigue. Analysis of measured fibre misalignments reveals a measurable and statistically-significant difference fibre misalignment between stitching patterns, and idealised fabric models show that changes in stitching geometry can be linked to variation in the patterns and magnitudes of fibre misalignment. Static compression testing reveals minimal variation in compressive modulus or strength as a function of stitching pattern, but fatigue testing shows some statistically-significant variation in fatigue life and in the rate of visible damage accumulation. Variation in stitching pattern may therefore be linked to not only differences in fibre misalignment, but also variation in composite compression-compression fatigue performance.

#1194

# Testing Burn-Through Performance of Thermoplastic Composites for eVTOL Battery Enclosures

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The use of composite materials for Lithium-ion battery enclosures has been investigated by the automotive industry for a number of years now, with solutions based on thermoset composites showing improvements in weight and volume over metallic equivalents. As the interest in eVTOL vehicles grows in aerospace, the focus has extended to composite solutions for battery enclosures housed in fuselages and wings. For this application, minimising weight and volume are even more critical, and therefore novel composites solutions are beginning to emerge.

In order to reach certification, eVTOL battery enclosures are required to survive a burn-through test, retaining structural integrity and minimising temperatures experienced on the enclosure's outer surface. In this research, the concept of a thermoplastic composite battery enclosure is investigated, and candidate materials are tested for mechanical performance and safety.

A range of thermoplastic composite panels are subjected to a propane-flame burn-through test in line with certification standards. Carbon fibre reinforced panels with PPS, LM-PAEK and PEI thermoplastic polymer matrices are included in the investigation. A novel, rotating experimental rig design is described that houses the test panel, propane burner, heat flux sensor, thermocouples and thermal camera.

The project progresses from monolithic panels to the potential enhancements provided by fire-retardant coatings such as intumescent or ceramic layers, and solutions are ranked according to their thermal performance in the test and their residual strength after the burn-through is completed. Results are compared with metallic and thermoset composite baselines, and the effects of parameters such as panel thickness, thermoplastic polymer type and coating material are explored.

#1195

# Integration of Embedded Sensor Systems for Process and Structural Health Monitoring in Smart and Sustainable Wind Turbine Blade Components

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Among the current challenges faced by the wind energy sector, the continuous increase in turbine size together with the repowering needs of existing wind farms and the development of new technologies to optimise installation, operation, and maintenance are key drivers for cost reduction. The design of next-generation wind turbine blades requires not only improved structural efficiency but also reliable monitoring capabilities during the manufacturing of large composite structures, as well as the adoption of more sustainable material systems. In this context, the integration of advanced sensor technologies for Process Health Monitoring (PHM) and Structural Health Monitoring (SHM), supported by predictive approaches for early failure detection, is becoming essential to enable effective maintenance strategies and extend component lifetime.

In this study, a novel single-wire sensor based on optical fibres embedded within a thermoplastic filament produced through a controlled co-extrusion process was developed. This neat sensor provides sufficient mechanical robustness for handling and positioning during lay-up, while ensuring compatibility with vacuum infusion processes and the manufacturing requirements for wind composite structures. The resulting laminates were comparable to reference materials, confirming that the embedded sensors do not compromise resin flow, cure behaviour or the structural quality of the final composite.

Furthermore, thermoplastic resins were selected for their clear advantages in recyclability, reparability, and compatibility with weld-based joining concepts, relevant for future blade architectures. The infusion fabrication of commercial epoxy resin and thermoplastic resins was optimized based on the manufacturing and scale-up requirements of the new solutions. The physical, mechanical, thermal, and microscopic properties of the composite material were compared.

Overall, the combined use of embedded novel sensor technology and advanced resin systems establishes a solid framework for the development of smart, damage-resistant, and more sustainable wind turbine blade components, supporting the transition to more durable circular composite structures.

#1196

# Understanding the effects of outdoor and accelerated hygrothermal ageing on the monotonic and fatigue performance of flax FRP composites

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Natural fibres are receiving growing attention as sustainable alternatives to synthetic fibres to reduce environmental impact of engineering structures made of fibre reinforced polymer composites (FRPs). Flax fibres are of specific interest due to their comparatively high stiffness and strength among plant fibres, enabling specific properties approaching that of glass-fibre composites. Nevertheless, the hygroscopic nature of those fibres raises critical concerns regarding long-term durability in outdoor applications. Cyclic exposure to moisture, temperature, and ultraviolet radiation can induce microstructural degradation, potentially altering structural performance. Although previous studies have demonstrated that hygrothermal ageing degrades the monotonic properties of flax composites, limited evidence exists regarding its influence on fatigue properties. Moreover, most ageing protocols rely on immersion or climate-chamber conditioning which may not accurately reproduce real environmental ageing conditions.

This study addresses these limitations by subjecting flax FRP laminates to realistic ageing; (i) natural outdoor exposure for one year in Delft, the Netherlands, encompassing fluctuations in humidity, rainfall, and solar radiation; and (ii) accelerated ageing in a chamber involving ultraviolet irradiation, water-spray, and elevated temperature, designed to mimic outdoor ageing effects. Two laminate configurations were investigated; one dominated by fibre-controlled failure [0/90/0]S and one governed by matrix, fibre/matrix interface, and interfacial shear failure [+45/-45]2S.

Both accelerate and outdoor ageing produced changes in the monotonic behaviour. The [0/90/0]S laminate strength decreased by over 20%, and strain-to-failure was nearly halved. For the [+45/-45]2S laminate, the main effect was an increase in stiffness accompanied by a reduction in strain-to-failure, suggesting loss of ductility. In fatigue, outdoor ageing caused the strongest fatigue life degradation. The [+45/-45]2S laminate exhibited reductions in fatigue life of approximately one order of magnitude across all stress levels under outdoor ageing, while the [0/90/0]S laminate showed reduced low-cycle fatigue life but convergence of aged and pristine S–N curves near 10^6 cycles.

#1197

# Physics informed geometric generator for unidirectional fibre reinforced composite microstructures with periodic boundaries

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Accurate descriptions of fibre reinforced composite microstructures are essential for reliable micromechanical modelling. Image-based generators often struggle with uncertain fibre geometry, limited control over spatial features, and the absence of enforced periodicity. To address these limitations, we introduce a physics-informed generator that constructs periodic statistical volume elements using experimentally measured fibre properties together with reconstructed spatial topology.

The generator combines a diffusion-based process with a parameter-based geometric grid. The grid stores fibre attributes directly at each location, enabling the generator to operate on explicit physical quantities rather than inferred image intensities. This representation removes resolution-related artefacts, eliminates ambiguity in fibre diameter estimation, and provides precise control over microstructural geometry.

Two complementary experimental sources supply the required inputs. Fibre diameters measured with a laser diffraction system define the geometric parameters, while topology is obtained from segmented computed tomography data. These measurements are consistently integrated into the grid, allowing the generator to create periodic, non-overlapping fibre arrangements. A refinement stage imposes additional physical constraints on local geometry and improves the accuracy of the generated structures.

The resulting synthetic microstructures reproduce key statistical features observed in reconstructed sample topologies. Quantitative agreement is obtained for fibre spatial distribution functions and for descriptors of resin-rich regions. The generator preserves measured diameters, maintains periodic boundary conditions, and produces microstructures directly suitable for micromechanical simulations. The same parameter-based generator architecture can be extended to three-dimensional systems to represent fibre continuity and geometry along the reinforcement direction.

#1206

# Development of a Robotic Winding Head with Active Tension Control

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Hydrogen pressure vessels promise a substantial contribution to the global target of sustainable, carbon-neutral mobility. These pressure vessels are typically manufactured using a carbon fiber wet filament winding process. For shape-optimized tanks, a high-quality robotic winding process is essential to ensure optimal manufacturing results. The precision of fiber placement and the quality of the tapes, in combination with tension control, are crucial for achieving optimal mechanical properties and thus maximum performance.

This contribution provides an overview of general design trade-offs for the selection of technological components of a robotic winding head for fiber-reinforced tapes with active tension control. Key decisions for the choice of an inductive hysteresis brake in combination with a pneumatic dancer over other options are discussed. The system utilizes an innovative spool-infiltrated, fiber-reinforced tape that combines the advantages of towpreg material and wet filament winding. It offers expanded flexibility in the combination of fiber and matrix materials and improved shelf life through on-demand resin infusion. Synergies with tow spreading can further increase mechanical properties. Additionally, an innovative protective film is introduced to physically separate the wet filaments tapes from the machine equipment in an effort to reduce cleanup requirements and wear.

Design choices and challenges in the software implementation of the active tension controller are discussed, and a quantification of the error due to inertial effects on the radial-axis sensor, cogging in the hysteresis brake, and offset by protective film system are provided. Experimental data of the introduced system processing thin-ply carbon fiber material on typical split-disc test specimen is presented as evidence of the improvements and a baseline for expected measurement errors.

#1207

# Multiscale modeling and experimental characterization of semicrystalline polymers for hydrogen barrier applications

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The MuMPol project aimed to develop a multiscale simulation chain for the assessment of sorption, diffusion, and permeation of gases in high-performance multiphase materials, such as semicrystalline polymers, for challenging industrial barrier applications like hydrogen storage and transportation at high pressure. A multiscale approach combining molecular dynamics simulations, equations of state and finite volume method was adopted to balance computational efficiency with predictive accuracy, focusing on HDPE and PA6 polymers, the current state-of-the-art materials for type IV hydrogen storage tank liners.

This study presents a comprehensive multiscale methodology that merges molecular-level insights derived from Molecular Dynamics (MD) simulations with macroscopic transport analyses via the Finite Volume Method (FVM). Our approach offers an in-depth examination of hydrogen diffusion through High-Density Polyethylene (HDPE) under various manufacturing scenarios. Through MD simulations, we explored the diffusion behavior of hydrogen within the semicrystalline structures of HDPE, focusing on different interfacial chain topologies which reflect prior studies on hydrogen sorption in this material. This enabled a precise measurement of the diffusion coefficients in the confined amorphous zones found between the spherulitic lamellae.

Further, we employed an innovative FVM-based technique to calculate the long-range tortuosity impacts, where the geometrical arrangement of multiple spherulites, each composed of radially growing lamellae, is modeled in a body-centred cubic lattice structure. By integrating sorption data, we were able to directly compute the hydrogen permeability coefficient, effectively bridging the gap between microscopic diffusion dynamics and the macroscopic transport phenomena observed in HDPE. This integrated approach not only enhances our understanding of hydrogen transport within polymeric materials but also aids in evaluating material performance under practical operating conditions.

This research forms part of the research program of DPI, project 844: Modeling and Design of Multiphase Polymeric Materials for High Performance Applications Across Multiple Scales (MuMPol).

#1208

# Synergistic Effects of Nanofiller Reinforcement and Surface Treatment on the Flexural Fatigue Behaviour of 3D-Woven Core based Metal-faced Sandwich Composites

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Metal-faced sandwich composite panels offer an excellent strength-to-weight ratio, high flexural stiffness, and superior fatigue life, making them highly suitable for aerospace, automotive, and defence applications. However, their structural integrity is often constrained by weak interfacial bonding between the core and the facesheets, which can lead to premature debonding under cyclic flexural loading. This study investigates the enhancement of interfacial strength through the combined use of nanofiller reinforcement within the adhesive and various metal surface modification techniques applied to the facesheets. Carbon nanotubes (CNTs) and graphene nanoplatelets (GNPs) were incorporated into the adhesive at 0.1%, 0.3%, and 0.5% volume fractions, and the reinforced adhesive was used to bond modified aluminium facesheets to 3D-woven solid composite cores. The shear adhesion strength, static flexural response, and flexural fatigue behaviour of the fabricated sandwich panels were evaluated as functions of nanofiller concentration and aluminium surface modification. The incorporation of nanofillers significantly enhanced core–facesheet adhesion, resulting in higher interfacial strength and more efficient stress transfer under bending loads. Chemically modified aluminium surfaces exhibited markedly superior interfacial bonding compared to mechanically treated surfaces. Flexural fatigue analysis further demonstrated that panels with chemically treated facesheets sustained a substantially higher number of loading cycles before failure, indicating improved resistance to cyclic damage. Additionally, nanofiller-reinforced panels exhibited higher dynamic stiffness throughout fatigue cycling, reflecting improved structural rigidity and slower stiffness degradation. Among the tested concentrations, the 0.3% volume fraction showed the most effective enhancement, while the improvement from 0.3% to 0.5% was not significantly pronounced, indicating a saturation effect at higher loading levels. These results underscore the synergistic effect of nanofiller reinforcement and chemical surface modification in enhancing the interfacial strength and flexural fatigue life of metal-faced sandwich composites.

#1209

# Multi-matrix composites: application rationales and manufacturing strategies

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The most common route to hybridising composite materials has traditionally been the combination of different fibre types. However, growing evidence indicates that hybridising matrices can also deliver significant benefits ranging from structural enhancements [1] and embedded functional capabilities [2], to improved processing efficiency [3] and measurable sustainability gains [4]. Despite these advantages, the industrial adoption of multi-matrix systems has been slow. Such materials often demand new manufacturing methods, revised design philosophies, updated certification procedures, and may introduce additional challenges in end-of-life recycling. Nevertheless, when approached holistically, these complexities can be effectively addressed.

This presentation outlines the justification for multi-matrix composite systems and explores strategies for designing and manufacturing a broad spectrum of matrix hybrids. Application cases discussed include mitigating stress concentrations [1,6], enabling repair and disassembly functions [3, 4], reducing forming-induced defects [9], improving dimensional stability of preforms [10], and enhancing the formability of otherwise non-formable architectures in structural power applications.

The fabrication of multi-matrix composites employs bespoke techniques such as liquid-resin printing [5,6], modular infusion [4], and hybrid processes including liquid-compression moulding [7] and inductive processing [1]. Beyond requiring new processing strategies, multi-matrix materials open the door to techniques rarely used in composites manufacturing. For example, integrating formable hinges into rigid laminates enables the use of sheet-incremental-forming methods, originally developed for metals, for post-cure forming operations [8].

Finally, the new testing strategies required for assessing new composites interfaces are overviewed and methods for examining fibre-bridged, uncommon for conventional composites, and composite-polymer interfaces, to assess inter-polymer adhesion, are presented.

References:

1. https://doi.org/10.1016/j.compositesa.2024.108272
2. https://doi.org/10.1016/j.matdes.2023.112446
3. https://doi.org/10.1115/1.4063091
4. https://doi.org/10.1016/j.susmat.2025.e01680
5. https://doi.org/10.1016/j.compositesa.2016.01.018
6. https://doi.org/10.1016/j.compstruct.2018.09.019

7. https://doi.org/10.21741/9781644903131-49

8. https://doi.org/10.21741/9781644903599-56

9. https://doi.org/10.3389/fmats.2022.867591

10. https://doi.org/10.1179/2055035914Y.0000000006

#1211

# Correlating pore-network model and high-fidelity CFD estimation of effective permeability from μ-XCT-derived stacked fiber layups

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Estimates of effective meso-scale permeability in large stacks of fibre-reinforced composites based on realistic pore space and fibre architecture are typically obtained from high-fidelity CFD. However, resolving the full voxelised pore geometry and solving the Darcy–Forchheimer (DF) equations is extremely CPU-intensive, and simple arithmetic or harmonic averaging of permeabilities from smaller samples often fails to represent the true equivalent permeability of large preforms. Structured-tensor analysis of XCT data has been developed to classify fibre orientations, generate voxel meshes and perform meso-scale CFD with the DF model, but this remains costly for large stacks. In contrast, pore-network modelling (PNM) can predict equivalent permeability with far lower computational effort.

In this study, fibre layups obtained from μ-XCT are segmented and partitioned into multiple stacked sub-volumes that capture realistic 3D pore geometries over a large domain. For each stack, the interconnected void space is extracted and used in two parallel modelling routes. First, PNMs are constructed via pore–throat identification and skeletonisation, and single-phase flow is solved on the resulting graphs to obtain directional permeabilities. Second, high-fidelity CFD simulations are performed directly on the voxelised pore domains by solving the DF model under imposed pressure gradients. PNM and CFD predictions are systematically compared across stacks to quantify accuracy, bias and scatter as functions of porosity, characteristic pore size and connectivity. Finally, the sensitivity to μ-XCT thresholding and segmentation is assessed to understand their impact on meso-scale permeability. The combined workflow structured-tensor analysis and pore-network models calibrated against CFD provides a practical, multi-scale route for efficient equivalent permeability prediction in large stacked fibre layups, directly relevant to process modelling in liquid composite moulding.

#1214

# Anisotropic AC/DC Electrical Conductivity Mapping of CFRP: From Single-Fibre Characterisation to Multi-Scale Electro-Thermal Modelling Using a Novel multi-Probe Method

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Electrical performance and properties of composites are cases where there is no full understanding of the composite's behaviour due to their anisotropy and heterogeneous nature.

The electrical properties of composites have been exploited across multiple industry sectors in many applications, such as electromagnetic shielding, heating elements, and manufacturing or disassembly processes, including induction welding and disband-on-demand for end-of-life disassembly. Industry also faces serious issues with lightning strike damage, electrostatic discharge in pipes and Galvanic corrosion. Without specific test standards, electrical properties are inconsistent, hindering design, manufacturing and causing overdesign or damage.

This PhD develops a fundamental, multi-scale methodology for mapping current paths and exploiting them in conductive composites by measuring AC/DC conductivity from the single fibre level up to laminates. A multi-probe jig is developed to characterise in-plane longitudinal, transverse and out-of-plane through-thickness conductivity. Sensitivity studies will analyse contact orientation, contact pressure and stochastic fibre orientation in unidirectional tapes. Microstructural analyses (SEM, elemental/XRD and STM) will reveal how fibre surface characteristics and contact mechanics govern electron transport across fibres and bundles.

Experimental results will feed a hierarchical modelling framework at the micro and meso scale, RVEs to capture fibre/matrix networks, and the models will propagate to the laminate scale FEA models. Models will consider anisotropy, stochastic orientation and contact resistance to predict electro-thermal response under direct and alternating currents. The goal is to exploit the developed knowledge to improve the current state-of-the-art joining methodologies, especially induction welding.

By combining high precision experiments, contact mechanics, microstructural characterisation and multi-physics modelling, the project will produce standards and predictive tools for AC/DC conductivity of anisotropic composites. The results will mitigate current path unpredictability, guide material selection and enable multifunctional components that deliver structural and electrical functions. It also aims to develop guidelines for standards and disseminate findings across the industry.

#1215

# Next-Generation Strain Sensor in Bonded Glass Fiber Composite Joints for SHM

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The structural integrity of composite airframes depends heavily on the performance of bolted and bonded joints, particularly in splice regions where laminate sections are connected to transfer critical loads. These joints are subjected to complex loading conditions, geometric misalignments, and significant stress concentrations that accelerate damage mechanisms, including matrix cracking and delamination. Early detection of these issues in glass fiber reinforced polymer (GFRP) structures remains challenging as a result of their anisotropic nature and the limited sensitivity and highly localized response of conventional structural health monitoring (SHM) techniques (e.g., metallic strain gauges). Traditional methods are often insufficient for capturing distributed, early-stage damage developing in complex splice joint geometries. To overcome these critical limitations, a novel distributed sensing strategy for high-accuracy, real-time damage detection has been proposed.

This work presents a new generation carbon nanotube (CNT)-based piezoresistive strain sensor with real-time damage monitoring capability, designed for bonded GFRP splice joints. Aerospace-grade laminates were manufactured using the vacuum infusion process (VIP), and conductive CNT ink was screen-printed onto these structures. This fabrication approach yields flexible, thin, and conformal sensing elements with controlled geometry and strong interfacial adhesion, making them well suited for adhesively bonded configurations. The sensing mechanism depends on tunneling-dominated resistance modulation within the CNT percolation network, enabling significantly amplified electrical responses under small strain variations. Static tensile tests established linear electromechanical behavior with a gauge factor (GF) exceeding 5, which is significantly higher than conventional strain gauges.

These results confirm that CNT-based printed sensing technology is a scalable, lightweight, and cost-effective SHM solution for composite splice joints. This approach demonstrates strong potential for improving maintenance strategies and enhancing the operational reliability of composite airframe structures.

#1216

# Screen-Printed CNT/CNC Sensors Integrated into 3D Orthogonal Woven Composites for Areal Strain Mapping and Impact Localization

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Three-dimensional orthogonal woven composites were employed due to their ability to mitigate interlaminar delamination, a dominant failure mode in conventional laminated composites. Their architecture, strengthened by through-thickness z-yarns, provided enhanced damage tolerance, making them suitable for developing integrated sensing systems. Given the critical role of structural health monitoring for such composite structures, the study focused on enabling strain-based areal mapping without the need for external sensors or add-on components.

Custom orthogonal fabrics were produced using a dedicated weaving machine with 600 TEX yarns. After achieving 3D orthogonal woven preforms, screen-printed carbon nanotube (CNT)-cellulose nanocrystal (CNC) based strain sensors were integrated directly onto the fabric, allowing the fabric itself to function as a distributed sensing medium. A CNT/CNC dispersion was first formulated at a 1.5:1.5 weight% ratio, yielding a stable, conductive, and piezoresistive ink suitable for printing. Layer number in printing is investigated in correlation with the achieved resistance values. Upon printing the two-layer structure, a final resistance of 0.5-3 kΩ was achieved. Multiple electrode configurations were implemented, including silver paste combined with copper wire and silver paste combined with silver yarn terminations, to evaluate robustness and compatibility during subsequent composite processing. Printed preforms were then consolidated into composites through a vacuum infusion process.

Finally, drop-weight impact tests were performed on a sensor-encircled region of the manufactured composites. During each impact event, simultaneous resistance data were collected from printed sensors via an Arduino-based acquisition system. Calculated impact energy was approximately 0.6 J with a ≈25% resistance change. These signals were processed to localize impact position and compare the performance of the different electrode strategies. Results demonstrated that the integrated CNT sensor network enabled effective areal strain mapping and spatial damage estimation without the need for external strain gauges, highlighting the potential of screen-printed CNT-functionalized 3D woven preforms for intelligent composite structures.

#1218

# Plasma-Enhanced Carbon Fibre-Reinforced Thermoplastic Tapes Fabricated from Waste Plastic Blends

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Despite many types of plastics qualifying as viable recyclate, large volumes are still sent to landfill, including hard-to-recycle materials such as rigid thermoplastics and contaminated blends. These are the subject of a current New Zealand research programme aimed at developing a more comprehensive circular plastics economy. This includes identifying new waste material use cases, such as upcycling for composite material applications.

Carbon fibre-reinforced thermoplastics have numerous benefits over thermoset alternatives, however certain characteristics hinder applications in wider industry. The high viscosity and thermal sensitivity of typical engineering polymers make achieving high-quality composite products challenging. The utilisation of contaminated blend matrices also requires complex fibre sizing to achieve adequate interfacial adhesion. These issues are addressed by an atmospheric pressure plasma jet-enhanced melt impregnation approach introduced in this study.

A novel wavy slot channel melt impregnator was developed to continuously manufacture unsized 12k carbon fibre-reinforced blended nylon-6:polypropylene (50:50 wt.%) tape, representing a worst-case scenario contaminated waste feedstock. Plasma jets were integrated in-situ to functionalise the carbon fibre tow surface immediately before melt die entry, with automated tape laying and compression moulding techniques ensuring generation of high-quality composite laminates. Cross-section and fracture surface micrographs highlighted a >90% degree of impregnation obtained through the melt impregnation process, with an enhanced fibre-matrix interfacial relationship observed for plasma-surface treated fibre specimens. Data from longitudinal and transverse tensile testing further confirms these findings. Stamp forming trials were conducted to assess formability of the contaminated matrix composites, and demonstrate the suitability of fibre-reinforced blended thermoplastic tapes to fabricate complex components.

Developments in the compatibility of carbon fibre and immiscible polymer blends with plasma surface treatment contribute greatly to improved composite processing and resulting structural performance. Outcomes also prove a value-added use case for hard-to-recycle plastic waste, reducing volumes sent to landfill and contributing to a circular plastics economy.

#1221

# Factors Affecting Thermoplastic Tape-to-Tape Bond Strength in Automated Composites Manufacture

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Thermoplastic composites offer distinct advantages over their thermoset equivalents, including improved material properties such as fracture toughness, opportunities for higher rate manufacture and potential for end-of-life recycling. However, the implementation of these materials in industries such as aerospace has been slow, in part due to the significant challenges in achieving full in-situ consolidation of composite tapes in automated processes such as Automated Fibre Placement (AFP) and Filament Winding (FW). In order to accelerate the adoption of these materials, a greater understanding is required of the relationship between their thermal history during high-rate automated manufacture and the final part quality.

In particular, the ultra-fast cooling rates inherent in AFP and FW are known to inhibit the recrystallisation of semi-crystalline polymers, which may detrimentally affect their mechanical properties. This paper investigates the effects of heating and cooling rates on the resultant crystallinity and bond strength of bonded (welded) thermoplastic composite tape pairs. Three thermoplastics are studied: Carbon fibre reinforced Polyether ether ketone (PEEK); Carbon fibre reinforced low melt - Polyaryl ether ketone (LM-PAEK); and Carbon fibre reinforced Polyamide 6 (PA 6).

Composite tape pairs are adhered by a novel heating technique using a xenon flash lamp, using its ability to apply highly controlled heating and compaction force onto the tapes simultaneously. A wide range of heating rates, cooling rates and compaction forces is investigated and the relationship between cooling rate and resultant crystallinity is described. The tape-to-tape bond strength of each tape pair is measured via a floating roller peel test, and results are related back to processing parameters such as compaction force, welding temperature and cooling rate, giving important insights into improvements required in automated processes to achieve high bond strengths and full in-situ consolidation.

#1222

# From Biomimetic Core Design to Circular Composites: PHA-Based Sandwich Structures with Natural Fibre Reinforcement

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This work aims to develop lightweight sandwich structures that are both high-performing and recyclable. In a first step, trabecular architectures of Cybister (rectangular) and Pteroplaticus inclinatus (hexagonal) elytra were abstracted into cores and 3D-printed (PLA) in flatwise (CF, PF) and edgewise (CE, PE) orientations, including modified variants (CME, PME) and a honeycomb reference (H). These cores were combined with flax fabric/green-epoxy skins and tested in core compression and four-point bending to benchmark and select the most efficient core designs for subsequent recyclable thermoplastic sandwiches. The results showed that the P. inclinatus clearly outperformed the Cybister variants and H. In core compression, PME reached the highest modulus and strength (524 ± 11.07 MPa and 14.17 ± 0.02 MPa at 378 ± 1.7 kg/m³). In bending, H carried the largest maximum load (5309 ± 194 N), but beetle-inspired panels were competitive at similar densities: the P. inclinatus edgewise PE configuration achieved 2800 ± 19 N, and PF provided the highest effective bending stiffness (113.56 ± 13.53 Nm²). Based on this combined performance, PE was selected as the target geometry.

In the second step, this PE core was realised in a fully thermoplastic system: cores were 3D-printed from PHA (ENMAT) and laminated with PHA/hemp and PHA/cellulose skins, enabling cores and skins to be jointly recycled by grinding, re-compounding to 30 mass% fibre and injection moulding over five cycles, with tensile strength reducing only from 49 to 45 MPa and modulus from 8.4 to 7.7 GPa. After 1000 h of UV ageing, PHA/hemp retained 47 MPa tensile strength, whereas prolonged water immersion led to strong degradation and eventual loss of stiffness, while cyclic wetting and UV-driven drying over 40 days caused negligible changes. Overall, beetle-inspired cores with PHA natural-fibre skins offer a promising basis for fully thermoplastic, recyclable sandwich composites for load-bearing applications.

#1224

# 2D nesting of fragmentable shapes applied to the upcycling of composite sheet manufacturing waste

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An important step during the manufacturing of composite laminates consists in nesting the layer cutouts within the material sheet while minimising the amount of waste. The material utilisation is not always very efficient, especially when the shapes are complex and have strong constraints on their orientation, resulting in a skeleton of unused material. This is the case when we use unidirectional prepreg carbon fibre patches to construct a discrete spatial distribution of fibre orientations. However, we can reduce the waste generation during this process by using the skeleton as material source for a secondary product, effectively upcycling the high-value unused raw material. Here we present a methodology for doing so based on heuristically solving the bin packing with fragmentation problem, in which we allow the components of the secondary product to be split into smaller pieces and nest them inside the fixed skeleton, while minimising the total number of cuts to preserve the mechanical properties of the original continuous fibres. The main difference from traditional bin packing solvers is the two-dimensional fragmentation heuristic we introduce, which is driven by manufacturing constraints coming from the robotic pick-and-place system used to automate the process of laying the laminate up from the nested pieces. The developed algorithm adapts methods more commonly used in computer graphics and computational geometry and applies them to the manufacturing of composites. The nesting tool is capable of handling the unusual set of geometrical constraints associated to this use case, while giving to the user control over the balance between efficiency of the material utilisation and ease of manufacturing. Ultimately we contribute to a short material use cycle which enables improved circularity of high performance composite material production waste.

#1225

# Mechanical and electrical characterization of an aeronautical out-of-autoclave multi-functional composite structure containing solid state battery cells

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In order to achieve the European net-zero goal, it is essential to improve the efficiency of air transport and reduce its climate impact through the electrification of aircraft systems. The functional integration of structural capabilities and electrical energy storage in the form of structural batteries is a low technology readiness level (TRL) technology with the potential to minimise the effect of battery energy storage on an aircraft's overall weight. As part of the European MATISSE project, the mechanical and electrical performance of an aeronautical multifunctional composite wingtip was investigated using experimental and numerical methods.

Firstly, the Reinforced Multilayer Stack (RMS) multifunctional battery cell, developed by AIT, was characterised mechanically through tensile testing, with its electrical performance also being evaluated. Secondly, the recently developed TR50/M90 composite material, which was produced using an out-of-autoclave process of interest to the aeronautical industry, was studied. The manufacturing process was optimised to produce a material that meets aeronautical standards while preserving the electrical properties of the battery cells. A multi-instrumented test campaign was conducted on different laminates to fully characterise the in-plane and out-of-plane properties of the unidirectional (UD) plies. Thirdly, sandwich composite coupons with TR50/M90 skin and foam core were subjected to bending tests to validate the characterisation campaign. Then, RMS battery cells were introduced into the foam to ensure electrical isolation within the composite material and limit the stresses carried by the cells. Bending tests were performed again with the battery cells to estimate the residual mechanical performance. Finally, a sandwich composite wingtip representative of a Pipistrel application and including RMS battery cells has been designed and tested at ONERA on the new JERICHO test platform, to evaluate its mechanical and electrical performance.

#1226

# Comparison of Compressive Material Property Measurement by Direct-Axial Compression (ASTM-D6641) and Four-Point Bending (ASTM-D6272)

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The accurate measurement of compressive strength at the coupon level is crucial for the design and validation of structures subjected to compressive or flexural loading. The methodologies that produce more accurate and precise measurements of compressive properties, and therefore better inform the design process, have been debated for forty years without consensus.

Four-point bending of monolithic beams is commonly adopted by French naval engineering groups, as specified in ASTM D6272. This allows for the measurement of the strength of thick laminates (>10mm) under pure bending, in a quasi-static loading scenario, with failure initiating from a compressive failure mode. Another common method, although not extensively used with thick laminates, is loading via direct axial compression, particularly the combined loading compression method, as specified in ASTM D6641.

Direct-axial compression methods are suited towards thin laminates, as these were typically used during methodology development (<2mm), as well as due to testing capacity limits. Without reference data or accurate compressive strength measurement for thick laminates, compressive properties are restricted to being an approximation based on scaling up of laminates.

This research examines the efficacy of the ASTM D6641 test method in relation to the compressive strength of thick laminates. Specimens derived from the same parent laminate were tested using both four-point bending and direct-axial compression, isolating variation in measurements of compressive properties to methodology alone. A sweep of fibre types, matrix materials, and stacking sequences was assessed. The research, therefore, elucidates differences between the methods of testing, enabling cross-method comparison of compression property data between bending and direct-axial compression.

#1227

# Non-destructive assessment of 3D printed continuous carbon fibre reinforced nylon 12 mechanical behaviour.

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Composite materials generally have superior properties than conventional materials at a reduced weight leading to their application in a wide variety of sectors, such as aerospace, biomedical and automotive. However, additively manufactured composites are highly susceptible to defects such as high void content and poor bond quality at the fibre and matrix interfaces. The current work deals with the non-destructive evaluation (NDE) of the mechanical behaviour of additively manufactured (AM) continuous carbon fibre reinforced polymer materials manufactured through Fused Filament Fabrication (FFF) method by means of Infrared Thermography (IRT) and Acoustic Emission (AE). AE monitoring was employed to record a wide spectrum of damage events enabling the identification and localisation of damage in relation to the applied load. IR thermography as a non-destructive, real-time and non-contact technique, allows the detection of heat waves generated by the thermo-mechanical coupling during the mechanical loading of the material. Through the online monitoring of the temperature distribution under monotonic loading the fracture behaviour was assessed, and the localisation of the final failure was achieved. Specifically, AM continuous carbon fibre reinforced nylon 12 samples with various fibre layouts and various infill patterns were manufactured through FFF. Their mechanical behaviour was assessed through concurrent non-destructive monitoring by means of AE and IRT. Damage mechanisms, stress concentration areas, microcracking events, localisation of damage events and early prediction of failure were successfully achieved through the combination of the two non-destructive methodologies. The thermographic assessment is in agreement with the AE results benchmarked by optical assessment, enabling the reliable mechanical behaviour monitoring of the additively manufactured continuous carbon fibre reinforced polymers.

#1228

# Continuous Recycled Carbon Fibre: Influence of Fibre-to-Preform Processing on Mechanical and Interfacial Properties

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In May 2022, carbon fibre (rCF) was successfully recovered from end-of-life composite pressure vessels in a continuous tow format. Demonstrated by the NCC in collaboration with Cygnet Texkimp and B&M Longworth, this represents a significant advancement in carbon fibre recycling because the resulting material matches the fibre format of virgin production, making it compatible with most preform manufacturing methods. Until this development, rCF had only been recovered in discontinuous form, producing composites whose mechanical properties were constrained by variability in fibre length, alignment, and inherent fibre properties. rCF is known to be a variable material, often with reduced mechanical performance. This has, to date, limited its use as a substitute for virgin fibre in high-performance applications. Although several short-fibre alignment technologies have been developed to valorise discontinuous rCF, the emergence of continuous rCF could offer a more consistent, higher-performance, and cost-competitive drop-in substitute for virgin carbon fibre, warranting in-depth study.

Currently, the performance potential of continuous rCF is not well understood. While mechanical property characterisation of rCF immediately after recovery is extensive, little is known about its performance during and after conversion into a preform. Physical and chemical fibre surface characteristics play an influential role at each stage of carbon fibre conversion. In theory, continuous rCF can be processed like its virgin counterpart; however, its surface condition often differs significantly. Upon recovery, rCF tends to exhibit a surface lacking sizing but retaining substantial and variable char residues.

This presentation outlines work done to determine the fibre-to-preform steps for continuous rCF and highlights where processing must diverge from virgin-fibre methods to accommodate rCF’s unique surface character. Quantitative data—including single-fibre tensile and micro-bond testing—from two studies are presented, demonstrating how electrochemical and thermal treatments, together with rCF re-sizing, influence surface homogenisation and functionalisation, and affect the fibre’s inherent mechanical and interfacial performance.

#1229

# Effect Of Nano-Silica, Nano Montmorillonite And Microcosmic Salt On The Flame Retardant And Mechanical Properties Of Epoxy Resin-Based Fiber Reinforced Composite

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The incorporation of nano-scale silica, nano-montmorillonite, and microcosmic salt into the epoxy matrix aims to enhance the flame retardancy, thermal stability, and mechanical performance of glass and sisal fibre-reinforced composites, addressing the need for advanced multifunctional materials in construction, automotive, and aerospace sectors. A series of hybrid composites was developed by varying the concentrations of these additives within the epoxy system. Flame-retardant behaviour was evaluated through Limiting Oxygen Index (LOI), vertical burning tests, and cone calorimetry, while mechanical performance was assessed using tensile and flexural tests. The results indicate that nano-silica significantly improves mechanical strength and stiffness due to its high surface area and strong interfacial interaction with the polymer matrix. Nano-montmorillonite enhances thermal stability and flame retardancy by forming exfoliated or intercalated silicate layers that act as a barrier to heat transfer and volatile diffusion. Microcosmic salt further contributes to fire resistance by decomposing at elevated temperatures to release non-combustible gases and form a protective char layer without compromising mechanical performance. The synergistic effect of combining nano-silica, nano-montmorillonite, and microcosmic salt yields composites with superior flame retardancy, improved thermal resistance, and enhanced mechanical integrity, making them suitable for applications that require high structural reliability and stringent fire safety standards.

#1230

# Study on chemical foaming in FFF and FGF 3D printing of PHA based blends

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Foamed polyhydroxyalkanoates (PHA) represent a significant advancement in sustainable materials technology, offering applications across multiple sectors such as sustainable packaging, biomedical and tissue engineering, and agriculture. However, several factors, such as low melt strength, brittleness, and a narrow processing window, pose challenges for the foaming of many types of PHA. Therefore, foam 3D printing, while being an innovative method to create lightweight structures with a high degree of freedom regarding shape and functionality, has not been a major focus for PHAs so far.

In the present work, blends based on semicrystalline poly(3-hydroxybutyrate-co-4-hydroxybutyrate) (sc-P34HB) and containing different chemical blowing agents (CBA) were prepared by melt compounding and further processed by filament extrusion and subsequently by 3D printing using the FFF (fused filament fabrication) method. A noticeable foaming effect correlating with the hot-end temperature was achieved, as indicated by a density reduction compared with non-foamed specimens. The foam structure was further investigated by scanning electron microscopy (SEM) analysis of fracture surfaces of the printed specimens. The mechanical performance was characterised by flexural and impact testing. Additional information on the flow behaviour of the blends was obtained from rheological characterisation, and differential scanning calorimetry (DSC) was used to gather information on the crystallisation behaviour of the blends as well as on the decomposition of the blowing agents.

In addition to the FFF printing trials, specimens for density measurement and mechanical characterisation were printed directly from pellets of selected formulations using the FGF (fused granular fabrication) method. For the purposes of the present work, this technique offers more flexibility in terms of material design than FFF and, moreover, reduces the risk of material damage by eliminating filament production as a processing step.

#1231

# Advanced modelling of composite materials for aerostructures: industrial state-of-the-art and challenges

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The certification by analysis of composite material aero-structures relies on linear modeling of their behavior, combined with empirical strength criteria calibrated against extensive databases covering all design domain parameters. This proven method, used for over 40 years, has enabled the justification of numerous composite aero-structures (V10F, Rafale, PH Falcon 900/2000, F7X tail, NEURON, etc.). While robust, this approach is limited by the initial design domain, generating risks, delays, and costs for any deviation—whether in new architecture design or in-service management of manufacturing defects and operational incidents.

The development of advanced modeling tools that simulate the damageable behavior of composite materials and their impact on failure mode prediction, followed by their integration into industrial processes, are therefore major challenges to control the risks, delays, and costs of composite aero-structures in design, production, or operation. Although the development of these tools has accelerated significantly over the past 10 years, their integration into industrial aero-structure justification processes still requires improving their maturity.

In this presentation, we will first discuss the development logics of advanced modeling, their maturity progression, and their integration into aero-structure justification processes at DASSAULT AVIATION. We will then illustrate these approaches and their current status with respect to delamination or ply failure. Finally, we will present the challenges we currently face in integrating these tools, particularly regarding the trade-offs between reliability, robustness, and complexity.

#1232

# Evaluating the Influence of Forming Process Simulation on the Performance of Recycled Composites for an Electric Vehicle Application

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In this preliminary study, digital twins of composite materials were developed to assess the feasibility of incorporating recycled materials into an electric vehicle (EV) component. The digital twins comprised process simulations of the forming stage and subsequent structural performance analyses of a mock-up battery lid under mechanical loading. Flow simulations were conducted using 3D Timon, informed by squeeze-flow measurements for viscosity characterization. A MATLAB-based algorithm was employed to map fibre distribution and orientation onto a mesh suitable for structural performance simulations, which were performed using LS-Dyna. Recycled PET-glass composites were compared with the PP-glass composites currently utilized in EV battery lids. The influence of incorporating process effects versus neglecting them was examined in both material systems to determine their significance in bollard test evaluations. Preliminary findings highlight the critical role of shear rate during both the characterization and flow modelling stages, particularly regarding its impact on fibre distribution uniformity. Future work will involve validating these simulations against experimental data as they become available, prior to drawing more definitive conclusions.

#1233

# Fully Discrete Modelling of Brittle Fracture Modes in Composite Materials

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Fiber reinforced composite materials play a pivotal role in modern civil and military aircraft by offering unparallel specific strength and tailorability. Being heterogeneous multiscale materials they, however, exhibit complex interacting failure modes. Two main methodologies have emerged to address the individual damage modes as well as the global behavior, namely discrete damage modelling (DDM) and continuous damage modelling (CDM). Thus, the delamination damage is most often described by DDM and explicitly meshing the interface combined with VCCT or cohesive zone models (CZM). It is the approach to modelling matrix cracking that is distinctly different in the two methodologies and allows for more accurate modelling of interaction between matrix cracking and delamination in DDM unless special meshing considerations, i.e. fibre aligned meshes are used in CDM. To date, however, no fully discrete modelling of all damage modes has been demonstrated and even with discrete x-FEM modelling of matrix damage a CDM methodology is needed for intraply (fiber) cracking. The principal issue here is the DDM modelling of complex inter-crossing crack networks, such as fiber cracks interlaced with matrix cracks or splits. The recently proposed Hierarchical Regularized x-FEM (Rx-FEM) technique is employed to allow such modelling. Note that the phase field technique has been previously applied in this context, however, it requires extreme mesh refinements to address the laminated nature of the composites. Another difficulty with the phase field methodology is modelling compression cracking where the nonpenetration condition must be enforced. The Rx-FEM, being a version of x-FEM, resorts to field enrichment and subsequent use of standard CZM for mesh independent crack propagation, which are well suited for tension-compression and mixed mode cracking. Both tensile and compression loading of carbon fiber composite laminates will be considered and the damage patterns and failure loads compared with experimental data.

#1235

# Effect of Moisture Absorption on the Dynamic Compressive Behaviour of Polymeric Syntactic Foams

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Polymeric syntactic foams are widely used in naval, submarine, and aerospace applications, where they are routinely exposed to moisture and water. These materials consist of a polymer matrix filled with hollow glass microspheres, creating a three-phase cellular structure that is sensitive to water uptake. As a result, moisture absorption can alter their mechanical performance. This study investigates the moisture intake and its effects on the mechanical behaviour of an epoxy syntactic foam and a polyamide syntactic foam.

Specimens were first dried in an oven at 75 °C, then fully saturated in deionised water, and finally re-dried until their mass stabilised. The mass change was continuously monitored to characterise the conditioning process. Quasi-static compression tests were conducted at a nominal strain rate of $10^{-3}$ $s^{-1}$, while high-rate experiments were carried out at approximately $3\times10^{3}$ $s^{-1}$. The compressive responses of dry, saturated, and re-dried specimens were compared to quantify the extent of degradation caused by moisture and to evaluate whether the effects were reversible.

Moisture absorption was found to significantly reduce the compressive performance of both syntactic foams under quasi-static and dynamic loading. In particular, compressive collapse strength decreased as moisture content increased. All material states exhibited pronounced strain-rate sensitivity, and the degree of this sensitivity was itself influenced by moisture uptake. At high strain rates, moisture was also observed to modify the deformation and failure modes.

The reversibility of moisture-induced degradation was examined through the re-drying cycle. Although both materials recovered a substantial portion of their compressive strength, the restoration was incomplete. The re-dried specimens consistently displayed lower compressive strength than the dry foams, indicating that moisture exposure causes partially irreversible changes to the material.

#1236

# Improving Fibre Segmentation in CFRP Micrographs Through Phase-Aware Shading Correction

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Accurate characterisation of fibre centroids, radii, and global/local volume fraction (Vf) from polished cross-section micrographs is essential for establishing reliable microstructural descriptors in fibre reinforced polymers (FRP). However, these images commonly exhibit low frequency illumination gradients caused by the imaging system and lighting conditions, introducing systemic bias into segmentation-based measurements. In addition, the laminates imaged in this study show substantial spatial variation in local fibre packing density, which produces corresponding brightness fluctuations: high Vf regions appear consistently brighter than low Vf regions. These microstructure driven intensity variations overlay the global shading field and further compound segmentation biases through higher frequency gradients. Existing shading correction algorithms - notably BaSiC, a low-rank/sparse decomposition model - were developed primarily for fluorescence microscopy rather than the three phase (void-resin-fibre) histogram structure of FRP micrographs, and are less efficient at mitigating the observed brightness/Vf coupling.

A “phase-aware” shading correction approach tailored to FRP micrographs is presented. The illumination field is inferred by cross-correlating local window histograms against the global void-resin-fibre histogram to estimate the required correction field intensity shifts. Additive and multiplicative passes are performed, each using a confidence model that down-weights windows whose local phase composition deviate from the global mix. Performance is assessed against BaSiC using a quantitative framework designed to isolate threshold insensitive effects: fibres are segmented once, centroids are used to compute a k-nearest-neighbour density local Vf proxy, and the maximum pixel values within each fibre serves as a brightness metric. The raw micrographs exhibit a positive correlation between fibre brightness and local Vf; the proposed method reduces this correlation more effectively than BaSiC, and performs comparably in removing low-frequency gradients. These results demonstrate that “phase-aware” shading correction markedly improves fibre segmentation, yielding more uniform fibre radius estimates across micrographs and offers a route towards standardised, bias-robust image processing for composites.

#1237

# A review of 20 years aeroelastic tailoring research at the Delft University of Technology

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A popular definition of aeroelastic tailoring is that it is the embodiment of directional stiffness in an aircraft's structural design to control aeroelastic deformation, whether static or dynamic, in a manner that benefits both the aerodynamic and structural performance of the aircraft. Although the concept sounds realisable, there are many challenges when it comes to designing manufacturable aeroelastically tailored designs. Extensive research has been carried out at the Delft University of Technology over the past 20 years. Mostafa Abdalla played a key role in these developments. This presentation will provide an overview of aeroelastic tailoring research, covering topics such as the appropriate fidelity of structural modelling for aeroelastic systems, lamination parameters, blending, fatigue constraints, and the interactions of the composite structure with control systems for manoeuvre and gust load alleviation.

In addition to describing the developed numerical models for aeroelastic tailoring, composite design optimisation methods, and interpreting the resulting designs, the presentation will also share information about various aeroelastically tailored experiments that have been conducted. These range from fatigue bench tests to static and dynamic wind tunnel tests of flexible wing models, demonstrating the benefits of aeroelastic tailoring. Even flight tests have been carried out on a 10m span drone.

The presentation will conclude by providing an outlook on the future of aeroelastic tailoring and a roadmap for the practical implementation of the technology in real aircraft wings.

#1238

# Decoupling compaction and flow in vacuum infusion: A local gradient sensing approach to property identification

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The race to net-zero depends heavily on the offshore wind industry, necessitating a 27 times scale-up of today's operations. Commercial trends are pushing production capacity and blade lengths beyond limits to meet escalating energy demands. However, blade defects will increasingly undermine such efforts by reducing turbine performance, increasing delays and downtime, and costing millions of euros in repairs. The most strategic opportunity for intervention is in the vacuum infusion manufacturing process, which is prone to dry spot defects that compromise blade quality and yield. By applying state-of-the-art sensor and process control technologies, manufacturers can potentially achieve right-first-time blade production, cutting rework costs and maximising competitive advantages.

The conventional use of sensors for flow front detection is not practically scalable to the enormous size of offshore wind turbine blades. However, combining sensors with flow simulations can drastically reduce the required sensor count – with the risk of undetected variations in the material properties leading to inaccurate flow front predictions, misjudged flow control and dry spot defects. To mitigate this, an efficient procedure based on Latin Hypercube Sampling and Nonlinear Least Squares regression calibrates the material properties in a Darcy flow model to match the measured data. Subsequent variations are detected, quantified, and incorporated into the flow front predictions. This real-time, corrected information can then guide the process toward right-first-time manufacture. The present work experimentally validates the methodology with real-world sensor data, quantifying its ability to accurately predict flow front progression by automatically detecting and accounting for defects in the preform.

The practical solution proposed maximises the information obtained from the fewest possible sensors, potentially making it applicable to large-scale serial production processes. The added resilience to processing and material variations will help to ensure defect-free production of wind turbine blades – a prerequisite for achieving scale and reliability to reach net-zero.

#1241

# Enhancing Damage Tolerance in Adhesively Bonded CFRP Leading-Edge Slat through Surface Toughening

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Structural adhesive bonds are a desirable joining method for light-weight composite structures. However, one main challenge regarding the certification of primary aircraft structures is that eccentric load transmission in single overlapping joints and elongation of adherends cause an inhomogeneous stress distribution along the bonded area. Stress peaks contributing to premature failure occur at overlap edges. The literature addresses many stress-reducing mechanisms, such as additional rivets. The surface toughening method is more advantageous for integration into fiber-reinforced plastics. This technology involves the local integration of thermoplastic films with higher ductility than adhesive and adherends. Depending on the position of the Poly(vinylidene fluoride) film along the bondline, disbond arrest or strength increase of structural bonds can be achieved.

In order to facilitate certification and material selection for the surface toughening film, a simulation-based determination of crack arrest and strength increase capability is aimed. For this purpose, an already available accurate progressive damage analysis for structural bonds is extended by the surface toughening material.

This work investigates the comparison of predicted and experimental results for strength increase and disbond arrest. For this purpose, Single Lap Shear (SLS) tests and Double Cantilever Beam (DCB) tests are modeled. Cohesive zone modeling for the adhesive layer and hydrostatic stress-sensitive Drucker Prager law for the surface toughening film are used. The simulated results show different accuracies towards the SLS and DCB experimental tests despite similar material laws for the surface toughening material.

In order to transfer this technology to larger aviation structures on subcomponent level, simulations of a foldable wing tip slat are conducted. The analysis aims to prove the damage tolerant design with surface toughening in the adhesively bonded slat-rip joint (risk reduction article). The simulation of this risk reduction article shows a strength increase and also disbond arrest effect with the help of surface toughening.

#1242

# In-situ Control and Modeling of the Liquid Composite Molding Process – Non-Intrusive Monitoring of the Degree of Polymerization

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The goal is to monitor the degree of curing of an epoxy resin during the Vacuum Resin Infusion process, using non-intrusive and non-destructive methods. To do so we combined numerical and experimental approaches to determine the link between the change in mechanical properties during the curing of the resin monitored with ultrasound waves by piezo-electric sensors, and the advancement of the polymerization. In order to establish this link, a reactional study was first conducted on the resin by Differential Scanning Calorimetry measurements, followed by a rheological study.

The models built from these studies were used to acquire entry values for a wave propagation model predicting the Lamb waves behaviour in the infusion mold. Numerical results showed that during the polymerization, the change in mechanical and geometrical properties in the resin has a noticeable effect on the wave propagation in the mould+resin system, which could be monitored by a network of piezoelectric sensors. From the viscosity and bulk modulus of the resin, the links established earlier allow its degree of curing to be directly determined. Experiments using a laser vibrometer on a plate coated with various oils showed a strong match with the propagation model, assuring the viability of this method to monitor the curing degree of a composite part. Curing reactions at different temperatures were then followed using a network of piezo-electric sensors to assess the feasibility of this method of polimerization monitoring in an industrial environment, leading to the observation of a strong effect of the curing reaction on Lamb waves propagation, especially after the gelification of the resin.

To conclude, this work shows piezoelectric sensors can be used to monitor the degree of curing during the VRI process in a non-intrusive way to guarantee the completion of the polymerization and avoid heating the composite for longer than necessary.

#1244

# Development of CFRP Incorporating CNT Fibers for Reducing Joule Heating and Shock Wave Damage under Lightning Strikes

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Carbon fiber-reinforced polymer (CFRP) is widely used in aircraft exterior materials due to its lightweight and excellent mechanical properties. However, compared to metals, its low electrical conductivity makes it vulnerable to lightning strikes. The resulting Joule heating and shock waves can lead to resin decomposition, fiber sublimation, and interlaminar delamination. Although many studies have focused on reducing Joule heating, the influence of shock waves has been rarely considered.

In this study, carbon nanotube (CNT) fibers with excellent electrical conductivity and specific strength were incorporated into CFRP to improve lightning-strike resistance. Two stacking strategies were designed, a surface-concentrated structure with CNT fibers placed only on the outermost layers, and an interleaved structure in which CNT fibers were periodically inserted between carbon fiber plies. The composites were fabricated using a vacuum-assisted resin transfer molding process and cured at 160 °C for 2 h.

Electrical conductivity tests confirmed that the incorporation of CNT fibers led to higher conductivity than conventional CFRP. Joule heating tests were conducted to examine electrothermal behavior. The CNT fibers effectively suppressed hot-spot formation by promoting current dispersion and through-thickness heat transfer, thereby mitigating local thermal degradation. Shock waves analysis revealed that conventional CFRP suffered severe damage, whereas CNT fiber–CFRP efficiently absorbed impact energy and minimized damage propagation. The mechanical performance showed that the interleaved structure exhibited significantly improved strength compared with the surface-concentrated structure due to the fiber-bridging effect at CNT fiber–CF interfaces.

Overall, the incorporation of CNT fibers into CFRP mitigates both primary lightning-strike damage mechanisms, Joule heating and shock waves. These results provide an effective design strategy for improving the safety, conductivity, and durability of aircraft exterior composites.

#1245

# Self-Sensing Capability of Hybrid Short Carbon/Glass Fiber Thermoplastic Composites for Damage Monitoring under Static and Fatigue Loading

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The demand for cost-effective and integrated Structural Health Monitoring (SHM) solutions is critical for the wide adoption of lightweight, complex composite materials in high-volume industries, particularly automotive. This work investigates the intrinsic piezoresistive behavior of Hybrid Short Carbon/Glass Fiber Reinforced Polyamide 66 (PA66) composites (51% total fiber content) to serve as a self-sensing material for damage detection.

The study employed Electrical Resistance Monitoring during comprehensive experimental campaigns. Specimens were subjected to static tensile testing and cyclic fatigue loading with a specific stress ratio of 0.1. In static loading, the relative change in electrical resistance showed a gradual, consistent increase, with an accelerated rate observed immediately prior to ultimate failure. This trend was successfully correlated with the progression of internal damage, specifically matrix cracking and subsequent fiber breakage.

Under fatigue conditions, the composite exhibited a clear drift in the mean electrical resistance, directly mapping the accumulation of irreversible damage. Furthermore, the alternating current signal showed a dynamic piezoresistive response whose magnitude was proportional to the instantaneous strain amplitude.

To demonstrate real-world applicability, the SHM technique was successfully implemented on a full-scale automotive suspension component. This component was tested under both static and fatigue conditions, confirming the potential of the approach for damage tracking in complex geometries. The primary advantage of this methodology lies in its simplicity, reduced cost, and elimination of external sensor integration. Future work will focus on modeling and mitigating the observed challenges, including signal variability and high scattering between specimens, and the combined influence of multiple damage effects on the measured resistance signal.

#1247

# From Scan to Part: A Digital Process Chain for Robotic 3D Printing of Fiber-Reinforced Thermoplastics on Curved Thermoset Surfaces

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Carbon fiber–reinforced polymers (CFRP) are essential materials for lightweight design due to their high strength-to-weight ratio. However, conventional mold-based manufacturing methods constrain geometric freedom and frequently rely on labor-intensive hand layup or secondary joining technologies to realize complex components. Moldless additive manufacturing approaches, such as fused filament fabrication using short or continuous carbon-fiber-reinforced thermoplastic, provide a viable alternative for producing stand-alone parts. These approaches also enable local enhancement of existing CFRP structures, allowing realization of geometries that would otherwise require joining operations. Nonetheless, direct material deposition onto thermoset substrates is typically hindered by interfacial incompatibility. This challenge can be mitigated by co-curing a thermoplastic interlayer film that provides a re-activatable bonding surface for subsequent deposition of fiber-reinforced thermoplastics.

Despite achieving material compatibility, reliable material deposition remains challenging due to geometric deviations between the digital model and the manufactured component, rendering offline path planning unreliable. Conventional 2,5D manufacturing systems are further limited by collision risks and insufficient nozzle orientation during non-planar material placement on curved substrates. To address these challenges, this study presents a digital, actual-surface-based process chain implemented on a multi-axis robotic manufacturing system for fabricating thermoset–thermoplastic hybrid components. The methodology integrates an in-situ laser line scanner to capture true substrate geometry and drive surface-based slicing algorithms that automatically generate robot paths. This adaptive approach maintains constant nozzle-to-substrate distance, avoids collisions, and ensures proper nozzle orientation for reliable adhesion.

The feasibility of this workflow is demonstrated through three validation strategies: (1) baseline deposition onto planar substrates, (2) adaptation to curved geometries, and (3) the functional reinforcement of curved components using continuous carbon fibers in a triangular mesh pattern. Experimental results confirm the successful fabrication of hybrid structures without the use of mold tooling or secondary adhesive bonding, validating a robust framework for the moldless functionalization of composite parts.

#1249

# Experimental investigation of the creep response of a 12.6m wind turbine blade

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Wind turbine blades are manufactured from fiber-reinforced composites due to their light weight and relatively high stiffness and strength. However, the polymer matrices are viscoelastic and show creep even at environmental temperatures. The viscoelastic response of the structure can lead to bigger deflections in operation. In addition, the cross-talk calibration of bending moments based on strain measurements becomes a function of time. The accuracy of cross-talk calibration affects the accuracy of static and fatigue testing. Therefore, investigation of the creep response of the wind turbine blade is essential for both standard certification testing and safe operation.

In this study, a 12.6m wind turbine blade made of glass fiber composite is tested under various constant creep loads, and the strain response at several cross sections and multiple positions in each cross-section is recorded up to 6 hours. The target loads are calculated based on aeroelastic ultimate bending moments that the blade undergoes during its operation. Constant creep loads equivalent to 30 to 60 % of ultimate static loads are applied by hanging dead weight at two saddles connected to the blade at radial positions 5.2m and 9.4m. In this way, the target bending moment distribution along the blade was simulated by two linear bending moment distributions.

It is observed that the blade shows creep strain in both flap and edgewise directions. The strain growth is less pronounced in the flapwise direction due to spar caps made of unidirectional composites with minimum creep response. However, strain development in the edgewise direction is considerable even in shorter loading times.

#1250

# Composites demanufacturing using debondable primers with expandable microspheres – a preliminary study of the debonding process

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Fibre-reinforced composites are key materials in the decarbonisation of manufacturing sectors such as aerospace, automotive and energy. With their suitability for lightweight design and their excellent durability, they are indispensable for a successful transition to renewable energies. However, achieving circularity with composite materials remains a major challenge. Whilst several recycling technologies have now reached technological readiness, many of these have limitations with respect to the materials post-recovery. New strategies targeting the disassembly process are needed to increase demanufacturing efficiency and to better preserve material properties. Fibre length is a key contributor to composites' high performance, and its preservation during demanufacturing is a major hurdle, but also a compelling target.

We explore a novel concept based on the introduction of a debondable primer between plies to allow for a targeted delamination at the end-of-life stage of a composite component, either to separate layers entirely, or to ease the start of such a separation. The primer carries small expandable acrylate thin shells containing volatile hydrocarbons. These microspheres trigger the separation by inflating at a specified temperature threshold. Preliminary experiments have shown that this expansion is sufficient to cause interlaminar separation in a thermoset laminate.

In this study, the behaviour of the expandable microspheres and of the microsphere-loaded primer were further explored using a combination of techniques. The expansion of the microspheres was studied combining hot-stage microscopy, DSC and simultaneous DSC-microscopy with image processing to establish microsphere dimensions following different thermal histories. Thermogravimetric experiments facilitated the determination of the hydrocarbon content, and thermomechanical experiments provided an estimate of expansion pressures. A physical model was assembled to aid with the prediction of microsphere behaviour during a triggered delamination. This design-for-disassembly approach is a promising route for enabling single ply recovery (and hence preserving fibre length) at end-of-life.

#1251

# Modelling and investigation of composites with predefined failure

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Polymer composites are gaining popularity due to their excellent mechanical properties and low density. However, in safety-critical applications, their failure process can be disadvantageous. The failure of composites is a complex phenomenon, consisting of several concurrent damage processes leading to the failure of a composite part. However, with the proper design of the composite system, this failure behaviour can be turned to our advantage, contributing to increased reliability of polymer composite materials.

Our research group developed a novel method to create composites with a designed interface via 3D printing specific patterns of polycaprolactone (PCL) interlayer material directly on the reinforcement system. PCL is soluble in epoxy; therefore, in polymer composites with an epoxy matrix, it does not create a new phase. PCL is able to locally modify the interfacial adhesion and the matrix material. Therefore, it can be used to modify the failure of composites by controlling delamination, increasing fracture toughness, and achieving pseudo-ductile behaviour. Furthermore, by applying PCL as clever interfacial patterns in the composite structure, the formation of damage and the final failure may be predefined in terms of mode and position.

In the current study, we carried out analytical and numerical modelling of UD carbon-fibre/epoxy composites containing regions modified with PCL to achieve a better understanding of the mechanisms of the interface engineering method and the effects related to the geometry of the PCL pattern on the damage processes and the failure behaviour of the composite part. Furthermore, we manufactured locally interfacially engineered composite plates and conducted material testing under the same loading conditions to validate the modelling results.

The study demonstrates that local interface engineering using 3D-printed PCL patterns provides a powerful tool to tailor the failure behaviour and improve structural reliability. The results can also contribute to the design process of composites with predefined failure.

#1252

# Additively manufactured high-performance polymer and composite for pump application

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Light-weighting is seen as the major source of industrial sustainability in the rotating machinery design. Polymers and polymer composites are gaining more acceptance in mechanical components industry due to the numerous advantages they possess over the traditional metallic materials.

This work focused on developing a novel solution to enabling new innovative lightweight propeller for downsizing drivetrain of a chemical pump in order to gain a significantly gain in energy efficiency. Material validation and integrity analysis through lab testing and finite element modelling were carried out respectively. The study involved an investigation of material chemical stability, thermal stability, thermo-mechanical behaviour, creep, fatigue, erosion, structural integrity, and dimension stability.

The results showed that all 5 selected materials (including additive and moulded materials) prove to be corrosion resistant to hot concentrated acid. Despite acid absorption (additive materials absorb more moulded counterpart due to large void content in additive material), their material properties are not negatively affected. Temperature effect was found more detrimental to the selected materials and lead to strength/stiffness loss, accelerated creep, reduced fatigue life, reduced propeller safety margin and dimension stability. Consequently, upper limit use temperature was found for long-term operation.

This study has demonstrated a strong possibility of using additive engineering polymers, and fibre-reinforced composites to create a wide range of new propellers/impellers for lightweight pumps. It opens up a new opportunity for innovative pump solutions.

#1253

# Material Processability of Continuous Reclaimed Carbon Fibre Tow Using Braiding

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This research presents the successful manufacture of braided composite tubes using 100% continuous reclaimed carbon fibre tow. This was completed as part of the award-winning Centre of Expertise in Advanced Materials and Sustainability (CEAMS) program. This work represents the first demonstration of processing reclaimed tow through the complete braiding workflow, from bobbin rewinding to the preforming stage of fibre deposition onto the mandrel.

Many composite manufacturing processes, including braiding, process the fibre reinforcement in a continuous tow format. This has restricted the use of reclaimed carbon fibre in this manufacturing process. To address this, Cygnet have developed the DEECOM® process designed to recover continuous carbon fibre from filament wound components. In this work, reclaimed T700s 12K tow, recovered via the DEECOM® process, was compared against virgin T700s fibre. The reclaimed tow was produced by filament winding onto aluminium cores, curing, and subsequently processing through DEECOM®. Continuous tow was then unwound, rewound onto braider bobbins using the NCC's CEZOMA winder.

Braiding and subsequent downstream processing of both reclaimed and virgin fibres was conducted using experimental facilities at the NCC and at the University of Nottingham (UoN). Fibre preforms were manufactured using the Steeger 48-carrier braider at the UoN. The infusion of the tubes took place at the NCC. 50mm diameter tubes were manufactured with both reclaimed and standard T700s fibres.

Manufacturability and processability were evaluated at each stage for both reclaimed and virgin fibres. The study confirmed that reclaimed continuous tow can be successfully braided into preforms and infused into components without compromising the manufacturing process. This achievement demonstrates a viable route for incorporating reclaimed carbon fibre into advanced composite manufacturing, offering significant sustainability benefits and reducing reliance on virgin materials.

#1257

# Traction-Separation Law of Bonded Composite Joints from Back-Face Strain via Optical Fibers

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The demand in developing high-performance structures has led to the vast application of adhesively bonded bi-material joints, typically composites-to-metal joints. The understanding of the failure mechanisms in such joints with ductile adhesives is still limited due to the stiffness and loading asymmetries across the non-linear interface. The traction-seperation relationship (TSR) is essential for analysis, design of bonded joints on top of the failure behavior understanding. However, the well-established experimental techniques for charaterizing the fracture behavior of bonded joints are inadequate in properly obtaining TSRs of bi-material joints bonded with ductile adhesives due to the asymmetries.

To address this issue, a novel experimental procedure has been developed to extract the TSR of bi-material joints. This methodology consists of two critical steps: first, the accurate measurement of strain distributions on the back surfaces of beam-configured bi-material joints, and second, the establishment of a quantitative relationship between the interfacial traction-separation distribution and these measured strain fields. To achieve the required precision, optical fibers with a high spatial resolution of less than one millimeter are employed for strain measurement. Subsequently, classical beam theory is applied to derive the analytical relationship that connects the mechanical distributions at the interface to the strain profiles on the outer surfaces of the bonded joints.

Double Cantiliver Beam (DCB) and End Loaded Split (ELS) tests were conducted on CFRP-to-titanium bonded with a ductile adhesive Araldite 2015. A strain based design criterion was used to design the joint to obtain pure mode I and mode II TSRs. The novel procedure was employed to experimentally obtain the TSRs. The results demonstrate that this approach not only accurately determines the TSRs but also precisely identifies crack tip locations and reveals the detailed failure mechanisms within the fracture process zone.

#1258

# Capacitive IoT Strain Sensing System for Structural Health Monitoring of Non-metallic Pipes

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In the energy sector, there is increasing interest for implementation of Non-metallic pipes due to their lower cost, ease of handling due to lighter weight and resistance to corrosion. However, as their application is newer than traditional metallic pipes, the knowledge on their behaviour and failure mechanisms in the field as well as the methods to manage their integrity is far less established. In response to this, a new IoT system based on patented capacitive strain sensors was developed to address the unique challenges of continuous Structural Health Monitoring in non-metallic pipes. Non-metallic pipes, due to their polymer-based construction have a much higher failure strain (>10000 microstrain) than common civil materials (i.e. concrete or steel, which typically fail <5000 microstrain) while at the same time experience relatively low operational strain due to their conservative design. Failure is not always associated with design operational loads but may occur from unexpected environmental factors such as soil settlement which takes place over a long period of time. Thus to monitor such conditions, a capacitive IoT system was developed to provide high sensitivity (~1 microstrain) while at the same time having very high measurement range (>10000 microstrain) compared to commercial resistive strain gauge systems. The system was also designed to have hardware interchangeability between transmitter and receiver enabled by a peer-to-peer communications network which lowers cost, enhances scalability of deployment and reduces constant transmission for better data security. Validation and benchmarking tests are presented under simulated operational loads and environmental conditions on pipe sections representative of the real assets targeted in the field, showing good performance compared to commercial alternatives. Finally, the system presents a potential pathway for further development of capacitive sensing systems in the field which can enable monitoring of other vital parameters such as aging of materials or curing of joints.

#1259

# Composite Magnetic Filament Fabrication and Characterization for Magnetically-Assisted FFF Aplication

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Magnetorheological (MR) composites, typically reinforced with ferromagnetic particles, possess the ability to exhibit tunable mechanical properties that can be controlled rapidly and reversibly by the application of an external magnetic field. MR composites can undergo reversible transformations that makes them ideal for multiple applications, including smart actuators, sensors, vibration dampers, and reconfigurable structures. This rapidly reversible transformation, known as the MR effect, encompasses controllable stiffness and frequency-dependent viscoelastic behavior. However, the full potential of the MR materials is often limited by the inability of traditional manufacturing techniques to create complex geometries. This study explores fused filament fabrication additive manufacturing as a viable pathway to address this fabrication constraint. It focuses on the formulation and extrusion of functional MR filaments, specifically balancing particle load with the rheological requirements for successful extrusion. Filaments are fabricated on a low-cost extruder machine using three polymeric matrices: polylactic acid and polycaprolactone, both manufactured in-house, and a commercially available polylactic-acid-reinforced composite filament from PROTOPASTA. During the analysis, each matrix was functionalized with fine iron oxide particles at three different weight percentages: 15 wt%, 30 wt%, and 45 wt%. Dog-bone samples of the composite filaments resulting from this work underwent initial analysis using optical microscopy to assess particle dispersion, followed by mechanical testing. The effect on the magnitude of the MR effect is studied to identify the optimal weight percentage and matrix material that minimizes common print defects (e.g., nozzle clogging, poor layer adhesion) while maximizing the mechanical response obtained when applying a magnetic field to an already printed part. The successful development of these functional filaments will provide guidelines for improving the quality of printed MR composites and advancing the potential of tailored mechanical properties of 3D-printed smart components.

#1260

# Dual CAN assisted self-healing and graphene oxide reinforced carbon fiber/epoxy laminates

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This work presents a dual dynamic covalent adaptive network (CAN) vitrimer sizing as an effective interfacial modification to enhance mechanical performance and impart self-healing capability to carbon fiber-reinforced epoxy (CFRE) composites. The dynamic crosslinker 3,3-dithiodipropionic acid, combined with a DGEBA epoxy prepolymer, generates a dual dynamic CAN within the system. Thermal transitions, degradation behavior, and viscoelastic properties were characterized by DSC, TGA, and DMA. The vitrimer-based sizing, together with graphene oxide (GO) dispersed in the matrix, acts synergistically, increasing interlaminar shear strength and flexural strength by 23% and 18%, respectively. After a healing treatment at 180 °C for 30 min, the interlaminar shear strength showed a 46% recovery. The GO–CFRE composite also exhibited an electromagnetic interference shielding effectiveness of −46 dB, and the modified system was further evaluated for electrothermal heating and de-icing performance.

#1261

# Coupled high-pressure resin transfer molding process and structural impact simulations for automotive composites

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Owing to excellent energy absorbing characteristics, fiber-reinforced plastic (FRP) composites may be suitable for automotive crash structures with potential to improve safety. While HP-RTM processes with highly reactive resins are more broadly considered for high-volume production automotive structures, they are prone to inducing defects in the final part such as fiber misalignment and wrinkling, void formation, and variations in resin degree of cure. Thus, it is imperative that process-induced defects are considered to accurately predict the impact performance of as-manufactured parts.

This paper provides a comprehensive overview of a collaborative project focused on developing a high-fidelity coupled HP-RTM process and structural impact simulation toolkit for unidirectional non-crimp fabric (UD-NCF) carbon fiber snap-cure epoxy composite structures. First, a two-stage process simulation model was developed to capture fabric preforming and resin infiltration/curing. The membrane, bending, and friction behaviour of a binder-stabilized UD-NCF was characterized and used to calibrate a hyperelastic material model, which was used in a validated macroscopic fabric forming simulation model. A local thermal non-equilibrium energy model was developed to simulate resin infiltration and rapid cure, whereby variations in degree of cure and part warpage were predicted for representative parts with various geometries. Next, the strain rate-dependent orthotropic response of the studied material was characterized and a new user-defined material model and invariant-based failure criteria were developed. These were validated for various multidirectional laminates, prior to integration into the commercial finite element software LS-DYNA. Finally, the two-stage process simulation model was coupled with a structural simulation model to predict the impact performance of various representative parts, whereby process-induced defects were mapped using deep-learning models. The results demonstrated that considering the process-induced defects improved the fidelity of the impact performance predictions. Ongoing work is focused on using the developed simulation toolkit to design an automotive frontal crush structure.

#1262

# Multifunctional and sustainable hybrid composites based bio-epoxy reinforced with basalt fiber and short recycled carbon fiber

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The drive towards greener composite solutions motivates the development of structural and semi-structural materials that combine bio-based constituents, recycling strategies and embedded functionality. Composite laminates were manufactured using a bio-based epoxidized resveratrol resin (RESEP) reinforced with continuous basalt fibre fabrics, and further modified with mechanically recycled short carbon fibres dispersed in the matrix in contents optimized to reach electrical conducitivity. The aim was to obtain sustainable laminates with high glass transition temperature, enhanced multifunctionality and potential for applications in transport and energy sectors requiring elevated service temperatures while giving a multifunctional approach due to electrical conductivity.

Composites were produced by hand lay-up followed by hot-press curing, and their thermal, mechanical, electrical and electromechanical properties were characterised. Dynamic mechanical thermal analysis showed glass transition temperatures close to 300 °C for all systems, indicating that the matrix Tg approaches the onset of thermal degradation and enabling high-temperature operation. TGA analysis of the matrix revealed high solid residue content which is also an indicator of good potential for fire resistance.

Flexural and interlaminar shear tests revealed that adding 7.5 wt.% recycled carbon fibres improved the elastic modulus by around 14% and slightly increased interlaminar shear strength, owing to the additional short-fibre reinforcement bridging adjacent plies.

The incorporation of recycled carbon fibres also generated a percolated electrically conductive network which enabled Joule heating above 100 °C at low voltages and effective de-icing of 2.5 mm ice layers in tens of seconds. Moreover, in situ monitoring of electrical resistance under three-point bending and ILSS loading demonstrated a gauge factor above 7, clearly outperforming conventional metallic strain gauges and allowing damage-sensitive structural health monitoring. These results demonstrate that RESEP–basalt–recycled carbon fibre laminates are promising candidates for sustainable, high-Tg, self-sensing and de-icing composite structures aligned with the sustainability and multifunctionality required by the future composite industry.

#1263

# A novel coupled mechanical-permeability approach for predicting hydrogen leakage in LH2 composite tanks

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As the world advances toward a sustainable future, hydrogen has emerged as a transformative alternative to conventional fossil fuels, offering the potential for zero-emission aviation. Despite this promise, one of the primary obstacles lies in storage. Hydrogen, being the smallest and most diffusive molecule, easily penetrates materials, particularly fibre-reinforced composites, where microscopic damage can create pathways for leakage. Understanding and predicting this phenomenon is critical not only for minimizing hydrogen losses but also for preventing explosions, given hydrogen's wide flammability range.

This study presents a modelling strategy to simulate hydrogen permeability in composite laminates, explicitly accounting for microscale defects and inter-fibre cracks. The approach integrates a coupled mechanical-permeability framework based on Darcy's law. Continuum Damage Mechanics is correlated with the permeability coefficient, establishing a novel link between crack opening displacements and permeability, a concept not previously extended to hydrogen leakage modelling.

The methodology is applied to analyse the influence of ply thickness and crack density on leak rates. Results demonstrate that thin plies act as effective barriers, delaying the onset of leakage and reducing overall permeability. Furthermore, the framework is extended to estimate leak rates in laminates after a loading cycle, producing values consistent with reported experimental data. Building on these findings, a leakage onset criterion is proposed to compute the critical leak rate for composite tanks.

Overall, the study provides a predictive tool for assessing hydrogen leakage onset and rate in composites. While the results are presented for representative volume element laminate models, the method is readily applicable to full-scale hydrogen tanks.

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#1265

# Multi-Fidelity Bayesian Optimisation for Inverse Design of Cellular Composites with Targeted Nonlinear Mechanical Response

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Machine learning and additive manufacturing have opened new possibilities for creating architected materials with tailored properties that exceed those found in nature. Although inverse design provides a data-efficient alternative to traditional trial-and-error approaches, most existing methods rely either on large datasets or on limited high-fidelity data from simulations and experiments. This becomes particularly challenging for architected materials with nonlinear mechanical behaviour, where complex deformation modes demand expensive evaluations. This work introduces a multi-fidelity Bayesian optimisation (MFBO) framework for the inverse design of cellular composites, targeting their full nonlinear response. By combining information from multiple fidelity levels and using a similarity metric to scalarise the response, the framework enables efficient exploration of the design space while reducing dependence on costly evaluations. The approach is demonstrated on spinodoid cellular composites using finite element analyses and validated through compression tests on short carbon-fibre reinforced PET-G specimens. Four target responses and three multi-fidelity strategies are benchmarked against a standard single-fidelity method. Across all cases, MFBO yields higher similarity scores and more reliably recovers the desired responses within the same evaluation budget. These findings highlight the potential of MFBO for the inverse design of stochastic architected materials, where high-quality data are limited but lower-cost proxies are available, enabling the creation of composites with precisely controlled nonlinear mechanical behaviour.

#1266

# Self-Healing Performance of Ionomer Integrated Composite Structures under Impact Damage

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Self-healing structures offer a promising route to enhancing survivability and extending service life in aerospace and defense applications. Ionomer enabled self-healing offers a practical approach to mitigate impact damage in composite structures. Ionomer based healing systems have been widely investigated for projectile-induced damage recovery. However, most studies focus on ionomer monolithic plates or thermoplastic laminates rather than hybridized composite structures. In this work, Surlyn® 8940 ionomer was integrated into a fiber reinforced polymer (FRP) composite architecture to evaluate its healing performance under impact and its behavior under fluid exposure. Comprehensive characterization performed on the ionomer integrated material included fluid permeability, tensile strength after fluid susceptibility conditioning and seam adhesion testing to assess mechanical integrity and fluid environment durability. Ionomer sheets with thicknesses of 2.0, 3.0, 3.5 and 4.0 mm were fabricated by hot pressing and impact performance was assessed using varying projectiles. Consistent with the literature describing healing driven by localized thermal softening and viscoelastic recoil, monolithic ionomer specimens exhibited partial recovery below 3 mm and complete closure of damaged zone at thicknesses above 3 mm. When embedded in the composite structure, the ionomer layer required greater thickness to achieve acceptable healing, revealing a confinement and substrate interaction effect that degrades the apparent healing ability compared with monolithic ionomer samples.

This study presents one of the first systematic evaluations of ionomer / FRP composite hybrid structures for self-healing architectures and identifies critical thickness thresholds for impact damage recovery in composite structures. Findings extend the current understanding of ionomer healing mechanisms by highlighting influence of substrate confinement, providing an experimentally validated design guideline for implementing ionomer-assisted self-healing in composite structures.

#1267

# Development of a mono composite leaf spring for light logistic truck using Finite Element Method

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This paper presents the development of a mono leaf composite spring for a logistic light truck. Glass fibre has similar strength and much lower modulus compared with carbon fibre and is ideal for making composite leaf springs, as certain thicknesses of the spring at different positions have to be maintained to keep the stress levels in different material directions within a safe range for a given fixed stiffness. Polyurethane resin has high strength, toughness and excellent processing properties. Thus the leaf spring in this study is made of glass fibre reinforced polyurethane composite. Main material stiffness and strength have been tested and the results have been presented in this paper. The spring specimens were made via high pressure resin transfer moulding process. Stacking sequence design and processing conditions have been optimized and presented here. Load levels at different loading conditions such as proof, starting and cornering have been considered. The spring's stiffness and ways of connection to the vehicle remain the same as those of the substituted steel leaf springs. Theoretical and finite element methods have been used for design optimization of the spring. Stress levels at different material directions under various loading conditions have also been predicted and presented in this paper. All maximum stress levels are within safe ranges and the predicted load deflection curve shows the spring stiffness meet the requirement well. Fatigue tests under the load range between tare and 2.3 time of laden load have been conducted and all five sample springs tested have passed 200,000 cycles. Two spring specimens have also been test on a proving ground and have passed 6000 km without any damage.

#1269

# Surface characterization of agro-industrial by-products for composites applications

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The objective of the work is to investigate the surface properties of different agro-industrial by-products in order to develop new bio-based composites materials. Four by-products were selected as reinforcement fillers : coconut shells, canarium fruit cores, palm kernels shells and raffia fruit cores.

The chemical composition of the by-products surface was determined by Fourier Transform Infrared Spectroscopy (FTIR), using an Attenuated Total Reflection (ATR) device, in order to identify the chemical groups present on the materials surface. The wettability properties of the by-products were also investigated by contact angles measurements in order to quantified the surface energy, which is an important parameter to predict the wetting of the material by a polymer resin. The thermal properties were determined by thermogravimetric analysis (TGA), in order to quantify the moisture content, the thermal degradation steps and the ash content of the biosourced materials. Correlation between surface energies values and chemical composition are proposed, and the results allow us to identify the more suitable biosourced material. Composites materials have been obtained by mixing particles of by- products with an epoxy matrix. Mechanical and thermal properties of initial by-products and final composites materials have been investigated by tensile test. The correlation between surface properties of by-products and composites performances was analysed.

#1271

# Regenerated Cellulose Fibre Composites: From Processing–Structure Relations to Advanced Sustainable Applications

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Regenerated cellulose fibres have attracted increasing attention as demand for sustainable, high-performance materials continues to grow. Produced by dissolving and regenerating natural cellulose, these fibres combine the advantages of a renewable resource with high structural uniformity, thereby overcoming key limitations of natural fibres such as inconsistent quality and limited reproducibility. This work provides a comprehensive review of regenerated cellulose fibre types, their manufacturing routes, processing techniques for composite formation, and the resulting mechanical and functional properties. Additionally, recycling pathways, durability aspects, and industrial application trends are synthesised to offer a holistic overview of current developments in the field.

Our analysis indicates that although the intrinsic properties of regenerated cellulose fibres vary considerably, due to differences in sourced raw materials and production processes, the mechanical performance of the resulting composites is primarily governed by the choice of polymeric matrix and the associated processing strategies. Thermoplastic matrices such as PLA and PP, thermosetting resins, and all-cellulose composites were examined across a broad spectrum of reported tensile strengths. The findings highlight that achieving high-performance composites depends strongly on selecting an appropriate matrix system and precisely controlled processing conditions. Furthermore, the manufacturing techniques used, including pultrusion, compression, and injection moulding, and increasingly 3D printing, significantly influence the microstructure and final material properties.

Despite their clear technical and ecological advantages, regenerated cellulose fibre composites have not yet achieved widespread market penetration. In addition to remaining processing challenges, this may partly stem from consumer perceptions of these materials as “unnatural,” despite their fully bio-based origin. This suggests that advancing the field requires not only further optimisation of fibre–matrix interactions and processing techniques but also strategic communication efforts to reshape perceptions and support broader acceptance. Together, these insights underline the substantial potential of regenerated cellulose fibres as sustainable, high-performance reinforcements for next-generation composite materials.

#1273

# Evaluation of resin temperature and pulling speed effects on CFRP and GFRP properties in closed injection pultrusion process

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Pultrusion is widely employed as a continuous manufacturing process for fiber reinforced polymer (FRP) composites due to its advantages of high production efficiency, low manufacturing cost, and consistent mechanical properties. In particular, pultruded FRPs are gaining attention as a potential alternative to conventional metal and concrete based structural materials in the construction sector, where cost efficiency is a critical factor.

Conventional pultrusion typically utilizes an open resin bath for fiber impregnation, which presents significant drawbacks such as excessive resin waste and high sensitivity to environmental conditions.

As a promising alternative, the Closed Injection Pultrusion (CIP) process has emerged to address these limitations. However, quantitative studies on process optimization for CIP remain limited.

This study experimentally investigates the effects of two key CIP process parametersresin temperature and pulling speed on the quality and mechanical performance of pultruded CFRP and GFRP composites.

Specimens were fabricated under varying resin temperatures and pulling speeds, and evaluated in terms of hardness, impregnation quality, void content, and tensile strength.

The results revealed that for both CFRP and GFRP, increasing the pulling speed from 30 cm/min to 50 cm/min led to a reduction in hardness from23.6% to 62.39%, and a decrease in tensile strength from 8.81% to 14.78%. In contrast, the effect of resin temperature on hardness and tensile strength was found to be negligible. These findings suggest that pulling speed has a more significant influence than resin temperature on the impregnation quality, void content, hardness, and overall mechanical performance of the composites.This study provides valuable insights into the optimization of process parameters for the CIP method and contributes to the advancement of efficient, high-quality FRP composite manufacturing for applications in construction and other industrial fields.

#1276

# Fabrication and Integration of Laser-Induced Graphene on Aerospace-Grade Thermoplastics for Structural Damage Monitoring

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This work presents the fabrication and characterization of laser-induced graphene (LIG) strain sensors integrated on aerospace-grade thermoplastic substrates for structural health and damage monitoring. LIG enables tunable electrical and mechanical properties through direct laser patterning, providing lightweight, flexible, and robust sensing elements that are fully compatible with thermoplastic composites used in aerostructures.

To identify the most efficient design, LIG sensors with different geometries—including U-shaped, meander, and linear patterns—were fabricated under varying laser power and scanning parameters. The resulting structures were comparatively analyzed to determine the optimal combination of geometry and processing conditions for maximizing strain sensitivity and electrical stability. Complementary COMSOL Multiphysics simulations were carried out to model the material under test (MUT) and to resolve the strain and electric field distributions for the different sensor layouts.

Sensor performance was evaluated using AC impedance spectroscopy under controlled mechanical loading, allowing correlation of impedance variations with structural deformation and early-stage damage initiation. Surface morphology and structural properties were characterized by SEM, Raman spectroscopy, and XRD, confirming the formation of high-quality porous graphene networks with strong adhesion to the thermoplastic substrate.

Overall, this study demonstrates the potential of LIG-based sensors as highly sensitive, flexible, and integrable solutions for damage monitoring in aerospace thermoplastic structures, paving the way toward smart, self-monitoring composite materials.

#1277

# Paper-Based Printed Sensors for Multifunctional Monitoring in Fibre-Reinforced Composites

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Digitalisation is rapidly transforming the composite sector, with structural health monitoring (SHM) becoming increasingly important for ensuring performance, safety and durability. Conventional sensors used for SHM are often bulky, difficult to integrate into fibre-reinforced polymers, and can introduce foreign-body effects that negatively influence the composite's structural integrity. To address these limitations, this work presents an innovative approach using printed sensors on renewable paper substrates as multifunctional, lightweight, and easily embeddable monitoring elements for composite structures.

In this study, paper-based printed sensors were developed and applied to monitor key phenomena relevant to composite manufacturing and long-term performance, including cure behaviour, moisture intrusion, strain evolution, and crack formation. The curing behaviour of epoxy-based composites reinforced with glass and natural fibres was characterised by tracking impedance changes during polymerisation, enabling a non-destructive and real-time assessment of the degree of cure. Moisture ingress, one of the critical degradation mechanisms in polymer composites was monitored through impedance variations correlated with water uptake inside the laminate.

To evaluate mechanical response, highly sensitive strain measurements were achieved using printed silver-ink sensor patterns on paper substrates, which enabled the detection of very small strain levels (<2%) in the composites. Crack detection was implemented by laminating printed conductive tracks directly onto the composite surface; the occurrence of cracks caused a measurable loss in electrical resistance, providing a simple yet effective damage-detection mechanism.

Overall, the integration of renewable, paper-based printed sensors demonstrated a versatile, low-cost and sustainable solution for real-time structural health monitoring in composite materials. Their easy integration, multifunctionality and compatibility with both synthetic and natural fibre composites highlight their strong potential for future smart composite applications in diverse industrial sectors.

#1279

# High-Speed Infrared Thermography to Capture Transient Thermal Response of Carbon Fibre Composites due to Joule Heating

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Carbon fibre reinforced polymers (CFRP) offer opportunities to light-weight electrical power system equipment for weight-critical applications including aerospace. Light-weighting examples include routing electrical cables across CFRP without additional wiring infrastructure, or replacement of metallic equipment enclosures with CFRP. However, such exploitation of CFRP creates new failure modes, where electrical current flows through CFRP components. In particular, conduction of electrical current through CFRP leads to localised Joule heating, which may be sufficient for glass transition temperature of the polymer matrix to be breached. Hence, appropriate measurement of the thermal response in tandem with electrical response of the CFRP is critical to the evaluation of these failure modes and subsequent design of resilient solutions.

Electrical failures where an unintentional electrical connection is made to CFRP, leading to a short circuit fault through CFRP, is characterised by an initial transient current, which decays rapidly to a sustained lower level fault current. The temperature of the composite rapidly increases during current conduction necessitating high-speed data capture to assess CFRP Joule heating. Furthermore, CFRP is electrically conductive, necessitating non-contact or electrically insulated temperature measurement devices, and measurement of variation of temperature over an area is needed to observe the transient thermal response spatially across the component to capture the maximum temperature reached.

This paper will describe the implementation of a passive infrared thermal sensor array to capture the rapid transient thermal response of CFRP during electrically-conducting failures. The use of this infrared thermography device to capture the thermal response of CFRP will be shown, and associated data sets presented. Lastly, it will be demonstrated how this experimental data enables the capture of electrical protection requirements for the design of resilient electrical power systems where such failure modes may occur.

#1281

# From Egyptian Sails to Modern Composites: The Sustainable Journey of Natural Plant Fibres

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Our research examines the long-term evolution of natural fibre composites by tracing the processing, cultural, and environmental significance of flax fibres from ancient times to modern times. It highlights how these fibres have consistently shaped human innovation through their intrinsic properties. Ancient civilisations such as Egypt relied heavily on flax for sails, ropes, nets, and textiles, enabling efficient transportation and trade along the Nile. Notably, worn sails were repurposed as mummy wrappings, demonstrating early resource-conscious recycling practices that foreshadow contemporary circular economy principles. As maritime cultures advanced, so too did fibre extraction and processing techniques. Traditional methods such as manual retting, spinning, and weaving gradually evolved into mechanised processes that improved fibre alignment, consistency, and performance. These developments enhanced mechanical properties and laid the groundwork for modern bio-based composites. Today, natural fibres are combined with polymers to create light, stiff, and environmentally friendly materials used increasingly in industries such as automotive manufacturing, maritime construction, and sustainable product design. The evolution of plant fibre processing reveals a continuous dialogue between tradition and innovation. Historical knowledge, gained through centuries of experimentation, adaptation, and reuse, provides valuable insights for addressing today's global sustainability challenges. Natural fibres offer key advantages, including renewability, biodegradability, low environmental impact, and compatibility with circular material flows. As concerns about climate change and resource depletion intensify, these fibres are receiving renewed attention as viable alternatives to industrially produced fibres. Our investigation demonstrates that the enduring value of natural fibres lies not only in their material properties but also in the long-standing sustainable practices embedded in their use. By revisiting historical applications and understanding their progression, we can better inform current efforts to develop high-performance, eco-efficient composites. Ultimately, the continued integration of plant fibres into modern engineering and design underscores their essential role in building a more sustainable future.

#1283

# Development of lignocellulosic fiber-based all-cellulose composites

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In this work, we adopted an innovative strategy to manufacture entirely circular regenerated cellulose matrix composites reinforced with lignocellulosic coir (CF) and bamboo (BF) fibers. A cellulose matrix was prepared using dissolved cellulose in an ionic liquid and regenerated using water to form a cellulose matrix, while CF and BF fibers were utilized as reinforcements. CF offers low density, high elongation and toughness, whereas BF is comparatively brittle, has a low strain-to-failure, and exhibits high tensile strength and modulus. The inherent low toughness of both the cellulose matrix and BF may cause structural failure to occur abruptly. To overcome this, hybridizing BF and CF to fabricate all-cellulose composites (ACCs) is a promising strategy to enhance ductility and failure strain by combining their complementary properties, while providing an environmentally friendly solution. The focus of this study is to fabricate and investigate the effects of the CF and BF stacking sequence, as well as to understand the hybridization effect on the mechanical performance of lignocellulosic fiber-based ACCs. The ACCs were fabricated using a hot press for 30 min under vacuum at 100 °C with a pressure of 0.2 MPa applied to the sample. Then, the ACC laminate was sunk into a water bath for a week to remove the ionic liquid and regenerate the cellulose matrix. The resultant laminates were dried using a hot press at 80 °C for 24 hours under a pressure of 0.2 MPa applied to the laminate. Results revealed that hybridization improved the failure strain characteristics. Compared to single-fiber ACC, the hybrid ACC exhibits a synergistic improvement in tensile failure strain while retaining good tensile strength and stiffness. This study provides an innovative approach to fabricating environmentally friendly composite structures, offering an alternative solution that advances resource-efficient structural composite materials and their applications for everyday use.

#1287

# Mode I fracture toughness at cryogenic temperatures: Is crack growth monitoring necessary?

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The transition toward liquid hydrogen-powered propulsion for zero-emission flight places stringent demands on composite structures operating at cryogenic temperatures. Ensuring structural integrity under these conditions is critical for future composite components such as cryogenic tanks and distribution systems, where failure could compromise safety and performance.

This work addresses one of the key challenges in this domain: the characterization of Mode I fracture toughness in unidirectional carbon fibre/epoxy composites at cryogenic temperatures. Traditional fracture toughness evaluation relies on visual crack growth monitoring, which becomes impractical at cryogenic temperatures due to frost formation and restricted optical access for several test systems. To overcome this, we investigated a compliance calibration method that enables accurate fracture toughness determination without direct crack observation. The approach was benchmarked at room temperature and adapted for cryogenic conditions (initially 77K) to ensure reliability and robustness. Additionally, a capacitance-based crack length monitoring approach was implemented, following published literature, to confirm the accuracy of compliance-derived results and investigate its feasibility for 77K – 20K test temperature. Preliminary findings demonstrate strong agreement between the two methods, validating the proposed approach for cryogenic fracture characterization.

By providing a practical and reliable methodology, this study contributes to the development of composite materials capable of meeting the demands of next-generation aerospace systems and other cryogenic applications, including hydrogen infrastructure and superconducting technologies.

Keywords: Cryogenic testing, carbon fibre epoxy composite, mode I, fracture.

#1288

# Accurate Filament Winding Simulation for Hydrogen Tank Applications

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This research develops a physics-based model of the filament winding process using a bespoke finite element (FE) solver. Current process simulation relies on geometric and kinematic software, which excels at generating winding paths and can analytically predict thicknesses across simple 1-D curves, but does not simulate inter-ply interactions or physical material behaviour during winding. Our new model allows for physical interactions including material stiffness and friction, and captures these interactions across complex curved dome regions.

A geodesic path is plotted across a mandrel geometry algorithmically, upon which tow elements are placed before being passed to the FE solver to apply compaction and tension, allowing the elements to move and deform.

The tow is modelled in one of two ways: either as a bundle of multiple line elements where each line element will represent many individual real fibres; allowing for intra-yarn interactions, and tow spreading with non-flat-edged tows. Alternatively, 3-D deformable solid-like shell elements can be used, which reduces contact computations, thereby decreasing runtime, whilst still accurately modelling inter-ply interactions like tow slippage.

Initial simulations confirmed the need for new contact model features within SimTex, including the recent development of a static frictional model, and a plan for future development of a cohesive contact to mirror the adhesive properties of resins - which are not accurately modelled with static friction alone.

The ultimate aim is to accurately predict final part geometry, such as thickness and tow paths, which will inform quality assessment and can be used in subsequent mechanical performance simulations.

#1291

# Enhancing Interfacial Adhesion in Chitosan/Zein Multilayers via Cold Plasma Surface Modification

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The widespread adoption of biodegradable food packaging is currently limited by the performance trade-off between sustainability and material functionality. Chitosan films are a promising solution due to their film-forming abilities and antimicrobial properties, yet their application is often constrained by high moisture sensitivity and limited barrier performance. Multilayer strategies utilizing water-insoluble proteins, such as corn zein, offer a pathway to improved barrier properties by combining the mechanical strength of chitosan with the water-resistance of zein. However, the inherent incompatibility between these biopolymers frequently results in poor interfacial adhesion, leading to delamination and mechanical failure.

To address this interfacial limitation, this study utilizes Cold Oxygen Plasma (CP) pretreatment, a solvent-free surface engineering technique, to fabricate a robust chitosan/zein bilayer structure. Unlike thermal methods, CP is capable of simultaneously tailoring surface chemistry, roughness, wettability, and surface energy without damaging the bulk polymer. In this work, the treatment introduced polar oxygen-containing functional groups and induced controlled nano-scale etching on the chitosan surface.

These modifications resulted in a significant reduction of the water contact angle from 78° to ~36°. This enhanced wettability enabled a stronger interface driven by chemical interactions via new functional groups and physical mechanical anchoring on the roughened surface. T-peel testing revealed a ten-fold increase in adhesion strength compared to untreated controls. Consequently, the optimized composite demonstrated substantial improvements in barrier performance, with water vapor and oxygen permeability reduced by approximately 70% and 62%, respectively.

Overall, this study advances the understanding of plasma-mediated surface activation, providing a scalable, eco-friendly solution for developing high-performance, multilayer bio-based packaging systems.

#1292

# Deterministic Control of Surface Topography in Suberin-Coated Paper Composites via Solvent-Driven Crystallization Kinetics

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The development of fully bio-based packaging materials requires high-performance coatings that can compete with synthetic barriers. Birch-bark suberin, a heterogeneous biopolyester composed of long-chain aliphatic domains, phenolic moieties, and glycerol-linked networks, is a promising candidate due to its inherent hydrophobicity and barrier potential. However, the functional performance of suberin coatings is strictly governed by their supramolecular organization and resulting surface topography. This study establishes a mechanistic framework for controlling suberin self-assembly on cellulosic substrates through solvent selection, specifically investigating the contrasting drying kinetics of acetone and ethanol.

The research demonstrates that solvent evaporation rates act as the critical determinant of nucleation density and structural packing. Using acetone, the rapid evaporation rate generated high supersaturation states early in the drying process. This kinetic regime promoted dense nucleation and rapid self-assembly, yielding a compact, fine-scale nanostructure that maximizes surface coverage. These morphologies minimized the solid–liquid contact area, resulting in enhanced apparent hydrophobicity and low droplet-adhesion behavior ideal for moisture barriers.

Conversely, the slower evaporation kinetics of ethanol extended the crystal growth period, shifting the system toward a thermodynamic regime. This facilitated the formation of larger, distinct micro-domains associated with increased surface roughness but greater droplet pinning. By correlating these drying kinetics with the resulting topographies and wetting behaviors, this work clarifies the design rules for suberin-paper composites.

These findings enable the rational fabrication of tunable, high-barrier bio-composites, overcoming the stochastic nature of biopolymer self-assembly to deliver reliable performance in sustainable packaging applications.

#1295

# Fast curing bio derived epoxy thermoset with tunable hardener systems for high performance industrial applications and demonstrated chemical recycling

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Abstract:

Developing sustainable thermoset systems that combine fast curing, high thermal performance and viable end-of-life management, is a critical challenge for next generation materials that fit industrial purposes such as fiber reinforced composites, coatings, adhesive and structural applications. In this work, bio-based formulations have been developed using an aromatic based building block monomer so-called phloroglucinol tris-epoxy resin cured with a range of biobased aromatic and aliphatic renewable hardeners, including anhydride and carboxylic acids. These were selected to investigate how hardener chemistry and hydrogen bonding interactions influence curing kinetics and the final polymer network structure. Using an accelerator significantly increased the reactivity of anhydride-based formulation, allowing the system to achieve fast curing (5 min) at 160 °C while increasing the glass transition temperature to > 180 °C. In contrast, curing the accelerator-free formulation exhibited a lower Tg (133°) and necessitated longer curing time. This highlights the essential role of accelerator in thermodynamical and kinetic control.

End-of-life consideration was carried out using a microwave-assisted recycling method based on alkaline saponification. This method enables rapid depolymerization of the cured network with reduced energy and reagent use compared with conventional methods. While the initial results demonstrated better performance compared to currently available recycling methods specific to thermoset composites, further optimization is required to enhance the thermo-mechanical properties towards those of the original system.

These findings demonstrate that bio-based epoxy precursors combined with tunable hardener systems and catalytic acceleration can produce fast curing, high performance and chemically recyclable thermosets. Such formulations provide a versatile platform for sustainable high-performance materials with controlled processing and end-of-life management.

Keywords: bio-derived epoxy resin, catalytical accelerator, anhydride hardener, fast curing, chemical recycling microwave saponification, sustainable thermoset composites.

#1296

# 3R Composite Manufacturing Technologies: Vitrimer Prepreg Innovations and R2R

## Processing

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TorPropel introduces a new generation of sustainable, high-performance composites for the world's first small-aircraft toroidal propeller. The project aims to advance the state of the art in two converging domains: recyclable aerospace-grade polymers and customized vitrimer-based prepreg manufacturing tailored to complement ICOMAT's Rapid Tow Shearing (RTS) technology.

Unlike conventional thermosets, which form permanent, non-recoverable networks, the selected vitrimer formulations retain high-temperature structural capability while enabling true circular-economy strategies for aerospace composites. Within TorPropel, custom vitrimer formulations will be designed specifically to meet the processing constraints, mechanical demands, and sustainability requirements of the toroidal propeller architecture.

Building on CIDETEC's patented 3R technology, the project develops conventional tacky prepregs and also incorporates the concept of enduring prepregs: Non-perishable prepregs that can be stored at room temperature without degradation yet still meet high mechanical performance requirements. Their long shelf life, ease of handling, and recyclability represent a significant advancement over conventional thermoset prepregs, which require cold storage and offer no viable recycling strategies.

To translate these chemistries into manufacturable products, Torpropel will evaluate both tow-to-prepreg and fabric-to-prepreg routes, aiming to produce thin, defect-free vitrimer tapes capable of withstanding the demanding fibre-steering paths of the toroidal geometry. By aligning material development with process requirements, this integrated approach will allow precise control of tape quality, curvature compatibility, and laminate architecture. A comparative study on aerospace-grade carbon fibres and fabrics will further support optimization of mechanical performance and manufacturability, ensuring the final prepreg system is purpose-built for TorPropel rather than adapted from commercially available solutions.

Together, these innovations position TorPropel at the forefront of sustainable aerospace composites, establishing a manufacturable 3R-enabled composite toroidal propeller for efficient propulsion, and circular composite manufacturing.

#1298

# Effective Mechanical and Diffusion Behaviors of Fiber-Reinforced Hydrogel Composites

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Hydrogels are increasingly utilized in fields like flexible electronics and soft robotics due to their unique stimuli-responsiveness; however, their practical application is often constrained by insufficient mechanical strength. While strategies such as fiber reinforcement and the modulation of polymer chain entanglements effectively enhance their performance, theoretical models capable of accurately describing the transient, coupled diffusion-deformation behavior of these complex composites remain limited. This study presents a comprehensive constitutive theory and finite element modeling framework to characterize the stress-diffusion behavior of fiber-reinforced hydrogel composites. The proposed model introduces an intermediate kinematic configuration to effectively decouple isotropic swelling from elastic deformation and employs Fick's law to describe solvent transport. Uniquely, our approach explicitly accounts for the microstructural effects of chain entanglement within the matrix and incorporates a nonlinear, dispersive model for the reinforcing fibers to capture their realistic mechanical response. We successfully implemented this framework into Abaqus through User Element (UEL) subroutines, covering plane strain, axisymmetric, and three-dimensional elements. The model is validated against theoretical predictions and existing numerical solutions, demonstrating excellent agreement. Furthermore, systematic parametric studies reveal that key factors—including entanglement ratio, fiber content, stiffness, and distribution—critically govern macroscopic properties. Results indicate that fiber incorporation induces significant anisotropy; specifically, higher fiber content reduces equilibrium solvent uptake and prolongs equilibrium time, whereas increased fiber stiffness reduces uptake but accelerates the diffusion process. This framework provides valuable insights into the chemo-mechanical mechanisms of hydrogel composites, offering a robust tool for optimizing the design of advanced soft material systems.

#1299

# An up-to-date overview of the key rules to improve fiber-matrix adhesion in composites.

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Composite materials are lightweight and high-performance solutions for mobility, transport, construction and green energy industries. They contribute to accelerate the global energy transition and are being adopted across a wide range of next-generation renewable energy systems, from wind turbine blades and hydrogen storage vessels to EV battery enclosures, and solar panel frames. In FRP composites, the fiber-matrix interface plays a crucial role and strong interfacial adhesion is required. Furthermore, strong interfaces are essential to increase strength, stiffness, durability and energy saving characteristics of composites. But what is interfacial adhesion, how to measure it, how to control it? What is the role of mechanical interlocking, intermolecular forces, dissipative and rupture mechanisms that contribute to composite performances? Answering the simple even complex questions requires bringing together knowledges in polymer chemistry and physics, surfaces and interfaces and often involves the implementation of advanced spectroscopic or analytical techniques. Thus, the global understanding of adhesion phenomena in composites is based on multi-disciplinary, multi-scales and multi-techniques approaches. Moreover, in many cases the development of an interphase impacts deeply the performances. Even if broad generalization is challenging, this presentation aims to deliver the key concepts to master in order to control performances and durability of composites. These are based on the control of wetting phenomena at surfaces/interfaces, through surface chemistry, roughness and porosity, knowing that interfacial forces act per “actual” contact area and requires intimate molecular contact, but also based on gradient of properties at surfaces/interfaces such as polymer chains selective adsorption and formation of an interphase that will control interfacial strength and energy dissipation mechanisms. Knowing that high dissipation mechanisms depend on bonding chemistry, mechanical properties, temperature and speed, they must be targeted as they mitigate crack propagation, increase resistance to failure and thus final properties, durability and sustainability.

#1300

# Improving Circularity of CF/PEEK Composites Using Mechanical Recycling Methods

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In this work, carbon fiber (CF)/poly(ether-ether-ketone) (PEEK) composite waste in the form of pieces (5.7 mm ± 1.6 mm) was homogenized by manual tumbling with different amounts of neat PEEK (50 wt% and 60 wt%) and placed in an aluminum mold, followed by hot compression molding to produce two reprocessed laminates. The recycled laminates were inspected by ultrasound, and standardized test specimens were machined using a CNC router. The reprocessed laminates were evaluated for their thermal properties (differential scanning calorimetry, DSC), mechanical properties (Izod impact strength), and the morphological characteristics of the fracture surface. The results indicated that thermal stability was preserved, and the fracture surface morphology revealed satisfactory fiber positioning, good adhesion, and effective interaction between the matrix and the reinforcement in the reprocessed laminates. However, a slight decrease in Izod impact strength was observed, although the waste acted as a barrier to crack propagation and contributed to energy absorption. Reprocessing thermoplastic composite scrap proved feasible and effective.

#1301

# Electro-chemo-mechanical modelling of the all-fibre structural battery

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A structural battery is a multifunctional material that can store electrochemical energy and carry mechanical load simultaneously. In the all-fibre structural battery, carbon fibres are used in both the negative and the positive electrode. The carbon fibes in the negative electrode act as active electrode material, current collector and mechanical reinforcement. In the positive electrode, lithium-iron-phosphate ($LiFePO_4$ or LFP) is coated on the carbon fibres and acts as lithium host and contributes with mechanical stiffening. Meanwhile, the carbon fibres retain their ability to provide mechanical stiffness and transfer electrons. A cellulose-based separator is placed in-between the two electrodes and the entire laminate is embedded into the structural battery electrolyte (SBE). The multifunctionality of the active electrode materials gives rise to the electro-chemo-mechanical coupling effect.

In this work, we aim to create a numerical representation in COMSOL Multiphysics of the all-fibre structural battery which considers electro-chemo-mechanical coupling. The study builds on recent work by Larsson et al., where a structural battery full cell with a commerical positive electrode, consisting of an LFP slurry adhered on aluminium foil, was modelled [1]. For the all-fibre structural battery, the LFP coating is modelled as a continuum around the carbon fibres. The elastic modulus of the SBE and carbon fibres is known, while the stiffness of the cellulose separator infused in SBE will be determined experimentally.

The electrochemical behaviour is considered with Butler-Volmer non-linear kinetics. Chemical, electrical and mechanical properties from literature and previous studies on structural battery is utilised and implemented into the numerical model. However, certain electrical and chemical parameters remain unknown. These remaining parameters are obtained through model calibration against experimental charge-discharge curves during galvanostatic loading.

[1] C. Larsson, F. Larsson, J. Xu, K. Runesson, L. E. Asp, Electro-chemo-mechanical modeling of structural battery composite full cells, npj Computational Materials 11 (141) (2025).

#1307

# A novel manufacturing process for complex-shaped composite parts based on tailored fiber placement made preforms from continuous mineral fiber / polypropylene and polycarbonate hybrid yarns

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This work presents a novel, efficient and material-conscious manufacturing route for complex-shaped continuous fiber reinforced thermoplastics. The foundation is an in-house development of tailored hybrid yarns, consisting of continuous Isomatex Tenron mineral fibers commingled with either Polycarbonate (PC) or Polypropylene (PP) matrix fibers. These yarns are subsequently processed into net-shape preforms using the Tailored Fiber Placement (TFP) technology. This highly automated technique enables the design of variable stiffness structures through stress-adapted, curvilinear fiber layouts, all while ensuring a completely scrap-free preform production. The core of the innovation is the subsequent consolidation and forming step. The TFP preform is placed in a two-part metallic tool that incorporates a reusable, flexible core. This tooling concept is the key to forming complex internal geometries and even undercuts in a single, efficient process step. After consolidation, the flexible core can be easily removed, simplifying the demolding of shapes that are difficult to produce with conventional methods.

A bike saddle demonstrator part has been successfully produced, confirming the process's capability to create components with high geometric accuracy, low porosity, and excellent surface quality. Mechanical characterization of flat unidirectional laminates revealed high tensile properties in the fiber direction and good transverse properties. Notably, the performance in the fiber direction significantly surpasses that of conventional glass fiber-reinforced thermoplastics, validating the high performance potential of the material system and the developed process chain. This holistic approach unlocks new potentials for the automated and functionally integrated design of advanced thermoplastic composite structures.

#1308

# Flame-Retardant Treated Structural Particleboard for Fire-Safe Timber Construction: Mechanical and Fire Performance

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This study investigates the enhancement of fire safety in a recently developed structural particleboard (SPB) intended for timber construction. The reference SPB already satisfied structural and durability requirements, including resistance to termites, decay fungi and moisture. However, its reaction-to-fire performance required improvement to meet quasi-noncombustible and semi-noncombustible building code criteria. To address this, phosphate-based flame retardants were applied through a dual strategy combining pre-treatment of wood particles and post-treatment of finished boards, together with optimization of the hot-pressing schedule.

Industrial softwood particles were classified into face, back and core layers and treated with an internal flame retardant prior to mat forming. Severe surface blistering observed in preliminary trials was mitigated by introducing a multi-stage hot-pressing schedule designed to relieve vapour pressure while ensuring complete resin curing. After pressing, a secondary surface flame retardant was applied and cured under controlled temperature and humidity. Mechanical properties and thickness swelling were determined according to KS F 3200, while fire performance was evaluated by cone calorimeter tests (ISO 5660-1, 50 kW/m²) and combustion gas toxicity tests (KS F 2271).

The optimized flame-retardant SPB exhibited total heat release consistently below 8 MJ within the first 10 min of exposure, fulfilling quasi-noncombustible requirements, and mouse immobility times exceeded 9 min, satisfying semi-noncombustible toxicity criteria. Reductions in modulus of rupture, modulus of elasticity and internal bond strength were limited to approximately 5–10%, and all values remained within structural grade limits, with thickness swelling complying with relevant standards. These results demonstrate that an appropriately designed dual flame-retardant treatment, combined with process optimization, enables the development of fire-safe, bio-based structural particleboard suitable for use in modern timber buildings.

#1311

# Durability of Wood-Based Panels after 3 Year of Natural Weathering in Three Korean Climates

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This study evaluates the durability of three wood-based panels – structural particleboard (SPB), oriented strand board (OSB) and conventional particleboard (PB) – after one year of natural outdoor exposure in three Korean climates (Seoul, Anmyeon and Jeju). Panels were installed horizontally to maximize UV and precipitation exposure, and changes in physical and mechanical properties were quantified to assess their suitability for exterior applications.

Thickness, density and moisture content were measured, and internal bond (IB), boil internal bond (BIB), bending strength, modulus of elasticity (MOE) and wet bending strength were determined according to relevant ISO standards. Visual inspections documented discoloration, surface cracking, fungal growth, warping and delamination.

SPB showed the highest weathering resistance, with limited thickness increase (approximately 4.5–8.2%), stable density and moisture contents generally below 12% even in Jeju. IB retention was 70–85%, and bending strength (13.5–16.5 MPa) and MOE (~2000 MPa) remained within structural ranges. OSB exhibited moderate degradation, including strand lifting, localized thickness swelling (up to 20–25%) and IB retention below 30%, particularly in Jeju. PB suffered the most severe deterioration, with thickness increases up to 30%, extensive delamination, fungal colonisation and near-complete loss of IB, and several Jeju specimens failed during handling.

Overall, SPB outperformed OSB and PB under all exposure conditions, especially in the harsh maritime climate of Jeju. These results indicate that SPB is a promising option for wood-based structural components in outdoor or high-humidity environments, although protective design measures remain necessary for long-term performance.

#1312

# Development and Properties of Room-Temperature-Curing MUF Adhesives for Structural Engineered Wood Products

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This study develops and characterizes room-temperature-curing melamine–urea–formaldehyde (MUF) adhesives for structural engineered wood products such as glued laminated timber (GLT) and cross-laminated timber (CLT). MUF resins were synthesized at a fixed formaldehyde-to-(melamine+urea) molar ratio of 1.5, while the melamine content was varied from 20 to 30%. To improve storage stability of the liquid adhesive, several alcohol-based additives, including polyvinyl alcohol (PVA), ethanol, methanol and propanol, were evaluated. PVA at 2–8 wt% was selected as the stabilizer because it did not impair the basic properties of the MUF resin. The formulation containing 25% melamine and 2% fully hydrolyzed PVA maintained acceptable viscosity and curing behaviour for more than 10 weeks at room temperature.

The MUF adhesive was mixed with 20% ammonium chloride solution at a mass ratio of 10:4 and applied at 250 g/m² to two-ply domestic pine veneers (2.6 mm) and two-ply pine lamellas (6.5 mm) with moisture content below 6%. Assemblies were cold-pressed at room temperature under 10 kgf/cm² for 828 min, and bond performance was evaluated. Dry, semi water-resistant and water-resistant bond strength tests all satisfied the KS requirement of 0.7 MPa, demonstrating that sufficient structural bond strength can be achieved under room-temperature pressing conditions.

Comparative tests using imported reference adhesives (European powdered melamine resin and a U.S. isocyanate resin) showed that the developed MUF systems provided equal or superior bond performance. These results indicate that room-temperature-curing MUF adhesives are a promising domestic alternative for structural engineered wood, with adequate storage stability and mechanical performance for practical application.

#1313

# Micromechanical progressive failure analysis of UD CFRP composites with 3D waviness under longitudinal compression

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Manufacturing-induced defects, particularly fibre waviness, are known to significantly degrading the longitudinal compressive stiffness and strength of unidirectional (UD) carbon fibre reinforced polymer (CFRP) composite materials. However, the three-dimensional (3D) characteristics of fibre waviness and their influence on material properties has not been thoroughly explored in the literature. This study develops a microscale model with representative 3D fibre waviness extracted from CT images to more accurately represent these manufacturing defects. The 3D waviness is constructed by combining two fundamental two-dimensional (2D) waviness geometries: a snake shape, representing in-plane fibre deviation, and a bridge shape, representing out-of-plane fibre undulation. Microscale representative volume element (RVE) models incorporating the 3D fibre waviness are developed to investigate the waviness influence on the compressive behaviour of UD composites. Furthermore, residual stresses generated by fibre deformation due to curing are introduced into the RVE models. The predicted stiffness and strength from the microscale models are validated against experimental data, and the results show good agreement with experimental findings, demonstrating the capability of the proposed micromechanical models to effectively capture the influences of complex 3D waviness on the longitudinal compressive properties of UD composites. The comparisons indicate that under the coupling effect of waviness in two planes, both the compressive stiffness and strength of UD composite with 3D fibre waviness are significantly lower than those with 2D fibre waviness. Furthermore, progressive failure analysis reveals that the failure mechanism of UD composites with 3D fibre waviness involves the interaction of failure modes observed in 2D waviness. Crucially, the magnitude of the 2D feature angles dictates the ultimate failure characteristics of the 3D structure.

#1315

# Derivation of a digital twin of cyclically loaded composite components using energy density based on representative structural elements

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The development of structural components made of fiber-reinforced plastics should preferably be carried out virtually, from the initial design to the finished component. In order to obtain a high-quality product that can be used for safety components under cyclic loading, fatigue assessment, including structural optimization with a view to exploiting the potential for lightweight construction, must be carried out numerically. The factors that influence material behavior are diverse and depend, among other things, on geometry and manufacturing. However, there are usually imperfections in the laminate that must be considered in the dimensioning. Due to the inhomogeneous material behavior, a local fatigue approach is preferred, but this increases the complexity of a finite element model. On the other hand, the requirements for a digital twin for fatigue assessment are growing due to industrial demands for short development times and low numerical effort and can only be met with a customized numerical concept with optimized material parameters.

Therefore, a local material-based approach offers advantages, provided that material behavior can be measured and considered in the numerical simulation. A method based on representative structural elements is presented that balances the required resolution of material behavior with the simulation effort. If cyclic tests with damage energy control are used in experimental determination instead of conventional force- and strain-controlled tests, the existing differences between the boundary conditions of cyclic tests and the assumptions about cyclic material behavior can be overcome within the framework of numerical life estimation.

The presentation discusses the individual influences and differences as well as how to overcome them and presents a precise digital twin.

#1316

# Thermal effects on the compressive response of CFRP: Experimental characterization and mesoscale simulation

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Quantifying the combined influence of fibre alignment, matrix behaviour, and thermal degradation on the longitudinal compressive strength of unidirectional CFRP remains an open challenge. Experiments and micromechanical simulations have shown that fibre-level instabilities e.g. micro-buckling, localised shear deformation, and kink-band precursors, govern compressive failure, and that these mechanisms are highly sensitive to temperature-dependent changes in the matrix response. We include this physics into a homogenised mesoscale constitutive framework informed by high-fidelity micromechanical models to predict the fibre-kinking response over a wide temperature range.

We specifically examine whether incorporating temperature-dependent shear nonlinearity alone is sufficient to capture stiffness and strength degradation in longitudinal compression. After calibrating the homogenised model at room temperature, we treat temperature solely as a material-property input without additional parameter fitting. We can reproduce the experimentally observed softening in the stiffness and strength reduction with increasing temperature, demonstrating that the shear behaviour is the main driver for the loss of compressive performance.

The enhanced model is then applied to Open-Hole Compression (OHC) specimens at room and elevated temperatures. Predicted load–displacement curves, damage evolution, and kink-band onset are compared against dedicated experiments, showing good agreement in both global response and failure mode.

Overall, this work bridges high-fidelity micromechanics and low-cost mesoscale simulations, offering a predictive and computationally efficient tool for assessing fibre-kinking and thermal degradation in CFRP structures.

#1317

# Mechanical Interlocking Design of Wavy Metal Sleeves to Enhance Fatigue Performance of Composite-Metal Joints in Wind Turbine Blade Roots

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The heterogeneous composite-metal interface at the root of large wind turbine blades is a critical load-transfer path, where interfacial debonding and fatigue damage remain key failure modes affecting blade reliability. Thus it is vital to improve the interfacial strength and durability at the root. Conventional strategies used by most investigators are based on single-material reinforcement or simply increase the area of the joint region. Focusing on sleeve-type bolted insert connections, this study proposes to enhance mechanical performance of the composite-metal interface by optimizing the wavy morphology of the metal sleeves to strengthen mechanical interlocking of the intinterface. A simplified metal-epoxy model has been developed and analyzed by using finite element simulations. Cohesive elements are introduced to capture damage initiation and evolution at the interface. The influence of wave number on the interfacial mechanical response is systematically investigated under quasi-static and cyclic pull-out loading. The results show that variations in the wave number and related geometric parameters can induce a distinct transition in failure mode, i.e. from interface debonding dominated to resin matrix shear failure dominated, which thereby significantly increasing the upper limit of energy dissipation dureing failure. Fatigue analysis further reveals that cracks nucleate at stress concentration zones near the wave troughs, and their growth rate is governed by the local stress amplitude. A damage accumulation approach based on the cohesive model is able to successfully predict the fatigue life of the interface. These findings demonstrate that the properly tailored wavy mechanical interlocking design can markedly improve the structural integrity and service durability of heterogeneous composite-metal interfaces. In conclusion, this study has provided a new theoretical basis and optimization strategy for fatigue-resistant design of wind turbine blade root connections.

#1318

# Advanced Thermoplastic Composite Pipes for the Hydrogen Economy

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A significant step towards achieving climate neutrality in the European Union (EU) by 2050 is the conversion of the energy supply to renewable energy sources. The availability of hydrogen ($H_2$) as a flexible energy source in sufficient quantities is currently a central challenge. At present, hydrogen is mainly produced from fossil fuels such as natural gas, while water electrolysis only contributes 4 % of total production. Less than 0.1 % of global production comes from renewable energy sources. Compared to the production of grey hydrogen, the production of green hydrogen with PEM electrolyzers is still associated with high costs. Reducing the procurement and production costs of PEM electrolyzers is therefore a key factor in realizing the goals of the EU's hydrogen strategy.

Around 50 % of the system costs are attributable to the system peripherals, meaning that savings can be achieved through the standardization of system components and the use of more cost-efficient materials. Currently, cost-intensive steel materials are used to guide media systems and cooling circuits in the plant periphery. Substitution by polymer materials offers a high cost-saving potential due to automated production processes and simple joining techniques.

In the collaborative project ‘PolyH2Pipe’, which is funded by the German Federal Ministry for Economic Affairs and Energy continuous fiber-reinforced thermoplastic (TP-FR) pipe systems are being designed, joining techniques developed and the requirements for the media piping validated. The objective of the research project is to conduct preparatory measures to initiate market launch activities for large-scale production of TP-FR media pipes for H2 electrolyzer and fuel cell systems. In the context of the presentation, methods and test results for validating the requirements of the pipes will be presented.

#1321

# Additive Manufacturing and Advanced Composite Materials in Electric Motors: A Review

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Electric motors (EMs) have become a key part of sustainable electrification. EMs have changed how energy is converted for industrial, and e-mobility uses. With climate change and limited resources becoming more of a problem, EMs offer advantages: significantly reduced greenhouse gas emissions when supplied by renewable energy powerplant; higher energy conversion efficiencies (exceeding 90-95%) compared to fossil fuel engines, where larger portions of losses are from heat; lower operational and maintenance costs as a result of simpler mechanical structure; less noise and vibration; and improved compatibility with renewable energy and smart grid systems.

Additive manufacturing (AM) has altered the design and fabrication of machines that convert electromagnetic energies into other forms of energy. It offers distinctive alternatives to improve shape, incorporate functionality, and increase weight reduction. EMs which include sophisticated rotors, are increasingly essential for improving the environmental sustainability of energy production. These machines could benefit significantly from such design freedoms. However, the shift from conventional manufacturing to AM for these critical components remains challenging and is still at an early stage.

This study aims to investigate scalability issues and offer solutions to establish a basis for industrial application. Furthermore, the study proposes addressing these drawbacks by synthesizing recent information, reviewing the challenges, and formulating a research strategy to improve additive manufacturing for the fabrication of electric motors.

This paper begins with the explanation of the advanced composite materials that were used for EM applications, such as soft magnetic composites (SMCs), hard magnetic composites (HMCs), high-performance electrical steels, polymer-based composite materials, and sustainable and rare-earth-free materials. Then, the AM techniques for producing EM will be explained. The review will also explore performance optimization and challenges, case studies, and industrial applications, as well as future perspectives to enhance understanding of the application of AM and advanced composite materials in EMs.

#1323

# Wood-polymer hybrid joints produced via ultrasonic energy for lightweight structures

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The ever-growing demand for mitigating greenhouse gas emissions from the automotive industry requires more sustainable and innovative solutions. The incorporation of lightweight materials and innovative joining techniques can reduce emissions by decreasing the vehicle's weight and improving fuel efficiency. Ultrasonic joining (U-Joining) is one of such novel joining techniques that can produce high-strength joints between dissimilar materials. U-Joining even allows the manufacturing of hybrid joints between wood and polymer composites, which is the focus of this work. The single lap joints between beech wood and additively manufactured carbon fiber-reinforced polyamide (PA6-15CF) were produced via U-Joining in this study. In this process, high-frequency vibrations are transmitted from a sonotrode to the wood-composite interface, where frictional heat generated by mechanical vibrations leads to local melting of the composite material. Process parameters, including joining energy, pressure, and sonotrode vibration amplitude, were optimized to maximize the lap-shear strength through a Box-Behnken design of experiment. Analysis of variance revealed that amplitude has a major effect on the achieved lap-shear strength. The optimized joints have achieved a lap-shear strength of 10.8 ± 0.6 MPa. The physicochemical properties of the PA6-15CF before and after joining were investigated by differential scanning calorimetry and Thermogravimetric Analysis. Scanning electron microscopy (SEM) analysis of the joint cross-section exhibited the micro-mechanical interlocking at the beech/PA6-15CF interface. Fractographic analysis of optimized joints showed that the failure occurred on the wood side, with wood fibers remained adhered to the PA6-15CF side after fracture. The study demonstrates the potential of the U-Joining to contribute to the development of lightweight material combinations and joining techniques for the transportation industry.

#1324

# An Investigation on the effects of fibre sizing on glass fibre Elium and Epoxy composites Interfacial shear strength

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The interfacial adhesion between reinforcement and matrix in fibre-reinforced composites (FRC) is critical to the mechanical properties of the bulk composite. This adhesion, commonly measured through the interfacial shear strength (IFSS), is influenced by several factors, including chemical bonding between the matrix and the surface of the fibres.

Fibre sizing is a thin coating applied to the surface of the fibres during manufacture and is an important tool in improving the strength of the fibre-matrix adhesion through enhanced chemical and mechanical bonding across the material interphase. Sizings are formulated to act as bonding agents between the fibre and the matrix, and so correct formulation is of great importance to the overall mechanical properties of the composite material.

In the present work, the influence of fibre sizing variation on the IFSS of glass fibre acrylic and glass fibre epoxy composites is investigated. Single fibres with epoxy-compatible sizing, multi-compatible sizing, and water sizing were prepared. Droplets of Elium191® acrylic and EPIKOTE™ RIMR035c epoxy, combined with EPICURE™ RIMH037 hardener, were then applied to each fibre type. The IFSS of each system was measured using a single-fibre microbond test, enabling comparison of the calculated IFSS values and revealing the influence of sizing on the interfacial performance of GFRP for each investigated matrix.

#1325

# The application of potential energy landscape based method in mechanical properties analysis of epoxy resin

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Nanoparticle-reinforced composite materials offer superior strength-to-weight ratios and stiffness compared with composites using conventional reinforcement. However, nanoscale defects such as nanoparticle agglomeration can degrade the mechanical performance of these materials. To better understand this behavior, it is essential to investigate nanoparticle–epoxy interactions at the atomistic level. Molecular dynamics (MD) simulations are commonly employed for such studies, but their high computational cost restricts simulations to short timescales (nanoseconds) and high strain rates ($10^{7}$–$10^{10}$ $s^{-1}$), making direct comparison with experimental results challenging. Potential energy landscape (PEL)–based approaches have demonstrated advantages in addressing long-timescale atomistic problems and therefore offer a promising route to overcome these limitations. In this study, a numerical simulation framework is developed to study the mechanical properties of an atomistic model simplified through coarse-graining. The framework integrates the extended autonomous basin climbing (ABC-E) method with a strain-rate-dependent state selection scheme to enable efficient exploration of the PEL under different loading conditions. PEL-based simulations at both high and low strain rates are conducted and compared with results obtained from all-atom and coarse-grained MD simulations at high strain rates, as well as experimental data at low strain rates. These comparisons allow assessment of the framework's capability to capture rate-dependent mechanical behavior. Applying this approach to amorphous epoxy provides a means to bridge atomistic and continuum scales by capturing microstructural evolution and its influence on macroscopic mechanical properties. This capability supports the design and optimization of advanced nanocomposites for structural applications by enabling a deeper understanding of material behavior across multiple length and time scales

#1327

# Evaluation of the Effect of Re-Sizing for Recycled Carbon Fiber Using Various Pyrolysis Conditions

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Carbon fiber-reinforced polymers (CFRP) are widely used due to their high strength-to-weight ratio and durability, yet carbon fiber (CF) production is energy-intensive and environmentally demanding. Recycling CFRP helps reduce waste and dependence on virgin fibers, supporting more sustainable composite manufacturing. As the market for recycled carbon fibers (rCF) grows, applications and challenges emerge, particularly the need for effective re-sizing strategies to restore fiber–matrix compatibility after recycling.

This study examines three pyrolysis-based CFRP recycling routes: rapid oxidation, rapid pyrolysis followed by oxidation, and prolonged pyrolysis plus oxidation [1]. These processes remove most of the polymer, including the original sizing, which normally protects fibers and enhances interfacial adhesion. To reintroduce surface functionality, rCF is re-sized using two epoxy-based film formers with high (FF2) and low (FF1) glass transition temperatures. The aim is to evaluate time- and energy-efficient recycling pathways and assess how re-sizing affects the performance of rCF.

Fiber characterization includes single fiber tensile testing, contact angle measurements, pull-out tests, and SEM imaging. Virgin CF, with a diameter of 7.3 µm, an elastic modulus of 220 GPa, and strength of 3267 MPa, serves as a reference. Recycled fibers show similar diameters, moduli of 204–210 GPa, and reduced strengths of 1229–1398 MPa. Resized samples (S3-FF1, S4-FF1) exhibit further strength reductions (~860 MPa) and a modulus of 193 GPa, indicating that the softer FF1 sizing may influence mechanical behavior.

Understanding how recycling and re-sizing modify fiber surfaces, wettability, and interfacial bonding is essential for improving rCFRP performance. The insights from this study aim to support more efficient and sustainable composite manufacturing.

1. M. Corvo Alguacil, K. Umeki, S. Gaidukovs, A. Barkane, S. You, and R. Joffe, “The impact of thermal treatment parameters on the preservation of carbon fiber mechanical properties after reclamation,” Curr. Res. Green Sustain. Chem., Oct. 2024, doi: j.crgsc.2024.100431.

#1328

# Enabling scalable structural battery composite production through process comparison

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A structural battery is a multifunctional material that combines the ability to carry mechanical loads with the capability to store electric current. It can be made from various materials; this paper focuses on structural batteries made from carbon-fiber composites. With this technology, no separate battery enclosure is required, as the structural battery itself carries the mechanical loads. Design possibilities expand significantly when limitations of conventional battery packs no longer need to be considered, allowing for lightweight and geometrically complex structures.

Structural battery composites are still at a low TRL, and current manufacturing is performed on single cells in a lab environment. Therefore, the process's manufacturability and manufacturing methodology remain largely unevaluated.

This paper reviews the current manufacturing process of structural battery composites and identifies key processes. The aim is to evaluate and consider needs to enable a scalable production for higher volumes. The manufacturing process is then mapped as a process flow aligned with conventional battery production, enabling transfer of learnings related to challenges such as quality assurance, process adaption and complexity. At the same time, challenges associated with high volume composite manufacturing processes are considered, such as process efficiency and production cost.

This study uses state of the art literature on composite manufacturing methods and commercial battery production to present potential improvements that may facilitate an easier transition to high volume manufacturing of structural battery composites. The findings support the continuous development of structural battery composites in lab environments by enabling more efficient and accelerated iteration cycles during early-stage cell development. Additionally, the paper identifies areas for further research related to manufacturing of structural battery composites, where composite manufacturing has to be combined with the requirements of battery production.

#1330

# Development and evaluation of a method for the one-shot integration of top layers onto lofted nonwoven based core structures (fiber spring-back) for the integral sandwich construction

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In this research, a novel one-shot process for integrating top layers onto core structures in a single-stage manufacturing process via the targeted use of different carbon fiber textile semi-finished products was developed and experimentally investigated to produce sandwich structures made solely of carbon fiber reinforced polymer.

Aiming to replace the conventional multi-stage production of sandwich structures to reduce processing time, effort, and cost, an adapted resin transfer molding (RTM) process was set up in which the core component, generated by expansion via the lofting/fiber spring-back of dry-laid nonwovens made of recycled carbon fibers, can be simultaneously infiltrated, lofted and cured with the corresponding top layer component.

Three different top layer textiles based on carbon fibers, a woven fabric and two wet-laid nonwovens with different fiber architectures, were assessed in their suitability for the process to tackle the challenge of potential “co-lofting” of the top-layer component while processing. To evaluate the correlation of textile type and integrability into the one-shot process, correspondingly generated sandwich structures via the textile stacking of semi-finished products for top layers and core to one textile preform have been benchmarked against structures with pre-consolidated reference top layer sheets.

The resulting sandwich materials of both integration routes were extensively tested to evaluate their structural and mechanical properties (tensile, flexural, indentation, peel tests). The results show that the mechanical properties of one-shot sandwich structures, particularly using woven fabric top layers, are only moderately reduced compared to the pre-consolidated variant, while at the same time a significant simplification of the process was achieved. Especially in terms of the generated interfacial connection zone between top and core layers, through the one-shot approach an interesting degree of fiber interlocking could be seen.

The one-shot approach represents a promising alternative for the efficient production of sustainable lightweight structures based on recycled fiber materials.

#1331

# A Unified Phenomenological Model for Elastoplastic In-Plane Shear Response in Composite Materials

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Notched composite laminates exhibit complex interactions between matrix cracking, delamination, fibre failure, and stress redistribution, making the accurate prediction of progressive damage and ultimate strength particularly challenging, especially in cross-ply configuration, in which split cracks and notch-blunting play a major role. Literature suggests that accurately simulating a laminate under in-plane loading via finite element modelling (FEM) requires the proper representation of three key factors: in-plane shear nonlinearity, element size effects, and the distinction between experimental fracture toughness and intrinsic pure-mode fracture toughness. This work uses a high-fidelity numerical framework for modelling progressive damage in notched composite laminates by combining a transversely isotropic continuum damage mechanics (CDM) model with a phenomenological constitutive law for uncoupled in-plane shear nonlinearity. The proposed shear model characterises the pre-damage nonlinear response using an elliptical formulation that requires only the elastic in-plane shear modulus and the in-plane shear strength as input parameters, thereby avoiding regression-based fitting of full shear stress-strain curves, making it suitable for preliminary design purposes. Furthermore, a parametric study is conducted to understand the effects of element size and fracture toughness properties on prediction accuracy and damage progression. The enhanced CDM framework is then used in a building-block campaign in which the strength and damage morphology of multidirectional open-hole tension/compression (OHT/OHC) and cross-ply double-edge notch tension and compression (DENT and DENC) tests are predicted using the same material properties. Overall, the proposed CDM model provides a computationally efficient methodology for predicting complex intra- and interlaminar damage interactions and the structural collapse of notched composite laminates while using a reduced set of material inputs specifically suited for preliminary design stage.

#1332

# Mechanical behavior of high content electrophoretically deposited carboxyl graphene carbon fiber/epoxy composites fabricated using combined hand lay-up and VARTM

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Graphene-deposited carbon fiber has a wide range of potential applications due to its improved strength and toughness achieved through interface/interphase modification. One effective approach to enhancing the interfacial/interphase strength is the incorporation of graphene fillers onto the carbon fiber surface using electrophoretic deposition (EPD). However, a higher amount of graphene deposition becomes an undesirable limiting factor for the mechanical properties, as it leads to void formation during the vacuum-assisted resin transfer molding (VARTM) process. Moreover, excessive graphene content in the form of a film-type deposition on the carbon fiber fabric has been shown to improve tensile properties but degrade flexural and interlaminar shear strength (ILSS) properties. This limitation was addressed using a combined Hand Lay-up and VARTM fabrication method. In this approach, resin was first applied to the electrophoretically deposited graphene layer to infuse only the top layers of graphene and fibers. Subsequently, the VARTM process was carried out to completely infuse resin into the remaining void regions between the fabrics. For comparison, pristine carbon fiber composites were also fabricated using the same Hand Lay-up and VARTM technique. In addition, composites were fabricated using only VARTM with the same graphene-deposited fabrics to compare with the combined process. Optical microscopy and CT-scan imaging were employed to analyze void content, while the tensile, flexural, and interlaminar shear strength (ILSS) properties of the composites were evaluated. The graphene-deposited Hand Lay-up and VARTM composite exhibited improved tensile, flexural, and ILSS properties compared to the VARTM-only composite. Furthermore, the combined Hand Lay-up and VARTM composite showed a lower void content than that of the VARTM composite. Additionally, transmission electron microscopy (TEM) analysis was conducted to examine the interphase region.

#1333

# Micromechanical modelling of inelastic deformation of fibre-reinforced polymers accounting for strain gradients

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The accurate characterization of the constitutive behaviour of polymer resins is crucial for the micromechanical simulations of fibre-reinforced polymers. Traditional plasticity models often lead to excessive strain localisation when applied to confined matrix regions, resulting in inaccurate predictions of crack initiation and of the resulting composite strength. Previous studies have emphasised the importance of incorporating strain gradients or interphases to more realistically capture these phenomena. In this context, the present work introduces a pressure-dependent implicit strain-gradient plasticity model for epoxy resins. The proposed model accounts for pressure sensitivity and the asymmetric behaviour under tension and compression. Strain-gradient effects are integrated through a non-local plastic variable governed by a Helmholtz-type equation. The performance of the model is evaluated by comparing experimental and numerical results from nanoindentation tests on neat epoxy and micromechanical tests of FRP microstructures usinf nano digital correlation. The additional constitutive parameters are calibrated using a composite Bayesian optimisation approach. The findings demonstrate that the proposed model effectively captures experimentally observed size effects and significantly reduces the unrealistic strain localisation associated with conventional plasticity models.

#1334

# Effect of Graphene-Enhanced Laminates on the Interfacial Strength in Overmoulded PEEK Composites

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Composite injection overmoulding is a manufacturing process that has the potential to significantly improve the manufacture of composite structures. The process involves injection moulding features onto a composite laminate contained within the mould prior to injection. Using this methodology, it is possible to achieve the superior strength of continuous fibre reinforcement while using injection moulding for complex features to reduce labour costs.

One major challenge associated with overmoulded structures is that bonds develop using the residual heat of the injected polymer. The interface temperature must be sufficiently high for bonds to develop across the interface making the formation of suitable bonds non-trivial [1]. For semi-crystalline polymers, this requires melting of the substrate. The strength of the interface is then further influenced by mechanical factors including load distribution through the reinforcement.

Aiming to increase the interface strength through the addition of graphene nanoparticles, initial experimental trials used 30 wt% PEEK injected over unidirectional carbon fibre reinforced PEEK with various wt% of graphene [0 0.2 0.5 0.7] % to produce single lap-shear coupons. It was found that the interface strength of the 0 and 0.7 wt% graphene enhanced specimens produced a weak interface of approximately 1MPa. The 0.2 and 0.5 wt% graphene specimens had a clear increase in lap-shear strength of up to 300%, suggesting a complex interaction associated with the inclusion of the graphene nanoparticles. A multiphase computational fluid dynamics simulation was combined with thermal characterisation of the graphene laminates to understand the heat transfer process during the mould filling process and elucidate the relevant mechanisms. The results of this investigation are useful for informing the design process of overmoulded composites by further understanding interfacial behaviour.

[1] M. A. Aravand, "Composite Injection Overmoulding," in Design and Manufacture of Structural Composites, L. Harper and C. M. Eds.: Woodhead Publishing, 2022.

#1335

# Processing-Structure-Performance Interactions in Recycled PA6-CF Flake-Based Composite Laminates

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Lightweight construction is a key technology for enhancing resource- and energy-efficiency across various industries. Organosheets, a fiber-reinforced plastic composite (FRP) with a thermoplastic matrix, offer significant weight-saving potential. Despite careful planning, the production of organosheets often generates considerable scrap, particularly in high-volume processes. Traditional recycling methods include mechanical processing, thermal recycling or the separation of individual components through solvolysis. After the mechanical recycling of thermoplastics, the shredded waste can be reused through injection molding or extrusion. However, the original fiber length is significantly reduced, leading to a decrease in the mechanical properties of the recycled material. An innovative recycling approach involves segmenting FRP scrap into small pieces, evenly distributing, heating them above the melting point and compressing them into a semi-finished laminate. The intrinsic heterogeneity of flake-based architectures introduces complex interactions between processing conditions, resulting microstructure, and final component behavior. These interactions remain insufficiently understood.

This contribution presents investigations of a selected processing route for PA6-CF flake-based laminates, combining insights from forming behavior, consolidation phenomena, and mechanical performance evaluation. Different laminate configurations and molding conditions were explored with the aim of identifying characteristic links between temperature management, heat-up behavior, and the resulting structural properties. In addition, first observations regarding the flexural response and overall mechanical robustness of these materials are discussed. The study highlights general trends and key mechanisms affecting component quality, without yet attempting to derive final design rules or fully validated mechanical/thermal models.

The results establish a foundation for further in-depth analyses - such as advanced mechanical characterization, process simulations, or detailed microstructure-performance modelling - to support the reliable manufacturing of complex recycled composite components. The presented work thereby contributes to an improved understanding of recycled PA6-CF flake materials and their potential in sustainable composite applications.

#1336

# The development of thermoplastic interleaved carbon fibre/epoxy composites from prepreg waste

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Carbon fibre/epoxy composites have been extensively used in engineering applications for their superior mechanical performance and lightweight. However, significant prepreg waste like off-cuts, trim waste, and end-of-roll waste are generated from component manufacturing. (In the UK, this is anticipated to be around 16000 tonnes in 2025 and predicted to grow to 60000 tonnes by 2035.) Most commonly, prepreg waste is cured, then landfilled, incinerated, or undergoes pyrolysis to recover fibres, all leading to greenhouse gas emissions. To address this, we propose an innovative recycling approach of converting prepreg waste to interleaved composite panels with remoulding capability.

In this study, commercial carbon fibre/epoxy prepreg offcuts (IM7/8552) and polystyrene-based SAN film (as interleaf) were used. SAN films (20 µm thick) were placed on both surfaces of the prepreg off-cuts before cutting into strips of 50 mm long and 5 mm wide with fibres aligned along the strip length. These strips were then used to manufacture two types of panels. Both panels were produced in a flat configuration and cured in autoclave.

Specimens of 120 mm long and 20 mm wide were trimmed from both panels. They were heated above the glass transition temperature (T_g) of the SAN (87°C) and then re-shaping to a ‘L-bend’ configuration subjected to vacuum pressure. This ‘new’ shape was maintained after cooling with the vacuum to room temperature. The observed springback angle was less than 1°. When re-heating above T_g, specimens were recovered to the original flat configuration, in approximately 5 minutes. Microscope examination showed no damage after re-shaping and after shape recovery.

Details of the manufacture and characterisation (including mechanical performance) of both panel types will be presented and discussed.

#1338

# In-plane shear progressive damage analysis of multiaxial three-dimensional woven composites

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Three-dimensional woven composites are a new-generation strategic materials that have been widely used in aerospace, national defense and other important fields due to their advantages of good overall structure performance, excellent interlayer performance and low preparation cost. In this study, based on the three-dimensional angle-interlock woven composites(3DAWC), multiaxial three-dimensional woven composites(MAWC) with different bias yarn volume fraction are designed. A micro-mesoscale progressive dam-age analysis model is established. Firstly, the equivalent mechanical properties of the yarn are calculated by the mi-croscale model. Combined with the observation of the yarn cross-section morphology, a three-dimensional woven com-posite unit cell modeling method based on realistic geometric features is proposed. According to Murakami 's stiffness degradation method, a transversely isotropic damage model of fiber bundles at meso-scale is established to simulate the damage evolution process of each component of three-dimensional woven composites, and the corresponding experi-mental validation is carried out. The result shows that the in-plane shear mechanical response of MAWC is changed after the introduction of the bias yarn. Compared with the 3DAWC, the in-plane shear modulus and strength of the MAWC are increased by 12.03 GPa and 127.96 MPa, and the failure mode is changed from the resin matrix cracking to the bias yarn compression failure. With the increase of the volume fraction of the bias yarn, the in-plane shear modulus and strength also gradually increase, and the damage propagation path of the bias yarn evolves from extending along the weft direc-tion to extending along the warp direction until the overall failure of the structure. The simulated modulus and strength are in good agreement with the experimental values, indicating that the adopted finite element prediction is in good consistency with the actual experimental results.

#1339

# Processing and characterization of asa-based filaments reinforced with recycled carbon fibers from CF/PEEK composites

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The recycling of carbon fiber (CF)/poly(ether-ether-ketone) (PEEK) composites is increasingly important for sustainable development in the aerospace sector. These materials offer an excellent balance of low density, high strength, and outstanding thermal and chemical resistance, but their high cost and the significant amount of waste generated during machining and forming processes demand efficient recovery strategies. In this study, CFs were recovered from aerospace-grade CF/PEEK waste through a microwave-assisted thermal recycling process under a nitrogen atmosphere for 5–20 minutes. SEM analysis confirmed that after 20 minutes, the PEEK matrix was almost completely removed, resulting in clean fibers with minimal residue. The recycled CFs were chopped to 5 mm and incorporated into an acrylonitrile–styrene–acrylate (ASA) matrix at 0.2, 0.5, 1.0, 2.5, and 5.0 wt% using a twin-screw extruder (AX16:40DR, AX Plásticos).The resulting composites were processed into 1.75 ± 0.05 mm filaments with a Filmaq 3D mini-extruder and used in fused filament fabrication (FFF) with an Ender 3 Pro (Creality®) printer. The same formulations were also molded by injection using an Arburg Allrounder 270V injection molding machine for comparative analysis. Tensile specimens were prepared by both techniques and characterized by tensile testing (ISO 527-1), impact resistance (Izod, ASTM D256), and FEG-SEM. The incorporation of recycled CFs improved the elastic modulus and tensile strength of ASA in both manufacturing routes. However, injection-molded specimens exhibited superior mechanical properties compared to 3D-printed ones, mainly due to better fiber alignment and lower porosity. This work demonstrates a sustainable and effective approach for transforming CF/PEEK waste into functional ASA-based composites, reinforcing the potential of recycling and reprocessing strategies in polymer engineering.

#1341

# 25 years of Lightweight materials innovations in Europe

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Lightweighting materials have transformed the design and performance of modern industrial applications, delivering significant environmental, economic, and societal benefits. This work provides a strategic overview of 25 years of progress in lightweighting materials innovation, focusing on multi-material structures, fibre-reinforced composites, and bio-based solutions. By connecting past scientific advances with ongoing European initiatives, we highlight the contributions of leading organisations and demonstrate the transformative potential of lightweighting across key sectors.

Previous collaborative efforts have already shown strong momentum in advancing lightweighting technologies within Europe. Current projects are working towards developing bio-derived and sustainable composites, including flax-fibre materials with 50–80% biobased content for automotive applications and bio-based resins that facilitate improved recycling and remanufacturing. Further optimisation of fibres and textiles, particularly glass and carbon fibres, is aimed at achieving weight reductions of up to 50% while maintaining structural performance. Advances in integrating high-performance polymer and metal matrices, combined with innovative solid-state joining techniques, have strengthened multi-material assemblies and enhanced system efficiency.

Building on this strong foundation, we will develop a comprehensive lightweighting roadmap aligned with the objectives of the European Green Deal. The roadmap will synthesise 25 years of progress, highlight ongoing initiatives, and provide early insights into emerging trends such as digital design workflows, circular material loops, and next-generation hybrid structures, while leaving room for future developments. It will identify priority research areas and outline an adaptable action plan to enhance recyclability, reduce emissions, and strengthen European industrial competitiveness. Future industrial impacts are expected to build on existing achievements, such as up to 40% $CO_2$ reductions through optimised multi-material joints (equivalent to preserving 304,000 km² of forest), 85% material recovery in aerospace components, and substantial weight reductions in mobility applications, while advanced digital technologies continue to accelerate production and improve the efficiency of critical lightweight structures.

#1342

# From Fiber Coating to Matrix Integration: Enhancing Strength–Toughness Synergy via Dual-Alternant Interphase in CF/Epoxy Composites

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The demand for sustainable high-performance materials is driving innovation in carbon fiber/epoxy (CF/EP) composites, where damage accumulation at the interphase remains a major bottleneck. To address this limitation, this study investigates integrating multifunctional biodegradable polymers to enhance the fiber/matrix interface. These polymers, featuring amine and aromatic groups, are designed to establish dual complementary interactions with epoxy and CF, respectively. Interfacial formation proceeds sequentially, with polymers initially bonding to one interface, followed by the polymers attaching to the opposing one, resulting in a CF–polymer–EP interphase. The sequence can be established with either CF–polymer when using the spraying technique, or EP–polymer when incorporating polymers into the epoxy matrix. The mechanical behavior of the interphase is examined for both integration strategies. Moreover, surface modification, curing behavior with epoxy, and spray deposition of the polymers are characterized using 1H NMR, FTIR, DSC, TGA, MALDI TOF, rheology, SEM, and AFM. Mechanical tests confirm substantial performance gains with 15%, 9%, and 39% increase in flexural strength, modulus, and toughness, a 49% rise in interlaminar shear strength (ILSS), and a 10% enhancement in Mode-II fracture toughness (GIIc), in epoxy-modified composites. Fracture analysis reveals that polymers integrated within the epoxy matrix create covalent crosslinks reinforcing the interphase. Additionally, π–π interactions dissipate energy through intrinsic and extrinsic toughening mechanisms, resulting in simultaneous strengthening and toughening.

#1343

# Polarization Image Analysis for the Monitoring of C-SMC Part Manufacturing

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Carbon fiber reinforced Sheet Molding Compounds (C-SMC) are lightweight composite materials increasingly applied in aerospace, automotive, and electrical industries. Their excellent strength-to-weight ratio and design flexibility make them attractive for structural and functional applications. However, their processing via compression molding introduces significant variability in fiber content, fiber orientation, and local inhomogeneities [1]. Monitoring and controlling these microstructural parameters during manufacturing is crucial for ensuring mechanical performance and reproducibility. Traditional approaches such as computed tomography are accurate but time-consuming, expensive, and unsuitable for inline process monitoring. This motivates the use of image-based techniques capable of operating in real-time production environments. The present work investigates the feasibility of using polarization imaging [2,3] for offline monitoring of C-SMC manufacturing part quality. Carbon fibers exhibit characteristic polarizing properties, enabling their detection and orientation analysis through polarization cameras. Modern CMOS-based polarization cameras, equipped with integrated micro-polarizers, allow simultaneous acquisition of four polarization states (0°, 45°, 90°, 135°) in real time. From these images, critical quantities such as the Degree of Linear Polarization (DoLP) and the Angle of Linear Polarization (AoLP) can be derived, and directly related to fiber content and fiber orientation. This makes the method promising for industrial integration. A total of 90 samples were produced from ten semi-finished plates, using five different C-SMC materials supplied by Polynt Composites Germany GmbH, varying in fiber volume fraction (40, 50 & 60 wt%) and bundle/roving sizes (3K, 12K & 50K). Each plate was imaged with a polarization camera both before and after compression molding. The image dataset therefore provides a systematic basis for studying how fiber morphology evolves during processing for different material recipes.

References

[1] https://doi.org/10.26204/KLUEDO/9013

[2] https://doi.org/10.1016/j.compositesb.2025.112146

[3] https://doi.org/10.1016/j.coco.2022.101456

#1344

# Overview of 20 Kelvin cryogenic mechanical and sensor testing at the University of Bath

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An overview will be provided of cryogenic composite material testing at the University of Bath. A number of bespoke mechanical test facilities, that enable understanding of composites material properties and failure behaviour at temperatures down to ~20 K, have been developed or are under development. Facilities include: a dry cryostat rated to deliver 300 kN compressive or tensile loading at ~20 K under static or fatigue conditions with cryostat inserts for carbon fibre based cryogenic hydrogen leak sensors; a cryocooler based gaseous helium cryostat for a Split Hopkinson Pressure Bar capable of high strain rate testing down to ~20 K; a liquid hydrogen immersion system and cryocooler based cryogenic microscope for assessing the differential thermal contraction of matrix and fibre that is due to be manufactured and trialled before ECCM 22. Aside from the sensor testing insert, all cryostats have optical access to allow capture of failure process with high speed digital imagery including digital image correlation and photoelastic measurements. The full work will discuss lessons learnt from development and use of cryostats when experimenting with carbon fibre and Somaloy composites; key observations of material behaviour and material property temperature dependence; fibre and particle based failure behaviour imagery with mechanical explanation and progress on use of the photoelastic effect to investigate fibre/matrix interface stresses built up during cooling. A description of the processes both successfully and unsuccessfully used to create DIC patterns for strain monitoring and determination of coefficients of thermal expansion will also be provided.

#1345

# Mapping damage in composite lattices for the design of tough architected materials

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Architected materials achieve unconventional mechanical responses through tailored topology, enabling behaviors such as auxetic deformation, enhanced toughness, or customized compliance. Geometric grading, thickness variation, and symmetry alteration further expand their tunability across diverse loading conditions, from opening load to compression. A further possibility for engineering latice materials is the combination of materials with different compliance, as well as their manufacturing using composite materials. In composite lattices, the inherent anisotropy of fiber-reinforced materials can be advantageously combined with the highly localized loading carried by individual beams, opening new pathways for directing stiffness, strength, and failure. However, realizing this potential poses challenges in manufacturing and process-parameter selection, as well as in experimentally resolving the local failure mechanisms that govern global response.

To clarify how local failure mechanisms influence the global response, we investigate the deformation and failure behavior of an additively manufactured composite lattice and compare it to a monolithic counterpart. Digital image correlation (DIC) provides full-field displacement measurements, enabling detailed tracking of damage initiation, crack nucleation, and propagation within both lattices. Incorporating an integrated damage criterion within a global correlation approach allows to localize strut failure and track the crack advancement and topology.

The results highlight how DIC is essential for bridging the gap between the local failure of monolithic and composite connected beams, and the global mechanical response of architected materials, ultimately offering guidelines for the design and manufacturing of tough, functionalized architected composites.

#1346

# Geometry-driven parametric analysis of transport and electrochemical performance of bpp flow fields for pemfc

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The urgent challenge of climate change has accelerated the development of hydrogen technologies, with proton exchange membrane fuel cells (PEMFCs) emerging as a clean and efficient energy conversion system. Despite their potential, the large-scale deployment of PEMFCs remains limited by cost, durability, and performance. Among their critical components, bipolar plates (BPPs) play a central role by ensuring gas distribution, water management, and electrical conduction across the cell. However, conventional BPP manufacturing struggles to meet the precision and cost requirements of industrialization.

In this context, additive manufacturing, and in particular selective laser melting (SLM), offers new opportunities to produce metallic BPPs with complex, optimized flow field geometries. This work proposes a combined experimental–numerical framework to design and validate enhanced BPP architectures. Experimentally, stainless steel 17-4PH and 316L powders were processed under varying laser power and scanning speed. Mechanical testing and SEM analysis revealed that low energy input resulted in lack-of-fusion defects, while excessive energy favored gas porosity due to Marangoni effects. Between these two extremes, an optimal processing window was identified, producing dense and defect-minimized samples with mechanical properties comparable to those of conventionally manufactured materials.

Numerically, a 3D multiphysics model was developed in Ansys Fluent with the PEMFC add-on, coupling heat, mass, momentum, and charge transport. Conventional serpentine and pin-type channels were compared with novel 3D non-planar geometries enabled by SLM. Polarization curves, current density maps, and water saturation profiles showed that the 3D designs improved reactant distribution, facilitated water removal, and reduced mass-transport losses, resulting in higher predicted power density.

These results highlight the potential of SLM to fabricate advanced BPPs with tailored flow channel designs. Future work will validate the proposed 3D architectures experimentally, paving the way for cost-effective and high-performance PEMFC systems.

#1347

# Damage identification, simulation and design of thermoplastic composites under impact loading

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Thermoplastic composites have gained importance because of their superior mechanical properties and recyclability, making them promising options for designing advanced composite structures. Among thermoplastics, thermoplastic polyurethane (TPU) is widely used as a matrix material. However, its mechanical performance, especially impact resistance, remains poorly understood in applications due to its behaviour as a soft material. During previous investigation of Kevlar/TPU composite laminates under low-velocity impact, an intriguing phenomenon was observed: composite wrinkling during the impact loading, particularly due to the soft response of the thermoplastic matrix, which might lead to a unique damage mechanism for soft composite materials. In this study, we recorded the formation of wrinkles with a high-speed camera during low-velocity impact. To have an accurate deformation, a mirror was taken under the specimens for camera to monitor. Damage of the composites, especially the one around the wrinkles, was identified on the specimens after testing. These wrinkles occur because of the specific material response and pulsed loading. The formation of wrinkles can absorb energy through an additional damage mechanism. Alongside experiments, numerical modelling was conducted to replicate the wrinkling process and the damage it causes. A ply-scale numerical modelling strategy was utilized to consider the TPU interface with simplified interface behaviour. While the nonlinear damage models were applied to replicate the occurrence of the wrinkles. Understanding such a mechanism can aid in the design of thermoplastic composite materials. A reliable design scheme for thermoplastic composites towards low velocity impact is proposed based on both experimental analysis and numerical replication in the current work.

#1348

# Graphene Reinforced Glass and Recycled Carbon fabric based, Mass Productive, Circular Recyclable Crosspreg®

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Within the frame of GIANCE project, Crossfire is directly involved in the development and prototyping of some Automotive and General structural parts to get important Extra Lightweight in a Circular Recyclable, Mass Productive environment. Given the target, over the technical improvements, to be Cost Competitive, and lowest LCA, Crossfire addressed the study to Virgin Glass and Recycled Carbon fabrics. The Recycled Carbon fabric, in particular, sources from an industrial existing line at HERA-FIB3R, built with the technical support of Chimica Industriale at UNiBo.

The used Resin system is Crosspreg®, a RT solid, hybrid (TS/TP) reactive prepreg, epoxy based and capable to impregnate by capillarity and create chemical bonds with Oxidized Graphene, from Graphenea, and with the reactive groups on the fabrics surface.

The study shows the important results obtained by the addition of very little % of Graphene Oxide on a Virgin Glass and a Recycled (by Pyrolysis) Carbon fabrics-based formulations. The presence of chemically bonded Graphene offers important advantages in Shear resistance, leading to higher E-Modulus and lower deflection under load. Furthermore, the Circular Recycling of the relevant production cutoffs and EoL, went developed in a high Value, technology with care of no Graphene dust release in the environment.

GIANCE Project is a European Union’s Horizon Europe research and innovation program under Grant Agreement No 101119286 and UKRI under Grant Agreement No 10090645 and No 10101683, Graphene Flagship sponsored, dedicated to developing technical advantages by the 2-D materials adoption inside Composite Materials.

All technical aspects, from the production of parts up to their final Circular Recycling technologies will be discussed

#1350

# Experimental characterization and monitoring of thermoplastic resin infusion through flax fabrics with stereo-correlation technique

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The current environmental context highlights the need for sustainable conception and production of composite materials. Therefore, research is oriented towards the use of natural fibers and thermoplastic resin. Nevertheless, there are technological barriers such as geometrical variability of fibers or interface between fibers and resins which restrict structural applications for bio-composites. The LINEN project, of which this work is a part, was born in this context. Its goal is to improve understanding of the impact of fibers' variability on the physical phenomena occurring at different scales, and the interaction between fibers and resin.

The liquid infusion process is considered sustainable due to the low cost of equipment and energy consumption. To characterize the different physical phenomena (swelling, compaction, polymerization, …) during the impregnation of fibers with resins, the stereo-correlation technique is used. This method involves extracting with a pattern, the in-plane and out-of-plane displacement of the outer vacuum bag. The resin flow front and the thickness variation are monitored in situ during the infusion process. Our initial study was performed on a quasi-unidirectional carbon fiber fabric infused with the liquid thermoplastic resin Elium. This work highlights a clear lubrication effect, which has been reported for other types of resin/fabric in the literature (Govignon et al. 2008). To further characterize the infusion process, an IR camera and µ-thermocouples will be added to obtain information on the resin polymerization kinetics. Finally the setup is tested with a comprehensive study on flax fibers and thermoplastic resin Elium.

Govignon et al. 2008 : Q. Govignon, S. Bikerton, J.Morris, P.A. Kelly, 'Full field monitoring of the resin flow and laminate properties during the resin infusion process', Composite : Part A, 2008

#1351

# Sustainable Polypropylene Composites Reinforced with Construction Demolition Wood Waste: Processing, Characterization and Optimization

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This study explores the development of sustainable polypropylene-based wood–plastic composites (WPCs) reinforced with wood fillers originating from construction and demolition waste (CDW). The recovered wood was mechanically processed through grinding, drying, and sieving to obtain controlled-sized fractions suitable for melt compounding. Two virgin PP grades with different melt-flow indices (MFI) and a recycled PP grade (cont. 50% post-consumer waste) were selected to investigate the influence of matrix rheology and recyclate quality. In addition, selected compatibilizers were incorporated to promote interfacial adhesion between the hydrophobic polymer matrix and the hydrophilic CDW wood particles. Composite formulations were produced in a twin-screw extruder varying in the wood content, particle size, and compatibilizer type to assess their combined effects on processability and performance. Standardized specimens were manufactured via injection moulding and subjected to a comprehensive characterization protocol. Morphological evaluation using SEM and micro-CT provided insight into matrix-filler adhesion and the dispersion of CDW wood particles. Rheological behaviour was assessed using a Parallel-Plate Rheometer to determine viscosity and melt-flow characteristics relevant to processing. Mechanical performance was evaluated through tensile, flexural, and impact testing, while thermal stability was examined with thermogravimetric analysis. Moisture uptake and dimensional stability measurements were also conducted to assess the hygroscopic response of the composites, as those pose an important property for real-world applications. The results highlight the correlations between CDW wood concentration, particle size, compatibilizer selection, and the resulting morphological, rheological, mechanical, thermal, and hygroscopic behaviours. Overall, the study demonstrates the technical feasibility of incorporating construction and demolition wood waste into PP matrices, offering a viable pathway for the valorisation of CDW streams and contributing to circular-economy strategies through the production of recycled WPCs.

#1354

# How manufacturing affects the mechanical performance of CMC/Ceramic sandwich structures

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The French Cigéo project [1], led by Andra (the French National Agency for Radioactive Waste Management), aims to design and operate a deep geological repository for high-level radioactive waste. The repository will consist of a network of tunnels excavated 500 m below ground in a clay formation. Within these tunnels, specific liners will be inserted to facilitate both the emplacement and the potential retrieval of disposal packages throughout the operating phase of the facility. A novel solution combining Ceramic Matrix Composites (CMC) with monolithic ceramic materials has recently been proposed for these liners [2].

To characterise the mechanical behaviour of this innovative sandwich structure, several Representative Annular Technological Specimens (RATS) were designed and manufactured. Each specimen features Carbon/Geopolymer skins and an alumina core. A coupled experimental and numerical approach was applied to assess their performance. Compression tests included Digital Image Correlation (DIC) and Acoustic Emission (AE) to detect damage. Micro-computed tomography (µCT) was performed to capture the initial geometries, identify manufacturing imperfections and generate as-manufactured finite element (FE) models.

The experimental results revealed the occurrence of several major phenomena: cracking within the ceramic core, progressive debonding at the core–skin interface, and a resulting reduction in global stiffness. The numerical modelling qualitatively reproduced these features and confirmed that, despite the presence of initial defects and local damage, the annular configuration remains structurally stable under the applied loading conditions.

Altogether, these findings provide a solid basis for developing a predictive model of the sandwich structure's mechanical behaviour and for quantifying the influence of manufacturing imperfections. This knowledge will guide the optimisation of the liner design and support the forthcoming fabrication of new proof-of-concept components, which will be tested in Andra's Underground Research Laboratory to assess its performance in more representative conditions.

#1356

# Enabling fail-safe composite design – Tailored laminate design for unstable compressive crack-arrest in Fibre-Reinforced Polymers

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Despite their outstanding tensile properties, fibre-reinforced polymers remain limited by their relatively poor compressive behaviour. This discrepancy becomes critical in presence of in-service damage. Unlike tensile failure, once compressive failure reaches unstable propagation, there are no currently implemented means of safely arresting it. Thus, industry is constrained to a “no-growth” design philosophy, in which any initiation of unstable failure is deemed catastrophic. This restricts structural efficiency, limiting the potential of composites.

This study introduced a concept to arrest unstable compressive cracks in multidirectional fibre-reinforced polymer laminates (propagating at ~1 km/s). The concept uses a local ply-discontinuity region that removes 0° plies, replacing them with off-axis ones. This “soft lay-up” zone possesses different preferential failure directions and failure mechanisms. Moreover, the discontinuity between “hard” and “soft” lay-ups reflects and diverts fracture energy, reducing crack momentum. This allows the arrest and compartmentalisation of the failure. Furthermore, by forcing the failure to propagate in oblique directions and triggering new failure modes, the concept seeks to increase strain tolerance.

The concept was validated via membrane compressive tests in IM7/8552 carbon-fibre reinforced epoxy panels. A finite element model, based on experimental digital image correlation data, was used to evaluate different off-axis ply angles and improve the lay-up. The new lay-up was then validated experimentally, remarkably doubling strain tolerance upon final failure, in relation to a suitable baseline. Additionally, high-speed imaging (310,000 fps) was used to characterise the evolution of failure propagation speed in both baseline and crack-arrest elements. Results were compared with dynamic fracture theory, obtaining good correlation, inside the limitations imposed by measurement uncertainty.

Such results evidence the potential of ply discontinuity in compartmentalising unstable compressive failure and greatly increasing composite strain tolerance. Thus, a promising foundation is established for lighter and safer composite designs.

#1357

# Enhancing Flame Retardancy of Mycelium Based Biocomposites

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Mycelium-based biocomposites are gaining interest in the composite industry due to natural sourcing, circularity, and low-energy manufacturing. Despite their broad scientific interest, their adoption in construction, transportation, and aerospace interiors is limited by poor flame retardancy, which is a key safety requirement. Synthetic flame retardants can contribute to this safety, though they compromise environmental benefits of biocomposites by introducing toxicity and reducing recyclability. Here, we evaluate the effect of biologically derived, non-toxic additives such as cork-based suberin, shrimp-derived chitosan, and silica nanoparticles on the properties and flame retardancy of mycelium-bound composites. We find that Suberin and Silica coatings significantly improve the flame retardancy of mycelium composites. Chitosan shows marginal improvement in the composite's flame retardancy as it follows the same thermal degradation profile as the chitin-rich mycelium skin. Silica at 10 wt% loading yields >77% char, while suberin exhibited a multi-step decomposition and >10% char retention. Silica, with its exceptional thermal stability, is highly potent; however, due to low interparticle cohesion and limited substrate adhesion, silica does not form a uniform coating. Suberin is an aliphatic–aromatic polyester that exhibits superior film-forming ability. Prolonged heating of Suberin in solvent promotes thermally induced network reorganisation and intermolecular reassociation, enabling the formation of continuous, coherent films onto the surface of mycelium composites. Thus, Suberin and Silica could both be utilised synergistically due to their respective advantages to make an optimised flame-retardant system for mycelium composites. Our experiments suggest a 5–10 wt% suberin–silica coating could achieve UL94 V-0 self-extinguishing performance, which will be crucial in the potential adoption of mycelium-bound composites. These findings support the use of biologically derived additives to safely functionalise mycelium and similar lignocellulosic biocomposites, promoting wider adoption in aerospace interior applications.

#1359

# Fractographic Insights into the Optimum Microstructures for Structural Supercapacitors

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Structural polymer composites are amenable to being imbued with secondary functions due to their relatively benign processing conditions and the broad scope to tailor their microstructures. However, the emergence of such multifunctional composites presents challenges beyond those of conventional monofunctional material design. In particular, the different property requirements for each function of the constituents and their interfaces present conflicts.

This paper focuses on structural supercapacitors: electrochemical energy storage devices with the capacity to bear mechanical load. Whilst conventional electrodes are assembled from particulates of active material held together with binders, such architecture offers negligible structural function. Hence structural electrode development has adopted a fibrous scaffold upon which active materials are deposited, providing stiffness and robustness whilst meeting the electrochemical functions. Similarly, whilst conventional electrolytes are liquids or soft solids, the best structural electrolyte architecture is a biphasic interpenetrating network consisting of structural and ion conducting phases. These illustrate that addressing multiple functions in microstructural designs leads to complexities in the optimum constituent microstructures and interfaces, and hence processing challenges during scale-up.

The paper will convey the challenges associated with the development of the cell constituents, and their associated interfaces, by drawing upon fractographic insights from structural supercapacitors. It will be shown that interfacial challenges manifest at multiple length scales. At the micron scale, the electrode/electrolyte interface must permit unfettered ion access but also permit stress transfer via interfacial shear. Similarly, at the mesoscale, the interfaces between the electrodes and separator must resist delamination whilst permitting transport of ion between the electrodes. Such conflicting requirements demand innovative material and interfacial design. Similarly, scale-up of these multifunctional composites require innovations in processing control and a deep understanding of the curing processes within the structural electrolyte. This paper will culminate in recommendations to achieving optimal multifunctional performance in future structural supercapacitors.

#1360

# Cryogenic permeability of LM-PAEK CFRP laminates under thermo-mechanical exposure

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Ensuring hydrogen containment at cryogenic temperatures is critical for the design of Type V composite tanks in aerospace applications. However, repeated temperature excursions from cryogenic to room temperature and mechanical loads can trigger damage events that eventually may lead to gas leakage. This study investigates gas permeability under cryogenic conditions in carbon-fibre-reinforced polymer (CFRP) laminates manufactured with a low-melt poly(aryl-ether-ketone) (LM-PAEK) thermoplastic matrix. The work examines the influence of material state on gas transport by comparing pristine laminates with those subjected to mechanical loading and repeated thermal cycling between room and cryogenic temperatures. Permeability measurements were performed at 77 K using a steady-state gas diffusion method, applying helium on the upstream side and maintaining vacuum downstream. The steady-state flux, combined with specimen geometry, was used to calculate permeability coefficients under controlled cryogenic boundary conditions. Identical test parameters ensured consistency across all cases. Results highlight the impact of mechanically induced damage and thermal cycling on permeability behaviour, providing insights into damage accumulation mechanisms. The outcomes establish a robust cryogenic helium-permeability testing methodology and deliver baseline data to support the qualification and modelling of LM-PAEK-based CFRP components for low-temperature applications such as liquid-hydrogen storage and transfer systems.

#1362

# Validation-Domain Guided Selection of Bonded Stiffener Configurations for Composite Panels in Bending

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Designing adhesively bonded stiffeners for composite panels is constrained by how many specimens can be manufactured and tested, so each configuration has to be chosen carefully. We propose a quantity-of-interest (QoI)–based computational workflow to select stiffener layouts for three-point bending that are both mechanically consistent and give good coverage of the design space. A shell–cohesive low-fidelity model is used to compute, at low cost, the hotspot Peel-to-Shear Ratio (PSR) in the pre-damage range and the membrane load sharing between skin and stiffener. Intralaminar failure onset is monitored via stress-recovery failure indices reconstructed from the shell fields, enforcing the intended sequence “debonding before intralaminar damage.” Design exploration follows a three-step Design of Experiments strategy (factorial at bounds, Morris screening, Latin hypercube sampling) to build a training set in which configurations that violate the failure-index constraint are removed. For each QoI, a tree-based surrogate model is then fitted to map geometric and fixture parameters to PSR and load sharing. Before densely sampling the validation domain in QoI space, we apply Mahalanobis-distance filtering to avoid extrapolation and use bootstrap resampling to estimate uncertainty in the surrogate predictions. Candidate configurations are generated from these surrogates, and a shortlist is selected directly in QoI space to maximize coverage with a small number of tests. Finally, high-fidelity models with ply-by-ply solid laminates and cohesive interfaces are used to check representative configurations at global level and at local level. The workflow produces a small, non-redundant set of stiffened-panel configurations ready for blind testing and later design guidance, while reducing experimental effort.

#1363

# PLA/PHBV/sepiolite nanocomposites with thyme essential oil for antimicrobial packaging

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The development of multifunctional food packaging materials that combine technological performance with active and biodegradable features has gained prominence due to the need to reduce food waste and prevent diseases associated with improper food handling. In this context, the use of biodegradable polymers such as poly(lactic acid), PLA, and poly(3-hydroxybutyrate-co-3-hydroxyvalerate), PHBV, shows great potential. PLA is a rigid and transparent thermoplastic, though brittle and with a low degradation rate, whereas PHBV, with superior gas barrier properties and a higher mineralization rate, can enhance PLA performance when incorporated into PLA/PHBV blends. Functionalization of such blends can be achieved through the selective incorporation of nanoparticles, such as sepiolite (SEP), which can act not only as reinforcing and compatibilizing agents but also as carriers and protectors of antimicrobial substances, such as thyme essential oil (TEO), rich in thymol and carvacrol, capable of inhibiting bacterial growth and extending food shelf life. In this work, PLA/PHBV (70/30) blends containing SEP (5 phr) and/or TEO (8 phr) were prepared by melt mixing using a torque rheometer (HAAKE Rheomix 600p, 180 °C, 100 rpm, 10 min) and compression-molded into films. The materials were characterized by rheological, thermal (DSC and TGA), tensile, water vapor permeability, and agar diffusion antimicrobial tests. TEO exhibited a plasticizing effect, reducing viscosity, thermal stability, and stiffness while increasing elongation at break and water vapor permeability compared with the neat blend. The simultaneous addition of SEP acted as both a reinforcing and compatibilizing agent and provided thermal protection to TEO, suggesting partial encapsulation of the active compound. The antimicrobial behavior of the modified blends confirmed their potential for application in multifunctional food packaging.

#1364

# Effects of high vacuum SEM on unaged and aged flax fibre/polyester composites

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Abstract

This study examines the effects of high-vacuum conventional SEM and NanoSEM imaging on unaged and aged dried flax fibre–polyester composites. The findings indicate that high-vacuum conditions in both conventional SEM and NanoSEM do not significantly alter the microstructure of unaged and water-aged flax/polyester composites when imaging durations are limited to a maximum of two hours.

## 1. Introduction

A common belief regarding SEM use in natural fibre composites is that the high vacuum used in conventional SEM induces a drying effect, leading to fibre contraction and potentially increased damage in the composites. However, to the best of the author's knowledge, no literature has demonstrated this effect.

The purpose of this study is to assess the effects of high vacuum conventional SEM and NanoSEM on flax fibre/polyester composites. The relevance of confirming or disconfirming this notion is to gain a better understanding of the reliability of SEM as testing equipment for the evaluation of microstructures of the composites.

## 2. Experimental procedure

The effects of high-vacuum conventional SEM and NanoSEM on unaged and aged flax/polyester composites were assessed by comparison with optical microscopy and low-vacuum NanoSEM.

## 3. Results and Conclusions

The results showed that after 2 h under high vacuum, the cracks within the fibre bundle and at the fibre/matrix interface were almost unchanged. There are no additional cracks at the fibre/matrix interface, fibre bundles are still intact, and the size of cracks is almost the same in a high vacuum. In conclusion, the high vacuum in conventional SEM and NanoSEM does not significantly affect the microstructure of flax/polyester composite when used at a maximum of 2 h. Therefore, the high vacuum SEM and NanoSEM are reliable for evaluating flax fibre composites' microstructure since the equipment can maintain the original sample's integrity.

#1365

# Off-Axis Mechanical Behavior and Damage Evolution of Plain-Weave Carbon/Epoxy Composites

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The mechanical behavior and damage evolution of plain-weave carbon/epoxy composites under off-axis tensile loading were systematically investigated through quasi-static experimental and analytical studies over off-axis angles ranging from 0° to 45°. The results reveal a strong angle-dependent anisotropic response. At small off-axis angles (0°-7°), the composites exhibit a nearly linear elastic response followed by abrupt brittle failure, primarily governed by fiber tensile fracture. With increasing of off-axis angle, pronounced nonlinearity emerges in the stress-strain behavior, accompanied by a substantial increase in ultimate strain and energy absorption capacity. Elastic moduli extracted from the initial linear regime agree well with theoretical predictions based on classical stiffness transformation, whereas strength predictions are highly sensitive to the selected failure criterion. Quadratic failure criteria incorporating stress interaction effects provide improved agreement with experimental strength data under off-axis and shear-dominated loading, compared to linear criteria. Acoustic emission (AE) analysis reveals a systematic evolution of damage modes with increasing off-axis angle, transitioning from fiber breakage and interfacial debonding toward matrix-dominated cracking. A sentry function based on AE energy and strain energy was employed to detect abrupt damage events, demonstrating an increasing number of damage stages as the loading direction shifts toward shear dominance. The limitations of AE in identifying passive interfacial failure are discussed in conjunction with scanning electron microscopy (SEM) observations of fracture surfaces. Finite element simulations and digital image correlation (DIC) measurements further support the experimentally observed strain localization and multi-stage damage evolution. This work provides a comprehensive experimental characterization of woven composites across a broad range of off-axis angles, including the rarely reported small-angle regime, offering valuable insights into anisotropic damage evolution and improving predictive damage models.

#1367

# Investigating the evolution of damage in 3D woven composites: thermomechanical experiments and an improved failure model

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Three-dimensional woven (3DW) composites, characterized by their distinctive integral yarn interlacing architectures, exhibit significantly superior interlaminar strength and exceptional impact resistance compared to conventional laminated composites. Owing to their high specific stiffness and near-net-shape manufacturability, these materials are increasingly considered as promising candidates for next-generation advanced aerospace load-bearing structures. However, their potential performance degradation under complex thermomechanical coupling environments remains insufficiently elucidated, thereby hindering their widespread application in critical spacecraft components. To address this gap, this study systematically investigates the uniaxial tensile and compressive behaviors of 3DW composites at room temperature (23 ℃), 85 ℃, and 150 ℃, comprehensively quantifying the critical temperature-dependent variations in mechanical properties. To elucidate the underlying damage mechanisms, in-situ micro-computed tomography (micro-CT) was performed at both ambient and elevated temperatures to capture the real-time initiation and progressive evolution of tensile damage in detail. Furthermore, optical microscopy (OM) and scanning electron microscopy (SEM) were employed to meticulously analyze the microscopic morphological characteristics of the resulting fracture surfaces. The experimental results reveal that tensile failure exhibits a distinct brittle nature primarily dominated by axial fiber fracture, with in-situ micro-CT observations highlighting the significant regulatory role of the 3D architecture in constraining crack propagation. In contrast, compressive failure involves a more complex progressive sequence comprising transverse yarn cracking, longitudinal yarn delamination, kinking, splitting, and ultimately, catastrophic longitudinal yarn shear fracture. Finally, finite element analysis (FEA) incorporating an improved LaRC05 criterion was implemented to simulate the thermomechanical response. The simulation accurately captures the temperature-dependent evolution of failure mechanisms, thereby validating the efficacy and reliability of the improved criterion in predicting the thermomechanical behavior of 3DW composites under varying thermal conditions.

#1368

# Characterization of the structural, thermomechanical, and piezoresistive properties of cnt-reinforced dlp printed resin

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Additive manufacturing has revolutionized the fabrication of biomedical implants by enabling precise geometry and rapid prototyping. Digital Light Processing (DLP) offers significant advantages over Fused Deposition Modeling, delivering superior precision and fabrication speed. This work investigates the mechanical, piezoresistive, and thermal properties of hydroxyapatite (HA) and multi-walled carbon nanotube (MWCNT) reinforced photocurable polymer composites fabricated via DLP for load-bearing biomedical applications. A homogeneous nanocomposite resin was formulated by dispersing MWCNT particles and HA into surgical guide resin (JAMG HE). The composite resin exhibits excellent biocompatibility, high electrical conductivity, low viscosity suitable for suspension-based 3D printing, and optimal printability. Viscosity measurements using a rheometer confirmed that the composite remained within specifications for DLP processing. HA significantly enhances biocompatibility and osseointegration potential, while MWCNT improves hardness, piezoresistive sensitivity, and wear resistance—creating a multifunctional implant material capable of structural load-bearing and in situ strain monitoring. Solid coupons and gyroid lattice structures were fabricated using a 405 nm DLP 3D printer and post-cured to complete cross-linking. Mechanical characterization included compression and tension testing on both solid specimens and gyroid lattice architectures. SEM imaging revealed a uniform dispersion of filler particles and interfacial bonding between the reinforcements and the polymer matrix. Contact angle measurements using a goniometer characterized the surface wettability, indicating potential biocompatibility. Piezoresistive properties were analyzed through the determination of gauge factor, demonstrating self-sensing capability. Preliminary results indicate that composite specimens achieve 20–35% higher compressive strength compared to unreinforced resin, with maintained electrical conductivity enabling strain-monitoring functionality.

These results demonstrate that DLP-fabricated HA/MWCNT/polymer nanocomposites present a promising platform for next-generation self-sensing biomedical implants combining superior mechanical performance with embedded structural health monitoring capabilities, particularly for cranial and spinal implant applications.

#1369

# Tailoring thermal properties of epoxy using magnetically aligned graphene nanoplatelets

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Polymer-based composites are widely employed in aerospace, automotive, electronics, and biomedical sectors due to their light weight, corrosion resistance, and design flexibility. Their performance can be significantly enhanced by incorporating high-aspect-ratio nanofillers such as graphene, which offers exceptional stiffness, strength, and multifunctional properties. With its two-dimensional nanosheet structure, graphene provides a large surface area and pronounced anisotropic behavior, enabling strong interfacial interactions and efficient load transfer compared to lower-dimensional fillers. However, harnessing these advantages requires complete exfoliation, uniform dispersion, and controlled orientation of graphene nanoplatelets (GNPs) within the polymer matrix. Magnetic-field-induced alignment presents a promising strategy to achieve this, as graphene's intrinsic diamagnetic anisotropy allows the applied field to generate alignment torque and direct platelet orientation. This approach also mitigates the limitations encountered in electric-field-based alignment, particularly at higher filler loadings where electrical pathways hinder polarization-driven reorientation.

The present work focuses on the fabrication and characterization of magnetically aligned GNP–epoxy composites processed under lateral static and rotating magnetic fields. Composites with varying GNP concentrations are prepared to determine the optimum filler loading and alignment response. To evaluate the structure–property relationships, a suite of characterization techniques is employed: X-ray diffraction (XRD) to quantify GNP orientation relative to randomly dispersed systems; high-resolution scanning electron microscopy (HR-SEM) to assess dispersion quality and alignment; dynamic mechanical analysis (DMA) to examine viscoelastic behavior and reinforcement effects; and laser flash analysis (LFA) to determine thermal conductivity and diffusivity improvements resulting from magnetic alignment. The overarching objective is to establish a correlation between magnetic-field-induced orientation of GNPs and the resulting mechanical and thermal performance of the epoxy composites, thereby demonstrating an effective strategy for tailoring anisotropic polymer nanocomposites for advanced engineering applications.

#1372

# Weathering durability of pultruded GFRP composites with polyester and vinyl ester matrices: Accelerated laboratory vs. natural ageing

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Fibre-reinforced polymer (FRP) composites have gained growing interest for use in civil engineering due to their superior performance compared with traditional materials. Despite their advantages, FRP composites remain susceptible to environmental degradation, and there is still limited durability data for such composites, particularly for thick pultruded laminates. To address this gap, an extensive experimental program was carried out within the Durable-FRP project to evaluate the long-term weathering behaviour of 8 mm thick pultruded glass FRP (GFRP) laminates produced with either an unsaturated polyester or a vinyl ester resin matrix.

The study combined accelerated laboratory ageing with in-situ natural weathering over a 24-month period. Accelerated ageing conditions included exposure to constant temperatures between 15 °C, 20 °C, 40 °C, and 60 °C, as well as up to 200 thermal cycles between -15 °C and 60 °C. Additional laboratory ageing involved water immersion at 20 °C, 40 °C, and 60 °C. For the natural weathering, four locations across Portugal were selected to provide different combinations of relative humidity levels including precipitation, temperature variations, freeze–thaw actions, and UV radiation.

Following environmental exposure, the degradation of mechanical properties was assessed through tensile (longitudinal and transverse), compressive, flexural, in-plane shear, and interlaminar shear tests. Overall, only minor mechanical degradation was observed under most thermal ageing scenarios and natural ageing. Non-negligible reductions occurred mainly in resin-dominated properties, namely in transverse tensile strength regardless of the type of matrix. The most pronounced losses across all conditions were recorded after water immersion when specimens were tested in the wet state, with minimum property retentions of ca. 60% for interlaminar shear strength in the vinyl ester composite and ca. 70% for compressive strength in the polyester-based composite.

#1375

# Certification by Analysis of Large Composite Structures – Vision or Delusion?

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The uptake of composites is adversely influenced by current regulations in some sectors, whilst other sectors where composites are well accepted and used increasingly are facing challenges directly linked to current practices for validation and certification. The most prominent example is the aerospace sector, which represents a success story for the adoption of composites, and where composites validation/certification is conducted through a rigorous performance-based framework known as the 'building block approach' (or 'testing pyramid'). However, there is evidence and awareness that the building block approach which relies heavily of physical testing poses severe challenges linked to high costs of certification and time to market. Research programs around the world aim to unlock the use of composites by developing the foundations of virtual testing, validation and eventually certification frameworks that rely less on costly and time consuming physical testing and more on numerical simulations. An example is the CerTest project funded by the UK Engineering and Physical Sciences Research Council (EPSRC). The presentation will discuss the fundamental challenges linked to uncertainty quantification, and recent progress on the development of enabling methodologies for multi-scale modelling integrated with advanced physical testing on sub-structure/component scale, utilizing a Bayesian Design of Experiments process for data fusion and uncertainty quantification.

#1377

# Laser-assisted pyrolysis: Towards the reclamation of continuous carbon fibers from thermoset wound composite structures

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Preserving the fiber length and alignment during the recycling of continuous fiber reinforced plastics is a major but necessary challenge in order to maximise the value and reuse potential of the recycled fibers. In this context, an innovative laser-assisted pyrolysis process, combined with a fiber reclamation strategy, has been developed and investigated as part of the project Digitain. The goal of the conducted investigations was to reclaim dry continuous carbon fiber roving from carbon fiber-epoxy rings manufactured by wet filament winding and representative of a high-pressure hydrogen tank material. To reach this goal, a dedicated test setup, consisting of a high-energy laser, a system for the inertization of the laser spot area and a fiber collection setup, has been implemented. After a specific laser treatment of the ring surface to free the end of the wound roving, a continuous fiber reclamation could be reached by placing the laser spot on the region ahead of the detachment area. A sensitivity analysis considering the laser intensity, reclamation rate and oxygen content at the laser spot area was conducted. The reclaimed rovings were investigated using scanning electron microscopy as well as tensile tests after the implementation of various specimen preparation strategies.

Process parameters could be found for which (i) the roving was detached from the wound ring without fiber bridging, highlighting a successfull laser-assisted pyrolysis of the matrix material at least until the first layer interface; (ii) the reclaimed fibers did not feature oxidation marks, indicating that they were not damaged while passing through the laser spot and (iii) the tensile properties of the roving were preserved during the reclamation process.

These results are very promising towards the development of an industrial laser-assisted pyrolysis process able to reclaim continuous rovings or layers from End-of-life continuous fiber thermoset composites.

#1378

# Mechanical properties and damage evolution in carbon aerogel modified carbon fibre electrodes

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Structural power composites represent a transformative innovation in both structural and electrochemical applications by integrating load bearing capability with electrical energy storage. This advancement in multifunctional materials is crucial for enabling lighter and more efficient systems. Within this field, structural supercapacitors stand out as a unique class, offering a distinctive balance of mechanical strength and high power density.

The design of structural supercapacitors parallels that of conventional electrical double-layer capacitors, consisting of two carbon fibre based electrodes equipped with current collectors on their surface, enclosing a separator layer. The entire composite laminate is infused with a structural electrolyte, typically composed of an ionic liquid blended with structural epoxy resin.

Much of the research on materials for structural supercapacitor electrodes has focused on carbon aerogel modified carbon fibres, first developed by Imperial College London. Although carbon aerogels were discovered thirty-five years ago, they have not been systematically utilised in combination with other forms of conventional composite reinforcements. The carbon aerogel offers high surface area (which elevates capacitance) and can also contribute to mechanical stiffness within the matrix. However, it has been shown that the carbon aerogel modification process depresses the strength of the electrode material, although the modulus is relatively unaffected. Additionally, defects in the carbon aerogel electrodes, such as shrinkage cracks and bowing, can also be observed, further affecting the structural integrity of the electrodes.

In this study, mechanical tests were performed to quantify the influence of the defects arising during different manufacturing stages, whilst fractographic techniques were used to glean the influence of the defects on the mechanical performance.

Keywords: Multifunctional materials, Structural supercapacitors, Carbon fibres, Ultra-thin composites, Spread tow, Carbon aerogel

#1379

# From AFP Waste to Flight-Ready Sandwich Skins: Strand-Tailored Skins, Core-Stabilized Geometry, and Plasma Activated Bonding

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Automated fiber placement (AFP) of continuous CF/PEKK tapes enables high-rate manufacturing, yet the associated slit-tape off-cut waste creates a strong need for efficient, scalable mechanical recycling routes for aerospace secondary structures. In this research topic, AFP CF/PEKK scrap is transformed into recycled randomly oriented strand (ROS) skins and then engineered into dimensionally stable honeycomb sandwich components. AFP off-cuts are mechanically fragmented into ROS feedstocks (long 90 mm strands, short 45 mm strands, and shredded morphologies) and consolidated into quasi-isotropic plates via vacuum-assisted hot pressing. A key barrier for ROS adoption is undesirable out-of-plane distortion (warpage). 3D surface scanning showed a high warpage of 13.80 mm for long-strand plates, reduced to ~8–9 mm for short-strand plates, with shredded plates showing intermediate warpage (~11 mm). Strand-engineering also improved tensile performance: short-strand plates achieved the highest average tensile strength (284.4 MPa), while long-strand plates exhibited the lowest (116.3 MPa).

Even with optimized strand size (45×6 mm adopted for skin manufacturing), tolerance requirements can still restrict the direct use of free-standing recycled ROS plates. To eliminate warpage at the component level, recycled ROS plates are used as face sheets in secondary-bonded Nomex-honeycomb sandwich structures, where the core ensures skin straightness. Because CF/PEKK surfaces can exhibit relatively low bonding performance, atmospheric plasma activation (APA) is applied prior to film-adhesive bonding to enhance skin/core adhesion via increased surface free energy and mechanical interlocking. Mechanical validation confirms robust load transfer and interface integrity (flatwise tensile strength 2.28 MPa; edgewise compressive strength 171.7 MPa) with no skin/core separation, and strong flexural and impact performance (facing strength 59.23 MPa; impact energy 49.96 kJ/m²), supporting use in aerospace secondary components such as floors, doors, engine cowls, and spoilers.

#1380

# Self-Diagnosing Composite Repairs: Constituent-Informed Acoustic Emission for Early Failure Prediction in CFRP Patches

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Adhesively bonded scarf repairs can restore aerodynamic smoothness and recover a high fraction of load-carrying capacity in damaged composite airframes, yet their wider industrial use is still hindered by the absence of a dependable, real-time structural health monitoring (SHM) method that can certify the repaired region is healthy during service. This work presents an in-situ acoustic emission (AE) framework that turns the repair into a self-diagnosing joint, enabling early damage detection, damage-type identification, and failure-mode prediction in tapered-scarf repaired carbon fiber reinforced plastic (CFRP) panels under tensile loading.

Two repair configurations are studied: a CFRP panel repaired with a pristine carbon/epoxy patch, and a second panel repaired with a thermally exfoliated graphene oxide (TEGO) nano-integrated carbon/epoxy patch. To handle the intrinsic complexity of repaired laminates (autoclave baseline, vacuum-bag-only patch plies, adhesive film with an internal fiber mesh, and a glass sanding ply), AE signatures are first isolated by mechanically testing each constituent while recording its acoustic activity. Since unsupervised clustering (e.g., k-means) can yield inconsistent cluster boundaries for repaired specimens, cluster ranges are instead defined from constituent-informed limits and validated through SEM fractography. Multi-parameter discrimination further separates damage mechanisms with similar peak-frequency ranges; in particular, a rising-angle criterion distinguishes adhesive-mesh fiber failure from carbon-fiber failure.

Applied to full repaired specimens, the approach resolves matrix cracking (brittle/ductile), fiber pull-out, delamination, and fiber breakage, and enables likely failure location (scarf region versus outside-scarf regions) to be inferred at early strain levels. Overall, the methodology offers a practical SHM route for qualification and in-service monitoring of both pristine and nano-integrated scarf repair systems.

#1381

# Fiber Steering for Variable Stiffness Composites: A Technology Development Program for Next-Generation Rocket Engine Frames

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This work describes a technology development program focused on advancing the use of Carbon Fiber Reinforced Plastic for complex next-generation rocket engine frames. The Engine Thrust Frame (ETF) of the Ariane 6 upper stage was utilized as the reference structure to mature this technology.

The ETF, which transfers engine thrust loads to the upper stage of the launcher, provide critical stiffness for upper stage stability, and withstand cryogenic temperatures, has a complex conical-to-cylindrical geometry. The innovative CFRP concept integrates these two shapes into a single, monolithic part, replacing the multi-part Aluminum design.

The core technological advancement lies in the variable stiffness approach applied to the ETF skirt design. Leveraging the capabilities of Automated Fiber Placement (AFP), an automated optimization approach was used to actively steer the fibers in a significant portion of the skin plies. This optimization focused on maximizing stiffness and structural stability while ensuring compliance with manufacturing constraints. The resulting optimal fiber architecture actively changes orientation across the structure's height. This entire optimization process, which also involved minimizing the number of blade stiffeners, resulted in a significant mass reduction compared to the initial composite design.

To validate the full-scale design, a geometrically scaled demonstrator was derived by means of analysis. The scaling methodology ensured similar failure modes and maintained the essential lay-up characteristics, including the actively steered plies, despite necessary geometric adjustments. The manufacturing process successfully utilized AFP and proved the readiness of the proposed production approach, which involves co-curing the skin and stiffener preforms.

The final step is the crucial validation test, where the demonstrator will be subjected to compressive loading while being cooled to cryogenic temperature. This test will be used to verify the requirements on stiffness and thrust load sustainability, and, most importantly, to demonstrate the predictive capability of the numerical models.

#1382

# Multi-scale quantitative analysis of potassium geopolymer: from macro to nano scale

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Pore topology governs transport, shrinkage, strength, and durability in alkali-activated binders, yet quantitative, scale-bridging pore-network descriptions remain scarce for potassium-activated metakaolin geopolymers. This work targets the three-dimensional pore network of a potassium metakaolin geopolymer activated with potassium silicate solution. By combining volumetric imaging, porosimetry and scattering, we construct a consistent pore-size spectrum and a set of connectivity descriptors linking nanometre-scale porosity to micrometre-scale percolation pathways.

A unified imaging workflow is implemented across micro- to nano-scales. Laboratory X-ray microtomography (μ-CT) is performed at two voxel sizes—323 nm for representative volumes and 22.57 nm to resolve finer pores and constrictions. Nanoscale pore domains are captured by HAADF-STEM tomography (−60° to +60°, 1° steps) reconstructed at a pixel size of 1.17 nm. Across both μ-CT and TEM/tomography datasets, pore-space segmentation is performed using the same AI-assisted strategy: a U-net deep learning model complemented by a Random Forest machine-learning classifier to improve phase separation, reduce operator bias, and quantify uncertainty consistently across resolutions. The resulting segmented volumes are analysed to quantify total and percolating porosity, pore and throat size distributions, percolation ratios, and tortuosity from the micrometre scale down to nanometre-scale pore domains.

To extend the measurable range and independently constrain throat sizes, water porosimetry is applied following the AFPC–AFREM vacuum saturation protocol, characterising pores from ~20 nm to 2 mm via saturation, hydrostatic weighing and controlled drying. Nitrogen adsorption (BET surface area with BJH pore-size distributions) quantifies meso/nanoporosity, while SAXS/USAXS yields continuous size distributions for gel-associated pores and characteristic gel length scales.

Integrating these complementary datasets yields a unified, multi-modal description of the geopolymer pore network and identifies which pore families control connectivity across scales, supporting predictive modelling of permeability, transport, mechanical strength and long-term durability in potassium-based geopolymers.

#1383

# Exploring the challenges of manuplants as a methodology for bio-composites manufacturing

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The planet planet has to take clear actions capable of mitigating the effect of climate change, namely in reducing the emission of greenhouse gases, particularly CO2, as well as in developing solutions for sequestering carbon from the atmosphere. Hence, the development of materials and products must evaluate efficiency of resources, environmental and social impacts. To solve problems and to explore new ideas, nature has always been a major source of inspiration, leading as to the use of biomietics in material development, design and manufacturing of products, particular bio-composites.

Regenerative Manufacturing is a concept that looks to balance nature and technology, aiming for a real balanced and sustainable business. In this paper, we aim to explore an original challenge investigate and develop a general concept of producing bio-based parts/products across the value-chain and life cycle of the materials and products, but with the fundamentals of permaculture, where trees or plants are kept growing and storing biogenic CO2, being partially pruned and harvested in each season.

PECCS – Product Enabled Carbon Capture and Storage can be a potential implementation for Regenerative manufacturing, overcoming current Bio-CCS challenges and “false hopes dead-ends”.

The vision is a model proposition based in Circular Economy and Regenerative Systems. ManuPLANTS© concept will be presented in its first materialization, the Green Automated Fibre Placement (GreenAFP) process development, where the production of a honeycomb structure core is here presented. Its implematation can ally Science Composites Materials and Natural-Based solutions, for efective CO2 sequestration in Permaculture Biomass Materials Production + Lean CO2 Product Manufacturing and Life Cycle Analysis.

#1384

# Design and simulation of load-bearing hydrogen tank integrations in wing structures

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The transformation of aviation towards climate neutrality requires disruptive technological approaches. In the general aviation and for small aircraft (CS-23) in particular, hydrogen-electric propulsion systems represent a promising solution for achieving emission-free flight operations with acceptable ranges. The gravimetric energy density of hydrogen offers advantages over purely battery-electric systems, but poses new challenges for aircraft design due to the volumetric requirements of storage.

The work is dedicated to the development, conceptual design, and numerical simulation of a novel fiber-reinforced-composite wing and fuselage structure that is optimized for the integration of load-bearing hydrogen pressure tanks. A key problem in the integration of pressure vessels into the primary structure is what is known as “tank breathing” – the elastic deformation of the tank as a result of pressure changes during operation. In a rigid integration, these radial and axial expansions lead to critical constraint stresses in the surrounding aircraft structure and the connecting elements.

To meet this challenge, a patent-pending loose- and fixed-bearing design was analyzed. The developed concept enables targeted decoupling of the axial and radial deformation modes of the tank. This kinematic decoupling ensures that the tanks can function as load-bearing elements in the wing without damaging the aerodynamic skin or spars through induced stresses.

The work includes detailed design and finite element simulations of the assemblies under typical load cases. In addition, a study was conducted to investigate the influence of various geometric and design constraints. The results show that decoupled mounting can significantly reduce stresses due to tank deformation in the surrounding structures. This enables weight-efficient integration of the energy storage systems and makes an essential contribution to the feasibility of high-performance, hydrogen-powered small aircraft. The most important optimisation results in the design process and their influence on the structural mechanical properties of the entire wing are presented.

# Impact of Environmental Conditions on the Fracture Toughness of CF/PEKK Composites and Their Adhesively Bonded Joints for Aerospace Applications

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The mechanical performance, durability, and reliability of high-performance carbon-fiber/poly(ether ketone ketone) (CF/PEKK) thermoplastic composites (TPCs) and their epoxy adhesively bonded joints (ABJs) are affected by aerospace-relevant environments. This study quantitatively compares effect of room temperature (RT), low temperature (LT), high temperature (HT), and cyclic hygrothermal (CHT) exposure on (i) CF/PEKK TPC adherends and (ii) CF/PEKK–epoxy ABJs under identical conditioning and test protocols. Mode-I and Mode-II fracture toughness were measured for both systems using double cantilever beam (DCB) and end-notched flexure (ENF) tests, respectively. Acoustic emission (AE) monitoring was employed during testing, and fracture surfaces were interrogated by stereo microscopy and scanning electron microscopy (SEM) to enable a direct, side-by-side comparison of crack-growth stability and damage mechanisms in TPCs versus ABJs. In Mode-I, environmental conditioning modifies crack-growth behavior in both materials and joints, but with different sensitivities. LT conditioning promotes more unstable crack propagation, whereas RT, HT, and CHT conditions generally exhibit stable crack growth. The magnitude and evolution of the Mode-I resistance differ between TPCs and ABJs, indicating that the bonded interphase responds differently from the bulk composite. In Mode-II, TPCs and ABJs show similar environment-dependent trends; however, ABJs consistently exhibit lower Mode-II fracture toughness than the corresponding TPCs. AE analysis identifies four dominant failure modes for TPCs and five for ABJs, and demonstrates that their relative contributions shift with RT, LT, HT, and CHT conditioning. These AE-based findings are supported by fractographic observations of environment-dependent interfacial morphology and damage types, and by SEM evidence that both composite and adhesive matrices are altered by temperature extremes and moisture cycling. In conclusion, the direct comparison shows that ABJs are more environmentally sensitive than CF/PEKK TPCs, underscoring the need to co-design adherends and bondlines for durable, reliable aerospace structures. The findings provide guidance for qualifying CF/PEKK structures and bonded joints for service.

#1387

# Impact Damage Evolution and Compression After Impact Performance of CF/PEKK Laminates at Low, Room, and Elevated Temperatures

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Aerospace structures are rapidly transitioning from thermoset to thermoplastic composites to enable higher-rate manufacturing, improved reparability, and recyclability while maintaining damage tolerance. In this transition, compression and CAI are critical because aerospace structures are often compression-driven and sensitive to barely visible impact damage over wide temperatures. This study experimentally quantifies the coupled effects of impact temperature and compressive loading temperature on low-velocity impact (LVI) response, damage development, and CAI strength of unidirectional carbon fiber/poly-ether-ketone-ketone (CF/PEKK) laminates. Laminates are manufactured from UD CF/PEKK tapes using vacuum bagging followed by oven consolidation, demonstrating an out-of-autoclave processing route for aerospace-grade thermoplastic composites. The consolidation cycle employs a two-step thermal process with dwell temperatures of 340 °C and 380 °C, followed by controlled cooling. A symmetric stacking sequence [(0/90°)7/0°]S is employed, producing laminates with an average thickness of 4.5 mm. Differential scanning calorimetry (DSC) is used to quantify the PEKK degree of crystallinity, and void content analysis indicates a void fraction of 3.60%. LVI tests are conducted at low temperature, room temperature, and elevated temperature. Force–time and force–displacement responses reveal pronounced temperature dependence: elevated-temperature impacts exhibit reduced stiffness and larger displacements, whereas low-temperature impacts generate higher peak forces and a stiffer response consistent with more localized damage development. For each impact-temperature condition, CAI tests are performed independently at room, elevated, and low temperatures, enabling temperature-resolved quantification of residual compressive strength. AE monitoring during compression tracks damage progression and indicates dominant failure modes under each test condition. The results demonstrate that impact temperature and CAI test temperature significantly influence residual performance: specimens impacted at elevated temperature exhibit the lowest CAI strength, while those impacted at low temperature retain the highest CAI values, indicating improved damage containment. In summary, the combined LVI–CAI–AE framework supports robust temperature-aware qualification and design of out-of-autoclave CF/PEKK structures for impact-prone service.

#1388

# Bioinspired Intermittent Plasma Deposition of APTES on Carbon and Glass Fibres for Tailored Interfacial Functionalisation

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Nature often achieves exceptional combinations of strength and toughness through hierarchical and patterned structures that guide crack propagation. Inspired by these strategies, an intermittent surface functionalisation approach is presented for unsized carbon and glass fibres, using atmospheric plasma deposition of APTES. The goal is to mimic nature's spatial control over adhesion to create engineered fibre–matrix interfaces capable of enhancing toughness in composite materials.

The method employs a coaxial dielectric barrier discharge (DBD) micro-torch at atmospheric pressure with argon as carrier gas, while APTES is introduced as a vapor-phase precursor into the core stream. Remarkably, complete circumferential coatings are achieved, at nano and micro level, even with unilateral fibre exposure. Grid masks with slit patterns (500 µm to 1 mm) placed in contact with the fibres create the intermittent coating effect on a flat surface. Properties of plasma treated and untreated segments (intermittences) were controlled by means of plasma parameters manipulation, as power, frequency, gas flows, working distances, and displacement speeds, among others.

Surface characterisation of the intermittently coated fibres using XPS showed increased Si signals, while FTIR analyses revealed stronger presence of Si–O and amine functional groups only in coated segments of treated fibres, confirming the selective deposition of APTES. Confocal and polarized light microscopy allowed the identification and measurement of intermittent areas of fibres, indicating consistence with the designed patterns.

The difference in interfacial shear stress between treated and untreated segments was established using single-fibre of pullout tests conducted with thermoset and thermoplastic matrices, controlling the embedding length. Individual fibres treated with APTES showed a higher IFSS at lowest embedding lengths, in which frictional effects are minimal.

This study demonstrates a scalable, vacuum-free, bioinspired approach for spatial functionalisation of reinforcement fibres, opening new possibilities for the design of composites with controlled failure mechanisms and tailored energy dissipation.

#1389

# A New Material-Efficient Approach for 3D Printing Complex Continuous Fibre-Reinforced Parts Using UV Curing Resins

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Lightweight construction is widely recognized as key enabler for reducing greenhouse-gas emissions in the mobility sector. By substituting conventional materials with fibre reinforced polymers (FRPs), significant weight savings can be achieved, directly lowering fuel consumptions and associated CO2 emissions. However, the production of FRP components typically relies on component-specific tooling, which limits the economic viability for small series production. In addition, a load-path optimised fibre reinforcement of complex part is very challenging using conventional methods.

Additive manufacturing (AM) of FRPs offers a promising route towards tool-less and automated fibre-reinforced part manufacturing. Commercial systems for fused deposition modelling (FDM) of continuous fibre reinforced parts have already demonstrated the potential for FRP prototypes and small-series applications. Yet, available FDM systems remain bound to planar, layer-by-layer deposition strategies, preventing true three-dimensional fibre reinforcement. In addition, the high melt viscosity of thermoplastic matrix materials limits fibre impregnation and the achievable mechanical strength.

Consequently, growing research efforts focus on continuous fibre reinforced AM using UV curable resins. Their intrinsically low viscosity enables high quality fibre impregnation, while rapid photopolymerization allows the fabrication of unsupported, free-standing structures, enabling highly materialefficient FRP part manufacturing. A central technological challenge, however, lies in generating controlled fibre feed during the printing process. Existing approaches either rely on fibre extraction through fixation on the build platform, which is unsuitable for free-standing structures, or induce fibre feed via drag forces acting at the fibre–resin interface as a result of the resin volume flow, leading to low fibre-volume fractions or low fibre impregnation.

This paper presents a novel alternative concept for continuous fibre reinforced UV resin-based AM by decoupling fibre feed and resin flow. The proposed approach aims to overcome limitations of current concepts preparing the industrial application of the technology.

#1390

# Evolution of experimental methods for characterisation of mechanical properties of composites

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It can certainly be claimed that composite materials would not have reached their current level of maturity without testing them. This necessity has led to the development of a wide range of methods, tools, and standards to accurately characterise these materials. The current chapter provides a comprehensive overview of the historical evolution of experimental techniques employed to characterise the mechanical properties of composites. From the early days of composite materials research to the advanced techniques of today, these methods have been instrumental in revealing the complex behaviour of these materials. The chapter delves into the development of various testing methodologies, including tensile, compressive, flexural, shear, and impact testing, as well as techniques for characterizing the fibre-matrix interface and in-situ analysis methods such as Acoustic Emission, Digital Image Correlation, X-ray Computed Tomography, and Photoelasticity. The evolution of these techniques, driven by advancements in technology and scientific understanding, has significantly contributed to the advancement of composite materials and their widespread application in various industries.

#1391

# Architectural Decoupling of Mechanical and Thermal Sensing in Dual-Layer Multifunctional Composites

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Traditional multifunctional sensors often suffer from signal interference, making it difficult to decouple responses to different stimuli. In this work, we present a dual-layer multifunctional sensing system designed for independent pressure and temperature detection. The system consists of a CNT/Ecoflex flexible film serving as a pressure sensor and a GNP/HDPE rigid film serving as a temperature sensor. Mechanical and thermal stimuli are transduced into electrical signals, which can be further analyzed using electrical sensing techniques. Experimental results demonstrate that both sensing layers generate reliable and stable electrical responses within the room-temperature to body-temperature range ( 0–40 ℃). Each layer exhibits selective sensitivity to its target stimulus while remaining insensitive to other environmental or mechanical interferences, enabling effective signal decoupling.

The sensing performance remains stable over multiple loading cycles as well as under constant stimuli for more than 12 hours, indicating excellent long-term reliability. Electrical impedance tomography (EIT) is employed to reconstruct pressure and temperature distributions in real time. In addition, finite element analysis (FEA) is used to further analyze the pressure and temperature distributions across the entire sensors. To overcome the inherently low spatial resolution of conventional EIT reconstruction, a machine method is introduced to analyze distinctive features from the electrical signals and enhance the shape recognition, providing a pathway for further improving EIT spatial resolution.

This dual-layer multifunctional composite system is particularly suited to wearable sensing applications, where mechanical compliance, signal decoupling, and long-term stability under repeated human interaction are essential. The demonstrated ability to independently map pressure and temperature fields in real time makes the system attractive for smart mattresses, human posture and activity monitoring, and body-surface thermal sensing. More broadly, the layer-wise design strategy provides a versatile framework for engineering human-centred multifunctional composites, enabling reliable multi-parameter sensing without signal interference in soft and hybrid composite platforms.

#1396

# Research on longitudinal torsional ultrasonic vibration assisted grinding of CFRP

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In order to improve the quality of CFRP drilling, this paper conducted a study on the longitudinal torsional ultrasonic vibration assisted grinding of CFRP with ordered arrangement brazed diamond core drill. Firstly, a mathematical model of the motion trajectory of abrasive particles during longitudinal torsional ultrasonic vibration assisted grinding was established, and the calculation and analysis of abrasive particle trajectory, velocity, acceleration, grinding length, and dynamic working rake angle were carried out. Theoretical research was conducted on the grinding characteristics of abrasive particles; Using MATLAB to simulate grinding morphology based on the motion trajectory of abrasive particles. Then the geometry of the core drill is optimized based on the delamination factor, and longitudinal torsional ultrasonic vibration assisted grinding CFRP experiments are carried out to analyze the influence and mechanism of processing parameters on drilling force, drilling temperature, and hole quality. The research results show that compared with ordinary grinding and longitudinal ultrasonic vibration assisted grinding, longitudinal torsional ultrasonic vibration assisted grinding has a higher total velocity, total acceleration, and dynamic working rake angle of the abrasive particles, which means that the abrasive particles are sharper and have more significant impact characteristics. It can effectively improve the discharge effect of chip dust, prevent the adhesion of chip dust and tool blockage. Longitudinal torsional ultrasonic vibration can effectively reduce axial force, torque, and temperature, but the reduction effect weakens with the increase of speed and feed rate, among which the effect of feed rate on longitudinal torsional ultrasonic vibration is greater than its effect on longitudinal ultrasonic vibration. Longitudinal torsional ultrasonic vibration causes secondary cutting and ironing of abrasive particles, which can effectively reduce the surface roughness of the hole wall, improve the quality of the hole wall, and generate smaller out of plane shear type tears, thereby effectively reducing delamination.

#1397

# High-Speed Projectile Impact Damage and Finite Element Simulation of 2D-SiC/SiC Composites

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Continuous fibre-reinforced ceramic matrix composites (CMCs) are increasingly adopted for high-temperature aerospace engine components due to their low density and strong mechanical performance. Nevertheless, their limited damage tolerance makes them vulnerable to foreign object damage (FOD) during service, creating critical reliability concerns. Here, the high-speed impact damage behaviour of 2D-SiC/SiC composites manufactured by chemical vapour infiltration (CVI) is examined using a single-stage light gas gun. Spherical projectiles are launched at selected velocities, and the resulting surface and internal damage are characterised by optical microscopy and X-ray computed tomography (CT). With increasing impact velocity, damage evolves from shallow indentation to penetration, accompanied by intensified interlaminar delamination near specimen edges. To interpret and predict the impact response, a three-dimensional finite element model is developed in ABAQUS through a user-defined material subroutine (VUMAT). The composite is described as an orthotropic continuum with progressive damage governed by coupled Hashin and Chang–Chang failure criteria and a stiffness-degradation scheme. Contact between projectile and target is modelled explicitly, and element deletion is employed to represent complete material separation under severe loading. Simulations are performed at the same impact velocities as the experiments to predict crater geometry and damage extent. The predicted crater depth and front-surface damage diameter agree closely with measurements across the tested velocity range, and the computed damage patterns are consistent with CT observations of delamination and through-thickness cracking. The validated experimental–numerical framework provides a practical tool for evaluating FOD tolerance and supporting impact-resistant design of SiC/SiC CMC components.

#1398

# Tack to the future: influence of resin tack and AFP process parameters on interlaminar performance in natural fibre composites

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Automated fibre placement (AFP) is well established for high-performance carbon fibre composites, but its transfer to natural fibre reinforced polymers is still in its infancy. The lower stiffness of natural fibre tows, their moisture sensitivity and the need for more sustainable, low-emission resin systems pose additional constraints on tow handling, consolidation and resulting part quality. This work investigates the feasibility of manufacturing natural fibre reinforced laminates by AFP and analyses how resin tack level and process parameters influence laminate quality and mechanical performance.

Unidirectional natural fibre tapes with three different matrix systems, covering a low, medium and high tack level, are processed by AFP under systematically varied layup conditions. Key process parameters such as placement speed, compaction pressure and tool temperature are adjusted within ranges compatible with industrial AFP equipment. The resulting laminates are evaluated in terms of tow placement quality, occurrence of gaps and overlaps, and apparent consolidation state. To quantify structural response, three-point bending tests and interlaminar shear strength (ILSS) measurements are conducted on coupons extracted from the AFP-manufactured panels.

The results reveal systematic correlations between resin tack level, AFP process parameters and the resulting laminate architecture of natural fibre reinforced tapes. Variations in tack and placement conditions manifest in distinct patterns of tow alignment, gap formation and consolidation state, which in turn are reflected in the measured bending response and interlaminar shear behaviour. Rather than identifying a single optimal parameter set, the study maps out interaction effects between matrix formulation and process window to balance manufacturability and mechanical performance. These interactions point to specific opportunities for exploiting AFP in the processing of sustainable natural fibre composites – and expose open questions regarding the underlying mechanisms that will be addressed in ongoing and future work.

#1399

# Recyclable, flame retardant epoxy vitrimers based on disulfide bonds and their composites preparation

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The development of flame retardant epoxy vitrimers which are suitable for use as a composite matrix material is essential for the transition to a sustainable circular economy. In this work the thermal and flame retardant properties as well as the vitrimer characteristics of a common epoxy vitrimer based on DGEBA and Butanediol diglycidyl ether cured with 4-Aminophenyl disulfide (4-AFD) with different reactive and additive Phosphorus based flame retardants (FR) with different chemical environments were studied. The use of 4-AFD as curing agent imparts vitrimeric properties to the material and allows repairing, reprocessing and recycling. A series of epoxy vitrimers (EV) were prepared aiming to improve the flame retardant properties while maintaining the dynamism of the disulfide bonds and reprocessability. The neat EV (Tg ~125 °C) showed no classification and heavy dripping in the UL-94 vertical burning test. With 1.5 wt% of Phosphorous (P) in the EV a V-0 classification with excellent self-extinguishing behavior was achieved. Especially gas phase active FRs with a lower number of oxygen atoms bond to the P showed better flame retardant properties with identical phosphorus content. In cone calorimeter test the EVs with 1.5 wt% P reduced the peak heat release rate (PHRR) up to 43 %. The addition of reactive phosphorous-based FRs did not influence the dynamism and recyclability of the material in dynamic mechanical analysis. After mechanical recycling of the epoxy vitrimers >73 % of the mechanical strength was recovered and the flame retardant EVs do reach as well a V-0 classification in the UL-94 vertical burning test.

#1400

# The First European Benchmark Exercise on Squeeze Flow Testing of High-performance C-SMCs: Quantitative Analysis of Interlaboratory Variability

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High-performance carbon-fiber sheet molding compounds (C-SMCs) exhibit complex flow behavior due to their high fiber content and long-fiber architecture. Although squeeze-flow testing is commonly used to characterize this behavior, the lack of a standardized protocol has limited the reliability and comparability of reported results. To address this, a European consortium is conducting an interlaboratory benchmark using in-house squeeze-flow facilities at multiple research institutions. Building on the methodological overview presented at ESAFORM 2025, this contribution presents a comprehensive statistical evaluation of the data collected across all participants.

Five vinyl ester–based C-SMC materials were tested following a harmonized procedure controlling specimen preparation, test setup, and execution order via institution-specific randomized sequences. The dataset includes specimen areal masses, force-displacement curves, and flow-front profiles extracted from post-test optical scans. All data were preprocessed consistently, including alignment of force-displacement curves and reconstruction of flow fronts. Statistical analyses were performed within and across institutions to quantify repeatability and reproducibility, assess consistency of mean responses, and identify potential sources of variability.

Results reveal distinct contributions to variability from both material heterogeneity and institution-specific testing conditions. For several metrics, inter-institution differences exceed within-institution scatter, highlighting the need for further harmonization of the squeeze-flow methodology. Also, the findings indicate a significant impact of sample size on variability. Overall, the statistical analyses provide valuable insights for developing a robust, standardizable testing protocol for high-performance C-SMCs and for improving the reliability of flow-modeling inputs in composite manufacturing simulations.

#1401

# Investigation of Electric Field Effects on Resin Impregnation Behavior and Interfacial Properties in the VaRTM Process

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The vacuum-assisted resin transfer molding (VaRTM) process, which is one of the out-of-autoclave (OoA) manufacturing methods, has gained significant attention due to its cost and size efficiency. However, the long resin infusion time required for large composite structures remains one of the main challenges of the VaRTM process. To address this limitation, numerous studies have attempted to reduce resin infusion time using various approaches, such as temperature control and multi-inlet placement. However, the temperature control method resulted in non-uniform material properties due to the initiation of the curing reaction at high temperatures during the infusion process. Furthermore, the use of multiple inlets increased the possibility of dry spot formation due to the presence of multiple resin flow paths. In this study, the electrowetting phenomenon was applied to the VaRTM process to reduce resin infusion time and enhance interfacial strength with a simple configuration. A resin infusion experiment was conducted to evaluate the effect of an electric field on resin flow behavior during the infusion process. Resin infusion time and flow front progression were simultaneously recorded to confirm the electrowetting effect under various applied voltages. Temperature was simultaneously monitored using thermocouples and a LabVIEW-based data acquisition system to confirm that the applied electric field caused no measurable temperature variation. As a proof of concept, the resin infusion time was measured and compared with that of the conventional resin infusion method. Furthermore, a multiphysics simulation was conducted to investigate the effects of the electric field on the resin infusion process. After the fabrication process, the resin impregnation state at the microscopic level was observed using scanning electron microscopy (SEM), and the interlaminar shear strength (ILSS) was measured to evaluate the interfacial strength. These results confirm the significant potential of the electrowetting-assisted impregnation process for various applications in the composite industry.

#1402

# Defect Identification in Composite Panels via GNN Models Trained on FEM Simulations

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Structural Health Monitoring (SHM) of composite structures with complex geometries, such as stiffened panels with stringers, remains a challenging task due to the strong interaction between material anisotropy, structural topology, and damage mechanisms. High-fidelity numerical simulations can provide detailed insight into damage evolution, but their direct use in real-time SHM applications is limited by computational cost.

This work presents a graph-based artificial intelligence framework for defect prediction in stiffened composite panels, leveraging Graph Neural Networks (GNNs). The proposed methodology represents the structure as a graph, where nodes correspond to sensor-relevant structural features, while edges encode geometric adjacency. This formulation naturally allows scalable learning across different structural configurations. A comprehensive dataset is generated through Finite Element Method (FEM) simulations, including variations in material properties and defect scenarios. The FEM models explicitly account for the presence of defects, which are used as labels in a supervised learning setting. The trained models are employed to predict the presence and spatial distribution of defects, supporting SHM-oriented damage assessment. From a methodological standpoint, the proposed framework is designed to support sensor placement strategies, as the graph formulation enables the evaluation of the relative importance of structural regions in relation to damage prediction. Furthermore, the integration of graph-based learning models with FEM data enables the development of a digital twin, where the trained surrogate model can be continuously updated with sensor measurements to provide near real-time damage prediction. The proposed approach demonstrates the potential of graph-based deep learning as an efficient surrogate model for FEM-driven SHM of composite structures, enabling accurate damage prediction while significantly reducing computational effort.

#1404

# Sustainable, Circular, and Performing FR-PET Composites

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This study presents a sustainable processing route for carbon fiber (CF)–reinforced poly (ethylene terephthalate) (PET) composites, employing a solid-state polymerization (SSP), conducted directly at the composite level (in-situ SSP). This approach effectively addresses viscosity challenges during thermoplastic composite impregnation without the need of solvents, enabling high-quality fiber-matrix impregnation, at mild conditions. The influence of PET intrinsic viscosity (IV) on transverse tensile performance was first investigated, revealing an ultimate strength plateau of approximately 69 MPa for PET-IV of 0.82 dL/g with corresponding failure strains near 1.18%. Further increase of IV led to some additional improvement in failure strain. This exercise was repeated on PET derived from post-consumer bottles, which followed the in-situ SSP route and provided practically alike performance to virgin-grade PET. Notably, both grades are matching, or even surpassing the properties of conventional epoxy-based composite systems.

The study further evaluated chemical recycling of CF–PET and glass fiber (GF)-PET composites via glycolysis. Results demonstrated that fiber presence did not hinder depolymerization; over 99% of the polymer was efficiently removed and recovered as pure, crystalline bis(2-hydroxyethyl) terephthalate (BHET), which is a key monomer to produce PET. Throughout the process, fibers retained their alignment and length, allowing for their reuse in structural applications comparable to the original composites. The extent of polymer residue was found to depend on factors such as depolymerization time, polymer crystallinity, and IV. Interestingly, residual polymer adhering to fiber surfaces can substitute conventional sizing, further enhancing process sustainability. Overall, this work establishes a robust, closed-loop methodology for manufacturing and recycling high-performance CF–PET composites, aligning mechanical performance with environmental circularity.

#1406

# Effect of hygrothermal ageing on the fatigue behaviour of pultruded composite materials

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As part of the transition to more sustainable mobility, the INFRAlight project aims to develop lightweight, eco-designed railway infrastructure suitable for light rail vehicles and small rural lines. One of the key areas of focus is the design of composite rails, whose long-term mechanical performance must be validated under severe environmental conditions (humidity, temperature, UV radiation) and under cyclic stresses. Among the materials considered in this project, pultruded PA6/Glass fibre and Elium/Glass fibre unidirectional composites with high fibre content of respectively 64 %vol and 70 %vol were studied for this application.

The fatigue behaviour of both composites was assessed both before and after hygrothermal ageing at 50 °C and 80 % relative humidity. In the unaged condition, the high fibre volume fraction promotes early damage accumulation under cyclic loading, which limits fatigue performance of both composites. During ageing, gravimetric monitoring and viscoelastic property analysis via vibrational testing were conducted. Additional characterisation, including DSC, DMA, and quasi-static mechanical tests, was performed to evaluate the evolution of the composite's thermophysical properties.

Preliminary findings indicate a significant reduction in mechanical properties during ageing in the transverse fibre direction, while properties in the fibre direction remain largely unaffected. Both composites exhibit pronounced fatigue degradation after ageing, primarily due to matrix plasticisation and interfacial degradation caused by moisture absorption. S-N curves for aged specimens reveal a marked decrease in fatigue life at stress levels above approximately 300 MPa, whereas a convergence between aged and unaged specimens is observed at lower stress levels, suggesting minimal impact of hygrothermal ageing on the fatigue endurance limit.

These results underscore the potential of both pultruded composites for railway applications and provide critical data for the design process, including the establishment of appropriate safety factors.

#1407

# Solar exposure patterns and self-shadowing effects on service temperature predictions in hybrid gfrp–concrete bridge

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Fibre-reinforced polymer (FRP) composites and hybrid FRP systems are increasingly employed in bridges and lightweight structures, owing to their high strength-to-weight ratio, ease of installation and reduced maintenance demands, although thermal actions influence both service and ultimate performances. The definition of service temperature limits is critical at the design stage, and accurate prediction of peak temperatures is required to capture temperature-dependent material behaviour and avoid excessive conservatism or insufficient safety capacity. However, solar exposure patterns may vary considerably across a structure, particularly in geometries prone to self-shadowing, and such variations can influence thermal fields and the environmental conditions experienced by individual surfaces. Therefore, this study examines how annual solar exposure, modulated by geometric self-shadowing, structural orientation and seasonal solar paths, relates to thermal extremes in a real hybrid GFRP–concrete footbridge used as a case study.

A developed solar position-based self-shadowing algorithm is used to evaluate the influence of sun-exposed and shaded conditions on maximum temperatures within the cross-section, as well as to quantify the differential exposure experienced by surfaces throughout the year. The results reveal pronounced spatial asymmetries: surfaces that do not reach the highest temperatures during the structure's global peak radiation and air temperature conditions may nevertheless experience greater annual solar exposure. These patterns, governed by geometry and solar trajectory, are not captured by simplified approaches based solely on the structure's global peak temperature.

The simulations also offer insight into the bridge's mechanical response after a decade in service. Experimental data indicate a reduction of the stiffness on the side identified as receiving the greatest annual exposure. In this context, the study proposes a dual perspective considering annual variations in solar exposure on FRP bridge structures: (i) influence on peak temperature predictions for design, and (ii) exposure metrics as complementary indicators with relevance to long-term behaviour and durability considerations.

#1410

# DIC-enhanced experimental platform with a multi-detector array for mechanical test of composite materials at 4 K and 77 K

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Mechanical testing of composite materials at very low temperatures is difficult, but it is required for many applications such as superconducting magnets, cryogenic hydrogen systems and space structures. To address this need, a DIC-enhanced experimental platform with a multi-detector array was developed for mechanical testing at 77 K and 4 K.

The platform is designed for tensile and fracture testing of composite materials under cryogenic conditions. It enables simultaneous, time-synchronised measurement of full-field strain evolution using digital image correlation (DIC), together with force, acoustic emission (AE) and temperature measurements. The tests are performed inside a stabilised cryostat that provides controlled thermal conditions while maintaining optical access for DIC measurements. Special solutions were implemented to ensure stable imaging, durable speckle patterns and reliable sensor operation at cryogenic temperatures.

The main advantage of the platform is the ability to measure both global mechanical response (force, displacement and temperature) and local deformation and damage processes at the same time. DIC provides full-field strain maps, while AE enables detection of damage initiation and evolution during loading. This combination allows clear identification of strain localisation, crack initiation and crack propagation during tensile and fracture tests.

The platform enables systematic studies of how composite materials deform and fail at 77 K and 4 K. It provides high-quality experimental data for understanding cryogenic damage mechanisms and for validation of material models used in the design of advanced cryogenic composite structures.

#1411

# Effect of temperature and strain rate on the translaminar fracture of thermoplastic composites

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Growing interest in the repairability and recyclability of high-performance composite structures in the aerospace and automotive sectors has accelerated the adoption of thermoplastic matrix composites. These materials also enable manufacturing cycle-time reductions of up to 80%, with parts produced in minutes rather than hours. Carbon-fibre-reinforced thermoplastics (CFRTPs) incorporating matrices such as PA, PC, PEEK, PEI, and PES have been widely investigated. Among them, CF/PEEK composites offer a compelling balance of strength, stiffness, and wear and fatigue resistance, making them well suited for demanding structural applications. However, the mechanical response of the CF/PEEK composites is strongly affected by strain rate and temperature due to the existence of thermal transitions in polymer behaviour. Beyond changes in stiffness and strength, these factors significantly influence energy absorption, crack growth mechanisms, and failure modes. Robust fracture-behaviour characterization under dynamic loading is therefore essential for high-performance design. This study examines the combined influence of high strain rate and temperature on the critical translaminar strain-energy release rate associated with fibre-dominated tensile fracture in CF/PEEK. Dynamic compact-tension tests were performed using a Split Hopkinson Pressure Bar across three temperatures: room temperature, 90 °C, and –55 °C. Digital image correlation (DIC) analysis was conducted on ultra high-speed images in order to extract the strain fields, crack tip location and the opening displacements and the area method was used to evaluate the fracture energies in the different cases. Post-mortem imaging of the fracture surfaces was conducted using SEM. It was found that at high strain rates, increasing the temperature to 90 °C resulted in a significant reduction in fracture toughness, likely due to matrix softening and interface weakening. DIC analysis show smaller damaged regions, in line with their lower measured critical strain energy release rate.

#1412

# Parametric Evaluation of Winding-Angle Effects on Fatigue-Induced Residual Burst Strength in Filament-Wound CFRP Hydrogen Tanks

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Filament-wound carbon fiber reinforced polymer (CFRP) tanks are widely used for high-pressure hydrogen storage, where the winding pattern strongly governs structural performance and burst behavior. However, the quantitative relationship between winding angles, failure initiation, and both initial and post-fatigue burst strength remains insufficiently systematized for use in early-stage design. To address this gap, this study aims to construct a winding-angle–dependent strength database for CFRP hydrogen tanks through a finite element analysis framework that integrates manufacturing-reflective geometry generation with advanced damage modeling.

Based on our previous research efforts, a numerical framework has been established that combines an intralaminar continuum damage mechanics (CDM) formulation with an interlaminar cohesive-zone modelling. This unified approach enables consistent simulation of matrix cracking, delamination, fiber-dominated failure, and final tank failure, and is capable of evaluating both initial burst pressure and fatigue-induced residual burst strength. Filament-wound geometries are generated using a modeling procedure that reproduces realistic fiber paths, thickness variations, and dome transitions so that manufacturing-related effects are appropriately reflected in the structural analysis.

Using this framework, the present study conducts a parametric evaluation of how filament-winding configurations influence burst strength and residual burst strength after fatigue loading. The helical winding angle and the hoop/helical ratio are systematically varied to explore their effects on stress distribution, damage initiation, and dominant failure mechanisms. The ultimate goal of this work is to develop a winding-angle–dependent strength database that supports early-stage design of composite hydrogen tanks and provides insights into optimal winding configurations. Comparative results for static and fatigue-induced burst behavior will be presented at the conference.

#1413

# Rheological property of Elium resin with different amount of graphenen oxide

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With increasing environmental concerns, thermoplastic polymers have gained attention as sustainable alternatives to thermosets. Elium resin is particularly promising due to its room-temperature polymerization and compatibility with conventional liquid molding techniques such as RTM and vacuum infusion, while maintaining mechanical properties comparable to thermosets. This study investigates the rheological behavior of Elium/Graphene Oxide (GO)/solvent mixtures, focusing on the effects of varying solvent content and GO loading. The baseline viscosity of neat Elium resin was first measured to establish processability benchmarks. The addition of GO increased viscosity, while acetone effectively reduced it. Notably, the sensitivity of viscosity to GO loading decreased at higher solvent ratios, indicating non-linear solvent effects. These results offer key insights for optimizing Elium-based nanocomposite formulations to achieve improved processability and uniform nanoparticle dispersion.

#1414

# Ultrasonic welding of 3D-printed lignocellulosic biocomposites with integrated energy directors

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The production and use of disposable materials, such as petrochemical-derived plastics, have notable negative environmental impacts, particularly with regard to climate change, resource scarcity, and greenhouse gas emissions. One strategy to address these challenges is the replacement of conventional plastics with bio-based and biodegradable polymers and composites. Wood-based materials, such as lignocellulosic biocomposites, are of particular interest in this context, as lignin and cellulose are the most abundant biopolymers on Earth. In this study, the ultrasonic welding of 3D-printed lignocellulosic biocomposites with integrated energy directors (EDs) was investigated. Solvent-based lignocellulosic inks were prepared using hydroxypropyl cellulose (HPC) and organosolv lignin (OSL) in a citric acid/water/ethanol solvent system. Lignocellulosic coupon samples with integrated energy directors were then fabricated with an HPC-to-OSL ratio of 60/40 wt.%/wt.% using direct ink writing (DIW). The specimens were ultrasonically welded in a single-lap joint configuration using a displacement-controlled operating mode, with weld depths of 95% of the average energy director height. The importance of energy directors was assessed by comparing the ultrasonic welding of coupon samples both with and without integrated energy directors. Furthermore, the influence of the shape, height, ink composition, and mechanical interlocking of energy directors on the weld quality of ultrasonically welded lignocellulosic coupon samples was investigated. Based on the experiments, this work demonstrates the successful ultrasonic welding of 3D-printed lignocellulosic biocomposites with integrated energy directors. The results presented in this study lay the foundation for further research to enable the fabrication of large, tailor-made lignocellulosic components for new engineering applications by means of direct ink writing and ultrasonic welding.

#1415

# Sustainable pathways for wind turbine blade recycling: From recycled carbon fibres to high-performance semi-finished products

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The paper focuses on the investigation of a sustainable circular pathway for wind turbine blades by upgrading recycled carbon fibers (rCF) into high-performance semi-finished products. In this study, rCF originating from the pyrolysis of composite waste as well as textile edge trim from woven fabrics are processed into highly oriented tapes and yarn-like structures.

The paper describes the complete processing chain, including fiber preparation, alignment, and tape and yarn formation. Particular attention is given to the influence of key process parameters on fiber orientation, consolidation behavior, and resulting material characteristics. A distinctive feature of the investigated manufacturing route is an unconventional curing step, in which wet-impregnated rCF tapes and yarns are cured in a free-hanging state without mechanical tooling or lateral constraint.

This approach enables continuous processing without dependence on a mould. Mechanical characteristic values are determined, microsections are prepared, and the results are discussed in relation to the applied process parameters. The findings demonstrate the feasibility of producing highly oriented rCF tapes and yarns from wind turbine blade waste streams and highlight their potential for secondary structural composite applications, contributing to circular material concepts in fiber-reinforced composites.

#1418

# Local Reinforcement of Cutouts in Filament-Wound Composite Cylinders Using Tailored Fiber Placement Patches

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Cutouts are unavoidable in many applications of filament-wound (FW) composite structures, but they introduce severe local stress concentrations that significantly reduce load-carrying capacity. This work investigates the use of Tailored Fiber Placement (TFP) as an additive manufacturing technique to place reinforcement patches at strategic locations, locally strengthening FW composite cylinders with cutouts subjected to axial compression. Carbon/epoxy cylinders with a ±45° winding angle were manufactured in five configurations: intact reference cylinders, cylinders with an unreinforced 40 mm circular hole, and cylinders reinforced with circular TFP patches of three different outer diameters (60 mm, 80 mm, and 100 mm). Axial compression tests were combined with Digital Image Correlation (DIC) to quantify the global mechanical response and local strain redistribution.

The introduction of an unreinforced hole reduced the maximum compression load by approximately 10% and generated pronounced axial and circumferential strain concentrations that governed premature failure at the hole edge. In contrast, all TFP-reinforced configurations effectively suppressed these localized strains by creating a low-deformation zone extending beyond the patch boundary. As a result, the failure mode from the reinforced cylinders were relocated to the cylinder ends, as observed in the intact cylinder. All reinforced specimens restored the maximum load to levels statistically indistinguishable from those of original cylinders and exhibited a consistent increase in axial stiffness of 5–6%, independent of patch diameter. Larger patches further reduced hole deformation but did not significantly alter the global strength or stiffness response. These findings demonstrate that compact TFP patches can neutralize the structural penalty imposed by cutouts while adding minimal mass, highlighting the strong potential of hybrid FW-TFP manufacturing for pressure vessels, pipelines, and other composite shell structures requiring local reinforcement.

#1421

# Digital Twin for Inline C-SMC Quality Assurance -

# Evaluating Strip Density Prediction via Learning-Based and Topological Approaches

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Inline quality assurance during Sheet Molding Compound (SMC) production requires accurate, real-time estimation of fiber strip density to ensure consistent mechanical properties of the final component. While machine learning approaches offer promising inference speeds, their development is hindered by the scarcity of accurately labeled training data from industrial manufacturing environments.

This work presents a physics-based digital twin framework for predicting carbon fiber strip density in C-SMC semi-finished products. Building upon a previously developed simulation environment that models strip deposition dynamics—including gravitational settling, friction, and conveyor belt motion—we employ deep learning models trained exclusively on synthetic data to predict strip counts within defined measurement regions. The simulation generates fully annotated datasets with precise ground truth labels, eliminating the need for manual annotation of real-world imagery.

We systematically compare three methodological approaches for strip density estimation: (1) a CSRNet-based density regression model trained on synthetic Gaussian density maps, (2) topological methods leveraging persistent homology to extract structural features from fiber arrangements, and (3) conventional computer vision segmentation techniques including watershed algorithms and morphological operations. Each approach is evaluated on both synthetic test sets and real polarization images acquired during industrial C-SMC production.

Preliminary results demonstrate that the physics-based synthetic training data enables effective transfer to real-world scenarios, with the deep learning approach outperforming conventional segmentation methods particularly in high-density configurations where strip overlap causes traditional methods to fail. Topological features provide complementary information about spatial fiber distribution patterns that enhance prediction robustness. The proposed framework reduces dependency on expensive real-world data collection while enabling rapid iteration of model development through controllable synthetic data generation.

#1424

# High performance biobased thermosets containing dynamic covalent bonds

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The increasing environmental concerns linked to the intensive use of petroleum-based and toxic compounds in traditional polymer manufacturing have intensified the global search for sustainable alternatives. Thermoset resins, widely used in space, aerospace, automotive, and electronics industries for their exceptional mechanical strength, chemical resistance, and thermal stability, predominantly rely on toxic raw materials, such as bisphenol A, thus contributing to pollution, limited recyclability, and health hazards.

Lignin, an abundant byproduct of the pulp and paper industry, has emerged as a promising renewable resource for the development of bio-based polymers. Its depolymerization yields aromatic aldehydes which offer versatile functional groups for the synthesis of bio-derived monomers. These aldehydes can react with amines to form Schiff bases, thus introducing dynamic covalent bonds that provide intrinsic recyclability to thermosetting systems. The incorporation of imine into epoxy networks represents a key strategy for achieving high performance and sustainability.

Recent studies demonstrated that Schiff-based epoxy monomers can be transformed into robust thermosets through various polymerization mechanisms. In one approach, the self-polymerization of glycidylated Schiff bases enables the formation of poly(imine-ether) networks without the use of external curing agents or catalysts. This method adheres to green chemistry principles and produces thermosets with high mechanical and thermal properties—storage moduli exceeding 2 GPa, glass transition values up to 249 °C, and excellent flame retardancy.

An alternative strategy involves anhydride-mediated cross-linking of the designed Schiff-based monomers, leading to the formation of poly(ester-imine) networks. In this route, biobased anhydrides react with the epoxy groups through copolymerization. The resulting thermosets exhibit Tg~ 90–170 °C, storage moduli up to 1.7 GPa, high flame-retardant properties, alongside low water absorption.

By valorising lignin-derived aldehydes and exploiting the dynamic chemistry of imine linkages, the research paves the way for next-generation epoxy materials that combine renewability, recyclability, and functional versatility—key attributes for future circular-material technologies.

#1425

# Exploring Nanoscale organic piezoelectric coatings for in -situ Non Destructive Structural Health Monitoring of carbon fibre reinforced Composites

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This study develops the integration of piezoelectric sensors into carbon fibre reinforced polymers (CFRPs) for non-destructive health monitoring. A uniform and continuous coating of Poly(vinylidene fluoride) (PVDF) nanofibres was applied directly onto the surface of carbon fibres (CF) via electrospinning process, creating fully embedded, flexible, and lightweight piezoelectric sensors. Careful optimisation of the crystalline structure of electropsun PVDF nanofibres leads to high piezoelectric performance for sensing, with a β-phase content of 84.1 ± 0.5% and a degree of crystallinity of Xc = 46.7 %. The sensor demonstrated promising properties, including a piezoelectric coefficient d33 of 5.42 ± 2.3 pC/N, representing the highest reported piezoelectric performance for sensing and exhibiting 90 times more sensitivity than the previous state-of-the-art of voltage response for organic sensors. The single-step production via the electrospinning process ensures strong adhesion and conformal coverage of the CF without the need for any additional poling or post-integration treatments, allowing direct integration into CF and simplifying optimisation of sensor fabrication. A reliable and repeatable data acquisition system was established to characterise the sensor response under mechanical loading. The materials exhibited mechanical robustness, leading to long shelf life with stable beta phase content and consistent voltage output performance for up to three months, enabling non-destructive and durable structural health monitoring (SHM) of CFRPs. Finally, the PVDF-based sensors were successfully embedded within CFRP laminates and subjected to mechanical testing. This work introduces an optimised integration strategy for real-time SHM applications. These advances represent a new benchmark for real-time, non-destructive SHM of advanced composites.

#1426

# Deep Learning-Based Surrogate Models for Resin Transfer Moulding Process Simulation

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Resin Transfer Moulding (RTM) simulation plays a fundamental role in predicting filling patterns and anticipating potential manufacturing defects such as dry spots, race tracking or local defects causing permeability variations in the preform. This is particularly relevant when preforms are manufactured using Automated Fibre Placement (AFP), where gaps and overlaps between adjacent tows are inherent to the process and significantly affect local permeability distributions.

High-fidelity simulations of the RTM process, while accurate, require significant computational times that limit their practical application in iterative optimization workflows, stochastic analyses, or real-time process monitoring scenarios. This motivates the development of surrogate models capable of providing rapid predictions while maintaining sufficient accuracy for engineering decision-making.

This work presents the development and validation of deep learning-based surrogate models for RTM filling time prediction. The methodology involves training neural network architectures on datasets generated from high-fidelity PAM-RTM simulations, where variations in permeability fields—including induced defect zones—are systematically explored. The trained models learn to map input features describing local material properties and mesh geometry to element-wise filling times, capturing the essential physics of Darcy flow in porous media.

Special attention is devoted to handling the challenge of defect zones, which represent a minority of elements but are critical for manufacturing quality assessment. A weighted loss function approach is proposed to ensure that the model adequately learns the behavior in these regions of interest.

The surrogate models are validated against unseen simulation configurations, demonstrating their capability to generalize to new defect patterns while achieving inference times orders of magnitude faster than full numerical simulations. The results establish the foundation for integrating such models as components of digital twin systems for composite manufacturing optimization and real-time process control.

This work was developed within the CAELESTIS project (Horizon Europe), aimed at advancing simulation-based digital ecosystems for European aeronautical manufacturing innovation.

#1427

# Sustainable Smart Facade Panels

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The construction industry is under growing pressure to deliver solutions that are more sustainable, cost-effective, and flexible in design. The Variable Geometry Panels - R2UTechnologies project addresses this need by developing composite facade panels that combine geometric freedom with a strong sustainability focus. By incorporating bio-based materials, the consortium seeks to reduce environmental impact while maintaining required performance levels.

The panels were manufactured using vacuum-assisted resin infusion, and a core innovation is the integration of multi-functional capabilities directly into the thermoset panels during this process. Printed electronics, optical fibres, and photovoltaic cells are embedded during infusion. Early results show successful integration: printed electronics and optical fibres have been incorporated into hemp- and flax-reinforced panels, while photovoltaic cells have been embedded into basalt-reinforced panels.

Overall, this work supports the development of more sustainable, versatile, and cost-efficient building solutions, contributing to a more environmentally responsible construction sector. This study was carried out within the framework of the project “Agenda R2U” [C 64487681000000019 | Project nº48], funded by PRR – Plano de Recuperação e Resiliência, under Next Generation EU from the European Union.

#1428

# Nanocomposite Formation via Reactive Bimetallic Nanoparticle Systems

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Aluminides (e.g., Pt/Al) are known to release stored chemical energy in response to external stimuli, producing heat, light, and sound. When synthesized as multilayer stack systems, such bimetallic combinations form stable or metastable nanocomposites, inter-metallics, and alloys upon ignition. This approach enables the formation of distinct phases and crystal structures of significant scientific interest. The present study aims to correlate calorimetric heat release with the morphology and phase evolution of nanocomposite films. While reactive aluminides have traditionally been employed in applications such as brazing, sealing, coatings, and micro-joining, this work differs from the state of the art by systematically investigating ignition-dependent nanocomposite phase formation in a Pt/Al nanoparticle-based reactive system.

Nanoparticles are synthesized using a plasma-based spark discharge process, where sparking between Pt or Al electrodes generates sub-5 nm positively charged nanoparticles via cathode erosion. These nanoparticles are selectively deposited onto an electrically biased patterned substrate within a cylindrical reactor. The carrier gas flow (typically $N_2$) controls the nanoparticle size, while spark power and gas flow collectively influence the porosity of the resulting aluminide multilayer stack. Upon ignition, the bimetallic stack undergoes a self-sustaining exothermic reaction, and the released energy drives the formation of Pt/Al nanocomposites, inter-metallics, and alloys. Thermal ignition temperature serves as a key control parameter for tailoring phase formation.

Heat release during ignition is quantified using differential scanning calorimetry, while phase identification is performed using X-ray diffraction. Microstructural and phase analyses are further supported by selected area electron diffraction and high-resolution transmission electron microscopy. The results demonstrate that nanocomposite formation and intermetallic phase evolution are governed by nanoparticle size, spark power, carrier gas flow rate, and ignition temperature. Despite these insights, fundamental knowledge gaps remain regarding bimetallic nanoparticle interactions, and the underlying heat release mechanisms, which is the focus of our future systematic investigations.

#1430

# A comprehensive study of epoxy nanocomposites for lightweight hydrogen storage tanks: from processing to gas permeability

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Hydrogen has emerged as a promising energy carrier for decarbonising the transport industry . One key challenge is storing gaseous hydrogen under high pressures to increase its energy density for practical use. Type V linerless carbon fibre-reinforced polymer (CFRP) vessels are the most advanced solution for weight reduction and recyclability. Hydrogen permeability is a critical material parameter controlling tank's resistance to hydrogen emission. While polymer matrices provide lightweight and chemical resistance their gas barrier resistance is much lower when compared with metals. However, reinforcing polymers with 2D nanofillers provide a promising route to reduce hydrogen permeability by forming tortuous diffusion paths inside the material. Therefore, the ultimate goal of this research is to develop epoxy-based systems reinforced with expanded graphite (EG) as matrices for linerless storage tanks. The nanocomposite systems were characterized in terms of curing kinetics, rheology, and mechanical behaviour. Kinetic and chemorheological models were used to assess processability under conventional manufacturing methods (e.g. filament winding). A comprehensive study of hydrogen permeability was performed under service-relevant pressures and temperatures to evaluate the influence of filler content and microstructural arrangement on gas transport. Experimental findings were complemented with analytical and numerical modelling to provide fresh understanding of the microstructure on hydrogen diffusion mechanisms. In summary, the composites showed enhanced stiffness and thermal stability, as well as reduced gas permeability. By coupling modelling and experimental approaches, this work correlated filler microarchitecture, curing behaviour, and barrier performance, providing a quantitative framework for designing nanocomposites for next-generation hydrogen storage systems.

#1431

# 4D printing of composite materials : Opportunity for disruptive fucntions ?

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3D printing allows for the custom design of materials according to a defined functional specification (Materials by Design). 4D printing, theorized since 2013, allows for the programming of the spatiotemporal shape change response (amplitude, response speed, work, etc.) of smart composite materials triggered by surrounding environment (temperature, humidity, etc.) or induced ones (e.g. Joule effect).

Currently, real-time control of absolute performance prevails leading to a segment of the 4D printing community is focusing on human stimulated composite materials. This presentation, however, will not be the focus of that discussion. The objective of this speach is to offer a perspective on 4D printed composite materials by exploring a radical and disruptive vision for 4D printed composites with autonomous response possibly without electromechanical, computer, wire or motor components, reducing maintenance problems and human-caused energy needs. The purpose is to apply biomimicry and reduce the environmental impacts on the whole life cycle.

Shape changes of composite materials can be therefore reversible or irreversible depending on whether the mechanisms involved depend on the state of residual stresses (resulting from the process) or internal stresses (during use). It offers significant advantages, particularly for applications in extreme environments where the design of these materials will not oppose the environment but rather utilize it to achieve unique functions.

#1433

# In-situ Curing of FRP Composites via Joule Heating Using Embedded Carbon Nanotubes

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The rapid development of aerospace, wind energy, and automotive industries has increased the demand for high-performance materials. Fibre-reinforced polymer (FRP) composites offer notable advantages including lightweight and high specific strength. However, conventional manufacturing processes such as oven and autoclave curing are limited by high energy consumption and long cycle times. Microwave, radiation, and induction heating methods, have emerged as potential alternatives, but facing challenges such as uneven energy distribution and material limitation, etc. Joule heating has been explored as one of the promising methods owing to its high compatibility with FRP composites, and ease of control.

In this study, carbon nanotube films fabricated by floating catalyst chemical vapour deposition were embedded into carbon fibre reinforced polymer (CFRP) composites, with glass fibre reinforced polymer (GFRP) composites in between for electrical insulation. Thermocouples were used to monitor the temperature variation during the curing process, with a power meter employed to record the energy consumption. . The interlaminar shear strength (ILSS) of the composites, cured by oven, autoclave and Joule heating with and without additional pressure, was evaluated using double beam shear tests.

The results demonstrate that the Joule heating method enabled efficient in-situ curing of FRP composites. Compared with conventional oven and autoclave curing methods, this approach achieved comparable curing quality and mechanical performance while offering significant energy reduction. The ILSS of composites cured by Joule heating with additional pressure (JH+P) exhibited a significant enhancement compared with the one without additional pressure (JH), surpassing that of oven-cured samples by 20.9%. It is comparable to autoclave cured samples, while the energy consumption was only 19.5% of autoclave curing.

#1434

# A Prediction Framework Integrating RF and ANN for Low-Velocity Impact Behavior of the Novel Composite Sandwich Structures

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Composite honeycomb sandwich structures are lightweight materials with excellent mechanical properties, widely used in aerospace and other high-performance applications. In our previous work, we enhanced the impact resistance of sandwich structures by introducing elastomeric interlayers between CFRP plies. However, this approach relied heavily on experimental testing and finite element simulations, which are time-consuming and costly. This paper develops an innovative hybrid machine learning framework combining Random Forest (RF) and Artificial Neural Network (ANN) with interpretability capabilities, providing an efficient solution for rapidly predicting the impact behavior of novel sandwich structures. First, we augment the original dataset using a previously proposed GAN-based data augmentation method. Second, we construct a predictive model using a hybrid framework that integrates both RF and ANN models, enhanced by 10-fold cross-validation and Bayesian optimization to improve generalization capability. Finally, we propose a SHapley Additive exPlanations (SHAP) interpretability analysis model based on the hybrid prediction framework. The interpretability analysis reveals significant nonlinear effects of material parameters, where transverse tensile fracture energy and longitudinal tensile strength are identified as critical factors influencing the impact performance of the novel sandwich structures. The proposed methodology effectively integrates data-driven approaches with physical knowledge, providing an efficient solution for the development of advanced composite sandwich structures in lightweight design applications.

#1436

# Lightweight Composite Transtibial Prosthetic System with EMG-Enabled Dynamic Movement

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Below-knee prosthetic devices are vital for enabling functional ambulation in individuals with transtibial limb loss. However, traditional designs frequently involve trade-offs among mechanical strength, mass, durability, and wearer comfort. This study describes the development of an advanced transtibial prosthetic system that integrates high-performance composite materials with an electromyography (EMG)-based control framework to improve both mechanical integrity and functional responsiveness. Composite structures fabricated from carbon and glass fibers were produced using hand layup and additive manufacturing techniques to evaluate processing routes and optimize stiffness-to-weight ratio, resistance to cyclic loading, and impact attenuation.

Structural behavior of the socket, pylon, and foot components was examined using finite element modeling under physiologically relevant gait-loading conditions, and the simulations were corroborated through experimental mechanical testing. These evaluations focused on load-bearing capacity, durability, and pressure distribution at the limb - socket interface. The resulting composite socket design demonstrated lower peak contact pressures, enhanced energy restitution, and a notable reduction in overall weight relative to conventional prosthetic materials. To enhance user - prosthesis interaction, a real-time EMG-driven control system was incorporated. Surface electrodes positioned on the residual limb, captured muscle activation signals, which were processed by an embedded microcontroller to generate adaptive motion commands. This approach enabled the prosthesis to respond in real time to the user's gait intent, leading to improved coordination, balance, and mobility.

By uniting advanced composite engineering with bioelectrical signal-based control, this work presents a lightweight, mechanically efficient, and user-responsive transtibial prosthetic system. The findings support the potential of such integrated designs to better replicate natural lower-limb function and substantially improve comfort and daily performance for amputees.

Keywords: Prosthetics, Composite Materials, Bioelectronics, Sensors.

#1437

# Characterization and Improvement of Fiber-Matrix Adhesion in Lithography-Based Additive-Manufactured Composite Materials

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While stereolithography (SLA) facilitates the creation of complex and customized products, the mechanical limitations of current photopolymers restrict their use in several industries, such as aerospace, automotive, and biomedical. To overcome these difficulties, our research investigates the integration of fiber reinforcement as a strategy to elevate the thermomechanical properties of SLA-processed high-viscosity photopolymers. Achieving effective stress transfer in such composites relies heavily on the fiber-matrix interface. To maximize adhesion, we employed a surface functionalization process to covalently bond polymer chains to the glass fiber surface. This surface functionalization method is critical, as it significantly enhances interfacial adhesion. The promoted adhesion between the functionalized glass fibers and the photopolymer matrix was characterized on the microscopic level by performing single-fiber pull-out tests. To enable accurate testing of high-viscosity photopolymers, a two-part setup was developed. The first component allowed for the precise embedding and subsequent curing of a single fiber within a photopolymer droplet under an strictly controlled inert atmosphere. A second device was used to measure the resulting interfacial shear strength, thereby ensuring accurate characterization of the interfacial properties. These findings were subsequently incorporated into our SLA printing process to fabricate continuous fiber-reinforced composites with controlled fiber orientation by an automated fiber deposition system. Finally, printed samples at the macroscopic scale were thermomechanically characterized to verify the performance improvements. Our research establishes a high-adhesion functionalization protocol compatible with demanding SLA processing conditions, contributing to a better understanding of the process and material influences necessary for manufacturing, lithography-based additive-manufactured glass fiber composite materials.

#1439

# Investigation on the Pseudo-Plastic Deformation Behavior of Staple Fiber Organic Sheets

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The global demand for carbon fibers (CF) increased from 53.0 kt in 2014 to 126.5 kt in 2024, corresponding to an average annual growth rate of 9.5%. Approximately 40% of the CF input is generated as production waste during component manufacturing, while an additional 20 kt of waste from rejects and end-of-life parts is projected by 2025. While dry fiber waste can be recovered with low energy input, reclaiming fibers from polymer matrices requires energy-intensive separation. To fully exploit the potential of recycled carbon fibers (rCF) in a second lifecycle, preserving fiber length and ensuring orientation in the primary load direction is essential. One promising approach is the production of rCF tapes, where discontinuous fibers can slide within the molten thermoplastic matrix, enabling local extension along curved paths and pseudo-plastic deformation during thermoforming.

The pseudo-plastic deformation was investigated using non-isothermal, temperature-controlled tensile tests with a newly developed test module and a high-speed tensile testing machine. A parameter study on rCF-based organic sheets (fiber length 80 mm, polyamide 6 matrix, fiber volume content approximately 44%) revealed clear temperature and test-speed influences. Increasing the heating temperature from the melting temperature (Tm) to Tm + 50 K reduced the maximum stress, while higher test speeds increased stress due to elevated strain rates.

The pseudo-plastic deformation showed pronounced inhomogeneity, with coefficients of variation between 29.7% and 39.2%, mainly caused by fibers fixed in unmelted regions. Higher heating temperatures slightly improved homogeneity, whereas the influence of test speed on the homogeneity remained inconsistent.

These findings were applied to optimize the two-dimensional thermoforming of an omega-shaped profile. In the thermoforming experiments, the coefficient of variation for the deformation homogeneity ranged from 5.13% to 10.59%. This improvement compared to the tensile tests is attributed to the extended heated zone, reducing the influence of partially unmelted regions.

#1440

# Hybrid Force and Trajectory Control for Improving Weld Quality in Robotic Continuous Ultrasonic Welding of CFR-TP

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Thermoplastic composites are gaining increasing importance in aerospace and automotive engineering, driving the need for efficient and robust manufacturing and joining technologies. Robotic continuous ultrasonic welding (cUSW) is a promising technique for joining carbon-fiber-reinforced thermoplastics (CFR-TP), offering high productivity, fast processing time, and design flexibility. However, achieving consistent weld quality and process robustness remains a significant challenge. Key weld characteristics, such as joint strength and long-term performance, are strongly influenced by parameters governing both the heat generation and consolidation phases. The dynamic interaction between the robot and the ultrasonic welding process, characterized by high static and dynamic forces, structural compliance of the robot and end effector, and trajectory deviations, directly affects force stability, trajectory accuracy, sonotrode alignment, and ultimately weld formation.

To address these challenges, this work introduces a sensor-driven hybrid compensation strategy that integrates force control and trajectory control to enhance process robustness and weld quality. The approach enables precise sonotrode guidance along the weld path, corrects trajectory deviations in real time, and maintains proper sonotrode alignment relative to the surface of the upper adherend. A 2D laser scanner integrated into the end effector provides geometric information ahead of the sonotrode, enabling accurate path following and trajectory correction. In parallel, integrated force sensors and the associated control system ensure a constant contact force beneath both the sonotrode and the consolidator throughout the welding process. Together, these control mechanisms facilitate efficient energy transfer and uniform melting during the heat generation phase, as well as controlled cooling during consolidation. The proposed hybrid strategy improves the reliability and consistency of robotic cUSW, supporting its application in the joining of thermoplastic composite structures.

#1441

# Life Cycle Assessment (LCA) of multi-material self-healed composites with improved circularity.

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A circular economy for multi-material composites relies on the use of debondable structural adhesives and embedding materials, as these enable the rework, repair, refurbishment, and recycling of bonded or embedded components.

In this study, we carry out a cradle-to-grave Life Cycle Assessment (LCA) to evaluate the environmental impacts of the repair and debonding strategies developed for the project's self-healing multi-material composites. The work follows the four phases defined in ISO 14040 and ISO 14044 (goal and scope definition, life cycle inventory, impact assessment, and interpretation), providing a prospective view of the environmental performance once the new repair and circularity solutions are implemented.

The assessment is based on a case study of an electronic component, for which different circularity strategies (rework, repair, refurbishment, and recycling) are examined and compared with conventional composite designs for the same application. Life cycle inventories covering material sourcing, manufacturing, use, and end-of-life have been compiled using project data, scientific literature, technical reports, and secondary sources such as the ecoinvent database. The impact assessment has been carried out in Activity Browser using the ReCiPe method with 18 midpoint indicators, including global warming potential to estimate the carbon footprint.

The results highlight both the environmental advantages and the trade-offs involved in applying these repair and debonding strategies. They also show the potential of these approaches to lower lifecycle impacts and strengthen the circularity of future composite products.

#1442

# Development of a Recyclable Thermoplastic composite helmet for motorcycles

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This project focuses on the development of a motorcycle helmet manufactured from a thermoplastic-matrix composite, addressing the growing demand for recyclable, high performance protective equipment. Replacing conventional thermoset matrices with thermoplastic systems offers two major benefits: (i) recyclability at the end of life, and (ii) enhanced impact resistance, enabling the reduction of the number of reinforcement layers and, therefore, a potential decrease in structural weight and production cost. To further exploit these advantages, the project investigates high impact resistant reinforcement fibers, including high molecular weight polypropylene and aramid fibers to maximize energy absorption while minimizing overall mass, providing added comfort to the rider. A key technical challenge is the identification of thermoplastic matrices compatible with industrially viable processing times (approximately 20 minutes).

The design and optimization of the laminate will be supported by dynamic structural numerical simulations, combined with an automated optimization algorithm for the definition of composite laminate stacking, namely fiber orientation and lamina thicknesses. The Head Injury Criterion (HIC) is adopted as the principal metric for assessing head-injury risk and serves as the key objective to be minimized, in accordance with the applicable norms, within the structural optimization framework considered. A detailed characterization of the thermomechanical properties of the selected materials assures the accuracy of the material constitutive modelling and reliable prediction of impact performance. The methodology aims to establish optimal material combinations and laminate stacking sequences for improved helmet safety and manufacturability.

#1444

# From Microcracks to Permeation: The Role of Fatigue in Hydrogen Composite Tanks

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The decarbonization of aviation requires innovative energy storage solutions, with hydrogen emerging as a key enabler for sustainable propulsion concepts. Fiber-reinforced polymer composites (FRPCs) are prime candidates for lightweight, high-pressure hydrogen tanks due to their excellent strength-to-weight ratio. However, a critical challenge lies in understanding hydrogen permeation under realistic service conditions, where cyclic mechanical loading—such as repeated filling and emptying—can induce microstructural damage. Such damage, including matrix cracking and fiber–matrix debonding, may significantly increase gas permeability, posing safety risks and compromising long-term performance.

This research, conducted within the German aviation research program LuFo (Luftfahrtforschungsprogramm) under the project APFEL, aims to establish a clear, quantitative relationship between cyclic fatigue-induced damage and hydrogen permeation in FRPC laminates. Specimens with varying layups are subjected to controlled cyclic tensile loading, followed by hydrogen permeation measurements at defined fatigue intervals. After each interval, high-resolution X-ray Refraction Topography (XRT) is also performed alongside permeation testing, enabling non-destructive visualization of microdefects such as cracks and delamination and tracking their evolution throughout the fatigue process. This iterative approach ensures a detailed correlation between structural degradation and permeability changes.

The poster will present the research concept and first insights from the initial experimental campaign, demonstrating the methodology and preliminary observations. These findings will show how cumulative damage correlates with permeability evolution and emphasize the role of microstructural degradation in hydrogen transport. By combining mechanical fatigue testing, permeation analysis, and XRT imaging, this study aims to provide fundamental knowledge for predicting material performance under cyclic operational conditions and support more accurate lifetime predictions and safety assessments for composite pressure vessels.

#1445

# Development of Sustainable Furan-Based Resin Matrices for Composite Materials via Catalyst and Flame Retardant Optimization

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The increasing demand for sustainable composite materials has driven significant interest in bio-based polymer matrices as alternatives to conventional petroleum-derived resins. Among these, furan-based resins derived from renewable feedstocks represent a promising class of thermosetting matrices due to their inherent thermal stability and chemical resistance. However, their broader application in structural composites remains limited by challenges related to processing, mechanical performance, and fire behaviour.

In this study, the influence of catalyst system variation and the incorporation of flame retardant additives on the performance of a bio-based furan resin matrix is systematically investigated. Different acid-based catalyst systems were employed to tailor the curing behaviour and network formation of the resin, aiming to optimise processability and final thermomechanical properties. Furthermore, selected flame retardant additives were introduced to enhance the fire performance of the resin while maintaining compatibility with composite manufacturing requirements.

The effects of these modifications were evaluated through a combination of thermal, mechanical, and fire-related characterisation techniques. Curing behavior and glass transition temperature were analysed using differential scanning calorimetry and rheological analysis. The mechanical performance was assessed through standard testing methods. Fire performance was examined using micro-combustion calorimetry.

The results demonstrate that especially the catalyst selection has a significant impact on the resin’s curing behaviour and resulting material properties. Moreover, the addition of flame retardants is effective to lower the heat release of the system, thereby expanding the potential application range to fire-critical interior components.

Overall, this work highlights effective strategies for tailoring bio-based furan resin systems for composite applications, contributing to the development of more sustainable, high-performance composite materials suitable for advanced engineering applications.

#1447

# Wet-Spinning and Carbonisation of Water coagulated Lignin/Bio-Based Thermoplastic Polyurethane Precursor Fibers.

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Carbon fibres (CF) find applications as a reinforcement high-performance composite materials due to their high strength-to-weight ratio. Lignin have widely been explored as a replacement to the current commercial petroleum-based CF. While melt-spinning has shown promise for lignin processing at the laboratory scale, it presents significant challenges for large-scale deployment, particularly since approximately 95% of commercial CF are produced using wet-spinning techniques and melt-spinning typically requires rare, high-purity lignin feedstocks. As a result, the development of lignin-based systems compatible with industrial wet-spinning processes using highly available lignin feedstocks is critical for scalable bio-based CF production.

This work reports the first wet-spun Kraft lignin (KL) and bio-based thermoplastic polyurethane (TPU) blend designed for cost-effective and scalable carbon fibre production using a water-only coagulation bath. Unlike previous wet-spun lignin systems that rely on solvent-rich, toxic, or difficult-to-recycle coagulation media, the use of water significantly reduces process cost and environmental impact. Hardwood KL was selected as a commercially abundant feedstock, and lignin contents above 50 wt% were targeted to ensure high carbon yield. TPU was employed as a co-polymer due to its strong interactions with lignin, enabling improved spinnability and precursor stability.

Material characterisation identified an optimal KL/TPU weight ratio of 60:40, exhibiting the strongest lignin–TPU interactions and the highest carbon yield. This formulation was successfully wet-spun using refined processing parameters to achieve uniform fibre morphology. Following stabilisation and carbonisation, the resulting fibres reached a tensile strength of 618.2 ± 64.71 MPa and a tensile modulus of 34.77 ± 5.10 GPa at an average fibre diameter of 23.8 µm. These results demonstrate the potential of wet-spun lignin-TPU carbon fibres as a lightweight and sustainable alternative to glass fibres, while maintaining compatibility with existing wet-spinning infrastructure.

#1450

# Enhanced Interfacial Energy Dissipation in Carbon Fiber Composites via Bioinspired Multilayer APTES Deposition using Atmospheric Micro-Plasma

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Nature achieves remarkable toughness through hierarchical layered architectures that control crack propagation and energy dissipation. Nacre's brick-and-mortar structure exemplifies this strategy, yet rigid nanoplatelet designs represent only one solution. This work presents an alternative biomimetic approach: precision-controlled concentric multilayer APTES coatings deposited around carbon fibers via atmospheric micro-plasma technology.

A coaxial dielectric barrier discharge (DBD) micro-torch enables conformal deposition of multiple discrete APTES layers with micrometer-scale control over individual layer thickness and inter-layer spacing. Unlike intermittent patterning or monolithic interphases, this architecture creates well-defined circumferential layers maintaining radial symmetry, as confirmed by scanning electron microscopy.

During fiber-matrix debonding, multilayer APTES coatings trigger the Cook-Gordon mechanism: compliant layers (modulus 4-8 GPa) induce tensile debonding ahead of propagating cracks, causing sequential interfacial failure. Each layer debonds independently at distinct stress thresholds, creating multiple energy dissipation windows. This staged failure mechanism contrasts with simultaneous crack deflection in rigid nanostructures, instead distributing stress concentrations across progressive delamination events.

Single-fiber pull-out testing demonstrates 20-40% improvement in energy absorption relative to untreated fibers. Interfacial shear strength values match those of homogeneous sol-gel APTES coatings, yet the multilayer architecture achieves superior toughness through sequential plastic deformation and crack deflection at multiple interfaces rather than monolithic barrier properties.

This bioinspired strategy, realized through scalable atmospheric plasma processing, demonstrates how compliant multilayer interphases can effectively dissipate energy through cumulative Cook-Gordon debonding events. The approach opens new biomimetic design pathways for high-performance composites with programmable interfacial failure mechanisms and enhanced damage tolerance.

#1451

# Empirical model for predicting surface roughness in CFRP during peripheral milling with lead and tilt angles.

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Carbon fibre reinforced polymers (CFRP) are widely used due to their superior mechanical performance and ability to facilitate load-adapted designs due to its directional properties. The key benefit is a high strength-to-weight ratio. Conversely, machining unidirectional CFRP is difficult because its anisotropy is problematic. Consequently, surface integrity depends heavily on fibre orientation, resulting in different surface roughness's despite identical processing parameters due to fibre orientation.

Machining CFRP can result in poor surface integrity when certain engagement conditions and fibre orientations are present. However, using peripheral milling with lead and tilt angles provides a high level of control over these challenging conditions. Using a recently introduced description of engagement conditions for CFRP, which takes into account the spatial fibre cutting angle $\theta_o$ and the spatial fibre engagement angle $\phi_o$, areas of poor surface integrity can be identified and probably avoided during peripheral milling.

This study uses the influence of spatial engagement conditions (θ_0,ϕ_0) on roughness determined with transverse internal turning, a machining process with constant engagement conditions and uncut chip depth. Determining the dominant wavelength PSW and its intensity in the amplitude density spectrum for each investigated engagement condition (θ_0,ϕ_0) creates a modelling basis for predicting the surface. Once the engagement conditions are known, the dominant profile wavelength and its intensity can be determined for the surface in question. This allows a three-dimensional model of the surface to be created, from which the roughness values can be obtained. Experimental investigations with unidirectional and multidirectional CFRP validate the prediction approach and show a good agreement between the experimental and predicted surface roughness's.

#1452

# Interfacial Characterization of Lignin-Derived Carbon Fibers for Sustainable Composite Applications

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Lignin-based carbon fibres (CFs) represent a sustainable alternative to petroleum-derived CFs for lightweight structural composites, offering the potential to reduce the environmental footprint of high-performance materials. The intrinsic variability of lignin chemistry complicates fibre processing and affects surface characteristics, which play a decisive role in fibre-matrix adhesion. The fibre-matrix interface is crucial for composite performance, and it remains underexplored for lignin-derived CFs. In this study, different lignin precursors were melt-spun with a bio-based thermoplastic carrier polymer to produce carbon fibres through a conventional stabilization and carbonization route. The processability and thermal behavior of each blend were evaluated, followed by detailed surface and mechanical characterization of the resulting CFs. Preliminary results indicate that lignin-derived CFs exhibit enhanced surface roughness compared to commercial carbon fibres, suggesting potential for improved mechanical interlocking and adhesion with polymer matrices. These surface features are expected to influence interfacial bonding behavior across both thermoplastic and thermoset systems. These preliminary results highlight the influence of lignin molecular structure and processing conditions on the surface and performance characteristics of bio-derived CFs. The next phase of this work will focus on the detailed characterization of the fibre-matrix interface using atomic force microscopy (AFM) and single-fibre push-out testing to determine the interfacial shear strength (IFSS). This approach will enable quantitative evaluation of interfacial shear properties and local adhesion mechanisms, providing direct insight into how lignin-derived CFs interact with various matrix chemistries. These results will demonstrate how lignin precursor selection and resultant carbon fibre surface govern interfacial performance across different composite types. This study aims to provide critical insight into tailoring lignin-based carbon fibres for optimized adhesion and compatibility, contributing to the engineering of next-generation bio-based, high-performance composite materials.

#1453

# Hierarchical design parameters driving the strain evolution in bamboo technical fibers

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This study investigates the microstructure-mechanics relationship in bamboo technical fibers to derive design principles for advanced composites. These fibers possess a complex hierarchical architecture, where tubular elementary fibers with central lumens are bonded via a middle lamella, forming a natural composite.

Our methodology combined experimental mechanics with computational analysis. A deep learning-based geometrical analysis quantified the spatial distribution of microstructural features. This data was correlated with full-field strain mapping obtained via micro-strain mapping techniques, which revealed oscillatory, cooperative deformation patterns across the fiber bundle. Further vector field analysis and adaptive image thresholding elucidated how alternating cell wall expansions harness and redistributes mechanical energy through cooperative, bundle-level mechanics. Key findings indicate that the lumen growth rate governs volumetric distribution and directly influences macro-scale fiber deformation. Damage analysis identified asymmetric defibrillation and cell wall cracking as primary failure modes, with semi-clean fractures correlating to higher fiber cooperation and ordered spatial arrangements. Machine learning segmentation and k-means clustering established quantitative correlations between specific geometrical domains and localized strain intensity fields. The average tensile strength was measured at 711 MPa. The research outputs precise geometrical gradients and identifies the mechanism of intermittent load-sharing among cells as a critical feature. These parameters provide a foundational blueprint for designing bio-inspired composite materials with optimized damage evolution and structural performance.

REFERENCES

[1] L. Osorio, E. Trujillo, F. Lens, J. Ivens, I. Verpoest, and A. W. van Vuure, “In-depth study of the microstructure of bamboo fibres and their relation to the mechanical properties,” Journal of Reinforced Plastics and Composites, vol. 37, no. 17, pp. 1099–1113, Sep. 2018.

[2] K. Haag and J. Müssig, “Scatter in tensile properties of flax fibre bundles: influence of determination and calculation of the cross-sectional area,” Journal of Materials Science, vol. 51, no. 17, pp. 7907–7917, May 2016, doi: 10.1007/s10853-016-0052-z.

#1455

# Flavonoid-Derived Thermosets: A Dual Strategy for High Performance and Polymer Circularity

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The global reliance on petroleum-derived epoxy materials necessitates the development of sustainable alternatives. In this perspective, the current research addresses this challenge by presenting two distinct, high-performance thermoset systems derived from renewable resources, primarily flavonoids and other natural phenolic compounds.

The study is focused on two strategies. The first one aims the creation of fully biobased polyether networks by cross-linking glycidyl ethers of ferulic acid, daidzein, and quercetin with a biobased hardener. The second one is focused on synthesis of polyester flavonoid-based thermosets based on the triglycidylether of naringenin (TGEN) and biobased anhydrides.

The flavonoid-based polyether networks are highly crosslinked and tough thermosets showing high glass transition values up to 173 °C, Young's moduli of ∼1.5 GPa, tensile strength values of ∼16−44 MPa, and low water absorption of ∼0.44−0.74%.

The flavonoid-based polyester thermosets exhibit also high thermomechanical performances while facilitating controlled chemical depolymerization and recycling. These resins show excellent industrial processability and robust properties, including storage moduli up to 3.3 GPa and high thermal stability (T5%>308 OC). Importantly, the re-use of 5-10% of the decomposed polymer in new formulations enhances the mechanical properties, boosting the storage modulus to 3.72 GPa, validating a crucial approach for polymer circularity.

Collectively, these findings introduce two innovative, high-performance approaches for sustainable polymer technologies: chemical recyclability while maintaining the materials performances, and the design of fully biobased networks with high Tg paving the way for greener materials in demanding applications as space, aerospace, electronics, etc.

#1456

# Advanced fracture and damage tolerance testing for liquid hydrogen composite tanks

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Liquid hydrogen ($LH_2$) storage is a key enabling technology for hydrogen-powered aircraft concepts targeting climate-neutral aviation by 2035 and beyond. Liquid hydrogen storage composite cryogenic tanks are essential to meet strict requirements of weight, volume and cost-efficiency; however, their structural behaviour at cryogenic temperatures remains insufficiently characterised, particularly in terms of damage resistance and damage tolerance. Although previous studies report increased strength at low temperatures, the associated increase in material brittleness raises concerns regarding fracture- and impact-driven failure mechanisms, which are critical for certification.

This work presents an experimental campaign to characterise the thermo-mechanical behaviour of aeronautical-grade composite materials under cryogenic conditions, following a Building Block Approach. At the material level (Level 1), standard mechanical characterisation is complemented by advanced fracture testing, including compact tension tests, to investigate fibre-dominated fracture toughness at cryogenic temperatures. At higher levels, open-hole tensile tests are performed to assess damage resistance in notched configurations, while tensile-after-impact tests are used to evaluate damage tolerance under representative impact scenarios.

All tests are conducted at three temperatures: room temperature (RT), 77 K, and 20 K, enabling systematic comparison across the operational temperature range of $LH_2$ tanks. The cryogenic tests are performed using in-house cryostats developed at the AMTEC and AMADE research facilities. Tests at 20 K are performed in a helium gas environment and the 77 K tests are carried out in liquid nitrogen.

The results show that, while both fibre- and resin-dominated ply strength properties increase under cryogenic conditions, this improvement does not necessarily translate into higher open-hole and tensile-after-impact strengths. This behaviour is attributed to composite brittleness, damage growth during cool-down, and reduced fracture toughness and ultimate strain in the cryogenic range. These findings highlight the importance of incorporating fracture and damage tolerance considerations in the design and certification of composite $LH_2$ tanks.

#1457

# Direct ink writing printed piezoresistive sensors based on MWCNT/elastomer composites

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Piezoresistive sensors utilizing multi-walled carbon nanotube (MWCNT)-elastomer composites exemplify an advanced category of flexible electronic devices designed for applications in strain and pressure sensing. The evolution of multifunctional composite materials has established extrusion-based direct ink writing (DIW) as a promising method for the fabrication of flexible piezoresistive sensors, designed to exhibit customized electromechanical functionality. This research examines the formulation and analysis of MWCNT-elastomer composite materials tailored for DIW processes aimed at producing highly effective piezoresistive sensors. Inks composed of MWCNT and elastomer with loadings ranging from 3 to 15 wt. % were developed, and rheological analysis determined that a loading of 9 wt. % represents the critical threshold for achieving printability. The composite formulation was methodically developed to attain optimal MWCNT loading, ensuring an even distribution within the elastomeric matrix, and facilitating the establishment of percolating conductive networks necessary for a robust piezoresistive response. Modifying the weight fraction of MWCNT and the ratio of elastomer composition allows the independent adjustment of the mechanical elasticity and electrical conductivity of the fabricated composite materials. The rheological analysis substantiated the shear-thinning behavior, facilitating smooth extrusion and ensuring precise structural fidelity during DIW printing. The analyses conducted using Fourier Transform Infrared (FTIR) Spectroscopy and X-ray Diffraction (XRD) demonstrated significant interfacial interactions and enhanced structural alignment between MWCNTs and elastomer chains. Concurrently, the microstructural characterization unveiled a well-connected CNT network, which allowed for effective charge transport under mechanical deformation. The refined sensor demonstrates a sensitivity of 0.89 kPa-1 within the pressure spectrum of 0-250 kPa, a minimal detection threshold of 15 Pa, a rapid response interval of 25 ms, and exceptional cycling stability across 2000 cycles. These outcomes highlight the exciting prospects of MWCNT-elastomer composites as a multipurpose material for next-gen flexible and adaptable sensing devices that can monitor physiological signals in real-time.

#1458

# Experimental Development of a Microscopic Shearography System for Composite Damage Detection

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Microscale damage in the form of microcracks is known to be an important factor in initiation and subsequent development of damage in fibre-reinforced composites, especially in Glass and Carbon Fibre-Reinforced Polymers materials. Such microcracks are known to be few microns in size and not easily detectable with conventional non-destructive evaluation methods. Although Shearography is a well established full-field technique based on optics for damage identification using strains, it was mainly used for a macroscale field of view, and hence not very sensitive to microscale damage.

This study addresses the challenge of extending shearography to the microscopic regime by developing a novel microshearography system capable of detecting and characterizing microcracks in composite materials.The primary challenge lies in achieving sufficient numerical aperture, magnification, speckle stability, and phase sensitivity simultaneously, while maintaining a usable field of view. Speckle decorrelation and interference stability become critical limitations at high magnifications.

The objective of this work is to develop and experimentally validate a microscopic shearography optical system with enhanced sensitivity to micron crack-induced strain fields. A Linnik-type interferometric microscope is being developed and tested for its optical resolution capability. It will then be integrated with a shearography configuration, enabling both in-plane and out-of-plane displacement of gradient sensitivity. Temporal phase-shifting would be employed to improve phase accuracy, and loading strategies are selected based on microcrack opening behaviour.

In its current stage, the system can be described based on optical resolution, sensitivity to strains, and stability of speckles. Future experiments will be conducted using both GFRP and CFRP samples with micro-cracks of different dimensions to assess their detectability and characterization.

The anticipated outcome will be an established microshearography technique that will be proven and able to identify microcracks in composites, hence widening the scope of conventional shearography methods in assessing damage in composites in their early stages.

#1459

# Mechanical capability of forming-optimized all-cellulose composite vulcanized fiber under wet and dry conditions

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Replacement of petroleum-based materials by renewable materials enhances the environmental sustainability of products. Biodegradability further reduces the environmental impact. All-cellulose composites (ACCs) are well suited for this purpose. One common type of ACC is vulcanized fiber, a catalytically converted cellulose paper, that exhibits material properties similar to thermoplastics, while showing higher abrasion and temperature resistance, antistatic properties, but also a sensitivity to moisture. Due to the base-papers orientation and production process the material is assumed to be transverse isotropic with a preferred orientation in machine direction (MD), but higher ductility in the cross direction (CD).

To evaluate the orientation dependent mechanical capability of forming-optimized vulcanized fiber, commercially available and forming-optimized vulcanized fiber was tested using highly instrumented quasistatic and cyclic mechanical tests. Surface strain development and stress field localization were monitored by means of digital image correlation (DIC). The evolution of microstructural damage mechanisms was characterized by means of advanced in-situ scanning electron microscopy (SEM) and X-ray computed tomography (CT), allowing correlation between macroscopic loading response and microscopic failure modes.

When saturated with moisture, stiffness decreases while ductility increases, with the strain at failure rising from 6% in MD to around 12% relative to the dry condition. By adapting the paper base materials, the formability of the composite was further increased by approximately 20%. In addition to the improved formability, higher stress levels were achieved. On the surface of the optimized material, both DIC and microscopic analysis revealed distinct local deformation patterns, particula in CD, while a homogenization of the deformation field was observed in MD.

#1460

# Microcrack repair in vitrimer-based composite matrices: A pathway to durable and reprocessable structures

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Vitrimers are polymer networks incorporating dynamic covalent bonds that enable topologi-cal rearrangements through associative exchange reactions, imparting unique capabilities such as stress relaxation, reprocessability, and intrinsic self-healing [1]. These properties address critical limitations of conventional thermosets in structural composites, where irre-versible crosslinking hinders repair and recycling.

This work explores vitrimer-based epoxy matrices in composite parts [2], focusing on their potential to mitigate damage through microcrack repair. The dynamic bond exchange mech-anism promotes interfacial diffusion and network rearrangement, enabling closure of microcracks formed under cyclic loading or impact. Such behaviour opens opportunities for restoring structural integrity without introducing additional adhesives or complex repair steps, supporting extended service life in demanding environments.

The study will present a repair protocol that combines thermal activation and controlled pressure to trigger bond exchange and promote crack welding. The influence of temperature gradients, dwell time, and applied pressure on healing kinetics will be analyzed to define operational windows for in-situ repair. Mechanical evaluation of repaired regions, complemented by diverse ad-hoc tests, will be used to assess the effectiveness of the protocol. Rheological characterization and time-temperature superposition will provide insights into relaxation phenomena.

Additionally, processability and reprocsesability maps [3] will be discussed as practical tools for integrating repair strategies into industrial manufacturing routes, such as RTM. These insights contribute to the broader vision of self-healing composites for structural applications, where durability, circularity, and cost-efficiency are critical drives for next-generation technologies.

[1] W. Denissen, J. M. Winne and F. Du Prez. Chem. Sci. 7, 30-38 (2016).

[2] Verdugo, P.; Santiago, D.; De la Flor, S.; Serra, A. ACS Sustain. Chem. Eng. 2024, 12 (15), 5965–5978.

[3] Sanchez-Rodriguez, D., Zaidi, S., Jahani, Y., Ruiz de Luzuriaga, A., Rekondo, A., Maimi, P., Farjas, J., & Costa, J. Polymer Degradation and Stability, 217, 110543, (2023)

#1461

# Vitrimeric composites based on oh-rich waste fillers

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Thermosetting polymers, particularly epoxy resins, are extensively employed in structural and high-performance applications due to their excellent mechanical strength, thermal stability, and chemical resistance. Nevertheless, their permanently cross-linked molecular architecture prevents melting and reshaping, making recycling extremely challenging and leading to significant environmental concerns. In response to these limitations, this work investigates the development of recyclable epoxy-based vitrimeric composites. Vitrimers are a class of reprocessable covalent adaptive networks characterized by dynamic covalent bonds that undergo associative exchange reactions, such as transesterification, enabling stress relaxation and topological rearrangement without loss of network integrity. In this work, a conventional epoxy resin system based on diglycidyl ether of bisphenol A (DGEBA) and an anhydride curing agent was first synthesized and subsequently converted into a vitrimer through mechanochemical functionalization using zinc acetylacetonate as a transesterification catalyst. Ball milling was employed as a solvent-free and environmentally friendly technique to ensure homogeneous component dispersion and activation of dynamic exchange reactions.

Hydroxyl-rich fillers from wastes were incorporated in different percentages to improve sustainability, promote transesterification reactions, and enhance the mechanical performance of the resins. The vitrimeric systems and composites were successfully reprocessed via compression molding and characterized using differential scanning calorimetry (DSC), thermogravimetric analysis (TGA), and dynamic mechanical analysis (DMA). The results demonstrate effective reprocessability, good thermal and stability upon reprocessing. Overall, this work highlights the potential of combining vitrimer chemistry, mechanochemical processing, and natural waste-derived fillers to produce high-value, recyclable thermosetting composites, supporting sustainable material design within a circular economy framework.

#1462

# Prevention of fusion during the thermal treatment of melt-spun lignin precursor fibres for scaled-up production of carbon fibres.

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Carbon-fibre-reinforced polymers (CFRPs) are widely used in high-performance applications due to their exceptional mechanical properties. Global demand for CFRPs is expected to grow by approximately 13.2% annually, reaching about 274kt by 2030. Currently, around 95% of carbon fibres are produced from fossil-derived polyacrylonitrile (PAN), which is costly and contributes significantly to the environmental footprint of CFRP manufacturing. Lignin, the second most abundant biopolymer and a by-product of the pulp and paper industry (≈70kt annually), offers a promising sustainable alternative due to its low cost, high carbon content and renewability.

During the manufacture of lignin-based carbon fibres, precursors undergoes thermal stabilisation and carbonisation. As the fibres pass the glass transition temperature (Tg) of lignin during stabilisation, it softens. The softening hinders further processing into composite material, as the fibres fuse into a mass. However, exceeding the Tg is essential to enable fibre stretching and molecular alignment required for high mechanical performance.

To overcome this predicament - preventing fibre fusion while preserving stretchability - two different strategies are successfully investigated in this work. First, carbon or silicon oil is applied to the fibres to act as a temporary physical barrier during stabilisation. Second, the fibre surface is pre-treated to induce controlled oxidation with H2O2 or crosslinking with toluene diisocyanate, forming a stabilised outer layer that inhibits thermoplastic flow while still permitting deformation during stretching.

The resulting surface reactions and structural modifications are analysed to compare with untreated lignin-based fibres in order to understand the influence of treatment strategies on fibre oxidation and mechanical properties. This work contribute in the development of scalable processing routes for lignin-based carbon fibres, enabling their full integration into composite materials.

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#1463

# Simulation-Driven Process Development for Integrated Manufacturing of Thermoplastic Aircraft Door Surrounds

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The production rate for structural composite parts for aircrafts is limited due to time-consuming shaping and curing steps, which are necessary in their manufacturing processes. Transitioning from thermoset to thermoplastic carbon fiber reinforced composites enables high-rate capable forming processes such as thermoforming and joining processes like welding or co-consolidation, drastically reducing the manufacturing time for parts and sub-assemblies. In this work, a highly integrated manufacturing chain for a thermoplastic aircraft door surround structure is developed. The process combines the forming of a double curved c-shaped doorframe in a single step, attaching a pre-manufactured intercostal and overmolding the joining interface for increased stiffness and load bearing capability.

A comprehensive simulation model enabling the prediction of deformation and spring angles for the thermoforming of the complex doorframe is presented to support the process development. The simulation is validated by manufacturing trials, outlining the influence of part geometry and processing parameters.

The model comprises the preform, the preform handling system, and tooling. Both handling system and tooling are modeled as rigid bodies with their respective movement sequence. The preform is represented as individual plies, each consisting of unit cells. These unit cells combine beam, shell, and solid elements to map mechanical and thermal properties. The process is simulated from the closing sequence of the tool up the cooling to room temperature without tool contact. After the final simulation step, the angles and deformations can be assessed.

Simulation results are experimentally validated with forming trials, focusing on critical part areas such as the radii and joining interfaces. The results indicate, that even though flange thickness is constant, the resulting angle deviate by 3° over the length of the profile, which is linked to the part geometry.

#1464

# Digital Twin for Large Format Extrusion Additive Manufacturing

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Large Format Additive Manufacturing (LFAM) enables the layer-by-layer fabrication of large, composite structures using pellet extrusion of short-fibre-reinforced polymers. For the shape fidelity, precise temperature control is crucial, as incorrect melt temperatures can lead to defects.

Thermal management has mainly relied on pre-print FEA simulations. While effective for predicting temperature distributions, these simulations are computationally intensive, and simplifying them for faster results often omits critical factors, such as geometric influences. Moreover, FEA models cannot inherently capture part-to-part variability that arises during actual production.

To overcome these limitations, data-driven approaches such as thermography-based in-process monitoring and deep learning models for thermal prediction have been introduced. However, most studies focus on side-view perspectives of prints, neglecting the influence of part geometry and overlooking layer-wise surface temperature, which is a key determinant of print quality. Even when surface temperature is considered, fixed thermal cameras often face occlusion from moving printer components, which complicates continuous observation and reduces the reliability of the captured thermal data.

Here, we mount two thermal cameras on either side of a large-format extruder, facing the nozzle tip and moving with it during printing. Their images are combined to generate a top-down view covering all four sides of the nozzle. This setup monitors the melt temperature in real-time along the toolpath, both immediately after extrusion and that of the previous layer just before new deposition. Simultaneously, the tool position and printing parameters, such as nozzle zone temperatures, extruder screw torque, and RPM, are logged to create a digital twin of the printed part. This digital twin provides a foundation for further analysis and predictive modelling of melt behaviour and will enable a physics-informed machine learning model to predict segment-wise melt cooldown behaviour in advance, allowing proactive thermal correction before the next layer is deposited.

#1466

# Valorization of Wood Waste Lignocellulosic Materials for PLA Biocomposites in 3D-Printed Construction Applications

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Biocomposites that combine biodegradable or bio-based polymeric matrices with bio-based reinforcements represent a promising renewable alternative to conventional composites. Poly(lactic acid) (PLA) is widely studied due to its renewable origin and industrial compostability. However, enhancing PLA long-term stability is essential for durable applications across diverse environmental conditions. Lignocellulosic materials can be extracted from construction and demolition wood waste through cascade biorefinement processes and these materials offer renewability, low density and inherent resistance to thermo-oxidative and UV degradation. Our work is under the Wood-to-Wood (W2W) Project, a Horizon Europe program, and focuses on cost-effective PLA/wood waste compounds through evaluating their behavior during melt processing and service lifetime under thermal, hygrothermal, and photo-oxidative aging protocols. The prepared biocompounds are processed through additive manufacturing to prepare composite components that are integrated into prefabricated façade panels for the construction sector (long term applications). The panels are further evaluated for their noise-reduction performance, with particular attention to honeycomb structural designs, demonstrating both functional and environmental benefits of this sustainable biocomposite system.

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement No 101138789.

#1468

# Optical Fibre Sensor Placement for Composite Hydrogen Tanks

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Due to its high gravimetric energy density and net-zero CO2 emissions, liquid hydrogen (LH2) has emerged as a promising alternative energy source to traditional fossil fuels for clean aviation. One of the key challenges of advancing LH2 towards sustainable aviation applications is in developing lightweight, reusable and long-term storage tanks. This requires the development of effective and efficient structural health monitoring (SHM) techniques for tank condition monitoring and evaluation. Composite materials are finding increasing application in the clean energy transition, such as in composite hydrogen tanks, across various industry sectors. This poses an urgent challenge to timely detect and monitor damage for assessing the health status of the tank. Among the various NDT/SHM techniques, fibre optic sensors, such as Fibre Bragg Gratings (FBGs), are promising candidates for composite LH2 tanks because of their lightweight nature, immunity to electromagnetic interference, and capabilities in multiplexing and remote sensing.

The objective of this study is to develop a design framework/strategy for the placement of FBG sensors for SHM of real-scale composite LH2 tanks. Sensor positioning and routing for both strain and temperature sensors are investigated. In both cases, the multiplexed FBG sensors are used. Placement of temperature sensors is illustrated with a spherical tank, where sensors are evenly distributed on the tank surface. Sensor placement in the different layers of the tank structure is also considered. Placement of strain sensors is demonstrated using a conformal thermoplastic composite tank, where sensors are positioned at the critical locations based on a finite element analysis. Factors including tank geometry, number of the sensors, coverage and fibre orientation are considered for sensor routing. The developed sensor placement strategies can be applied to various tank geometries and sensor configurations. This research was performed as part of the Horizon Europe COCOLIH2T project (101101404) and OVERLEAF project (101056818).

#1469

# Failure of filament wound hoop tubes by internal open-ended pressure testing

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Composite pressure vessels (CPVs) are commonly designed using a monotropic model for their composite skin, where the pressure bearing capacity of the vessel is considered to be governed solely by the fibre-direction properties, strength and stiffness. Accurate characterisation of these material properties at the meso-scale requires test methods that utilise coupons representative of typically filament wound CPVs' composite skin. Standard material testing methods present some limitations in this respect, either due to difference in manufacturing method, part geometry or the presence of undesirable stress states. These methods include tensile testing of flat panels, manufactured either via filament winding or hand lay-up, or mechanical testing of rings using a split-disk rig, a method that induces unwanted bending in the sample. To try and overcome the above limitations, a method based on the internal pressurisation of hoop-wound pipes is presented, which allows testing in a pure hoop stress-state. There are some reports of similar tests on helically wound glass fibre composite pipes under different boundary conditions; however, our research focuses on using an open-ended state to test much stronger carbon fibre composites. The materials fibre tensile properties are characterised by progressively pressurising the pipe while recording strain vs pressure data using a Digital Image Correlation system synchronised with the pressurisation rig, until fibre failure occurs. A key novelty is the use of full-field imaging during the pressure test with a novel set-up using low-cost machine vision cameras and in-built protection system, enabling strains to be obtained over a wide viewing area up-to the final failure event. The results show that this method can be used to characterise the fibre-direction strength and modulus of filament wound structures, but its use could be further extended to improve understanding of damage and failure in composite overwrapped vessels and ultimately lead to more reliable design approaches.

#1471

# Polymer blending as a pathway towards high performance lignin based carbon fibres

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Objectives:

This work systematically studies the impact of polymer blending on the quality of the carbon of lignin-based carbon fibres. Lignin is a unique source of aromatic carbon in the biosphere. As such, it has been extensively studied as a precursor for carbon materials. However, the main challenge when spinning lignin is its low processability. Therefore, spinning aides such as high molecular weight polymers are used to process lignin into carbon fibres precursors.

Method:

Here, several polymers are extensively studied as potential spinning aids, such as polyethylene terephthalate (PET), thermoplastic polyurethane (TPU) and polyvinyl alcohol (PVA). Several factors are investigated, such as the lignin source, the polymer aid molecular weight and the spinning method. The theory of miscibility is extensively used to determine the homogeneity of the precursor materials, and its impact on the carbon phase obtained after oxidative stabilisation and carbonisation. In addition, the biobased content of the carbonised blends is determined using a 14C titration method.

Results:

The theory of miscibility offers a pathway towards the modeling of miscible polymer blends. The resulting blends were assessed with regards to the quality of the resulting carbon phase using Raman Spectroscopy. The determination of the 14C content offers a unique method to determine the impact of the thermal treatments on the resulting carbonised blends.

Conclusion:

The miscibility of lignin with blending polymers is key to the processing of the biomaterial into carbon fibre precursor materials. The subsequent thermal treatments that are undergone by the polymer blend and its understanding is paramount to the determination of the resulting carbon fibres performance.

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#1473

# Lattice reinforced co-moulded joints between sheet moulding compound and aluminum: A novel unit cell-based modelling strategy

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Metal additive manufacturing has recently gained traction in the field of metal to composite bonding. The inherent high roughness and the presence of partially melted particles on the surface of the printed material, lead to micro-level interlocking and good adhesion strength. Moreover, the possibility to produce geometrically complex structures opens new scenarios for advanced toughening strategies, such as using lattice structures which are infiltrated by the composite's fibers significantly increasing the strength of the joint.

In this context, finite element modelling is essential for predicting the mechanical response of such joints as a function of the lattice geometry, type of composite and surface treatments. However, modelling the full bondline is extremely time-consuming and computationally demanding.

Here we propose a novel methodology for the extraction of the homogenized interfacial behavior for a pyramidal lattice-reinforced aluminum-sheet moulding compound joint. The methodology is based on a unit cell including a single lattice structure with a portion of the aluminum and composite adherend. For the composite material, a map of the fiber volume fraction and orientation has been imported from a computational fluid dynamic simulation of the co-moulding process in the structural model. Periodic boundary conditions have been implemented and the interface between the lattice structure and the composite has been modelled with cohesive-zone modelling. The damage of the composite adherend has been modelled with a pseudo-grain approach.

The results have been validated via an experimental campaign with lattice reinforced sheet moulding compound-aluminum co-moulded joints both in opening and shear loading mode, showing that the numerically homogenized behavior is in good accordance with the experiments.

#1474

# Industrial-Scale Multiscale CNT Integration to Tailor Temperature-Dependent Delamination Resistance in Aerospace CFRPs

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Delamination remains a primary damage mode limiting the reliability of aerospace CFRP structures, and the challenge becomes sharper when components cycle between cold and elevated service temperatures. While carbon nanotubes (CNTs) are widely reported as effective tougheners at the lab scale, their translation to manufacturing ready prepregs with consistent interfaces and repeatable performance remains a key barrier. In this work, we address that gap by developing an industrial scale multiscale nano integration route for unidirectional carbon epoxy prepregs, combining ultrasonic spraying of functionalized CNTs onto carbon fiber surfaces to engineer the interphase and dispersion of functionalized CNTs within the epoxy resin to reinforce the matrix. Mechanical performance is evaluated through tensile testing and Mode I (DCB) interlaminar fracture toughness across representative thermal conditions (−40 °C, +23 °C, +80 °C), while in situ acoustic emission (AE) is used to resolve how damage mechanisms evolve with temperature and nano integration. The results reveal a clear temperature dependent trade off. CNT integration increases stiffness and redistributes ductility, with reduced longitudinal ductility but improved transverse ductility. Under cold conditions where the epoxy becomes more brittle, optimized CNT integration improves fracture toughness and promotes more distributed energy dissipation, with CRCF1 and CRCF4 showing about 31% and 13% higher GIC than the neat reference, respectively. At elevated temperature, the neat laminate exhibits the highest toughness (about 1500 J/m²), while CNT modified systems lose toughness (about 70% to 78%), indicating that CNT induced constraint and or agglomeration can suppress the beneficial matrix ductility contribution. Overall, the study maps an actionable design space for industrial prepreg nano integration. CNTs can be highly beneficial for cold temperature delamination resistance, but require careful loading and dispersion control to avoid performance penalties at high temperature.

#1475

# Physics-Informed Deep Learning Modelling of Fatigue in Composite Materials Using a Conditional Variational Autoencoder

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In this work, a physics-informed, data-driven prognostics framework is presented for thermo-mechanical fatigue in polymer matrix composites. The framework directly learns a conditional distribution of failure time from cycle-resolved monitoring signals. It operates on fixed-length sliding windows of the recorded history, where recent evolution is encoded using a long short-term memory (LSTM) network. A conditional variational autoencoder (cVAE), conditioned on static test descriptors such as loading frequency and cooling condition, provides a low-dimensional stochastic representation that enables uncertainty propagation. To promote physically consistent trajectories and improve model identifiability, physics-based regularisation terms are incorporated during training to penalise deviations from (i) a specimen-scale lumped thermal relation linking temperature rise to dissipated energy, (ii) a phenomenological law for hysteretic energy evolution on the logarithmic cycle axis, and (iii) a stiffness-degradation model based on modulus reduction.

Failure prognostics are formulated on the recorded cycle grid using a discrete-time hazard head that outputs the conditional event probability at each recorded point. The resulting hazard sequence is transformed into survival, a discrete failure-time probability mass and cumulative distribution, and fatigue-life quantiles, enabling probabilistic remaining-life estimates and horizon-based alarm rules.

The framework is demonstrated on very-high-cycle fatigue tests of glass-fiber/epoxy laminates with a $[\pm 45]_{2s}$ layup, tested under constant-amplitude loading at a stress ratio of R=0.1 across three configurations: 10 Hz without cooling, 40 Hz without cooling, and 40 Hz with forced cooling. Each recorded point includes thermo-mechanical descriptors such as stress and strain mean and amplitudes, hysteretic energy density, surface temperature, and dynamic modulus. The model reconstructs measured thermo-mechanical trajectories with high fidelity and predicts fatigue life over multiple decades. Configuration-specific coefficients differ systematically between cooled and non-cooled tests, reflecting distinct thermal boundary conditions and confirming that coupled thermo-mechanical evolution can be learned while delivering calibrated, data-driven prognostics.

#1477

# Development of surface sizing to revive the interfacial properties of recycled glass fibers with Polypropylene

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The increasing popularity of sustainable composites has turned the tide towards recycling strategies and recovery of fibers for reusability at the end-of-life polymer composites. Though the pyrolysis method to recover fibers has been proven to be efficient and commercially viable, it severely degrades the fiber's mechanical properties and the physical and chemical architecture of the surface. This leads to poor adhesion with the matrix and overall loss of mechanical properties of composites as compared to the benchmark composites. This study focuses on developing a novel surface sizing for recycled glass fibers (rGF) intended to combine with a Polypropylene (PP) matrix. The Polypropylene grafted Maleic anhydride (PP-g-MA) based sizing is tailored to rejuvenate the surface chemistry and introduce roughness to improve compatibility and better mechanical interlocking with PP. The developed sizing exhibited a 50% reduction in crystallinity and a decrease in Tg from 106 to 61 °C compared to PP-g-MA. The comprehensive surface characterizations of fibers, such as FTIR, contact angle, and SEM, show that the surface morphology consists of a uniform coating of the sizing and an increased roughness, improving the wettability of PP on rGF. A significant improvement (>100%) in the interfacial shear strength (IFSS) has been observed in microdroplet debonding tests, validating the contribution of the sizing in improving interfacial adhesion. The results underline the importance of interface re-engineering in closing the recycling loop of glass fiber-reinforced plastics and creating pathways towards achieving economic and environmental sustainability goals in composite manufacturing.

#1479

# Fatigue Testing of Post-Buckling Mode Evolution in Multi-Stable Composite Panels with Metallic Stringers

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Buckling is prone to occur in thin-walled aeronautical composite structures under in-service loading and has been traditionally regarded as detrimental, as the resulting nonlinear large deformations and complex damage accumulation can significantly threaten load-bearing capacity. However, if buckling is controlled, predictable and confined to the elastic regime, significant weight reduction could be achieved, while multiple stable configurations could be introduced by switching among different buckling modes for developing advanced aeronautical structures [1]. To mature this design concept towards practical application, it is necessary to explore whether the buckling mode switching remains repeatable and predictable under fatigue loading.

Our preliminary study [2] demonstrated that the buckling modes of a multi-stiffened specimen can switch among different local regions by tailoring the layups of the composite skin. A series of static tests and variable-amplitude fatigue tests were conducted to track the evolution of these buckling modes. It was observed that certain mode switch occurred at a lower load level under fatigue than in the corresponding static results. In addition, new buckling modes emerged after certain number of fatigue cycles. To further understand the post-buckling mode evolution under fatigue loading that is different from the corresponding static results, the present work focuses on the fatigue performance of several multi-stable composite panels bonded with metallic stringers. Post-buckling modes of the composite skin can be derived from full-field out-of-plane deformation measurements using digital image correlation techniques, and debonding between the composite skin and metallic stringers can be monitored by digital cameras from the side view. Results will be presented at the conference.

References

[1] C. Bisagni, Nabucco take-off: multi-stable panels for an adaptive wing, ICAS Proceedings, 2024.

[2] X. Li and C. Bisagni, Post-Buckling Behaviour of a Multi-Stable Composite Stiffened Specimen under Low-Cycle Fatigue – A Preliminary Study, the proceedings of CEAS-AIDAA Joint Conference, 2025 (accepted).

#1480

# Processing of Short Natural Fibers into Unidirectional Tapes: Influence of Process Parameters on Orientation and Properties

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This paper presents a comprehensive investigation into a processing approach aimed to upgrade short natural fiber waste by transforming it into oriented fiber tapes using polypropylene as a thermoplastic matrix. Short natural fibers from plants like hemp and flax are currently predominantly used in low-value applications such as thermal or acoustic insulation, despite their potential as sustainable reinforcement materials in composite structures. A high degree of fiber orientiation is required for the processing and usage in composite applications.

The study focuses on the alignment of short natural fibers and the formation of continuous tape-like semi-finished products. Key process parameters influencing fiber orientation, process stability, and overall processability are systematically analyzed. The influence of machine parameters on tape quality is evaluated.

To assess the structural perfomance of the developed natural fiber tapes, extensive mechanical characterization is performed. Tensile and flexural tests are performed to quantify stiffness, strength, and failure behaviour, allowing for a direct comparison with different oriented short fiber composites (e.g. recycled carbon tapes). In addition, density measurements are carried out to determine the achieved fiber volume content (FVC) and to enable density-specific evaluation of the mechanical properties.

The results demonstrate that the proposed process route provides a viable pathway for upgrading natural fibers into higher-value products. The results also show that the controlled orientation of short natural fibers is feasible and enhances mechanical performance compared to non-oriented natural fiber composites. From an industrial perspective, the developed tapes represent a promising class of semi-finished products for fiber-reinforced plastics manufacturing. Due to their geometry, the materials are well suited for integration into established industrial processes such as tape laying, and hybrid laminate manufacturing.

#1481

# Influence of conductive materials and fabrication methods on sensing properties of the additively manufactured multi-material implantable sensors

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Implantable sensors recently gained significant interest for applications like biotelemetry due to their effective data transfer rates and wide communication range. Several manufacturing approaches like photolithography, inkjet printing, and screen printing were reported in the recent past for producing conductive parts or circuit networks on to the substrate. In this study, the polyvinylidene fluoride (PVDF) reinforced with hydroxyapatite (HAP) and chitosan (CS) has been used as a substrate material that has further been processed through material extrusion (MEX) process for fabricating the substrate of the senor which works on the principle of microstrip patch antenna (MPA). Direct metal laser sintering (DMLS) and inkjet printing have been used to prepare the conductive parts of the sensor using 17-4 precipitated hardened (PH) stainless steel (SS), respectively, other than the commercially available copper (Cu) adhesive tape to address the biocompatibility issue. Primarily, the sensors equipped with different conductive materials are designed and simulated in Ansys high-frequency structural simulator (HFSS) software, and their radio-frequency (RF) are compared. Further, the fabrication routes of the conductive parts were analyzed to optimize the parameters for sensor development with high accuracy, and suggestions are given on the basis of the current state of research.

#1484

# Three point bending analysis of sandwich structure with a novel hybrid cellular structure for in-plane and out of plane loading

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Sandwich composites are widely adopted in lightweight structures because of their excellent stiffness- and strength-to-weight ratios, yet their performance under combined in-plane and out-of-plane loading is often constrained by the limitations of conventional core architectures. This work investigates the three-point bending response of sandwich beams incorporating a novel hybrid cellular core, specifically designed to enhance flexural stiffness, and energy absorption for multifunctional load-bearing applications. The hybrid core merges two complementary cellular topologies to activate tailored deformation mechanisms under bending, including controlled cell wall buckling and progressive crushing, while maintaining efficient in-plane load transfer.

A detailed numerical study is carried out using finite element analysis, incorporating appropriate material nonlinearity and contact to capture local buckling, core shear, and global deformation behavior. Key metrics such as load–displacement response, initial bending stiffness, peak load, specific energy absorption, and failure patterns are extracted and compared against reference sandwich configurations with hexagonal honeycomb and re-entrant diamond cores. Parametric variations in relative density, hybridization ratio, and core thickness are explored to identify core designs that jointly optimize energy absorption metrices.

The results demonstrate that the proposed hybrid cellular core can deliver notable gains in bending strength, specific stiffness, and energy absorption characteristic

#1485

# Influence of the matrix degradation on the fiber direction compressive Strength

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The longitudinal compressive behavior of composite materials remains a challenge, especially in the case of fatigue damage or high temperature degradation. The main objective of this work is to demonstrate the reduction in longitudinal compressive strength as matrix degradation increases. Tests were conducted on woven fabric CF/PEEK and CF/epoxy samples utilizing different testing techniques.

First, four points bending tests were conducted on the CF/PEEK ply samples. The influence of matrix degradation on compressive properties was studied using elevated temperature four points bending tests on hourglass-shaped samples. Analysis shows large decrease of compressive failure stress versus temperature.

In order to study the influence of matrix damage on the longitudinal compressive strength, another experimental procedure was used. Woven plies CF/epoxy hourglass-shaped tubes with the longitudinal direction aligned with the axial direction were used. Results showed that the matrix damage affects significantly the compressive strength in the fiber direction.

This presentation does not deal with the improvement of the longitudinal mechanical strength but with the reasons which can lead to a reduction in this performance. If the fibers play a major role because the longitudinal failure is probably associated with the buckling of the fibers, the matrix also plays an important role because it retards the buckling mechanism. We have shown that the degradation of the matrix, by raising the temperature or by generating matrix micro-cracks which lower the stiffness of the matrix, also induces a drop in strength

#1487

# Numerical Analysis of Coupled Thermomechanics, Kinetics and Residual Stress Development in Fibre-Reinforced Composites Using Fast-Curing Resins

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The production of fibre-reinforced polymers (FRPs) with fast-curing polymer systems reduces technological cycle times to a matter of minutes or even seconds. However, the rapid and often violent course of the polymerisation reaction poses significant challenges for mechanical engineering, particularly in achieving precise process control. The main issue is uneven curing, resulting from limited transport of initiating energy into the material, which leads to steep gradients in polymerisation shrinkage and temperature. These gradients are the primary source of critical residual stresses in the final component. This necessitates advanced modelling approaches that couple physical and chemical phenomena to ensure structural integrity.

This work focuses on the development and application of an advanced methodology for coupled analysis in the Finite Element Method (FEM) domain, using the integrated environment of ANSYS Mechanical and ANSYS Fluent. The goal is to accurately predict residual stresses and assess the critical integrity of the fibre-resin interface during the polymerisation process of fast-curing polymers. The numerical model considers the implementation of non-linear cross-linking kinetics, precisely linked to local energy supply, which enables continuous tracking of the development of the degree of curing in time and space. In the mechanics module, the dynamic change in the constitutive properties of the matrix (e.g., elastic modulus) is closely linked to the progress of DoC. Residual stresses are generated by the superposition of deformations resulting from chemical shrinkage and thermal shrinkage, induced by the significant exothermicity of the reaction and cooling. FEM analysis enables detailed visualisation and quantitative assessment of stress concentrations in the critical phase boundary zone, which is fundamental for predicting cohesion failure and delamination. The presented approach is an essential engineering tool for optimising technological cycles and minimising internal structural defects in FRP composites based on fast-curing polymers.

#1490

# Effect of interface ply orientation on mode II delamination observed by in situ X-ray computed tomography

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Delamination is a critical damage mechanism limiting the durability and reliability of fibre-reinforced polymer (FRP) composites. Under mode II (shear-driven) loading, delaminations often develop in a complex three-dimensional manner that remains largely inaccessible using conventional edge-based observation techniques such as visual inspection or microscopy. This hampers the understanding of crack growth, crack migration, and associated damage mechanisms, and limits the development of more damage-tolerant composite designs. This work investigates damage mechanisms in FRP laminates under mode II loading using in situ X-ray computed tomography (XCT). Four-point end-notched flexure tests were performed inside an XCT scanner, enabling direct three-dimensional visualisation of delamination initiation, propagation, and migration inside the specimen. The study systematically examined the influence of interface ply orientation on delamination behaviour by comparing laminates with 0°//0°, 0°//10°, and 0°//90° delamination interfaces. Particular emphasis was placed on assessing whether the small ply misalignment in the 0°//10° interface was sufficient to trigger crack migration, and how its behaviour compared to that of strictly unidirectional and cross-ply delamination interfaces. The results reveal distinct delamination morphologies and damage mechanisms depending on interface orientation. While 0°//0° interfaces promoted relatively stable delamination growth, the introduction of ply misalignment led to changes in crack-front shape, local damage accumulation, and, in some cases, delamination migration. Comparisons between the three interfaces provide new insight into the threshold conditions for migration under mode II loading. In addition, the influence of specimen geometry and scale on the observed fracture response is discussed. Overall, this work demonstrates the unique capability of in situ XCT to resolve hidden mode II damage mechanisms and provides new experimental evidence linking interface design, crack migration, and fracture behaviour. These insights support the development of more durable and damage-tolerant composite laminates.

#1491

# Design of hybrid leading edge based on titanium lattice structure architecture and CFRP for improving the damage tolerance under bird strike conditions

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The using of carbon fibres reinforced plastic materials plays a primary role in achieving challenging performance. Such materials are a benchmark for modern aerospace structures thanks to their high specific stiffness and strength, and to the possibility of tailoring the desired mechanical properties in accordance with the applied loads and requirements. However, the solid composite structures can be very sensitive to damage status induced by low/medium energy impacts and up to now a full understanding of damage propagation under operative load is missed and for such a reason a very conservative design roles are applied. The combination with the promising additive manufacturing technologies offers new possibilities to overcome such limitations by exploiting the intrinsic benefit in generating complex geometries hard to produce with traditional manufacturing technologies. Among these, the lattice structures represent one of the most innovative solutions, since they offer a very high strength-to-weight ratio, freedom in the design space and high energy absorption capabilities. In particular, the titanium alloys like the Ti6Al4V are the best candidates for coupling with CFRP, thanks to their chemical, thermal and mechanical compatibility. The combination of these materials and the specific structural architecture related to them give to the designer a very high customisation level to satisfy any requirements. In this work, a hybrid structure characterised by a Ti6Al4V lattice structure core made with EB-PBF additive technology and a CFRP skin was used to develop an innovative wing leading edge capable to withstand to bird strike events with a reduced mass with respect to standard structural architecture. The adopted numerical models were validated and calibrated with respect to experimental tests performed in different load conditions at different complexity levels. The final demonstrator, derived from literature, has been investigated under different impact conditions to estimate the damage tolerance of hybrid composite/titanium wing leading edges.

#1493

# Simulation and Validation of Rubber Vulcanization Process

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Vulcanization is a crucial step in the manufacturing of complex rubber parts such as rubber tracks made of a stack of many different materials. The process, happening during molding, ensures those parts show good mechanical performance. The molding of thick rubber parts contains many obstacles, the most notable being the overcure of the surfaces while the middle of the part is still under-cured and has poor mechanical properties. Also, the vulcanization itself releases heat that affects the curing rate of rubber during molding. Because of this, the rubber industry often uses a trial-and-error method to optimize the vulcanization process, resulting in a waste of time, materials and energy. Numerical simulations are therefore necessary to optimize the complex vulcanization process and limit the wastes generated. In the literature, numerical models were proposed to simulate the vulcanization reaction, but these models are often only compared against experimental measurements of the temperature inside the part and lack the validation of the degree of vulcanization predicted by the model. Moreover, they are generally fitted with isothermal rheometric experiments, so it must be verified they are also applicable in the non-isothermal conditions observed in the vulcanization of thick rubber parts. This paper presents a finite element model that simulates both the curing of the rubber and the heat released during molding. The results of the simulation are compared with experimental measures of temperature and degree of vulcanization in molded rubber bricks. Experimental results obtained using a non-isothermal test method with a RPA rheometer are in good agreement with simulated results. This model can be used to better predict vulcanization degrees in thick rubber parts and drastically reduce the trials and errors that result in wasted material and energy.

#1495

# Engineering the Interphase: Rapid Hot-Pressing of All-PESU Sandwich Panels for Stronger, More Conductive Aircraft Interiors

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Thermoplastic sandwich panels are increasingly attractive for aircraft interiors because they can be lightweight, durable, and recyclable. The practical barrier is rarely the raw material; it is the interface. In all-thermoplastic designs, the foam core and the thermoplastic composite skin must be joined strongly and repeatably, or the structure fails where it matters most; at the core-to-skin bondline.

In this study, we tackle that interface bottleneck by developing an all-PESU sandwich architecture that pairs a polyethersulfone (PESU) foam core with glass fiber reinforced PESU film skins (rGF/PESU). The panels are consolidated using a rapid lower-side hot pressing route, systematically varying temperature (265 and 270 °C) and short dwell time (45 and 60 s) to tune bonding while keeping manufacturing realistic for industrial cycles.

A central outcome is that bonding is not simply contact and pressure. Advanced imaging reveals that processing creates a distinct transition region between core and skin, leading to three identifiable phases in the final structure: the PESU core, the rGF/PESU skin, and an interlayer that forms during pressing. With increased temperature and time, this interlayer grows, reaching an interlayer thickness of about 500 µm for the 270 °C, 60 s condition.

This engineered interlayer directly translates into performance. The best condition shows a pronounced increase in thermal transport, with out-of-plane thermal conductivity rising by approximately 145% compared with the unmodified PESU core, alongside the highest flexural strength of 20.1 MPa in three-point bending. Overall, the work reframes core-to-skin joining as interphase design and defines a manufacturable processing window for high-performance, recyclable thermoplastic sandwich panels in aircraft interior applications.

#1496

# Mechanical and interfacial performance of recycled carbon and glass fibres from a novel solvolysis recycling method

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This study examines the mechanical properties and fibre–matrix interfacial behaviour of recycled carbon and glass fibres recovered via a mild solvolysis process. Epoxy-based composites were recycled using hydrogen peroxide, enabling the recovery of reinforcing fibres in near-pristine condition [1]. Scanning electron microscopy (SEM) revealed no surface damage induced by the recycling process. Single-fibre tensile tests were performed on virgin and recycled carbon and glass fibres, with large sample sizes (75–100 repetitions per group) ensuring statistical reliability. Recycled carbon fibres showed an almost negligible reduction in tensile strength, indicating excellent retention of mechanical integrity. Glass fibres exhibited a larger, though still moderate, strength reduction after recycling. Interfacial properties were investigated using microdroplet debonding tests to quantify the interfacial shear strength (IFSS) at the fibre–matrix interface. Recycled glass fibres showed a pronounced reduction in IFSS, whereas carbon fibres experienced a comparatively smaller decrease. This difference is attributed to distinct surface characteristics and adhesion mechanisms. Glass fibres rely on hydroxyl-rich surfaces and silane-mediated chemical bonding, such as Si–O–C and Si–O–Si, which are sensitive to sizing removal during recycling. In contrast, carbon fibres possess chemically inert graphitic surfaces where adhesion is governed primarily by polymeric sizing and limited mechanical interlocking. Overall, the results demonstrate that the proposed hydrogen-peroxide-based recycling process preserves fibre mechanical performance to a significant extent while significantly affecting interfacial behaviour, particularly in glass fibres.

References

[1] G.N. Petropoulos, P. Tsokanas, A. Kotrotsos, V. Kostopoulos, Recycled glass fibre–epoxy composites based on recovered fabrics from an environment-friendly combined solvolysis and thermolysis route. Composites Science and Technology 263 (2025) 111048.

#1497

# Seeing and Simulating: Automated X-ray CT-Based Mesoscale Modeling of As-Manufactured Textile Composites

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The mechanical properties of textile composites are affected both by the constituent properties and the textile reinforcement architecture. The textile architecture is defined by aspects such as fibre type, tow size, weave type etc., but also by manufacturing conditions such as amount of draping, injection flow rates and the amount of compaction. Therefore, the mechanical properties can vary between components with the same geometry, but also between different areas of the same component. Therefore, predicting as-manufactured composite properties requires a detailed understanding of the underlying mesoscale geometry.

In this contribution, we are presenting a fully automated and open-source pipeline to generate digital finite element twins of as-manufactured 3D-woven composite materials. The starting point is large field of view CT scans of composite specimens that are automatically segmented by a machine learning model, the result of which is translated into finite element models with spatially varying tow orientations and fibre volume fractions. A key component in the pipeline is the segmentation model, and it's training from purely synthetic data (virtual scans of synthetic mesoscale geometries). The capabilities of the pipeline have been demonstrated through accurate predictions of elastic properties, with deviations of less than 6.5% compared to experimentally obtained engineering properties.

Having validated the ability of the pipeline to accurately predict elastic properties, the next step will be further studies of the mechanical response of as-manufactured 3D-woven composites under more extreme loading conditions, accounting for tow reorientation, (visco)plasticity and progressive damage.

#1499

# Structural integrity of leaves as sandwich structures

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The plant leaf has structural properties often seen in a composite sandwich structure - please see Reference: https://doi.org/10.1016/j.engfracmech.2021.108121.

Imperial is part of a consortium, led by Professor Anja Geitmann, at McGill University, with Yale and Aalborg Universities, researching a Human Frontier Science Program (HFSP) Grant on “The Architecture of Photosynthesis”. The Imperial contribution focusses on the structure of the plant leaf and measures mechanical properties by uniaxial tension and vibration bending experiments, to determine the tensile modulus and bending modulus characteristics of a leaf. This is for rectangular sections of leaf material extracted from freshly grown leaves of Arabidopsis. The experiments are performed rapidly after the section of leaf is cut so as to avoid internal loss of turgor from the leaf. The tensile and bending response of the Arabidopsis Col-0 strain (called wild type) and a Arabidopsis CGR30X strain (called mutant type) are compared. In so doing, this study assists in understanding the mesophyll’s contribution to the overall mechanical properties of the leaves of Arabidopsis.

The oral presentation will describe the current research on modelling deformation and damage in composite sandwich structures and how this has been applied to understanding the mechanical properties of leaves. This is with appropriate experimentation to characterize material properties of the leaf.

#1500

# Fracture Response of Unvented Aerospace Sandwich Panels: Effects of GAG Pressurization and In-Plane Loads

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This study investigates the fracture behavior of unvented honeycomb-core sandwich panels subjected to in-plane loads with and without Ground-Air-Ground (GAG) pressurization, with particular focus on facesheet/core disbonding. The analysis considers sandwich configurations representative of large commercial aircraft and helicopter structures composed of CFRP/Nomex honeycomb. The influence of disbond size, internal pressure, and in-plane loading magnitude and orientation on crack propagation is evaluated in detail. These parameters are shown to strongly affect disbond bulging, local stress redistribution, and disbond progression, all of which may compromise the structural integrity of the component under operational conditions.

A fully automated computational fracture-mechanics tool, termed FSDA, is developed and ready for industrial implementation. The methodology integrates Python in-house scripts with global finite element models in Abaqus with a refined sub-modeling strategy to achieve high-fidelity mesh resolution near the disbond front. The energy release rate components (GI/GII) and phase angle are computed using the Crack Surface Displacement Extrapolation (CSDE) technique. To accurately capture the in-plane stiffness contribution of the facesheet/core interface—often neglected in traditional modeling—Becker's homogenization scheme is incorporated. The framework has been experimentally validated and demonstrates high accuracy in predicting out-of-plane deflections and identifying crack-growth thresholds for a representative set of loading conditions and structural configurations.

Results indicate that GAG pressurization alone produces predominantly mode-I driven disbond growth, whereas the application of uniaxial or biaxial in-plane compression substantially increases the energy release rate and leads to asymmetric, elliptical disbond growth. The introduction of shear loading further modifies the disbond-front energy release rate distribution, shifting peak locations and promoting mixed-mode fracture behavior. Additionally, in the absence of GAG pressurization, post-buckling of the disbonded facesheet induces intermittent self-contact between the facesheet and the core, and locally altering the energy release rate distribution along the disbond front.

#1503

# From Alkali Treatment to Interface Tailoring: Optimising Flax–Epoxy Composites by NaOH Pretreatment

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The growing demand for sustainable lightweight materials has directed increasing attention towards natural fibre-reinforced polymer composites. Among them, flax fibres are particularly attractive due to their low density, low cost, high availability and favourable ecological footprint. Yet, their implementation in structural applications is limited by comparatively low mechanical properties and weak fibre–matrix interfaces, which can significantly constrain composite performance. Improving the adhesion between flax fibres and epoxy matrices is therefore a key step towards unlocking the full potential of these bio-based materials.

This research investigates the effect of alkaline surface pretreatment on the mechanical behaviour of unidirectional flax–epoxy composites. Unidirectional flax fabrics are immersed in aqueous sodium hydroxide (NaOH) solutions with systematically varied concentration and exposure time, followed by rinsing, neutralisation and controlled drying. The pretreated fabrics are then processed into composite plates using a heated vacuum-assisted resin transfer moulding (VARTM) process. The resulting laminates are characterised by quasi-static tensile tests to quantify stiffness, strength and failure strain relative to untreated reference specimens. Particular emphasis is placed on identifying processing windows in which improved fibre–matrix adhesion is achieved without inducing detrimental fibre damage such as embrittlement, surface degradation or loss of integrity.

The poster will present the experimental concept, the parameter matrix for NaOH pretreatment and first results from mechanical testing, highlighting trends that link NaOH concentration and exposure time to the resulting composite properties. These insights are expected to provide guidance for tailoring alkaline surface treatments of flax fibres and, more broadly, for designing high-performance, bio-based fibre-reinforced composites for engineering applications.

#1504

# Towards Green Sensing in Composite Aerostructures: European Ecosystem for Green Electronics (EECONE) Project

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The rapid rise of IoT and smart infrastructure is driving a growing wave of electronic waste (e-waste). Structural health monitoring of composites relies heavily on sensors, but conventional devices are often highly material-intensive, difficult to recycle, and rarely designed with sustainability in mind. In the current project, European Ecosystem for Green Electronics (EECONE) project, funded under CHIPS Joint Undertaking, we address this by comparing standard sensor technologies (e.g. straing gage) with flexible printed and microwire alternatives for evaluating sensor material reduction and easier recovery. Our aim is to lower the environmental footprint of SHM sensors by:

• reducing weight, material use, and toxicity through printed sensor technologies,

• benchmarking sustainability with life-cycle assessment (LCA),

while also highlighting gaps in available data and the challenges of applying LCA methods to electronic components.

Early prototypes show flexible printed sensors and microwire sensors could replace traditional strain gauges, reducing material use. Their accuracy and performance will be benchmarked against in-service strain gauges. Advances in sparse sensor placement modeling methodologies will also be highlighted. The exploration of debondable adhesives can also further support reuse and recovery of these sensors in service. Beyond direct performance comparisons, our LCA work finds critical data limitations and methodological challenges that must be addressed to properly assess the sustainability of electronic sensing systems for usage in composite structure health monitoring. Embedding these insights into design-guided by the EECONE "6R" framework-moves us toward more sustainable, lower-impact monitoring technologies, projecting Structural Health Monitoring systems toward the next step in a resource-efficient future.

#1505

# Active Learning–Based Optimization of Stepped Composite Repairs

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The widespread use of fiber-reinforced polymer (FRP) laminates in naval and aeronautical structures has increased the demand for efficient bonded repair solutions capable of restoring compressive load-carrying capacity. Stepped composite repairs provide smooth load transfer and geometric continuity, but their design involves a challenging trade-off between strength recovery and excessive material removal. High-fidelity finite element modelling (FEM) can accurately capture compressive failure mechanisms such as local buckling, adhesive decohesion, and fiber kinking, yet its computational cost renders conventional parametric or evolutionary optimization impractical for complex repair geometries.

This work presents a data-efficient optimization framework for stepped composite repairs under compression, based on Bayesian active learning and Deep Kernel Gaussian Processes (DKGP). The proposed approach combines a deep neural network feature extractor with a Gaussian Process surrogate, enabling accurate modelling of non-linear geometric interactions while providing epistemic uncertainty estimates to guide adaptive sampling. A two-stage learning strategy is employed, transitioning from smooth exploration to higher-fidelity exploitation as the dataset grows.

High-fidelity FEM simulations incorporating cohesive zone modelling and validated failure criteria are used to evaluate candidate repair designs. The optimization is formulated as a multi-objective problem, maximizing ultimate compressive strength while minimizing repair volume, which directly correlates with manufacturing time in automated laser-based repair processes. Strict geometric and manufacturability constraints are enforced throughout the search.

The active learning framework converges to physically optimal repair designs in fewer than 100 FEM evaluations, achieving an approximate 96% reduction in computational cost compared to conventional evolutionary approaches. Distinct optimization behaviors are observed between standard and off-axis laminate configurations, highlighting the role of geometry-driven buckling mechanisms. The results demonstrate that uncertainty-aware machine learning can substantially accelerate composite repair design while delivering manufacturing-ready solutions for critical structural applications.

#1508

# Manufacture and testing of self-reinforced UHMWPE composites post-treated with gamma-irradiation and heat treatment for joint implant inserts

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Due to the extended life expectancy of the human body, it must function properly for an increasingly longer period. This is further complicated by our accelerated pace of life, which also places additional strain on our body's performance. This is why our joints often break down, which is treated by implanting prostheses. Joint prostheses are complex structures, the development of which poses a serious challenge for both doctors and engineers. Like all technical devices, joint implants also deteriorate over time and need to be replaced, which is revision surgery. The most common cause of revision surgery is wear. The most popular design for implants today is a metal-polymer sliding pair construction. In this case, the insert material fails, requiring replacement of the whole system. Currently, these inserts are made of UHMWPE (Ultra-High Molecular Weight Polyethylene).

In our research, we developed a manufacturing technology that allows us to produce self-reinforced UHMWPE implant inserts. In this process, we mix UHMWPE fibers into UHMWPE powder, then sinter the system according to a specific temperature and pressure program. We then developed post-treatment processes that include gamma irradiation and softening heat treatment softening to increase the composites performance.

We examined the hardness, wear and tribological properties of the finished, self-reinforced, and gamma-irradiated samples with a tribometer. We compared the results with factory-made reference UHMWPE samples. Our measurements showed that self-reinforcement alone significantly improves wear properties, but gamma irradiation and subsequent heat treatment can further enhance this effect. The wear marks were analyzed using a confocal microscope and an electron microscope.

With self-reinforced UHMWPE composites post-treated with gamma irradiation and heat treatment, our main goal was to improve tribological properties and reduce wear, which we succeeded in achieving. Overall, the developed self-reinforced UHMWPE inserts can provide extended lifetime and help reduce the number of revision surgeries.

#1509

# Analysis of Delamination in static and fatigue in a laminated composite

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This work investigates the initiation and propagation of delamination in a balanced woven Carbon/PEEK laminate currently used by Airbus Helicopters, under both static and fatigue tensile loading. Quasi-isotropic stacking sequences with different in-plane orientations are designed so as to promote distinct combinations of interlaminar normal and shear stresses, and hence different delamination modes. Under unnotched tensile loading, these configurations develop strong out-of-plane edge stresses that trigger free-edge delamination.

For this woven system, delamination can be confined to a single interface and monitored along the specimen length using 3D digital image correlation and a dedicated transverse-strain–based post-processing. This original and relatively simple tensile test configuration enables stable monitoring of crack growth in both static and fatigue, without resorting to dedicated fracture coupons. It is then possible to quantify the influence of key fatigue parameters – frequency, load ratio R and stacking sequence / damage mode – on delamination kinetics.

The experimental database, consisting of static tensile tests and S–N curves enriched with crack-length versus cycle-count histories, is used to calibrate and validate finite element simulations using cohesive zone modelling implemented via user subroutines in ABAQUS. Finally, a complementary physico-chemical interpretation is explored by adapting a cooperative time–temperature model to the PEEK matrix system, allowing for a better understanding of the mechanisms acting at the polymer scale within the thermoplastic matrix and ultimately link them with the mechanical approach and cohesive zone modelling. Together, these experimental and modelling efforts provide an integrated framework for assessing delamination resistance of aerospace-grade woven thermoplastic laminates under realistic tensile fatigue conditions.

#1513

# Mitigation of process-induced stress in unsymmetrical laminates via vitrimer relaxation

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In composites with asymmetric or unbalanced ply configurations, a mismatch in the coefficient of thermal expansion (CTE) between plies leads to development of significant residual stresses during the curing cool down phase. In conventional thermosets, theses stresses are permanently locked into the structure, resulting in undesirable warpage.

The use of vitrimer prepregs for composite manufacturing offers advantages. Vitrimer polymers possess a dynamic covalent network that enables bond exchange reactions at elevated temperatures. This mechanism enables network to rearrange its topology, enabling macroscopic stress to dissipate without compromising the material's structural integrity. The stress relaxation behavior of vitrimers can then play a decisive role in mitigating those process-induced defects.

This study investigates the hypothesis that the inherent stress relaxation capability of a vitrimer matrix can be leveraged to reduce or eliminate post cure curvature in asymmetric laminates. The investigation focuses on unsymmetrical laminates [0°2/90°2] cured with a standard thermal cycle, followed by a post curing thermal treatment designed to activate the vitrimer bond exchange mechanism and quantify the resulting change in dimensional stability.

After the primary curing cycle, the laminates exhibited significant and measurable curvature. The samples were then reheated to 200°C, and held at that temperature for 45 min to provide sufficient time for network relaxation. During the 45-minute hold at 200°C, the sample remained flat, indicating that the internal stresses responsible for the initial warpage had been fully relieved. Upon cooling (figure 1), a portion of the curvature reappeared, but the final residual curvature was significantly lower than the initial value. Because the stress reference state of the material was reset at 200°C, the magnitude of the reintroduced stress was considerably reduced.

Figure 1: Out-of-plane deflection and curvature evolution during heating phase (orange) and cooling (green) for asymmetrical laminate

#1514

# Fiber path optimization for highly challenging surfaces in AFP manufacturing

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Automated Fiber Placement (AFP) is a state-of-the-art manufacturing process widely used in the aerospace industry especially for structural applications with high geometrical complexity and requirements towards mechanical properties. In addition to its near-net shape fiber deposition capability, AFP technology is particularly suitable for these challenges due to its ability to place tows along curved paths, known as "fiber steering". Rendering load path optimized fiber architecture possible, fiber steering acts as a technology enabler to allow for complex design approaches with a highly automated and accurate manufacturing technology.

While these characteristics offer unmatched advantages in structural design, this also requires complex design methods for the development of fiber paths. In particular, double-curved surfaces, local cavities for sandwich elements, or curved reference curves result in local steering effects or discontinuities in the fiber path when implemented directly, and thus local stress peaks, resulting in similar effects on structural performance as notches. Deviations from the design orientation or locally lower coverage rates must therefore be taken into account in the structural design by means of knockdown factors.

This paper presents systematic approaches to fiber architecture optimization developed at the IGCV on the basis of typical use cases. The results achieved are evaluated in terms of relevant KPIs such as cover ratio, fiber angle deviation, and steering radii, and compared with established design methods. One focus is on the uniform coverage of sandwich pockets and an optimization algorithm for components with variably curved neutral fibers, which allows 100% coverage while minimizing critical steering radii.

In addition, potential applications for using fiber paths generated in this way ex ante in component design are demonstrated, thereby illustrating a design-for-manufacturing (DFM) philosophy that can enable a design that is nearly tolerance-free and minimizes defects induced by manufacturing constraints.

#1515

# High-Quality Manufacturing of T-profile Beams Using Thermoplastic Prepreg Tape Pultrusion with Multi-directional Servo-controlled Compression

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Continuous fiber-reinforced thermoplastic (CFRTP) long rods, which feature continuous axial fiber orientation, are highly anticipated as lightweight, high-strength structural materials due to their capability for secondary processing like thermal welding and forming. However, the efficient, continuous manufacture of CFRTP long rods with modified cross-sections remains a manufacturing challenge, often requiring extensive tape stacking or complex layup that causes defects. Therefore, this study originally developed the thermo pultrusion machine for manufacturing unidirectional carbon fiber reinforced poly-ether-ether-ketone (CF/PEEK) long rods with T-shaped cross sections directly from prepreg tape bundles.This machine is equipped with a multi-directional compression mold featuring independently controlled servo-press driven slide cores on the top and both sides. In the pultrusion forming of the T-shaped rod, the web is formed by compressing the fed prepreg bundle with the left and right slide cores. Subsequently, the flange is formed by compressing the prepreg pushed upward using the upper slide core. The apparatus allows the T-shaped rods to be continuously pultruded by this process. Load data for each slide core, obtained by the servo press during pultrusion, indicated that compressive pressure was applied across the entire cross-sectional area during continuous production. The forming accuracy of the pultruded T-shaped rod was evaluated by measuring the flange width, web height, thickness and flatness of the upper flange surface using an optical 3D shape measurement system. Mechanical properties were evaluated by cutting specimens of the same shape from the web and flange sections and conducting three-point bending tests, thereby confirming the uniformity of forming within the cross-section. The forming process and its uniformity were observed and evaluated from the perspective of sectional observation and consistency of mechanical properties in the respective parts, successfully establishing the forming quality of the pultrusion process.

#1516

# Adaptive by design: 4D-printed metamaterials inspired by marine life

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Establishing sustainable human presence in extreme environments, such as deep space or extraterrestrial surfaces, requires innovative materials capable of achieving autonomous motion with low energy consumption and minimal maintenance. Living systems can provide inspiration for such mechanisms driven by surrounding environmental fluctuations. Beyond commonly applied biomimetic approaches based on well-studied species, and thanks to a multidisciplinary research team, we draw insights from rarely described marine organisms: crinoids. These deep-sea invertebrates possess articulated columnar structures formed by stacked ossicles connected via mutable collagenous tissues. This architecture combines stiffness and compliance, enabling passive shape morphing in response to external stimulation while maintaining structural integrity.

Here, we translate these biological principles into a new class of 4D-printed columnar metacomposites capable of autonomous bending. The bioinspired columns consist of polymer ossicles reinforced with high-stiffness, high-strength continuous-fibre-reinforced composites. Differential thermal expansion between the active polymer and passive fibrous components induces controlled, fully reversible bending, i.e. angle ranging from 0° to 60° when exposed to temperature variations up to 160 °C. Parametric studies reveal how geometric parameters (ossicle diameter, composite reinforcement distribution) tune the bending amplitude and kinetics, enabling programmed motion and mechanical response. Crucially, inspired by the balance between compliance and stiffness observed in living systems, these shape-changing metamaterials are not only capable of large displacement but also of exerting force. We demonstrate that the columns can lift masses and deliver work up to 500 J·m-3 through bending, outperforming most bending actuators in the literature and highlighting their structural potential in addition to shape morphing. Their modular design further allows multi-axis motions and complex actuation patterns through assembly of multiple columns into metastructures.

Overall, this work demonstrates how abstracted natural mechanics can guide the design of resource-efficient, autonomous reconfigurable actuators suited for extreme environments, expanding the range of achievable motions in programmable materials.

#1518

# Manufacturing Routes for short, potentially recycled Carbon Fibres to close the Loop

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The utilisation of short recycled carbon fibres (rCF) in structural composite applications is limited by discontinuous fibre length, insufficient fibre alignment, and restricted processability of rCF-based semi-finished products in established textile and composite manufacturing routes. This paper presents a process chain for the production of oriented rCF tapes from short fibre feedstock and investigates their mechanical integrity and suitability for further textile processing and thermoset composite manufacturing.

The processing route comprises fibre preparation and opening, card-based web formation, controlled fibre alignment, and tape consolidation. During tape production, the tensile loads transferable by the dry rCF tapes are quantified as a critical parameter for continuous handling and processing. The influence of selected process and machine parameters on tape width stability, areal weight distribution, fibre orientation quality, and structural integrity is systematically analysed.

The produced rCF tapes are subsequently processed on a Non-Crimp Fabric (NCF) machine to generate defined reinforcement architectures with controlled fibre placement, representing a scalable and industry-relevant processing step. The resulting preforms are impregnated with a thermoset resin system and consolidated into composite coupons. Mechanical characterisation is performed by tensile and flexural testing. Density measurements, fibre volume content determination, and microsection analyses are conducted to correlate processing parameters with internal structure and resulting mechanical performance.

#1519

# Effect of Electrophoretically Deposited Graphene Coating Morphology on the Hygrothermal Ageing Behavior of Carbon Fiber Epoxy Composites

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Carbon fiber reinforced polymer (CFRP) composites are widely employed in high-performance structural applications due to their high specific strength and stiffness; however, their long-term reliability is often limited by interfacial degradation under hygrothermal environments. In the present study, carbon fibers were surface-modified through electrophoretic deposition (EPD) of graphene to enhance the fiber–matrix interphase and improve environmental durability. Two graphene coating morphologies were investigated, namely a particle-type coating with a loading of approximately 0.43 wt% and a film-type coating with a higher loading of about 1.3 wt%. Epoxy-based laminates were subsequently fabricated using the vacuum-assisted resin transfer molding (VARTM) technique to ensure uniform resin impregnation and controlled laminate quality. The influence of graphene coating content and morphology on the hygrothermal ageing behavior of the composites was systematically examined by immersing the specimens in hot-water environments maintained at 50 °C and 75 °C. The moisture absorption and desorption behavior of the composites was quantified to evaluate water diffusion characteristics and moisture retention tendencies. In addition, the tensile strength behavior of CFRP composites fabricated with varying graphene contents was evaluated before and after hygrothermal ageing to assess mechanical performance degradation. Prior to ageing, the composite containing 0.43 wt% particle-type graphene coating exhibited higher tensile strength compared to both pristine CFRP and 1.3 wt% graphene-coated composites, which may be attributed to formation of a more robust fiber–matrix interphase. The evolution of tensile strength behavior following hygrothermal ageing is currently under investigation to establish long-term durability trends. Overall, the results highlight the critical role of graphene loading and deposition morphology in governing moisture resistance, interfacial stability, and durability of CFRP composites exposed to hygrothermal environments.

#1520

# TheTorpropel Project: Concept, Objectives, Methodologies, Impact

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The TorPropel project aims to deliver a breakthrough in sustainable aircraft propulsion by developing, and upscaling next-generation composite toroidal propellers. While studies have highlighted the acoustic and aerodynamic advantages of toroidal geometries, their application at meaningful propulsion scales remains limited. TorPropel directly addresses this gap by designing and validating a real-scale composite toroidal propeller for small aircraft, advancing the technology to TRL 4 through an integrated approach that combines advanced materials, automated manufacturing, structural health monitoring, and high-fidelity simulation.

The initial phase of TorPropel focuses on computational fluid dynamics (CFD) analysis to investigate the flow physics around toroidal propeller configurations. This aerodynamic optimization will be followed by comprehensive aeroacoustic assessments to analyze noise-generation mechanisms. Iterative optimization strategies will be subsequently deployed, refining key geometric parameters, such as blade number, curvature, and twist angle, to enhance thrust efficiency while mitigating noise emissions.

A key technological pillar is dynamic-network (vitrimer) resins, enabling composite structures that are reprocessable, repairable, and recyclable. These materials retain the performance of conventional thermosets while significantly reducing waste and enabling circularity in propulsion system manufacturing. Complementing this material innovation is Rapid Tow Shearing (RTS), a robotic fabrication method capable of defect-free steering of composite tapes along the complex curved paths required by toroidal geometries. To guarantee safe, efficient, and long-life operation, TorPropel aims to integrate an online Structural Health Monitoring (SHM) system, providing early-damage detection, real-time operational data, and predictive maintenance capabilities.

TorPropel will contribute to greener aviation and support future electric and hybrid aircraft architectures. Its manufacturability innovations introduce transformative advances for composite-based propulsion systems.

Over 36 months, TorPropel will implement four technical work packages supported by coordinated management and dissemination activities; to ultimately demonstrate how material science, robotics, and unconventional aerodynamic design can converge to reshape the future of aircraft propulsion.

#1521

# A new components made from used rotor blades—is that possible?

# Component recycling of wind turbine rotor blades

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The research project “power*stage aims to prove that reusing disused rotor blades from wind turbines to roof an open-air stage represents a further use in the sense of a circular economy. This novel and previously unexplored approach are necessary because there is currently no alternative to disposal for large FRP components. The power supply is to be ensured independently via solar sails and recycled vehicle batteries, which are integrated into the rotor blades. How can it be ensured that the “Powerstage” meets all strength requirements? Based on the operational strength of FRP and their failure behavior, an initial concept will be presented here, starting at the component level, which makes it possible to qualify used rotor blades or FRP for reuse.

The damage tolerance of FRP, as defined in the CS 27 or 29, is a key factor in this regard. It is well known that cyclic loading of multi-axially reinforced FRP can lead to continuous progressive damage and thus to a loss of stiffness. The extent and type of loss of stiffness depends heavily on the layer structure of the FRP. Damage and its progression are determined by the special and operating loads that the component had to endure during its initial service life. For an assessment, it is therefore important to know what loads the rotor blade was exposed to during its initial service life. However, as this is usually not known, the material condition can only be realistically estimated on the basis of chemical material aging and the internal damage that has occurred.

Based on this, a concept is presented that makes it possible to evaluate the FRP component and thus indirectly also the material in terms of its reusability with reference to the loads that the component must be able to withstand in its new application.

#1522

# The behaviour of paper composites under pressure loads and their failure modes

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A current research project at hda is investigating whether paper laminate is a sustainable material for lightweight design. Paper is made from paper fibres, which, according to [1], are mainly obtained from annual plants, thinning wood and sawmill waste. Unlike other short fibre-reinforced materials, which mostly use glass fibres, the fibres in paper laminates are renewable and recyclable. In addition to a low density similar to that of wood, the unevenness in growth typical of natural products is evened out during paper production. In direct comparison with wood, these advantages of paper are offset by additional energy and water requirements for production, as well as reduced strength and stiffness values due to the shorter fibre length and less favorable fiber orientation.

The thick-walled material examined here consists of thin layers and, due to the fibre reinforcement, exhibits slight anisotropy in relation to the direction of manufacture. Predictability is generally required of structural materials. Comprehensive investigations of paper laminates under tensile loads are presented in [2]. Under compressive loads, this material exhibits complex failure in the form of symmetrical or asymmetrical layer buckling due to its layered structure. This instability results in a local reduction in stiffness. This is offset by an increase in stiffness with increasing specimen length.

In order to understand the failure behaviour, compression tests in the form of end-loading tests with defined strain rates were carried out on thick-walled specimens of varying lengths stored in a climate-controlled environment. At the same time, attempts were made to simulate the material behaviour using FEM and to describe it using a simple spring approach. This paper presents the latest test results and compares and discusses the fracture patterns. The aim is to generate an initial material model for compressive loads that considers the special characteristics of paper composites in failure.

#1524

# 3D printing of bio-inspired multi-composite material for energy dissipation in coastal environments.

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The issue of protecting our coastal environment is becoming increasingly significant. Most of existing solutions primarily aim to stop waves, which often results in the reflection of wave energy toward the seabed or the coastline, leading to accelerated bottom erosion in front of the structure.

A novel concept of a nature-inspired composite material, manufactured using multi-material (organic/inorganic) 3D printing, is proposed to provide original energy dissipation properties.

Our design is based on the concept of biomimicry. Our concept comes from Sabellaria alveolata, a marine worm that lives in sand tubes of its own making. This organism assembles sand particles suspended in seawater and binds them together using a biologically secreted adhesive.

The entire colony, through the architecture of its tubes, dissipates the energy of incoming waves. An abstraction of this biological model with an architectural analysis based on tomography is proposed, this analysis revealed a circular architecture close to that of brick and mortar found in Nacre.

By abstracting the biological model, a parametric model that replicates the essential functions of the tube has been designed. Indeed, the grains of sand are reproduced using cementitious mortar, and the glue with properties similar to those of a viscoelastic material, is made of polymer. To best reproduce the mechanical characteristics of the biological model, composite prototypes have been manufactured using an original customized multi-material 3D printer.

This presentation will outline the results of transversal compression and the relationship between bioinspired architecture and the specific energy absorption.

#1525

# Reusing composites production waste into recyclable structural applications

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The increasing demand for composite materials in structural applications has resulted in a significant rise in production waste, particularly dry fiber offcuts from glass and carbon fabrics. These remnants, often discarded, represent a valuable source of high-performance material that can be reintegrated into the manufacturing cycle, reducing both environmental impact and production costs. Conventional recycling methods typically yield short fibers, which are unsuitable for structural components and face major challenges in penetrating other markets, especially for glass-reinforced composites.

This work investigates innovative strategies for reusing dry fiber waste by producing mats and hybrid fabrics incorporating continuous unidirectional (UD) fiber inserts. The approach involves collecting and processing offcuts to create mats with tailored properties for liquid composite molding (LCM) processes such as infusion and RTM. To further enhance sustainability, these mats are employed in the fabrication of new recyclable composites using both thermoplastic binders and a novel thermoset resin featuring reversible bonds.

The study demonstrates the feasibility of converting production waste into valuable resources, fostering cost-effective and eco-friendly solutions for composite manufacturing. Future research will focus on optimizing fiber orientation and resin systems to improve mechanical performance and expand application fields.

#1529

# Experimental Modal Analysis of a Hybrid Composite Carousel Disc of an Indexing Gearbox

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The carousel of an indexing gearbox consists of a shaft, four discs, pins, and a roller, forming the output part of the mechanism responsible for converting continuous rotary input motion into intermittent, precisely indexed output motion with dwell periods. Due to high dynamic loads and strict requirements on positioning accuracy, the reduction of mass and moment of inertia of carousel components is of major importance. This study focuses on a hybrid carousel disc design composed of a composite body with steel inserts for the shaft and pins, which offers significant advantages over a fully metallic disc, particularly in terms of mass reduction, inertia decrease, and vibration damping, while preserving functional contact surfaces and assembly accuracy. An experimental modal analysis was performed to investigate the dynamic behavior of the hybrid composite disc and to validate its suitability for dynamically loaded applications. Four disc configurations with combinations of steel inserts were tested using impact hammer excitation and accelerometer response measurements, and their natural frequencies, damping ratios, and mode shapes were identified. The experimentally determined modes were predominantly bending and torsional modes, with the lowest natural frequencies ranging from approximately 3.2 kHz for discs with multiple inserts to above 6 kHz for simpler geometries, indicating a clear influence of mass distribution and insert integration on dynamic properties. The results confirm that, despite the added steel inserts, the hybrid composite discs exhibit sufficiently high natural frequencies well above the operational excitation range of the indexing gearbox, demonstrating favorable dynamic performance and supporting the applicability of the hybrid design for high-speed, high-precision mechanical systems.

#1531

# Phase-Field Formulation Accounting for Interfacial Fracture in Additively Manufactured Polymers

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Keywords: Phase-field Modeling, Fracture Mechanics, Interfacial fracture, Crack Propagation, Finite Element Simulation

Advanced additive manufacturing (AM) processes for polymer composites, particularly Fused Filament Fabrication (FFF), have seen rapid adoption in high-performance industries such as aerospace and automotive over the last decade. However, the layer-by-layer deposition nature of FFF induces intrinsic anisotropic properties and defects such as porosity, inclusions, and weak interfacial bonding. These material features may then lead to crack initiation and propagation, potentially compromising the structural integrity of mechanical components throughout their service life.

To address this challenge, this study proposes a phase-field formulation to simulate crack propagation within FFF composite parts. While the standard phase-field method regularizes sharp cracks through a diffuse damage zone, the novelty of this work lies in extending this regularization to account for the specific mesostructure of AM parts, i.e. inter-filament interfaces. Specifically, the fracture toughness (Gc) is therefore modeled as a spatially dependent field, transitioning smoothly from a bulk value (Gc,bulk) to an interface value (Gc,inter), thereby capturing the mechanical weakness of inter-filament boundaries without explicit interface meshing.

Formulated within a thermodynamically consistent framework, the model is implemented in an in-house finite element code developed in Julia. Benchmark simulations are then conducted on various filament orientations and toughness ratios (Gc,bulk/Gc,inter). As a key result, the model successfully reproduces the characteristic "zig-zag" crack patterns observed in literature. Furthermore, the model is validated against experimental data from tensile and Compact Tension (CT) tests. Finally, this novel phase-field model is applied to complex geometrical configurations to demonstrate its predictive capabilities and representativeness in realistic mechanical scenarios.

#1532

# Mode I fracture characterization of high-temperature 3D-printed PEI-CF using an adhesion-inhibition pre-cracking methodology

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This study presents a mechanical characterization of the mode I fracture properties, namely the critical energy release rate (G_Ic) and the fracture toughness (K_Ic) of polyetherimide reinforced with short carbon fibers (PEI-CF) manufactured with high-temperature Fused Filament Fabrication (FFF).

One of the main objectives of this work is to support the calibration of numerical fracture-mechanics models dedicated to simulating crack propagation in additively manufactured polymers. Such models, based on cohesive laws for instance, require accurate and reproducible fracture parameters to reliably account for the material's anisotropy. Consequently, printing parameters, such as build orientation, were varied to characterize this process-induced behavior.

The study further introduces a modified characterization methodology based on the ASTM D5045 mechanical test standard, adapted to capture the anisotropic behavior of additively manufactured polymers. The new methodology relies on a Sharpie marker to produce thin and reproducible pre-cracks in 3D printed Compact Tension specimens. The marker functions as a bonding inhibitor applied directly onto the underlying layer, thereby preventing the proper adhesion of the subsequent printed layer and creating a controlled initial crack. This approach improves repeatability by reducing the G_Ic confidence interval by 60% and minimizing operator-dependent variability. In addition, it ensures better control over the crack front shape compared to the standard suggested razor tapping method, the former being a critical factor known to influence measured fracture properties.

Our findings highlight inherent limitations of the existing standard, as fracture property measurements remain dependent on notch and pre-crack geometry. Finally, these observations emphasize the need for adapted testing protocols to ensure reliable characterization of high-performance polymer composites manufactured by FFF.

#1534

# High-Throughput Fused Granulate Fabrication of Short Fiber-Reinforced Thermoplastic Composites

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Fused Granulate Fabrication (FGF) is an emerging additive manufacturing process that uses a rotating screw extruder to melt and deposit thermoplastic and composite granules. By eliminating the limitations of filament feeding and localized melting associated with Fused Filament Fabrication (FFF), FGF enables significantly higher and more stable material throughput. While typical volumetric flow rates in FFF are limited to 25 $mm^3/s$ for desktop printers and to ~150 $mm^3/s$ for industrial systems, screw-driven FGF systems can surpass these values at comparable machine scales.

This work presents the development of a high-throughput FGF platform and its application to processing short fiber-reinforced thermoplastic composites. The platform integrates a single-screw printhead mounted on a custom gantry system equipped with a heated bed. Granules are gravity-fed into the printhead and melted in a two-stage heating system prior to extrusion. A range of polymer and composite feedstocks were processed, including neat polylactic acid (PLA), PLA reinforced with short carbon fibers (PLA-CF), polyethylene terephthalate glycol reinforced with short carbon or glass fibers (PETG-CF, PETG-GF), and polycarbonate reinforced with short carbon fibers (PC-CF).

Three case studies (CS) were conducted to evaluate the high-throughput capability of the FGF platform. The first, CS, involved printing an 82 cm-long PETG-CF longboard with a sandwich architecture, achieving a flow rate of 575 $mm^3/s$ with a 2.5 mm nozle and producing a 1.6 kg part in 75 minutes. The second, CS2, an acoustic panel with cellular micro-scaffolds, demonstrated the ability to reproduce smaller features using PLA and a 1.2 mm nozzle. CS3 consisted of a cosmetic aerospace component measuring 75 × 45 cm printed using PC-CF and a 1.8 mm nozzle, reaching 380 $mm^3/s$. The part was printed in 50 minutes and weighed 0.8 kg. These results demonstrate that the developed FGF platform supports stable high-rate deposition across diverse geometries and composite formulations.

#1536

# Development of thermal simulation for Additive Manufacturing Using Kalman Filtering and In-Situ Monitoring

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Controlling thermal history in the additive manufacturing (AM) of thermoplastic composites is critical for ensuring interlayer adhesion, dimensional stability and reduced residual stress. Consequently, meeting the quality and repeatability criteria for sectors such as aeronautics with high standard demands requires a comprehensive understanding of the underlying thermal phenomena. This study introduces an instrumented 3D printing platform coupled with a thermal model to feed a Digital Twin.

Existing monitoring techniques fail to fully capture the complex thermal gradients during the AM process. To address this limitation, we propose a methodology that integrates an experimental setup with a predictive thermal simulation combining finite difference resolution and using “Kalman Filter”, a white-box algorithm. This approach allows for the real-time reconstruction of the full temperature field within the printed part by combining measurements from an infrared thermal camera, embedded thermocouples, fans speed. These data fusion bridges the gap between the real process physics and the predictive model to achieve a reliable numerical representation of the system.

We demonstrate the capability of a novel moving-window Kalman Filter to correct model deviations in the thermal behavior of a cooled polymer. By reducing the size of the state vector, this method outperforms open-loop simulations and reduces computation time compared with the classical linear Kalman Filter, achieving a Root Mean Square Error of below 3°C between experimental data and simulation results. These results demonstrate our approach potential for precise system in-situ monitoring of the system and provide a foundation for future closed-loop process control and in-situ quality insurance in AM.

#1537

# Reinforcing Element Technology for Complex Composite Structures: A Comparative Study of Solid Modeling Approaches

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Accurate modeling of layered composite structures remains a critical challenge in structural analysis, particularly for geometries where conventional layered solid elements are impractical. This work presents an advanced workflow utilizing reinforcing element technology within Ansys Composite Prep (ACP) to enhance stiffness and strength in solid meshes without requiring mesh alignment to laminate directions. Two representative examples—a bio-inspired T-Joint and a generic jet engine fan blade—demonstrate the versatility of this approach.

The T-Joint case compares reinforcing elements applied to quad-dominant and tetrahedral base meshes against a reference layered solid model. Results indicate that reaction force discrepancies remain below 2%, confirming reinforcing elements as a reliable alternative for thick-walled composites. The second example addresses a fan blade geometry where quad-dominant meshing is infeasible. Here, reinforcing elements combined with imported CAD-based ply definitions enable accurate representation of complex layups. Analyses reveal sensitivity to base mesh type, with quad-dominant meshes providing improved stiffness predictions compared to tetrahedral meshes.

Key advantages of the reinforcing element method include independence from mesh topology, seamless integration with imported plies, and full 3D stiffness contribution to the base solid mesh. These capabilities significantly expand modeling options for aerospace and automotive components where geometric complexity and performance requirements converge. Recommendations for mesh selection and workflow optimization are provided to guide practitioners in adopting this technique for high-fidelity composite simulations.

#1538

# Simulation strategy for liquid hydrogen composite pressure vessel

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The development of liquid hydrogen systems for clean aviation requires a rigorous and systematic approach ensuring structural integrity, safety, and performance under various operational and extreme conditions. However, there is currently no established consensus or standardized building-block framework dedicated to the design of composite pressure vessels for cryogenic applications.

Within the EU Clean Aviation project CONCERTO, new simulation methods and strategies incorporating uncertainty quantification are under development to support future certification by analysis. A liner-less type V composite pressure vessel application is selected to demonstrate how modelling and simulation can be applied to determine onset of leakage under cryogenic conditions. The presentation will provide insights into the overall simulation strategy from small coupon to large structural level to assess material and structural behavior under thermomechanical loading. Inevitable uncertainties due to material variability, manufacturing tolerances and loading conditions as well as related modelling assumptions are considered at different levels of the test pyramid. This shows how modelling and simulation can effectively support design decisions and provides an important step towards future certificatino by analysis.

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#1539

# Bird Strike Resistance of Composite UAV Wing Leading Edges Enabled by Additive Manufacturing

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In the aerospace industry, lightweight components have gained interest in recent years due to their economic and environmental benefits. Additive manufacturing has the potential to manufacture intricate lattice structures and open new possibilities to manufacture light weight components in aviation. This study focuses on the bird strike phenomena on the initial or root section of a UAV wing. It compares the structural response of conventional metallic rib structure with three different infill lattice structures such as BCC, Diamond, and fluorite to optimize the L.E. The innovative approach is adopted to manufacture the wing section by employing the filament of reinforced carbon fibre (carbon fibre, CF/polyamide, PA) as replacement of metallic skin and aluminium alloy infill lattice as replacement of rib structure. This approach reduces significant weight by around 53 % compared to metallic wing configuration and displacement at the bird impact zone by around 36 %. Moreover, the comparison has been made between different infill lattices, and the fluorite lattice exhibits better results. The analysis was conducted through Abaqus dynamic explicit solver and the numerical bird model used in this study has been assessed by experimental-numerical correlations. The results were compared in terms of weight, stress distribution, and impact displacement.

#1545

# Unleashing the Potential of Carbon Black - Polylactic Acid (CB/PLA) 3D Printed Electrodes as Sensing and Energy Platforms

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Commercially available conductive filaments are not designed for electrochemical applications, resulting in 3D printed electrodes with limited exposed conductive surface area and poor electrochemical behavior, restricting their implementation in energy and sensing technologies. The appropriate electrode treatment and/or modification can enhance the electrochemical behavior of conductive filaments, unlocking their capabilities to form 3D printed electrodes with improved performance in various electrochemical applications.

Herein, we explore the impact of electrochemical activation of carbon black/polylactic acid electrodes of different layouts and unlock their potential to function as promising platforms for Zn-ion batteries and sensing applications. Rectangular electrodes made from CB/PLA filament were 3D printed with different layouts (grid and compact) and then activated using a highly reproducible, readily applicable eco-compatible electrochemical (EC) treatment. The electrodes were characterized for their morphological, structural, and electrochemical characteristics through various techniques. Overall, the results indicated strong potential for applications in Zn-ion batteries and electrochemical sensing of a wide range of analytes.

Finally, EC activated CB/PLA 3D-printed electrodes served as sensors for the amperometric determination of hydroquinone in water samples, while their modification with carbon nanofibers enabled their application as Zn-ion batteries in both liquid and solid electrolytes.

The demonstrated dual functionality of CB/PLA electrodes for energy storage and sensing highlights their potential for self-powered wearable electronic applications and paves the way for the development of fully integrated and autonomous sensing devices.

#1547

# Electro-Responsive Stiffness Modulation in an Epoxy-Based Hybrid Composite Reinforced with Polypyrrole-Coated Cotton Textiles

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In this work, we report the development and characterization of a tertiary epoxy-based hybrid composite reinforced with polypyrrole (PPy)-coated cotton textile layers, exhibiting electrically induced and thermally tunable stiffness. The cotton fabric is rendered electrically conductive through a thin PPy coating deposited via oxidative vapor phase polymerization, which enables the formation of a uniform and active conductive layer on individual fibers without adversely affecting their inherent mechanical integrity or flexibility.

Six such functional textile layers are strategically stacked and embedded within an epoxy matrix to fabricate the composite laminate. Electrical characterization reveals a high in-plane volume resistivity (>$10^9$ Ω·cm), indicating insulating behavior along the plane of the laminate, while a significant reduction in resistivity (by approximately three orders of magnitude) is observed across the thickness direction due to the presence of conductive textile layers.

Upon application of an external electrical voltage across the composite, Joule heating is generated within the conductive PPy-coated layers, leading to localized thermal softening of the epoxy matrix, particularly near the fiber–matrix interfacial regions. This thermally induced softening results in a pronounced and controllable reduction in composite stiffness. A nonlinear stiffness modulation of approximately 91% is achieved, with stiffness decreasing from 6371.2 $N \cdot m^{-1}$ at 0 V to 566.4 $N \cdot m^{-1}$ at 63 V.

Furthermore, the composite demonstrates stable and reversible electromechanical performance, as confirmed by cyclic voltage application tests. The stiffness modulation is repeatable over multiple cycles, with up to 95% recovery of the original stiffness after 14 continuous actuation cycles, highlighting the composite's potential for use in adaptive and smart structural applications.

#1549

# Recycled glass fiber from waste solar panel cover glass, for advanced circular economy and economic sense

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Circularity and sustainability are essential issues for the composite, and a glass fiber is also required to contribute to this demand. Regarding the aspect of sustainability, the glass fiber is originally a low environmental impact material, the carbon foot print is lower than other materials. On the other hand, to achieve “Recycled Glass Fiber” which has both a high circularity and economics is the big issue.

The representative initiative is recycling from a composite, which is called the “Closed Loop Recycle”. However, the cost of the separating process is significantly higher than the raw material, thus the current situation is basic research and limited prototype trial.

Therefore, we currently focused on the soda lime glass (likely a bottle, plate and solar panel cover glass), which the initiative’s position is the “Open Loop Recycle”. These glass compositions are different from a glass fiber composition as represented by the E-glass, but the amount of feedstock is relatively abundant, and the cost is reasonable. Also, waste solar panels are expected to be discarded in large quantities all over the world, so it is highly meaningful from the perspective of a circular economy. The most important technical issue is the achievement of a similar property with the E-glass composite, because the mechanical property is lower due to the composition difference.

In this study, we considered the recycle ratio and surface treatment to achieve a similar mechanical property with the E-glass composite by using recycled glass fiber from waste solar panel cover glass. We evaluated PA6 and PBT, and as the result, there occurs a similar property for the 25% recycle ratio by using a specialized surface treatment.

In the full paper and presentation, we introduce the details of the recycle feedstock's situation, manufacturing trial of recycled glass fiber, and evaluation of the composite property.

#1554

# Nonlinear vibration and delamination identification of composite structures considering temperature dependence effect

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Under the coupling effect of high-temperature service environment and complex loads, the synergistic effect of the deterioration of the thermal physical properties of composite materials and interlayer delamination damage significantly intensifies the complexity of the nonlinear vibration behavior of the structure. Meanwhile, the sensitivity characteristics of modal parameters to damage provide a key basis for dynamic response analysis and damage identification. Both jointly affect the operational safety of high-end equipment such as aerospace. Research on nonlinear vibration characteristics, modal parameter responses and delamination damage evolution under temperature coupling is carried out around the composite material laminated plate structure. Based on the classical laminated plate theory, von Karman large deformation theory and Hamilton principle, a dynamic model considering the temperature-dependent effect and layering damage is established. Temperature-related material performance parameters (elastic modulus, Poisson's ratio, interlaminar fracture toughness) are introduced to quantify the modulation mechanism of temperature on the stiffness distribution, energy dissipation and damage evolution of the structure. At the same time, integrate key modal parameters such as natural frequency, damping ratio, modal mode shape and curvature mode, clarify the correlation between each parameter and temperature, delamination damage, and reveal the evolution law of structural dynamic behavior under the combined effect of temperature and delamination damage. The validity of the theoretical model was verified through hammering experiments and finite element simulation. The influences of different temperatures, layering parameters and initial static loads on the nonlinear vibration behavior were analyzed. The research results provide theoretical support and technical reference for nonlinear vibration control and online monitoring of stratified damage of composite material structures in extreme temperature environments, which is of great engineering significance for improving the adaptability of high-end equipment to extreme working conditions.

#1557

# Stress analysis and energy release rate in a single-lap shear joint

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The single-lap shear joint is widely used for the characterisation of adhesion and delamination propagation in composite laminates due to its simplicity, versatility, and relevance to practical bonded structures. By introducing a bonded overlap between composite adherends, the joint, when subjected to tensile loading, generates a combined state of shear and peel stresses within the adhesive layer, closely resembling the stress conditions encountered in real engineering applications. This makes it particularly suitable for assessing interfacial strength, as well as delamination onset and growth under quasi-static or fatigue loading.

A novel closed-form analytical solution for the stress field in a single-lap shear joint is presented, based purely on the principle of minimum complementary energy. In contrast to several analytical solutions proposed in the past, the present formulation precisely satisfies equilibrium, continuity of traction at the interfaces, and zero-traction conditions at free surfaces and delamination crack surfaces. The resulting stress distributions show good agreement with finite element predictions, including the shear stress in the adhesive layer and the peel stress at the adhesive–composite interfaces.

Energy considerations are also applied to the unbonded regions of the adherends, which, depending on the joint parameters, may exhibit geometric nonlinearity when the applied tensile force significantly influences adherend bending. The unbonded adherends are modelled as geometrically nonlinear Timoshenko beams, for which a complementary energy functional is derived to account for shear deformation, which may be significant in composite joints.

Based on the total complementary energy of the joint, the energy release rate associated with the onset and propagation of a delamination crack is evaluated. The effects of joint geometry and loading conditions on the energy release rate are demonstrated.

#1558

# Heating process analysis in ultrasonic welding of thermoplastic composites based on dynamic viscoelasticity and vibration phenomena

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Ultrasonic welding is a friction welding technique using mechanical vibrations and static welding force, enabling fast and energy efficient process for thermoplastic composites. Resin rich feature (Energy Director) is used to concentrate heat generation at the interface through a combination of surface friction and viscoelastic heating. Those heating rates can be described through the equations based on the parameters such as frequency, cyclic strain, elastic and loss moduli of the resin, and friction coefficient. The strain was obtained by the amplitude of vibration, but the real amplitude is lower than the sonotrode amplitude (Hammering effect), which is sensitive to many factors. In addition, these two moduli depend on the temperature, resulting in their variation during the welding process. Previous studies have been conducted to predict the heat generation. However, there are still unclarified factors related to those phenomena. The difficulty in temperature control causes serious issues with non-uniform and unstable welding behavior.

This study focused on the effects of dynamic viscoelasticity and vibration phenomena on the heating process. The temperature dependence of elastic and loss moduli of polyamide 6 (PA6) film was measured using DMA. These moduli at the frequency of vibration were estimated by fitting the master curve. Two types of adherends were prepared; neat PA6 plates and CF woven/PA6 laminates. Those were welded into a single-lap configuration while the temperature at the interface was measured. The welding was conducted repeatedly using the same specimen to evaluate the contribution of surface friction and viscoelastic heating, respectively. On the other hand, the vibration phenomenon of the adherends was measured using a laser displacement sensor to investigate the effect of hammering effect on welding behavior. Finally, the heating process were characterized based on these parameters, and fundamental information was obtained for optimizing ultrasonic welding process.

#1561

# Mechanical property variation after incremental sheet forming of woven fabric reinforced polymer structures

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The conventional mold-dependent manufacturing processes for fiber-reinforced polymers (FRPs) are increasingly challenged by the growing demand for flexible and highly customized production. In this study, a novel method combining the incremental sheet forming (ISF), which act as pre-forming, and vacuum bag curing process is proposed. Prior to preforming, an initially flat multilayer woven prepreg laminate, covered by two dummy sheets on both sides, was prepared. The resulting sandwich panel was then formed into a complex-shaped component using two-point incremental sheet forming (TPIF). After TPIF, the formed prepreg was covered with a vacuum bag together with one of the dummy sheets, which was simultaneously formed during TPIF and subsequently acted as “mold” during the curing process. Finally, vacuum bag curing, with or without an autoclave, was conducted to cure the composite. The porosity, fiber orientation, and three-point bending properties of specimens cut from the cured components were examined to evaluate the influence of the TPIF process on the defects and mechanical properties of the final part. The results indicated that the mechanical properties were significantly affected by the tool diameter, dummy sheet properties, and step-down size used in TPIF. The bending strength and modulus of components formed by the new method reached 98% and 93% of those formed by hand layup. Process-induced cracks and voids on fragile fibers is probably the dominant reason for mechanical property degradation according to the mirco-CT and SEM test results. This study provides insights for future research aimed at developing economical and agile manufacturing solutions for FRP structures.

#1562

# Mechanical Behavior and Failure Mechanisms of 3D-Printed Curved Composite Sandwich Beams with Continuous Carbon Fiber Reinforcement

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Curved composite sandwich beams are widely used in advanced structural applications because of their high strength-to-weight ratio and efficient load transfer along curved paths. However, their mechanical performance is often limited by complex stress states—especially interlaminar and radial stresses—which can cause premature failures such as delamination and local buckling. With recent advances in additive manufacturing, particularly 3D printing with continuous carbon fibers, it is now possible to produce curved sandwich beams with customized and asymmetric reinforcement, offering new ways to improve their performance.

This study investigates how geometry and reinforcement asymmetry affect the mechanical behavior of 3D-printed curved sandwich beams with continuous carbon fiber reinforcement. Two curvature ratios were considered, representing moderate and highly curved shapes. For each geometry, three types of beams were fabricated: one made only of thermoplastic, one with symmetric fiber reinforcement, and one with asymmetric fiber reinforcement.

Mechanical tests combined tension and bending in a curved beam setup. Full-field strain was measured using 3D Digital Image Correlation, while Finite Element Analysis was used to support the experiments and to study stress concentrations at the core–face-sheet interface.

The results show that carbon fiber reinforcement significantly increases stiffness, but in beams with a smaller radius, it can actually reduce the maximum load due to higher radial tensile stresses at the interface. Asymmetric reinforcement helps delay compressive buckling and increases failure loads in beams with a larger radius, while delamination remains the main failure mode in beams with tighter curves. Overall, the study highlights the importance of both geometry and reinforcement layout in optimizing the mechanical performance of 3D-printed curved sandwich beams.

#1564

# Experimental Evaluation of Fiber-Orientation Anisotropy on Flow and Mechanical Behavior in Discontinuous Long Carbon Fiber Thermoplastic Composites

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This study experimentally investigates the effects of fiber-orientation anisotropy on the mechanical properties and material flow behavior of discontinuous long carbon fiber (DLCF) thermoplastic composites, focusing on chopped-tape materials manufactured by press molding.

Two laminate designs were intentionally designed, fabricated, and evaluated in this experiment. First, to examine the difference between anisotropic and quasi-isotropic orientation states, random-orientation laminates were designed by varying the in-plane orientation range, resulting in different degrees of anisotropy within the specimen plane. Second, to evaluate the influence of orientation-angle composition, random laminates were designed using simplified stepwise angle sets, in contrast to conventional full-angle random laminations. Each tape was placed individually at programmed in-plane coordinates and orientation angles using an automated tape-placement system. All laminates were subsequently press-molded and cut into specimens for mechanical and flow evaluations. Material flow behavior was evaluated by planar compression flow tests, and apparent viscosity was calculated under identical press-molding conditions. Mechanical properties and specimen-to-specimen variability were evaluated by tensile testing. Fiber-orientation distributions were quantitatively characterized using statistical orientation indices. Internal structures were examined using X-ray CT and X-ray phase-contrast imaging.

The experiments led to the following findings. Anisotropic laminates exhibited unstable flow behavior and higher apparent viscosity, indicating increased fiber resistance to flow and greater variation in mechanical properties. In contrast, quasi-isotropic laminates showed stable flow behavior, reduced variability, and improved isotropy in tensile properties. Furthermore, random laminates designed using a limited number of predefined orientation angles, specifically a quasi-isotropic four-angle configuration, exhibited mechanical and flow properties comparable to those of laminates with full-angle random orientation.

These results demonstrate that fiber-orientation design directly controls both material flow behavior and mechanical properties in DLCF thermoplastic composites, and suggest that the orientation components governing these behaviors in tape-laminated structures can be clearly identified.

#1565

# Preparation of polymer-based composite scaffolds functionalized with titanium dioxide nanoparticles for water remediation.

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3D-printing is one of the most promising frontiers in sustainable additive manufacturing, as it allows renewable polymer-based composite materials to be integrated with advanced manufacturing technologies to produce functional, customizable, and biodegradable components. At the same time, per- and polyfluoroalkyl substances (PFAS) and polycyclic aromatic hydrocarbons (PAHs) are currently two of the main classes of emerging contaminants in drinking water, subject to increasing regulatory and health attention at European and global level, as they are characterized by high environmental persistence, bioaccumulation, and chronic toxicity.

In this work biopolymer composite scaffolds based on polylactic acid (PLA) using additive manufacturing techniques, subsequently functionalized with titanium dioxide ($TiO_2$) nanocrystals were developed. The latter were obtained through a controlled synthesis based on the thermal decomposition of precursors in coordinating solvents, a methodology that allows to produce nanostructures with restricted dimensional distribution, high crystallinity, good solubility in the most common organic solvents, and versatility in surface modification through the replacement of ligand molecules.

In particular, the Fast Hydrolysis Method was used to synthesize nanorods $TiO_2$ nanocrystals with anatase crystal phase, confirmed by XRD (X-ray Diffraction) analysis. The PLA scaffolds were then functionalized by dip-coating with these nanorods and tested on a laboratory scale using methylene blue as organic contaminant model and UV irradiation as photocatalytic activation source.

After approximately two hours of treatment, complete degradation of methylene blue was observed in systems containing the functionalized scaffolds under UV irradiation, while no significant degradation was found in the control system without scaffolds.

The preliminary results obtained on a small scale indicate promising photocatalytic efficiency of the PLA/$TiO_2$ composite system and will be followed by pilot plant tests to validate its scalability and industrial applicability in the treatment of water contaminated with persistent organic compounds.

#1567

# Effect of Automated Fiber Placement Gap Defects on Mode II Interlaminar Fracture Toughness and Crack Propagation in Carbon/Epoxy Laminates

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Gaps are among the most frequently observed defects in automated fiber placement (AFP) deposition and can promote resin-rich pockets, local fiber waviness, and voids in the cured laminate. Although the effects of gaps on mechanical performance (e.g., tensile, compressive, and open-hole properties) have been investigated extensively, their influence on Mode II interlaminar fracture toughness, which is critical for shear-driven delamination that governs the residual strength and durability of many aircraft components, remains scarcely reported.

In this work, the effects of AFP gaps on the Mode II interlaminar fracture behaviour of laminates are systematically investigated. End-notched flexure (ENF) tests were conducted to quantify Mode II interlaminar fracture toughness for different defect configurations, i.e., 0/0, 45/0, and 90/0 interfaces with gap sizes ranging from 0 to 3.75 mm. A quasi-isotropic layup, $[0/-45/90/+45]_3S$, was first evaluated; however, stable propagation along the target interface, where the gaps were embedded, could not be consistently maintained. Therefore, a crack-path-controlled layup, $[0_{11}/\theta/0/0_{11}]$, was adopted. Load-displacement responses and crack evolution were recorded, and a side-view imaging system was employed to track crack-tip evolution and to capture crack-defect interactions as the front entered the defect zone.

The results exhibit good repeatability and demonstrate that the layup sequence exerts a pronounced influence on Mode II crack propagation. The findings indicate that gap orientation activates distinct crack-growth mechanisms, while gap size governs the magnitude of these effects in an orientation-dependent manner. This work elucidates the mechanisms by which AFP gap defects alter Mode II interlaminar fracture toughness and provides a basis for reducing over-conservatism in quality decisions and for supporting risk-informed tolerance definition in AFP laminates.

#1568

# A Process-Structure Integrated Simulation Framework for Automated Fiber Placement of Complex Composite Structures

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Automated Fiber Placement (AFP) has been widely used to manufacture complex composite components, including empennage panels, inlet ducts, and other aeronautical structures, etc. For such components, the AFP process involves strong interactions among geometric features, path planning, and structural performance. Process-induced deviations, such as fiber angle errors and gap/overlap defects, are often unavoidable. However, in practice, path planning and performance evaluation are typically conducted in isolation, i.e. path planning focuses on balancing competing objectives (e.g., minimizing angle deviation and limiting gap/overlap) without explicitly assessing structural consequences, whereas performance analyses often do not incorporate the as-deposited state as input. This largely limits the effectiveness of AFP process design and optimization.

This work presents an automated framework to transfer tow-level AFP path information into finite element (FE) models. In the framework, the as-manufactured path state is mapped onto the FE mesh, with explicit fiber orientations and process-relevant material information introduced via Digimat CN - Abaqus coupling. Representative operational loading conditions are then applied. Hence, the resulting FE models explicitly capture process-induced fiber orientation fields and gap/overlap distributions, enabling structural performance evaluation based on the as-deposited state. A representative doubly curved component is used as a demonstrator. Multiple path-planning strategies and parameter sets are examined, and stiffness metrics and stress distributions are used to perform performance-informed comparisons among candidate solutions. The framework holds the promise to establish a continuous AFP process simulation chain - from path planning and manufacturability assessment to structural performance prediction - supporting the further digitalization of AFP process design and a more comprehesive multi-objective optimization for complex composite components.

#1573

# The Single Lap Joints (SLJ) with laminated composite adherends under buckling load

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Adhesively bonded SLJs under tensile loads are being investigated extensively by numerous researchers, yet their mechanical behaviour under compressive (buckling) loading remains unknown, especially the case for the joints with laminated composite adherends. Previous investigations show that some aircraft components such as fuselage splice, stringer-stiffener and wing spur experience buckling loading, which implies the same for the SLJs. This study aims to investigate the SLJs with glass fibre reinforced epoxy matrix adherends under compressive (buckling) loading and give an insight into their mechanical behaviour. The specimens with a 25 mm of overlap length, and 0.2 mm adhesive layer and 2.2 mm adherends thickness, respectively, were bonded using an film adhesive, AF-163-2K. It was observed that failure mechanisms of the joints was totally different from those under the tensile loading. Unlike the tensile case, the adhesive layer at the ends of the bonded region remained in compression, so peeling effects caused by the eccentricity of the compressive loading were not the case for the layer. On the other hand, especially one end of the unloaded adherend connected to the stationary part of the tensile machine's jaw exposed to peeling effects leading to delamination of laminates in the out of plane direction. The experimental results showed that the joints strength diminished substantially, about 1.5 kN, but displacements to failure increased considerably, about 10 mm. These results for the tensile case were about 16 kN and 1.6 mm, respectively. The experimental results from the buckling (compressive) mode were related to the adherend thickness. The results show that these joints could be considered for the crashworthiness cases as they have a high energy absorption capability. The joint was also analysed numerically to see stress distributions and critical points, which validated the experimental observations.

#1576

# Preparation and characterisation of poliamide composite materials filled with recycled short carbon fibres for 3D printing application

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Carbon fibre reinforced polymers (CFRPs) have become essential in various industrial fields, particularly in aerospace, automotive, and sports applications, thanks to their exceptional strength-to-weight ratio and durability. However, to date, most carbon fibre composite materials are neither recycled nor reused, and their primary end-of-life destination remains landfill. In this context, the use of recycled carbon fibre (rCF) obtained from CFRP waste represents a promising solution. The adoption of rCF not only reduces the environmental impact associated with waste management but also avoids the high energy consumption required for the production of virgin carbon fibre, thereby improving the overall sustainability of the composite materials' life cycle.

Recycled carbon fibres are highly effective as reinforcements in thermoplastic polymer matrices, such as polyamide 12, which was used in this study, resulting in composites with enhanced mechanical properties compared to the virgin matrix material. Four families of polyamide 12–based composites with different carbon fibre weight fractions (0%, 10%, 20%, and 30%) were produced by twin screw extrusion. Standard dumbbell specimens were subsequently manufactured via injection moulding and fused granule fabrication to perform mechanical and thermo-mechanical characterisation tests.

The processing parameters were optimised to improve the mechanical and thermal performance of the composites, and the results were benchmarked against those of the unfilled virgin material. Overall, the findings demonstrate the successful upcycling of recycled carbon fibres as structural fillers in polymer matrix composites, contributing to the development of sustainable solutions within a circular economy framework.

#1577

# 「Ultra-Fast Manufacturing of High-Pressure Hydrogen Tanks Using REDOX-Curing RTM and Non-FW Preforms

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In this study, we demonstrated a production rate of 5 minutes per line in the fabrication of a demonstration tank using a two-stage impregnation synthesis method with a tow prepreg made of REDOX-curing resin and a low-pressure RTM process.

To address the future expansion of fuel cell vehicles, our goal is to realize a high-pressure hydrogen tank that achieves both high productivity and reduced carbon fiber usage. For this purpose, we developed an innovative high-rate manufacturing process based on a non-FW (filament winding) / separate preform structure combined with low-pressure RTM.

We first established high-speed manufacturing technology for thermoplastic tow prepregs by developing an innovative REDOX-curable resin and new tape-impregnation equipment. The in-situ polymerization formulation using a monofunctional acrylic monomer enabled ultra-fast tape production.

Using these tapes, we developed a method for manufacturing split preforms for the dome and cylinder sections, and validated the non-FW / separate preform configuration through a demonstration tank prototype.

Unlike conventional FW processes, this approach separately manufactures dome and cylinder preforms using tow tapes and integrates them via RTM. Because the tow tape is a thermoplastic tow prepreg in which polymerization is already completed, no curing is required. Only a small amount of resin is injected into the gaps between tapes, allowing the RTM process to be completed in a very short time even under low pressure. By employing the newly developed REDOX-curing resin, high-rate tank manufacturing was achieved.

This paper presents a prototype validation of ultra-fast tank manufacturing using a two-step impregnation molding method with low-pressure RTM and REDOX-curing resin, demonstrating that a production rate of 5 minutes per line was successfully achieved.

#1580

# Sustainable Jute, Coarse Sheep Wool and GGBFS Reinforced Epoxy Composites: Fabrication via VARTM and Performance Evaluation

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The transition toward circular economic models in the materials science sector requires the strategic use of agro-industrial waste for high-performance structural applications. This study aims to develop a novel bio-derived hybrid composite by mixing plant-based jute fiber and bio-derived coarse sheep wool fiber. To improve the tribomechanical properties, a functional ceramic filler, ground granulated blast furnace slag (GGBFS), is added to the epoxy matrix. The results showed that the hybridization strategy yielded a significant "pseudo-ductile" effect, with the jute/wool synergy delivering a 30% enhancement in tensile and impact strength. The adoption of vacuum-assisted resin transfer molding (VARTM) proved transformative, as tensile and flexural strengths surged by 177% and 145%, respectively, compared to the hand lay-up method, validating the necessity of pressure-assisted consolidation for natural fiber hybrid composites. The incorporation of GGBFS (optimal at 10 wt.%) further enhanced the matrix hardness by 14.45% and reduced the specific wear rate under air-jet erosion, governed by effective filler-assisted crack deflection mechanisms. Also, the ceramic nature of the slag filler addressed the flammability limitations of natural fibers. The GGBFS acted as a thermal barrier, delaying ignition and promoting char formation, which contributed to the claimed fire safety. Simultaneously, water absorption was reduced by 22–26%, thereby mitigating moisture-induced degradation. This research confirms that hybridizing diverse waste streams, including animal wool, bast fibers, and industrial slag, via VARTM yields a robust material system. The developed composites offer a balanced combination of mechanical stiffness, erosion durability, and flame retardancy, positioning them as viable candidates for semi-structural applications in automotive interiors, rail panels, and sustainable construction.

#1581

# Experimental and Numerical Analysis of L-Flange Joints in Large Sandwich Composite Structures

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Composite materials are increasingly employed in large-scale structures owing to their high specific stiffness and strength, superior impact and fatigue performance, and excellent weight efficiency. In particular, sandwich composite structures composed of thin face sheets and lightweight cores provide high bending stiffness and enhanced damage tolerance, and are therefore widely adopted in aerospace, marine, and wind energy applications. As structural dimensions increase, spatial constraints and high production costs limit monolithic manufacturing, making assembly-based structural design inevitable.

In large composite structures, joining strategies are commonly implemented through a complementary combination of adhesively bonded joints and mechanically fastened joints, considering load transfer characteristics, manufacturing and assembly processes, and maintenance requirements. Adhesively bonded joints enable continuous load transfer and reduce stress concentrations, whereas mechanically fastened joints enhance structural reliability by allowing inspection, disassembly, and repair, and by accommodating manufacturing and operational uncertainties.

This study investigates the structural behavior and strength characteristics of L-flange joints applied to large sandwich composite structures. Experimental and numerical analyses were conducted focusing on key design parameters, including the core geometry in the L-flange region and the stacking sequence of the reinforcing flange laminate. Quasi-static tensile tests were performed to evaluate joint strength, load transfer behavior, and failure modes.

Finite element analysis (FEA) was carried out using three-dimensional solid elements to model composite plies and core materials, enabling accurate representation of through-thickness stress distributions. Interlaminar stresses, shear stresses in the adhesive layer and core, and ply-level fiber and matrix failure indices were extracted to evaluate damage initiation and dominant failure mechanisms. Numerical results were compared with experimental observations to validate the finite element model and assess the influence of key design parameters on joint behavior and strength. The findings provide design guidelines for improving the structural performance and reliability of L-flange joints in large sandwich composite structures.

#1584

# Mechanical properties of thick laminates using multiple different epoxy resin systems

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The manufacturing challenges for composite parts increase with thickness. Standard cure cycles for thin laminates often lead to significant temperature overshoots and uneven curing across the part's thickness, which can negatively impact the final product's mechanical properties. Various techniques have been proposed to mitigate temperature overshoots, including cooling the laminate during curing, using low-exotherm resin systems, or incorporating thermally conductive particles into the resin. Additionally, cure cycles can be optimized using simulations and genetic algorithms.

This study experimentally explores a novel approach to reduce temperature and cure degree gradients within thick laminates: varying the accelerator concentration in the inner and outer layers of the laminate. In FEM-simulation this approach can reduce cure degree gradients within the laminate by up to 50% or reduce the cure time by up to 25% for comparable cure degree gradients.

Three 100 mm thick glass fiber-reinforced epoxy laminates were cured in a hot press with simulation-optimized cure cycles that minimize cure time, temperature gradients, and cure degree gradients For comparison a fourth laminate is manufactured according to the cure agents` data sheet. The laminates were then tested for their tensile, compression, and interlaminar shear properties. Test specimen were cut from four different layers with different distances from the laminates center. The results show that a reduction of the cure degree gradient increases the average tensile modulus as well as the average compressive and interlaminar shear strength of the laminate while the average tensile strength is mostly unaffected. Property gradients within the laminate are also reduced. Laminates manufactured with one and two accelerator concentrations and a similar cure degree gradient result in laminates with comparable properties. Manufacturing thick laminates with different accelerator concentrations in thickness direction offers new possibilities to reduce process times and improve part quality.

#1585

# Prediction of the stiffness loss in woven composites in the presence of transverse bundle cracks due to cyclic loadings

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The first observable damage event in woven composites subjected to cyclic loadings is the formation of cracks in bundles oriented off-axis with respect to the load. In particular, the number of cracks—and thus the so-called crack density—increases with the number of cycles, leading to a loss of stiffness.

In this work, two possible innovative approaches are proposed for estimating the apparent elastic properties of cracked woven composites. Both approaches combine a homogenization model based on the Mori–Tanaka theory with a shear-lag analysis, commonly used for unidirectional composites.

The first model, referred to as the Equivalent Cross-Ply (ECP) model, consists of two steps: the shear-lag analysis of an equivalent cross-ply laminate to obtain the properties of the damaged bundle, followed by their use in the homogenization model. The second approach, referred to as the Modified Shear-Lag (MSL) model, directly integrates Mori–Tanaka theory into the shear-lag formulation, allowing the apparent elastic properties of the woven composite, as well as the (albeit approximate) stress fields, to be obtained directly.

The models are validated through 3D numerical simulations and experimental data on fabrics with different architectures tested under cyclic loadings. For both approaches, very good agreement is achieved, demonstrating the capability of the models to predict the stiffness degradation due to crack formation, while also accounting for meso-structural features such as bundle waviness and shape.

#1586

# Innovative analysis of fatigue damage evolution and stiffness loss in structural composite components

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Fatigue failure and in-service loss of stiffness of composite parts are due to a multi-mechanisms damage evolution which mainly includes cracks, delamination and fibre failures. A comprehensive framework for the fatigue design of composite parts, based on the actual physics of damage evolution, was recently developed by the authors. The initiation and growth of each mechanism, the interaction with the others and the effects on the strength and stiffness of the parts are described by suitable and experimentally validated models. All these models were integrated into a single design framework, the Rescomp FLA software, a significant step forward with respect to the design tools available on the market resulting in an enormous increase in the safety and reliability of the structural applications made with composite materials.

The paper illustrates the path for the application and validation of the framework on the prediction of the fatigue response (stiffness loss and final failure) of an automotive component: the front wing pillar of a Formula car. In-service loading conditions were first simulated by the integration of Ansys® and FLA® software, producing damage patterns and stiffness trends over the fatigue life. Then a dedicated test setup was designed and great attention was devoted to the possibility of monitoring the damage evolution via a backlight setup. Fatigue tests were eventually carried out on a glass/epoxy pillar and the results, in terms of damage patterns and stiffness loss at specific fraction of life, were compared with those obtained from the simulations. A very satisfactory agreement was found, highlighting the capability of the developed tool to boost both the performance and the safety of composite parts in the design phase, reducing also the costs usually associated with the extensive experimental campaign needed to validate traditional models.

#1587

# Effect of defects on fatigue crack initiation in carbon/epoxy laminates

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Structural composite components often contain manufacturing-induced voids, which are particularly detrimental to their mechanical performance. A predictive methodology for fatigue crack initiation in porous laminates was developed by the authors and validated on glass/epoxy laminates containing uniformly distributed voids. Fatigue tests were recently carried out on carbon/epoxy laminates containing artificial defects simulating voids. S–N curves for the initiation of the first cracks were obtained for two different defect sizes. The objective of this work is to extend and validate the proposed predictive methodology to the new experimental data, showing its capability of addressing a more general defect condition.

The previously developed methodology, based on the Finite Element analysis of micro-scale material RVEs containing voids [1], was suitably modified to account for the specific features of carbon/epoxy laminates – namely fiber material orthotropy, thermal stresses due to manufacturing, and the presence of a single defect with dimensions comparable to the ply thickness. In particular, the RVE geometry and the boundary conditions adopted in the finite element analyses were revised. In addition, a modification in the calculation of the local stress parameter proposed to drive the fatigue crack initiation (i.e.: the average Local Hydrostatic Stress in a control volume of the matrix – LHS* [1]) is proposed.

When expressed in terms of LHS*, the S–N curves for crack initiation corresponding to different defect sizes fall within a single scatter band. The results highlight the capability of the methodology to predict fatigue crack initiation in conditions different from those considered in its original validation, including orthotropic fibres, thermal stresses and isolated defects, highlighting the potentiality of the tool to assist no-damage or damage tolerant (stiffness-driven) design of structural composite parts.

[1] Maragoni L, Carraro PA, Quaresimin M. Prediction of fatigue life to crack initiation in unidirectional plies containing voids. Composites Part A 2019;126:105638

#1588

# Tailoring Energy Absorption in Honeycomb Sandwich Panels via Additive Manufacturing-Enabled Density Grading

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Honeycomb core sandwich structures are widely recognized for their high specific energy absorption, high stiffness-to-weight ratio, and efficient load distribution capabilities, making them a preferred solution in lightweight structural applications. Due to their cellular architecture, honeycomb cores enable significant weight reduction while maintaining structural integrity, which is advantageous in structures that will be exposed to crushing and impact. The mechanical performance of honeycomb cores can be further tailored through density grading, allowing controlled deformation and enhanced energy absorption under bending loads. Recent advancements in additive manufacturing have enabled the fabrication of complex, density-graded honeycomb architectures that are difficult or impractical to produce using conventional manufacturing techniques. In this study, honeycomb sandwich cores with continuous density-grades will be designed using CATIA and manufactured using fused filament fabrication (FFF). Moreover, the samples will be experimentally and numerically investigated to evaluate their energy absorption behavior. Density-graded design will be achieved with core thickness variations along both in-plane axes. Five density-grading strategies—linear increase, linear decrease, linear increase followed by decrease, linear decrease followed by increase, and linear increase–pause–decrease—will be examined and compared with a uniform-density reference configuration. The designed honeycomb cores will be fabricated with PLA filament, demonstrating the capability of FFF to produce multi-layer density-graded cellular structures with high geometric flexibility. Finite element analyses will be performed under three-point bending loading conditions to obtain flexural beam responses and energy absorption characteristics. Experimental three-point bending tests will be conducted to validate the numerical models and assess the influence of density grading on flexural performance. The results would reflect on the ability of density distribution and core thickness variation to affect the flexural response and energy absorption capacity of honeycomb sandwich panels, highlighting the effectiveness of additive manufacturing–enabled density grading for the development of lightweight, energy-efficient aerospace structures.

#1594

# Toward a circular economy for Hydrogen storage

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The development of sustainable composite structures requires both recyclable matrix systems and effective strategies for reusing high-value carbon fibres. This study presents a closed-loop manufacturing approach that combines continuous carbon fibre recovery from filament-wound composites with robotic GRAM® wet filament winding. A recyclable thermosetting resin (EzCiclo®, Swancor) is benchmarked against a conventional Araldite epoxy, with emphasis on structural performance, interfacial behaviour, and industrial applicability.

Continuous carbon fibres were recovered while preserving fibre length and subsequently reused to manufacture composite tubes via robotic GRAM® filament winding. Fibre quality and surface condition were characterised using scanning electron microscopy (SEM) and X-ray photoelectron spectroscopy (XPS), confirming effective matrix removal and preserved fibre morphology, albeit with partial loss of surface hydroxyl groups. Thermogravimetric analysis demonstrated retained thermal stability, with approximately 5 wt.% mass loss occurring around 625 °C under oxidative conditions.

Mechanical performance was evaluated through single-fibre pull-out and split-disk tests. Recycled fibre composites exhibited a 17–25% reduction in hoop strength compared to virgin systems, primarily due to reduced interfacial adhesion and minor surface damage induced during recovery. Compared to epoxy, the EzCiclo® resin showed more progressive interfacial debonding and higher energy dissipation, indicating enhanced damage tolerance and potential advantages for crash-relevant applications. Cross-sectional observations further revealed improved fibre spreading and resin impregnation, highlighting the capability of the GRAM® process to produce structurally relevant components using recycled materials.

Overall, the results demonstrate the feasibility of producing high-performance composite structures from recovered continuous fibres and recyclable resins. This work provides experimental benchmarks supporting circular composite manufacturing routes and identifies key levers, including interfacial refunctionalisation and process optimisation, for enhancing mechanical performance. The approach shows promise for lightweight industrial and automotive applications, enabling structural performance while advancing circularity and sustainability in composite systems.

#1600

# A parametric diffusion-deformation study for polymers used in the hydrogen transport infrastructure

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Hydrogen in its gaseous form is emerging as an important energy carrier within the energy supply sector, particularly in applications such as transportation and energy storage, with the aim of promoting decarbonization of fuels and reducing greenhouse gas emissions. It presents a promising power-to-gas solution for effectively utilizing the intermittent electricity generation associated with renewable sources. However, hydrogen transport remains a challenging endeavor, as potential leakage in the hydrogen pipelines could have detrimental effects due to the gas's flammability. Therefore, ensuring secure and reliable hydrogen transport is essential, beginning with verifying that the selected materials exhibit appropriate behaviour. Metals have been extensively investigated in the past, however one main drawback for some metals is their susceptibility to hydrogen-induced embrittlement. Polymers, unlike metals, are generally chemically inert to hydrogen, which renders them interesting alternative materials for such applications. Nevertheless, while permeation still occurs throughout the polymers' structure, the most critical reliability concern is Rapid Gas Decompression damage, which requires further investigation. In this study, the barrier performance and the mechanical behaviour of multiple polymers with or without fillers are examined as they undergo a full cycle of pressurization in a pressurized hydrogen gas environment, followed by rapid depressurization. The aforementioned are analyzed through the lens of a parametric coupled diffusion-deformation model, developed and validated using experimental data and implemented in the commercial finite element software ABAQUS using a Representative Volume Element. A material property degradation method is also incorporated to account for post-failure behaviour of damaged materials. The effects of hydrogen diffusivity, applied hydrogen pressure and depressurization rate on saturation time and damage initiation are studied.

#1604

# A Preliminary Thermo-Mechanical Analysis of LH2 Tank Elements Health Status Under Biaxial Load in Cryogenic Condition

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This study is part of the H2ELIOS project within the Clean Aviation Programme. The final goal is to manufacture and test a demonstrator of a liquid hydrogen tank for aviation, with a representative storage capacity, aimed at demonstrating an innovative hydrogen storage approach. The walls of this kind of tanks experience biaxial loading caused by internal pressure, in turn able to suffer multidirectional cracking due to the material's anisotropy. The presence of these cracks can plays a remarkable impact both in terms of load-bearing capacity and leakage resistance of the tank structure. For this reason an integrated monitoring system must be considered as a necessary tool for safety and reliability purposes. The experimental campaign presented in this paper, is an intermediate stage of analysis and focuses on the thermo-mechanical test of a cruciform element and intends to estimate the functionality and sensitivity of the SHM system accounting for biaxial stress conditions and cryogenic thermal residual stresses. The monitoring of static and cyclic response at cryogenic temperature is entrusted by fiber optic sensors bonded on the surface of the specimens and optical based acoustic emission sensors. Data are then processed by an algorithm based on cross-correlation in time and space domain. The effects of temperature environment over the mechanical load is analyzed and possible system faults are monitored to estimate the grade of sensitivity of the system. This work offers an empirical foundation for improving the mechanical performance and leakage resistance toward the final target of the composite cryogenic storage systems.

#1605

# Robotic Processing of Reclaimed Timber

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Robotic processing of reclaimed timber is complicated by severe surface irregularities, variable local stiffness, and heterogeneous contamination such as cement, paint, and embedded grit, which make it difficult to maintain a safe and effective contact force with conventional rigid tools or pad-only compliance. This study shows the design and initial evaluation of a compact spring-based passive compliant end-effector suited for sanding and wire-brushing operations on recovered boards. The mechanism sets a linear compression spring directly between the robot flange and a DC-motor-driven tool, with the motor–tool weight providing the nominal machining force while the spring accommodates normal-direction position inaccuracies and attenuates impact loads. An mathematical model combines robot displacement, spring compression, and normal contact force, showing that common surface variances lead to modest force changes that successfully mimic constant-force behavior without sensors or closed-loop control. The architecture further works as a mechanical buffer that decreases vibration and stress transferred to the robot joints when the tool encounters fast height changes or hard inclusions, and a limit switch at the conclusion of the stroke provides a simple fail-safe against overload. The study explains the design reasoning, modelling, and experimental setup on polluted, uneven lumber samples and highlights how such passive compliant end-effectors can constitute a low-cost, durable base for scalable robotic reclamation procedures.

#1607

# Optimization of variable-angle tow slender structures in the post-buckling regime using gradient-based method and an implicitly differentiated reduced-order model

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Composite shell structures enable highly efficient lightweight designs. In particular, variable-angle tow (VAT) composites offer enhanced design freedom by allowing spatial variation of fibre orientations to locally tailor stiffness and load-carrying capability. These advantages, however, are often accompanied by increased susceptibility to geometrically nonlinear behaviour due to the high slenderness ratios typically associated with composite shells. As a consequence, post-buckling response becomes a critical aspect in the assessment of both structural performance and safety.

In the post-buckling regime, the response of VAT composite shells can be highly complex, involving multiple equilibrium branches and strong mode interactions. Small geometric, material, or loading imperfections may significantly influence post-buckling behaviour by directing the structure toward specific equilibrium paths. Imperfection sensitivity analyses are therefore essential to fully exploit the material tailoring potential of VAT laminates while ensuring safe and robust designs. This highlights the need for efficient post-buckling analysis tools that can be consistently integrated within optimisation frameworks for composite materials.

Reduced-order models (ROMs) based on finite element implementations of Koiter's theory provide an efficient and accurate framework for post-buckling analysis of composite shells. ROMs derived for the perfect structure remain valid when imperfections are introduced a posteriori, enabling efficient imperfection-sensitive analyses. Despite their maturity, however, the integration of Koiter-based ROMs within gradient-based optimisation frameworks remains limited by the lack of exact analytical derivatives with respect to high-dimensional material and structural design variables.

This work addresses this limitation by proposing an implicit algorithmic differentiation scheme for Koiter-based ROMs, enabling the exact evaluation of analytical gradients. The approach is applied to the gradient-based post-buckling optimisation of slender composite shells with VAT laminates. Numerical results demonstrate that the proposed analytical gradients significantly outperform finite-difference-based derivatives in terms of robustness and computational efficiency, making the method well suited for high-dimensional VAT composite material optimisation.

#1609

# Sustainability-Based Design Optimization of a Cruise Missile Canister

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Historically, aerospace and defense structures have been designed to maximize performance and minimize cost, with limited consideration of environmental and societal impacts. However, limited resources, and global sustainability targets have changed design priorities immensely. In recent years, sustainability has emerged as a critical design criterion along with traditional metrics, particularly for composite materials.

Fiber-reinforced polymer composites offer significant advantages in terms of weight reduction and structural efficiency, contributing to lower fuel consumption and improved operational performance. Despite these benefits, they have energy-intensive manufacturing processes, and limited end-of-life recycling options. Thus, sustainable composite design requires a holistic approach that addresses material selection, manufacturing, structural optimization, environmental and social impacts throughout the product life cycle.

This study proposes an integrated sustainability-driven design and assessment framework for composite structures, demonstrated through a representative aerospace defense case study involving a cruise missile canister component. A component traditionally manufactured from aluminum is re-designed using both virgin and recycled composite material systems, and optimized to increase its sustainability performance rather than focusing solely on its mechanical efficiency.

In this study, structural behavior and performance constraints are evaluated using finite element modeling, while geometric optimization is conducted through Design of Experiments and Response Surface Methodology to efficiently explore the design space. Various design alternatives are systematically compared using a sustainability index, which is calculated using five normalized parameters: mechanical performance, cost, energy consumption, social impact, and circularity. To integrate these parameters into the sustainability index calculation, and to compare and rank the design alternatives, Multi-Criteria Decision-Making methods are used.

The study aims to highlight how optimal design solutions change depending on strategic sustainability objectives. The preliminary results demonstrate the potential of recycled composite materials combined with sustainability-based design optimization for future aerospace and defense applications.

#1610

# Processing Concepts for Incorporating Thermally Sensitive Ceramic Polymorphs into Eurofer Steel by Cold Spray

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Low-temperature processing routes enabling controlled microstructural design are of increasing interest for advanced composite ceramic–metallic systems. In this contribution, the cold spray technique is explored as a solid-state deposition approach for Eurofer steel modified with ceramic additions whose crystal structures can exist in multiple polymorphic forms, such as $SiO_2$ and $TiO_2$. Preservation of these low-temperature polymorphs during processing represents a key challenge, as conventional high-temperature consolidation routes often induce phase transformations that fundamentally alter the intended microstructural and functional characteristics.

The study focuses on the overall processing concept and experimental strategy for combining Eurofer powders with ceramic particles and depositing them under conditions designed to minimize thermal exposure. Cold spray offers a unique processing window in which particle bonding is achieved predominantly through severe plastic deformation rather than melting, making it particularly attractive for the incorporation of ceramic phases that are sensitive to temperature-driven transformations. Emphasis is placed on powder preparation routes, including the selection of ceramic polymorphs, their synthesis, particle size considerations, and mixing strategies, as well as on the identification of deposition parameters that promote effective embedding of ceramic particles within the metallic matrix.

Rather than reporting finalized material properties, the contribution critically discusses the challenges associated with maintaining phase stability, achieving homogeneous dispersion, and controlling interfacial characteristics in Eurofer–ceramic systems processed by cold spray. The expected implications of these factors for microstructural development, including the potential formation of bimodal or composite steel concepts, are outlined. Overall, the work highlights cold spray as a promising low-temperature fabrication route for Eurofer-based composite materials and provides a framework for future studies aimed at tailoring microstructures while preserving metastable or low-temperature ceramic phases.

#1613

# Biopolymer composites reinforced with fruit pits, an ecological alternative for tribology

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A novel attempt concerning materials selection for plain bearings (sliding bearings) made of biodegradable polymeric materials has been studied. The major advantage, is that the products of wear abrasion of plain bushing surface will not pollute the envirenment. Moreover, applied agricultural wastes (like fruit pits) as an organical fillers may substantially reduce coefficient of friction due to presence the residual fatty acids. In the presented work the agricultural wastes like cherry pits and plum pits were combined with biopolymer poly(lactide acid) PLA and the bioplastic polyamide 11 (PA 11). At the first stage the shells were pulverized to a powders by using a high speed grinder and then subjected to separation into different grade fractions: 0-200 µm, 200-400 µm; 400-630 µm. Composites with 15% by weight of cherry/plum powders and grades of Ingeo biopolymer PLA 2500 HP and Rilsan Polyamide 11 were melt mixed via co-rotating twin screw extruder. Final samples for tribological tests in the form of plain bearings were injection overmolded on a bearing hub placed into the injection cavity. A plain bearings with sliding bushing surface made of biopolymers reinforced with pulverised cherry/plum pits were subjected to tribological tests, under dry friction conditions. Tests were carried out with the application of the “block-on-ring” system (metallic block used as a counter-surface was made of AISI 1045 steel). The frictional behaviour was analysed on the basis of the measured values for the friction torque and the CoF (coefficion of friction). During the test, the surface temperature of sliding bushing has been registered. The most signifficant reduction in the value of CoF was noted for PLA 2500HP/15% of cherry pits (200-400 um particle size range). Acknowledgments The research was financially supported by the Ministry of Science and Higher Education, Poland, internal subsidy 0613/SIGR/2403

#1618

# Nanocarbon-Based Composites for Wearable Physical Sensors

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Wearable piezoresistive physical sensors have attracted tremendous attention due to their broad applications in human-machine interfaces, robotics, health-monitoring, personalized medicine and therapeutics. Conventional metal- and semiconductor-based sensors are rigid, fragile, and opaque, restricting their applications in wearable electronics. Among various nanostructured materials that have been explored to construct stretchable piezoresistive sensors, nanocarbon materials show the potential of achieving improved sensing performance. We present several novel carbon-based interconnected networks including expanded graphite, carbon nanofiber, graphene woven fabric, graphite nanoplatelet welded carbon nanotube networks, wrinkled and crack-bridging graphene film, unidirectional graphene aerogel, and graphene foam as highly sensitive, flexible, and stretchable physical sensors capable of detecting human motions. By bridging the technological gap between signal collection, processing and transmission and allowing data transmission to a smartphone via a custom-developed application consisting of a user-friendly interface, several wearable applications including wireless wearable musical instrument prototype, human motion detection and switch controls are demonstrated. The novel approaches reported here offer a wide range of practical applications, including medical diagnosis, health monitoring, early warning systems for structural failure, and wearable displays.

#1622

# Viscose leno weave as a sustainable alternative to glass fiber leno weave in gypsum-based composites

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Gypsum-based composites reinforced with leno-weave glass fiber mesh are widely used in interior construction applications, including temporary exhibition structures, due to their low weight and favorable mechanical properties. However, the incorporation of glass fiber reinforcement significantly complicates end-of-life disposal and recycling, often resulting in increased environmental burden and higher waste management costs. Consequently, the development of alternative reinforcement solutions based on renewable or regenerated materials represents an important step toward more sustainable building materials.

This study investigates the potential of viscose leno weave reinforcement as a sustainable alternative to conventional glass fiber leno weave in gypsum-based composites. The experimental approach is focused on a comparative evaluation of the mechanical properties, alkaline durability, and microstructural integrity of both reinforcement types. Tensile properties of glass and viscose leno weaves were initially characterized in their initial, unexposed condition. Subsequently, both reinforcements were exposed to an alkaline environment with controlled pH in order to simulate conditions relevant to mineral-based matrices. Following the exposure period, changes in tensile performance were evaluated, and degradation mechanisms were analyzed using scanning electron microscopy (SEM).

In parallel, the mechanical behavior of the gypsum matrix was evaluated using three-point bending tests to establish reference properties of the unreinforced material. Gypsum composite specimens reinforced with either glass or viscose leno weave were then manufactured and tested to assess flexural performance and failure behavior.

The results aim to determine whether viscose leno weave reinforcement can achieve mechanical performance comparable to glass fiber reinforcement while maintaining sufficient resistance to alkaline environments. From an environmental perspective, the replacement of glass reinforcement with viscose-based materials may simplify disposal processes and improve the sustainability of gypsum-based systems, particularly in short-term construction applications.

#1624

# Structural Health Monitoring of Composite Structures Through Electrical Measurements and Deep Learning

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Fiber Reinforced Polymers (FRPs) are widely used in advanced engineering applications but are inherently susceptible to early damage such as matrix cracking and delamination, which lead to stiffness degradation and reduced load-bearing capacity. Early damage detection is therefore essential to ensure structural integrity and enable Condition-Based Maintenance.

Among Structural Health Monitoring (SHM) techniques, Electrical Health Monitoring (EHM) is particularly attractive, as damage in conductive composite laminates induces measurable changes in electrical resistance. In this work, previously developed analytical models for electrical resistance variation and stiffness degradation in multidirectional laminates are integrated to establish a direct electromechanical correlation.

A damage diagram linking normalized stiffness and electrical resistance is constructed and used to train a Deep Neural Network (DNN). The methodology is validated on a CNT-modified glass fiber/epoxy laminate with a [±45/90/0]s stacking sequence by simulating multiple damage scenarios.

The trained DNN predicts stiffness degradation from electrical measurements with errors below 5%, demonstrating the robustness of the proposed data-driven approach and its potential for advanced Electrical Health Monitoring of composite structures.

#1625

# On the durability of non-crimp fabric composite exposed to water bath and freeze-thaw aged

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In this work, the durability of a Non-Crimp Fabric (NCF) composite material immersed in water solutions and aged with Freeze-Thaw (FT) cycles is addressed via an experimental approach. The present work aims to describe how an FT aging performed in water influences the viscoelastic and mechanical properties of an NCF composite material at a coupon level. Coupons were pre-aged in three different media: immersed in (i) distilled water, (ii) seawater, and (iii) exposed to dry air, all at 40 °C. Consequently, all the coupons were aged while in the same medium with 100, 200, and 300 FT cycles. Each cycle consisted of 3 h of exposure at -60 °C, and 3 h at +40 °C, with 1 h of transient, for a total of 8 h per cycle. After aging, the composite performance was assessed for viscoelastic, mechanical, and physico-chemical properties. The characterization involved the employment of a Dynamic Mechanical Analysis (DMA), tension tests, and Fourier Transform Infrared Spectroscopy (FTIR). Furthermore, X-ray computed tomography (XCT) was selected to observe the evolution of internal damage due to cyclic thermal aging. The Time-Temperature Superposition Principle (TTSP) was selected for the durability assessment. Tensile properties were evaluated at both Room Temperature (RT) and with Liquid Nitrogen (LN2) at -196 °C to highlight the effects of the moisture absorption.

#1627

# Similitude in cyclic delamination crack growth with large-scale fibre bridging

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Large composite structures can develop damage in the form of delamination between layers. Fibre bridging is a phenomenon that leads to rising fracture resistance under static loading and can significantly decrease the crack growth rate under cyclic loading. Fibre bridging gives increasing safety, but it is not straight forward to establish design rules so that fibre bridging can be fully utilized in structural design. Design with large-scale bridging is more challenging than design using linear-elastic fracture mechanics (LEFM). In LEFM, a key assumption is that the fracture process zone and crack tip plastic zone are so small that they are embedded in a so-called K-dominant zone. Then, cyclic crack growth rate, measured on a test specimen, can be expressed in terms of the stress intensity factor, K, and used in the design of structures of another size and geometry that the test specimen. This has be called the similitude concept.

Under large-scale bridging, the transferable of cyclic crack growth rate requires similitude for both the crack tip and the bridging zone. Within the bridging zone, ligaments connecting crack faces creates bridging tractions, and it is expected that the bridging tractions depend on the cyclic opening history. The present paper examines the conditions for similitude in cyclic crack growth with large scale bridging. One situation that can be analysed is steady-state crack growth. In steady-state, the crack tip and the fully-developed bridging zone translate along the specimen at a constant growth rate in a self-similar manner. Then, each bridging ligament will experience the same cyclic opening history. The conditions for similitude between two specimen of different dimensions will be established theoretically. Examples will be given on how the cyclic crack growth rate under steady-state can be transformed to another cyclic growth rate in a specimen of another size.

#1629

# Laser-Induced Graphene Metasurfaces with Anisotropic Conductivity for Load-Bearing Broadband Radar Absorbing Structures

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Modern fighter aircraft require radar-absorbing structures (RAS) that achieve broadband electromagnetic stealth while simultaneously functioning as load-bearing elements of the airframe. However, conventional frequency-selective surface (FSS)-based RAS are commonly fabricated by screen printing conductive inks onto flexible films, a process that restricts design freedom, scalability, and effective structural integration. Overcoming these limitations is therefore essential for the development of next-generation composite stealth structures.

In this work, a mask-free fabrication strategy for load-bearing composite FSS-RAS is presented using direct lasing of laser-induced graphene (LIG) periodic patterns with controllable sheet resistance. LIG patterns are directly engraved on polyimide precursors and subsequently transferred and embedded into glass-fiber-reinforced polymer (GFRP) prepregs. Square-loop and Jerusalem-cross LIG frequency-selective patterns were designed, optimized, and fabricated, resulting in composite RAS with total thicknesses of 3.20 mm and 2.91 mm, respectively. Both structures exhibit more than 90% radar absorption across the full X-band (8.2–12.4 GHz).

The electrical anisotropy of LIG, arising from overlapping laser pulses and a zigzag laser scanning strategy, was systematically investigated through scanning electron microscopy and four-wire measurements. An indirect evaluation method was further employed to estimate the effective high-frequency sheet resistance of LIG embedded within cured composite laminates along directions parallel and perpendicular to the laser scan path. In addition to electromagnetic performance, short-beam shear testing demonstrates that incorporating LIG interlayers between GFRP plies enhances the interlaminar shear strength by 25.1%.

These results demonstrate that laser-induced graphene can simultaneously deliver broadband radar absorption and mechanical reinforcement, establishing its potential as a multifunctional, load-bearing metasurface for advanced fighter aircraft and other stealth platforms.

#1635

# Bacterial cellulose composites for the next decade: From fabrication to application

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Bacterial Cellulose (BC) offers excellent mechanical properties and biodegradability, yet faces challenges in practical scalability and applicability. To bridge the gap between fabrication and application, this study integrates multiple research advances. First, we established a scalable production platform utilizing a continuous tank-by-tank bioprocess. Driven by aerobic induced fiber-fiber self-entanglement and nanofibril alignment, this method enables the continuous fabrication of robust BC rolls, facilitating versatile in-situ and post-modification. To demonstrate the versatility of this platform, we developed two distinct applications of food packaging and battery separator. For sustainable packaging, we engineered a multilayer, hydrophobic, and heat-sealable film by integrating in-situ spraying of chitosan, sodium ion-driven mercerization, and waterborne polyurethane (WPU) coating. These films exhibited superior transparency and barrier properties, demonstrating freshness preservation efficacy comparable to commercial plastics in fresh food testing. Transitioning to energy storage, we leveraged the unique 3D fibrous network of BC to construct a functional separator for Lithium-Sulfur (Li-S) batteries. The BC network enables homogeneous dispersion of catalysts, effectively mitigating the polysulfide shuttle effect and uneven Li+ transfer. Furthermore, we integrated Physics-Informed Neural Networks (PINN) to validate theoretical models against experimental mechanisms. Collectively, this work presents a holistic approach to BC composites, moving from scalable manufacturing to high-performance applications for the next generation of sustainable composites.

#1636

# Valorisation of Hydrophilic Textile Waste in PLA Biocomposites: Mechanical and Thermal Properties

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The use of biodegradable polymers combined with renewable fillers represents a promising approach to reducing the environmental impact of polymeric materials. This study focuses on biocomposites based on a polylactic acid (PLA) matrix reinforced or filled with hydrophilic textile waste derived from textile manufacturing processes. Specifically, natural fibres originating from flax, hemp, cotton, nettle, and wool were employed. These materials are commonly generated as by-products of the textile industry and remain insufficiently utilised from a materials engineering perspective.

The main objective of this work was to evaluate the influence of different types of natural textile waste on the mechanical and thermal properties of the resulting PLA biocomposites. The materials were prepared using standard processing techniques and subsequently characterised by tensile and flexural mechanical testing. Thermal behaviour was investigated using differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA), with particular attention paid to thermal transitions, thermal stability, and the effect of fillers on the crystallinity of the PLA matrix.

The results demonstrate that the incorporation of natural fibres significantly affects the mechanical performance of the biocomposites, with the extent of these changes dependent on the type, morphology, and chemical nature of the applied fibre. Distinct differences in thermal behaviour were also observed, particularly with respect to thermal stability and the crystallisation behaviour of the PLA matrix.

The hydrophilic character of the applied textile fillers suggests a potential influence on the material response under conditions of increased humidity. This material concept therefore opens possibilities for influencing later stages of the product life cycle, particularly after the end of its functional use. The proposed approach may contribute to the effective valorisation of textile waste and to mitigating the issue of bioplastic persistence in the natural environment, although these aspects have not yet been quantitatively evaluated.

#1641

# Hydrogel Composite-Based High-Sensitivity Flexible Capacitive Tactile Sensor for Soft Robotics and Wearable Devices

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Pressure sensors are devices that convert mechanical stimuli into measurable signals, such as changes in capacitance, resistance, or voltage properties. In recent years, flexible pressure sensors have attracted significant attention due to their ability to conform to complex surfaces and their potential in emerging applications. Among various types of pressure sensors, capacitive-type sensors are particularly favored for their relatively simple structure, high sensitivity, and low power consumption. These sensors typically consist of a dielectric layer sandwiched between two conductive electrodes, where applied mechanical pressure causes deformation of the dielectric layer, resulting in detectable changes in capacitance.

In this study, we present a multilayer flexible composite-based capacitive tactile sensor, featuring hydrogel composite electrodes, a soft PDMS dielectric layer, and an amplification layer designed to enhance signal response. The sensor operates as a parallel-plate capacitor, where mechanical deformation of the PDMS dielectric under applied pressure alters its thickness and effective permittivity, while the hydrogel composite electrodes and amplification layer magnify the resulting capacitance variation. The amplification layer may incorporate functional fillers or microstructured architectures, such as micropores, pillars, or pyramids, to enhance interfacial polarization and local electric field concentration, improving signal-to-noise ratio without compromising flexibility.

Electrode and amplification layers are optimized in terms of material composition, filler content, and microstructure to achieve stable conductivity, mechanical durability, and reproducible performance. Sensor characteristics, including sensitivity, pressure resolution, response time, hysteresis, cyclic stability, and environmental robustness, are systematically evaluated. The proposed composite-based tactile sensor demonstrates strong potential for applications in wearable electronics, soft robotics, human-machine interfaces, and intelligent surfaces, highlighting the advantages of multifunctional composite architectures in next-generation flexible sensing systems.

#1643

# Towards new products from recycled composites via fused granulate fabrication

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In this study we focus on new methodology to accelerate thermoplastic composite waste conversion into new functional products. To achieve this, fused granulate fabrication (FGF) is utilized throughout as predominant manufacturing technology allowing the processing of variable waste streams directly on-site. Within our framework, complementary and prior to manufacturing, composite waste treatment included shredding and compounding to generate granulates needed for production and testing. Initially a model system, consisting of commercially available recyclates, was selected. Subsequently, the granulate model system was prepared in various morphologies varying not only their dimensions but also shape. Finally evaluation of materials processability was done by determining the relation between the granulate's bulk density and associated flow for different feed rates. Our results indicate that the morphology of the granulate significantly affect the quality of the extrudate, in particular its flow consistency. Even when aggregates and clumps are removed, and ruled-out the presence of bridging during feeding. Moreover pelletizing upon adding fillers, in our case via formulation dosing, can help improve processability while ensuring that mechanical properties are similar or even superior to that of the starting recyclate material. In the end we discuss how using this methodology fits in the new regulatory landscape where usage of recycled materials aims at reducing waste and enable circular economy principles to be implemented.

#1644

# Numerical Investigation of Damage Evolution and Energy Absorption in 3D Auxetic Sandwich Structures Under High-Velocity Impact

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Sandwich structures are widely used in aerospace and defense applications due to their high strength-to-weight ratio, but they remain vulnerable to high-velocity impacts such as bird strikes and ballistic debris. In this study, we investigate the impact response of 3D auxetic sandwich structures with re-entrant honeycomb cores using finite element modeling. Auxetic materials, known for their negative Poisson's ratio, offer superior energy absorption and are promising candidates for protective applications. A progressive failure modeling framework is developed using a Johnson-Cook (JC) constitutive law for metallic materials combined with a cohesive surface interaction method to simulate delamination at core-face interfaces. The JC material model accounts for strain rate sensitivity, thermal softening, and stress triaxiality, while the cohesive model simulates interface failure. Impact velocities ranging from 200 to 260 m/s are analyzed, with a projectile mass of 50 g, replicating realistic ballistic loading conditions. The sandwich panels, composed of aluminum face sheets and various core geometries (auxetic, hexagonal, and rectangular), are fully clamped to mimic operational constraints. Key performance indicators such as rebound velocity, time to rebound, and rate of deceleration are examined to assess impact resistance. The auxetic cores show the best performance, with prolonged deceleration, minimal rebound, and energy dissipation through ligament buckling, plastic crushing, and delayed perforation. These findings demonstrate the potential of auxetic sandwich architectures in enhancing impact resilience and inform the design of advanced protective materials for extreme loading environments.

#1646

# Fear-Inspired Strain Amplification Layers for Composite Structures

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Early damage detection in composite structures is often constrained by the limited sensitivity and design rigidity of conventional surface-mounted sensing layers. Inspired by biological defence mechanisms in which organisms amplify their apparent response to external threats without significant in-plane growth, this paper introduces a fear-inspired mechanical strain amplification layer for composite structures. The proposed concept employs kirigami architectures as a compliant, non-composite sensing layer that locally amplifies strain when attached to a composite substrate, enabling enhanced signal generation under modest global loading.

Straight parallel slit kirigami geometries are investigated as a baseline due to their simplicity, predictable deformation, and ease of parametric control. Finite element modelling is used to efficiently explore the design space and identify deformation modes, buckling behaviour, and strain localisation zones responsible for mechanical amplification. This modelling-driven approach allows rapid and low-cost iteration of multiple designs prior to fabrication. Selected architectures are manufactured using elastomer-based additive manufacturing and mechanically tested under uniaxial tensile loading to validate strain amplification behaviour.

The validated kirigami layers are then integrated onto composite substrates as a replacement for conventional sensing layers, positioning strain-responsive materials at kirigami-induced strain hot spots. Results demonstrate significantly increased local strain levels and earlier sensor response compared to flat surface-mounted configurations. Owing to its geometric simplicity, material independence, and compatibility with diverse manufacturing techniques, the proposed platform offers a flexible and scalable route for composite sensing, with strong potential for future data-driven and artificial-intelligence-assisted optimisation of sensing architectures.

#1647

# Linking physicochemical properties of selected lignocellulosic residues to the performance of lime-based insulating biocomposites

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Climate change pressures are tightening building-envelope requirements, increasing demand for insulation materials that deliver low thermal conductivity and improved thermal buffering. Conventional polymer-based insulations can achieve low conductivity, but they are carbon-intensive and typically provide limited heat storage capacity. Lime-based insulating biocomposites incorporating lignocellulosic bio-aggregates offer a lower embodied-carbon alternative with favorable thermophysical behavior. Hempcrete is a widely recognized example, yet broader adoption is limited in many jurisdictions because hemp remains a regulated crop with region-dependent availability. To support locally available alternatives, lignocellulosic residues from Canada and Chile were evaluated as substitutes for hemp shiv and linked to biocomposite performance.

Ten residues were screened against hemp shiv using bulk density and scanning electron microscopy (SEM) for morphology, while Fourier-transform infrared spectroscopy (FTIR) and thermogravimetric analysis (TGA) were used to assess chemical signatures and thermal degradation behavior. Derivative thermogravimetry (DTG) peak deconvolution was applied to estimate relative contributions of hemicellulose, cellulose, lignin, and extractives. Five candidates—pine shavings, poplar shavings, corn stalk, corn cob, and vine prunings—were selected to span a range of physicochemical profiles. Biocomposites were fabricated with a lime binder under consistent conditions while varying biomass volume fraction from 30% to 60%. Performance was assessed through density, compressive and flexural strength, and thermophysical properties.

Residues most similar to hemp shiv—characterized by rougher surfaces, lower bulk density, higher polysaccharide-associated fractions, and lower lignin—delivered the best overall mechanical and thermophysical performance in the resulting biocomposites. Pine and poplar shavings and corn stalk performed most favorably, whereas corn cob and vine prunings performed the weakest. Increasing biomass volume fraction generally improved thermal performance, although responses were feedstock dependent, while mechanical performance followed a binder-controlled trend with lower biomass fractions yielding higher strengths. High-lignin residues showed poor binder affinity, underscoring chemical compatibility as a key selection criterion.

#1649

# Robotic Large Format Additive Manufacturing of Short Glass Fiber Reinforced ABS Composite Moulds: Overview on Material Characterization and Process Simulation

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Large Format Additive Manufacturing (LFAM) is becoming a promising technology to produce large composite tooling, as it offers greater freedom to generate the complex mould geometries required, while providing reduced cost and lead times. This publication is focused on characterizing the Fused Granular Fabrication (FGF) additive manufacturing process of Acrylonitrile Butadiene Styrene (ABS) reinforced with 20% short glass fiber, as this material's properties allow it to be extensively used in low temperature tooling applications. Therefore, extensive material analyses were undertook to assess the thermal and mechanical properties of the glass fiber reinforced ABS after extrusion, including coefficient of thermal expansion measurements and tensile tests. The results reveal high material anisotropy, mainly generated by the manufacturing process, as the reinforcing short glass fibers tend to align with the printing direction. It was then decided to generate a finite element method (FEM) which could compute and predict the warpage of the produced tools, by creating a multiphysics simulation workflow that uses the printing path ".gcode" file as an input. With ANSYS' feature of element activation, it is possible to model the layer deposition, and assess the process induced deformations. The simulated warpage was compared with experimentally measured deformations of three probes, in order to evaluate the consistency between the numerical results and physical responses. This approach and the data it provides can be used to guide the 3D printing operation, as it helps to identify potential tooling tolerances to be included during the part design, in an attempt to achieve first-time-right manufacturing of the composite moulds.

#1650

# Sustainable High-Performance Epoxy Thermosets via Polythiol Hardeners and Bio-Based Thermo-Latent Catalysts

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Anhydrides are widely used in the epoxy industry as curing agents, providing high-performance epoxy networks with excellent thermal and mechanical properties. However, this class of compounds possesses a significant toxicological potential, motivating the development of safer and more sustainable alternatives. Polythiol-based hardeners represent a promising solution in this context due to their lower toxicity and high reactivity toward epoxy resins, with bio-based polythiols being readily synthesized. Although numerous studies have demonstrated the high reactivity of epoxy–thiol systems, the resulting networks generally exhibit a lower glass transition temperature than commercially available formulations — a critical limitation for many applications. In this study, Fourier-transform infrared (FTIR) spectroscopy, differential scanning calorimetry (DSC), dynamic mechanical analysis (DMA), and tensile testing were employed for an in-depth characterization of the curing behavior of the investigated resin systems and the thermo-mechanical properties of the resulting networks. Particular attention was paid to the relationships between curing kinetics, network formation, and final material properties. Based on these analyses, the key factors governing the thermo-mechanical performance of epoxy–thiol systems were identified, including formulation stoichiometry, base concentration, thiol molecular structure —offering a high degree of tunability — and the resulting network architecture. Control over these parameters enables the design of robust, high-performance thermoset materials. We also demonstrated that employing bio-based thermo-latent catalysts offers a powerful means to tailor resin reactivity, processing window, and storage stability, while maintaining high final performance. Overall, our findings highlight that polythiol-based hardeners combined with bio-based thermolatent catalysts represent a promising and sustainable route toward one-component, high-performance epoxy thermosets.

#1652

# Multi-scale Damage Assessment of Composites under Cryogenic Conditions

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The shift towards new energy sources demands the development of advanced storage systems, such as cryogenic tanks required for various liquid propellants (LOx, LCH4, LH2). For aeronautic application, reducing energy consumption relies on lightweight and compact designs. The storage at liquid state is therefore required to achieve viable energy densities (e.g. more than 800 times the gas density for hydrogen under atmospheric pressure) while limiting the thickness of the structures otherwise necessary for high pressure storages. In addition, composite materials offer promising tank solutions thanks to their high specific strength. Current developments are thus focusing on all-composite tanks with the additional challenge of ensuring tightness without the use of a liner.

At low temperature, the polymer matrix of composite materials becomes brittle and shrink significantly in comparison to room temperature. These mechanisms, as well as pressure loading, triggers thermomechanical stresses which can lead to transverse cracking, and ultimately leakage by crack coalescence. This complex phenomenon requires characterisation technics at the different scales of the composite laminates: on single plies to observe the cracking process, on several plies to analyse the interaction between the damage in adjacent plies, and on laminates to measure the resulting leakage rate. In addition, these tests are not only performed on simple plates but also on tubular samples to better consider the manufacturing process and biaxial loading of pressurised tanks.

A complete range of testing methods for characterising the mechanical behaviour (properties and damage) and the permeability of composite plates and tubes at low temperatures will be presented: from -30°C to -130°C under liquid nitrogen spraying or at -196°C immerged in liquid nitrogen. Examples of the various instrumentations employ in these experiments to analyse the composite material at the different scales will also be provided: optic microscopy, X-ray tomography, mass spectrometry and acoustic emission.

#1653

# Additively Manufactured Deployable Lattice Booms with Tailored Fiber Placement

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Additive manufacturing offers the potential to reduce the need for costly moulds and labour-intensive manual processes in composite manufacturing, which enabling access to design spaces that are difficult or impossible to realise using conventional fabrication techniques, such as lattice structures with slender members and spatially varying fibre orientation. By combining fused filament fabrication (FFF) with discrete in-situ consolidation (DISC), a proprietary post-deposition technique used to remove voids and increase interlaminar adhesion, thermoplastic composites with high fibre volume fraction (>55%) can be produced with low void content (<2%), demonstrating the feasibility of additive manufacturing to produce for structural composites.

In this work, FFF combined with DISC is leveraged to manufacture lightweight bistable slit tube booms with lattice shell architectures and tailored fiber placement for potential application in satellite systems. Although lattice shell architectures offer higher flexural rigidity properties than continuum architectures on an equal-mass basis, they are difficult to produce using conventional processes, e.g. hand layup. To address this, Grasshopper, a programming plug-in for Rhino 3D, is used to parametrically define lattice geometries and generate tool paths. A computational procedure for automatically generating finite element models directly from material deposition paths is presented, with predicted shell behaviors showing strong agreement with experimental results using both homogenization and full-scale modeling approaches.

The influences of fiber angles, lattice density, and initial shell curvature on the existence and form of stable coiled configurations as well as flexural rigidity properties are investigated. Finally, the ability of additive manufacturing to individually tailor fibre orientation through tool-path design is exploited to achieve unique secondary stable configurations, which may offer advantages for the long-term storage of deployable space structures.

#1656

# The affect of temperature on time dependent properties of 3D printed PLA

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The field of Additive manufacturing is expanding each year. The manufacturing method of 3D printing offers design freedom unchallenged by any other manufacturing method. This is especially important for polymer prototyping and optimization. In addition, additive manufacturing reduces waste production and energy consumption. However, during manufacturing, the polymer undergoes significant temperature changes that alter its physical, chemical, and mechanical properties. These changes, in combination with other factors, can cause creep, shrinkage, and aging, ultimately leading to significant shape distortions or material failure. To better understand the effects of various properties on time-dependent behavior, with an emphasis on viscoelasticity and viscoplasticity, the time-dependent behavior of 3D printed poly lactic acid (PLA) was studied. Specimens with filament placement in the loading and perpendicular loading directions were studied. The viscoelasticity and viscoplasticity have been analysed. The effect of elevated temperature on time-dependent behaviour has been studied. The master curves with respect to temperature have been obtained. The tests reveal very small nonlinear viscoelastic behavior at higher stresses and a high dependency on the filament direction.

Within our study, Fused Filament fabrication (FFF) was used, where the polymer structure is built as a layer-by-layer deposition of feedstock materials. The FFF can be used to produce polymer structures with increased strength. However, this method also produces a composite-like structure – each filament is partially joined to other filaments. The complex microstructure of 3D printed materials even further complicates the ability to predict a structure's long-term performance. To study the effects of this microstructure in detail, short-term creep tests will be conducted at various stress levels within a scanning electron microscope.

#1657

# Modeling Process-Induced Degradation in Thermoplastic Polymers Under High Shear Rates

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Thermoplastic polymer processing by Fused Filament Fabrication (FFF) with rotating nozzles subjects molten materials to high deformation rates, leading to shear heating and potential thermal degradation. While maximizing production rates is industrially desirable, these extreme thermo-mechanical conditions can compromise the mechanical performance of final components due to process-induced degradation. Predicting this degradation is critical for virtual design and reliable manufacturing of thermoplastic parts, particularly in FFF with rotating nozzles where localized heating effects are pronounced.

This work explores physics-based modeling to quantify degradation under high shear rates. We review the existing models that describe thermo-mechanical degradation of semi-crystalline thermoplastics, focusing on polyamide systems, and identify the pertinent degradation descriptors (and characterization methods) at the material level. We implement numerically the selected models at the material scale to perform sensitivity analyses, which allow us to assess the influence of processing parameters (e.g., shear rate, temperature, residence time) on degradation extent and validate against experimental data, with emphasis on AM-specific conditions (e.g., nozzle geometry, rotation speed).

Preliminary results highlight the coupling between shear heating and degradation kinetics, suggesting that localized temperature spikes in FFF may lead to premature degradation in critical regions. This approach enables predictive virtual design, reducing reliance on trial-and-error prototyping.

#1658

# Transferred and Embedded Frequency-Selective Laser-Induced Graphene Pattern on Dielectric Radar Absorbing Materials

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Laser-induced graphene (LIG) has emerged as a promising next-generation conductive material due to its ability to form highly conductive carbon networks at room temperature through simple laser irradiation. In recent years, LIG has been actively explored for radar absorbing material (RAM). In this study, RAM was developed by transferring a LIG-based frequency selective pattern (FSP) fabricated on a PI film onto a multiwalled carbon nanotube (MWCNT)–polydimethylsiloxane (PDMS) composite. Unlike conventional approaches, the proposed process embeds the LIG pattern directly into the PDMS matrix, followed by complete removal of the PI film. During the transfer process, liquid PDMS infiltrates the porous LIG network and subsequently cures, leading to stable mechanical bonding between the LIG layer and the dielectric composite.

To evaluate the feasibility of the FSP, the microstructure of LIG formed on PI was systematically investigated together with its sheet resistance according to laser processing parameters, anisotropic resistance, and variations in sheet resistance induced by the transfer process. Under a laser power of 9 % and a scanning speed of 200 mm/s, the sheet resistance of LIG on PI was minimized to 31.75 Ω/sq (0°) and 44.95 Ω/sq (90°), exhibiting reduced directional deviation. After transfer, PDMS infiltration increased the sheet resistance to 37.56 Ω/sq and 69.67 Ω/sq along the respective directions.

For broadband absorption, a square-loop LIG pattern was designed using geometric parameters, dielectric constant, and thickness as key variables. Despite the anisotropy in sheet resistance, the fabricated LIG-FSP RAM with a thickness of 3.2 mm and a dielectric constant of 4.91 − j0.81 at 10.3 GHz achieved more than 90 % absorption across the entire X-band frequency range (8.2–12.4 GHz). A minimum reflection loss of −18.07 dB was observed at 10.4 GHz, demonstrating the strong potential of LIG-based FSS structures as high-performance electromagnetic absorbers.

#1659

# Structural Design of CFRP Sandwich Structures Using Spread-Tow Carbon Fiber Fabrics for Radiolucent Surgical Tables

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Hybrid operating rooms are advanced surgical environments that integrate real-time medical imaging with operative procedures. In these settings, cantilever-type surgical tables are widely employed to provide unobstructed imaging access for intraoperative C-arm systems, leading to structural behavior governed primarily by long-span uniaxial bending. Under such configurations, deflection control becomes the primary design constraint, while conventional approaches based on laminate thickening are limited by radiolucency requirements.

In this study, a stringent deflection limit of less than 20 mm over a total span of 2,125 mm (approximately 0.94%) was adopted as a primary design criterion, reflecting stiffness-dominated requirements for functional alignment in medical imaging environments. To satisfy this constraint without compromising X-ray transparency, a CFRP sandwich architecture consisting of composite skins and a lightweight foam core was proposed. The CFRP skins were designed using a hybrid layup combining unidirectional (UD) plies and spread-tow carbon fiber woven fabrics, enabling high longitudinal bending stiffness while maintaining thickness uniformity across a large-area panel. To capture the non-negligible contribution of core shear deformation inherent to thick sandwich structures, an analytical framework based on Timoshenko beam theory was established. The analytical predictions were validated through finite element analysis (FEA) under representative distributed loading conditions, showing strong agreement in terms of global deflection and stress distribution. Parametric studies on skin thickness, core density, and total panel thickness identified a feasible structural design window that satisfies the imposed deflection constraint while preserving radiolucency.

This work addresses a structural regime that has received limited attention in CFRP-based medical platforms and proposes a generalized, analytically predictable design methodology for large-area radiolucent composite structures subjected to long-span uniaxial bending, where precise stiffness control and imaging compatibility are simultaneously required.

#1660

# Engineering Magnetic Carbon Fibres by incorporating of Metal-Oxide Nanoparticles

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The integration of metal oxide nanoparticles into carbon fibres (CFs) offers a pathway to multifunctional materials with enhanced performance and recyclability. In this study, $Fe_3O_4$ nanoparticles (NPs) were incorporated into polyacrylonitrile (PAN) precursor fibres using a pilot-scale continuous wet spinning process, producing magnetically responsive CF precursors. The influence of $Fe_3O_4$ nanoparticle loading (0.3, 0.6, and 1.0 wt.%) on fibre morphology, thermal behaviour, and mechanical properties was systematically investigated using scanning electron microscopy (SEM), differential scanning calorimetry (DSC), and thermogravimetric analysis (TGA), respectively. Thermal stabilization and subsequent carbonization of the doped precursor fibres resulted in CFs with homogeneously distributed $Fe_3O_4$ domains, imparting pronounced magnetic functionality. The magnetic properties of the resulting CFs were evaluated using a superconducting quantum interference device (SQUID) magnetometer, revealing that a 1.0 wt.% $Fe_3O_4$ addition enhanced the saturation magnetization to 1.09 emu $g^{-1}$. In addition, the electrical conductivity of the same fibres, measured using the four-point probe method, reached 36.95 $k\Omega^{-1}$ $m^{-1}$, confirming the successful integration of multifunctional magnetic and electrical properties within the carbon fibre matrix. The integration of $Fe_3O_4$ nanoparticles (NPs) has been shown to significantly influence both the microstructure and functional properties of the CFs. Exploiting the intrinsic magnetic response, short CFs were aligned under external magnetic fields, demonstrating a direct correlation between nanoparticle content and alignment kinetics, enabling anisotropic architectures in composite systems. The resulting magnetically aligned fibres offer multifunctionality (magnetic, thermal and electrical conductivity), including potential applications in thermal interface materials, energy storage, electromagnetic interference shielding, sensing, and biomedical devices, while also facilitating enhanced recyclability via field-assisted fibre orientation. This work bridges the gap between nanoscale electro-spun magnetic fibres and scalable continuous CF production, providing a versatile platform for next-generation high-performance, multifunctional, and recyclable carbon fibre composites.

#1662

# Stress–Strain Behavior of Auxetic-Reinforced Mortar Under Cyclic Compression

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Driven by growing interest in auxetic composites for enhanced energy absorption and ductility in structural elements, recent research has explored their behavior under varied loading conditions. However, their response under cyclic compression remains insufficiently investigated. This study addresses that gap by investigating the stress–strain behavior of auxetic-reinforced mortar under cyclic compression. Two types of 2D auxetic frames are fabricated using 3D-printed nylon filaments (ePAHT-CF) reinforced with 15% carbon fibers designed in missing-rib and re-entrant geometries. The unit cells of these structures were configured to produce cubic samples with dimensions of 40×40×40 mm to optimize the time and material needed for printing. Due to the complex shape of the auxetic frame and the small sample size, a mortar mixture was prepared using fine quartz sand (<0.5 mm) and superplasticizer to properly fill the voids and spaces within the auxetic frames. The prepared mixture is then cast into the auxetic frames, and cured under standard conditions. Constant-amplitude compressive fatigue tests were subsequently conducted on cubic specimens using an MTS 815 machine, with a stress range of 5 (minimum) to 30 (maximum) MPa and a frequency below 1 Hz. The results characterize the composite response through cyclic stress–strain curves, revealing that auxetic reinforcement is a viable option for enhancing the fatigue performance of cementitious composites. Notably, the addition of these frames improves structural integrity and ductility, offering a resilient alternative to the traditional brittle failure typical of cementitious structures. A transitional, highly deformable, low-stiffness phase was also observed across the full loading range, showing a distinctive response to these elements compared with conventional cementitious materials.

#1665

# Development of a leading-edge rib based on short carbon fiber reinforced thermoplastic using additive manufacturing

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Advances in materials science and engineering play a crucial role in the development of the aerospace industry. Research into lighter metallic alloys and thermoplastic matrix composite materials is driving the design of complex structures with high strength and lightweight, which will help mitigate the environmental impact of NOx and CO2 emissions. Currently, interest in thermoplastic composite materials is largely driven by progress in the automation of manufacturing technologies, such as Automated Fiber Placement (AFP) and 3D printing, which could potentially lead to an increase in the production rate of complex parts and a reduction in costs. Due to their physicochemical properties, thermoplastic composites can be reprocessed after consolidation, allowing them to be reshaped, recycled, or welded through thermal activation processes.

This research focuses on the design of a structurally optimized rib using short carbon fiber reinforced polyether ether ketone, processed via additive manufacturing. The structural analysis of the rib was performed using the finite element method, considering loads generated during a bird strike event. Subsequently, topology optimization of the geometry was carried out using the density method to maximize the component's stiffness. Based on the optimization results, the geometry was redesigned for validation through additional structural analysis. Finally, the rib was successfully fabricated using fused deposition modeling (FDM). This manufacturing process required further modifications of the optimized geometry to meet FDM process constraints.

#1667

# Multiscale statistical failure analysis of filament wound unit cells accounting for process induced variation

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The filament winding method is a process by which a roving is wound around a rotating mandrel to form the load bearing structure. To do this, a winding head traverses forwards and backwards, depositing fiber on a rotating mandrel until its completely covered, creating a distinct undulation pattern on its surface. During winding, the chosen process state (defined by variables like pressure, temperature, pretension, and speed) has an influence on geometric parameters like roving width, roving thickness, roving spacing, and the local winding angle. Disturbances in this process state can lead to variations in the geometric parameters in the manufactured pattern, resulting in fluctuations in performance parameters like stiffness or strength. However, the sensitivity of each performance parameter to a change in each geometric parameter is generally unknown, preventing one from adjusting the process in an informed way. To address this, a parametric analysis is undertaken using the NASA Multiscale Analysis Tool (NASMAT) to understand the sensitivity of a filament wound RUC to changes in various geometric parameters. To do this, a filament wound RUC model was developed in [1] that lends itself to large parametric analysis and was further built upon to allow for multistep homogenization schemes within NASMAT. Using multistep homogenization, computational speed can be adjusted to allow for a large simulation data set [2]. This enables one to investigate, in short time, the influence of each geometric parameter on the performance of each unit cell (stiffness and strength), an important aspect if this methodology is to transfer into industry.

#1668

# Development of a Dual Analytical–Computational Framework for the Design and Modelling of Hybrid Filament-Wound and AFP Carbon Fiber Rollers

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Filament-wound carbon fiber rollers are increasingly replacing metallic counterparts in industrial applications due to their superior specific mechanical properties. Despite this trend, the design and modelling of such structures is still either heavily dependent on numerical methods (e.g., FEM) or based on design practices originally developed for metallic components. A dedicated and consistent methodology tailored to hybrid and full-composite roller structures is currently lacking.

This work presents a unified analytical–computational framework for the accurate mechanical modelling of filament-wound composite rollers. The approach is based on an analytical sectional model founded on coaxial cylinder theory, capable of describing the full three-dimensional stress state at any cross-section of a cylindrical beam. This formulation allows the explicit investigation of key manufacturing-related parameters, including thermal residual stresses, hydrothermal effects, curing-induced stresses, as well as the influence of weave architecture and stacking sequence on interlaminar behavior and delamination.

To obtain the complete three-dimensional response along the length of the structure, a complementary longitudinal solution is employed. This is implemented computationally using one-dimensional beam formulations based on Euler–Bernoulli and Timoshenko theories. The coupling of the analytical sectional solution with the longitudinal beam model yields a comprehensive representation of bending, torsion and axial loading for cylindrical composite and hybrid structures.

Model accuracy is assessed through mechanical testing of full-scale rollers. Preliminary experimental results indicate the necessity of model calibration and the inclusion of correction factors, a process that is currently ongoing alongside further experimental characterization. The final objective of this work is to establish the proposed framework as a robust, accurate and computationally efficient design tool for carbon fiber rollers and advanced hybrid cylindrical structures.

#1670

# Quadrilateral Microstructured Optical Sensors for Monitoring the Manufacture and Performance of Composite Structures

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Optical fibres offer an attractive route for in-situ strain monitoring in composite materials due to their small size and fibrous form-factor. A novel silica optical fibre sensor capable of resolving both axial and transverse strains is presented. The sensors are characterised by flat, high aspect ratio cross-sections (500 - 1000 µm wide, 50 - 100 µm thick), specifically designed to be embedded between the plies of a laminated fibre reinforced composite. Unlike, conventional circular optical fibre sensor containing FBGs (fibre Bragg gratings), the novel sensors are unable to rotate during assembly and component manufacture. Instead, the sensor orientation is maintained between layers, meaning that their polarity is fixed. As the sensors have birefringent properties, i.e. their refractive index is stress dependent, the changes of stress in the sensor cross section can be linked to the through-thickness strains in the composite laminate. The sensors have the potential to monitor the behaviour of composite laminates during manufacture as well as remain in the finished structure to facilitate in service monitoring.

The optical fibre internal microstructures enable changes in through thickness strain to be sensed using the birefringence changes in the sensor waveguide, resulting in measurable spectral separation of the FBG reflection. A finite element model has been developed to evaluate and optimise the influence of internal microstructure. Hydrostatic pressure tests on the sensors have confirmed the predicted increase in birefringence response. In the paper it is demonstrated that the sensors can be embedded in symmetric cross-ply CFRP laminates manufactured in a closed mould tool. It is shown the through thickness residual and cure induced strains can be successfully monitored enabling quantitative assessment of multi-axial strain evolution during composite component manufacture.

#1671

# Micropolar Homogenization of Elastic Fibrous Networks for Bio-Inspired Materials

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This work presents a higher-order modeling approach for random fibrous networks based on micropolar elasticity, aimed at describing the influence of microstructural organization on the macroscopic mechanical behavior of planar fibrous materials, such as those encountered in biological tissues like collagen gels. A finite element framework is adopted in which individual fibers are represented by Timoshenko beam elements and their intersections are modeled as rigid crosslinks, allowing the transmission of both forces and moments throughout the network. The formulation explicitly incorporates bending, shear, and microscale rotational mechanisms, which are essential for capturing non-classical continuum effects. A micromechanical homogenization procedure is developed to determine the effective micropolar constitutive parameters and to analyze their dependence on key structural characteristics, including fiber density, internal bending length, and the size of the representative analysis domain. The results highlight the dominant role of microstructural attributes in governing the emergent elastic and couple-stress responses of the network. This study establishes a consistent link between structural topology and higher-order effective properties, providing a robust multiscale framework for the prediction of mechanical behavior in disordered fibrous media, with potential applications in bio-inspired materials and advanced engineered composites.

Keywords: Micropolar elasticity, Fibrous networks, Micromechanics, Multiscale modelling, Timoshenko beams, Structural behavior.

#1672

# Effect of eggshell-derived additives on curing of fully bio-based epoxy resin systems

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Bio-based epoxy systems have gained significant attention in recent years, primarily due to efforts to replace commercial fossil-based products with greener alternatives derived from renewable resources. Reinhardt et al. have demonstrated a fully bio-based epoxy thermoset based on epoxidized linseed oil (ELSO) and tannic acid, exhibiting a glass transition temperature of 147 °C and a flexular modulus of 2986 MPa, demonstrating competitive mechanical performance relative to traditional petroleum-based products. Using ELSO and citric acid, Anusic et al. prepared a high-performance thermoset with a storage modulus of 1380 MPa. However, the primary limitation of such systems usually resides in long curing times at high temperatures, thus impeding their broader adoption in commercial applications.

One promising approach to effectively enhance the curing behavior of bio-based systems is through the incorporation of a catalyst. Recently, eggshell (ES) powders have been explored as promising curing catalysts of bisphenol A diglycidyl ether epoxy resins. Given the annual generation of approximately 8 million metric tons of ES waste and its associated environmental burden, ES waste presents a substantial potential for recycling and valorization. Strategies have targeted ES-derived powders as renewable fillers in composite formulations, enabling the replacement of conventional mineral $CaCO_3$.

In this work, ES powders are examined as potential multifunctional additives in an ELSO resin cured with carboxylic acid hardeners delivering composites with 100% bio-based carbon content. Differential scanning calorimetry is employed to investigate curing kinetics of various compositions, and several isoconversional models are used to assess the kinetic parameters. For comparison, several amino-acids found in eggshell membrane are selected and their respective effect on the curing is investigated. Additionally, effects of the powder additives on thermal and mechanical behavior of selected formulations are evaluated.

#1674

# Valorization of vitrimer matrices in composite processing: from prepreg manufacturing to composite remanufacturing and repair

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In the light of the circular economy and growing environmental concerns, the end-of-life management of thermoset-reinforced composites poses a significant and escalating environmental challenge. The limitations associated with remanufacturing and repairing these thermoset materials highlight the need to expand the use of thermoplastic composites across various applications. However, thermoplastics generally fall short of matching the superior thermomechanical properties and thermal stability of thermosets. In this context, vitrimer-based composites are being developed to overcome the withdraws of thermoset composites in a more sustainable way. These materials enable reuse through efficient repair and remanufacturing, thereby supporting a more circular composite lifecycle. The results presented in this paper stem from the EVERGREEN project carried out at the IRT Saint Exupéry and the collaborative DYNA project conducted jointly by SOFTMAT and IRT Saint Exupéry. The objective of the present work is to explore the potential of epoxy-based vitrimer matrices to be manufactured using conventional composite manufacturing techniques, including prepreg production via the IRT SE pilot-scale impregnation line, thereby offering new opportunities for sustainable composite manufacturing. Vitrimer properties are induced by the incorporation of dynamic reversible covalent bonds. Herein, a comparative analysis is conducted between petro-based and bio-based disulfide hardener. Produced carbon fiber-reinforced vitrimers were evaluated through reshaping tests to demonstrate the possibility of remanufacturing these materials without degradation. Besides, reconsolidation tests were performed on vitrimer composites to repair residual porosities. Obtained results showed the potential of these materials to offer new possibilities to repair distorted or defective composite parts during manufacturing or in-service use, as well as reusing and recycling end-of-life composites.

#1675

# Static and Free Vibration Analysis of a Sandwich Shell with an Auxetic Honeycomb Core via the Unified Formulation and Generalized Differential Quadrature Method

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Over the past decade, auxetic materials have attracted considerable attention due to their superior buckling resistance, enhanced vibration performance, and high energy absorption capacity. This distinctive response arises from their negative Poisson's ratio, which causes them to expand laterally when stretched and contract laterally when compressed. The free vibration analysis of rectangular auxetic honeycomb shells represents a crucial area of research with significant implications for the performance of advanced engineering applications such as aerospace, automotive, and defense industries. For that purpose, this research investigates a static and free vibration analysis of a sandwich shell with an auxetic honeycomb core, utilizing the Carrera Unified Formulation (CUF) and Generalized Differential Quadrature Method (GDQM). The CUF models the displacement field with expansion orders ranging from 1 to 4 through an Equivalent Single-Layer (ESL) approach. The governing equilibrium equations and boundary conditions are derived using the virtual displacements principle and resolved using GDQM. To validate the results, we compare the results with existing solutions, highlighting the benefits of using variable kinematic models for analyzing sandwich shells with a honeycomb auxetic core, including both hexagonal honeycomb (HH) and a re-entrant honeycomb (RH). A parametric study is carried out to evaluate the effects of multiple parameters, including cell orientation, wall thickness, inclination angle in the honeycomb core, core thickness, and honeycomb type. Overall, the present work provides a versatile framework for the static and free vibration analysis of auxetic honeycomb sandwich shells, providing benchmark solutions and fundamental insights that support the development and validation of advanced shell theories and numerical models.

#1676

# Development of Quality Control Strategies for Reclaimed Timber towards Optimized Upcycling

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Global climate change has enforced concerns regarding the sustainable management of natural resources, including wood, which has been extensively exploited as result of its low cost, particularly in Scandinavia. This problem has raised the need to extend the lifespan of available but unutilized wooden structures by repurposing well-preserved components. This initiative is supported by stricter legislation in landfilling, compelling the Construction, Manufacturing, and Demolition sectors to adopt recycle-oriented practices. Although the collection of reclaimed wood is growing, the absence of a global quality assessment methodology limits its utility, underscoring the demand for classifying wood according to its variability resulting from previous service conditions.

This work emphasizes on the development of Non-Destructive Testing (NDT) routines to evaluate efficiently the status of differently contaminated wooden samples. Fourier-Transform Infrared Spectroscopy (FTIR) and visual inspection using RGB camera systems are employed for the observation and chemical characterization related to surface contaminations. For the characterization of internal features such as knots, cracks, and residual regions X-ray Computed Tomography (CT) is performed. As most of the developed results are image-based, emphasis has been placed on process automation, therefore image processing methods are applied to enable rapid defect detection.

To correlate the state of wood to its performance, the samples are further tested destructively on their strength and stiffness.

This study allows the establishment of a predictive model between NDT-derived parameters and mechanical performance indicators. The results contribute to the mapping of multi-modal non-destructive data in favor of the classification of reclaimed wood according to its suitability for direct reuse or modification into engineered wood alternatives in structural and non-structural applications.

#1678

# Optimization of mechanical properties in fibre-reinforced composite materials made with aeronautic reused uncured prepreg cutoffs

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Transition towards sustainability in the current industry landscape is enforcing the development of strategies to reduce waste during production and define roadmaps for the end of life of products (recycling or repurposing for other applications). The composite materials industry faces particular challenges because of the complexity for separation of materials and the toxicity of the materials involved. In addition, there is still a lack of standardization for waste management in composite materials. In Aeronautics industry, the majority of waste is set to come in 20 to 30 years, but there is a more urgent situation to manage the waste generated everyday in factories. In particular, cutoffs of uncured prepreg tapes produced during cutting of the laminate preforms. Around 10-15 % of the prepreg material is discarded.

Most efforts up to now focused on strategies for recycling FRP composite material, but there are much fewer works on reusing uncured prepreg cutoffs. To this end, the present study proposes the use of prepreg cutoffs for re-manufacturing of composite panels that can be used in added-value components for an aeronautic factory like layup toolings or drilling templates. A strategy for reusing the prepreg cutoffs and manufacture panels has been developed. The reused material has been characterized to determine average mechanical properties that can be used during design of new components. In addition, mechanical properties can be tailored by processing the cutoffs and controlling their size. Therefore, the effect of size and aspect ratio on the mechanical properties has been studied. The study shows that, due to the short fibre nature of the reused material, there is always a trade-off between mechanical performance, dispersion and directionality of properties. An autoclave layup tool was manufactured as technology demonstrator. The long-term behaviour was studied by performing thermal cycles in an autoclave, obtaining excellent results.

#1679

# Crashworthiness capability of thin-walled hybrid wood–composite tubes under axial crushing: Influence of spiral-wound architecture and fiber material orientation

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This study presents a novel crashworthiness design based on spiral-wound thin-walled hybrid tubes (SW-HT) aimed at improving specific energy absorption under axial loading. The tubes are fabricated by spiral winding alternating layers of poplar wood veneers and composite sheets around a mandrel, forming a thin-walled tubular structure. This interleaved hybrid arrangement enhances mechanical interaction between the wood and composite layers, resulting in stable and progressive crushing behavior.

Two types of SW-HTs were developed using poplar wood veneers combined with either carbon/epoxy (SW-HT-V/CF) or glass/epoxy (SW-HT-V/GF) composite layers. For each system, different composite fiber orientations (0°/90° and ±45°) were investigated to evaluate their influence on crushing mechanisms and energy absorption performance. Quasi-static axial crushing tests were conducted to characterize the load–displacement response, failure modes, and crashworthiness indicators.

The experimental results demonstrate that the hybrid configurations achieved high energy dissipation levels with a stable, progressive crushing profile. Quantitatively, the SW-HT-V/GF [±45°] configuration outperformed all other systems, reaching the highest total energy absorption of 2548 J and a specific energy absorption (SEA) of 28.5 J/g. While the SW-HT-V/CF [0°/90°] configuration exhibited a comparable SEA of 28.4 J/g, its total energy capacity was significantly lower at 1741 J. Analysis of the load–displacement curves revealed a controlled initial peak force followed by a sustained and elevated constant-load plateau, maximizing the area under the curve.

These findings confirm the strong potential of SW-HTs as economic, lightweight, efficient, and sustainable crashworthiness solutions. The results further highlight that a ±45° fiber orientation is particularly effective in stabilizing the crushing process and optimizing energy dissipation efficiency.

#1681

# Modeling uncertainties and variability in hygro-elastic behavior of moisture-exposed composites

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Nowadays, composite materials are widely used in structural design for various engineering applications due to their excellent mechanical properties combined with low weight. During their service life, these components are exposed to harsh environments which, together with classical mechanical loadings, may lead to premature structural aging. Among the various aggressive phenomena, water absorption by the hydrophilic matrix is of primary importance, as the resulting hygroscopic swelling may initiate or exacerbate damage mechanisms. To improve predictive capabilities, accounting for uncertainties and variability in modeling, as well as in ad-hoc numerical simulations, can be highly beneficial, since significant dispersion is often observed in experimental data.

In this work, we propose an extension of classical hygro-elastic model based, for instance, on Fick's law within a stochastic framework. A parametric representation of uncertainties is adopted, leading to a probabilistic model based on independent random variables. These variables are used to model uncertainties in parameters such as the water diffusion coefficient tensor, the maximum moisture absorption capacity, the hygroscopic expansion tensor, as well as geometric variability of the composite component.

To perform uncertainty propagation and quantify the resulting variability in the physical response outputs, various spectral stochastic approaches may be employed. These methods rely, among others, on representing input and output quantities using specific orthonormal polynomial bases.

The efficiency of the proposed approach is demonstrated through numerical examples. Different analyses are carried out for various composite materials at both the micro and macroscales, focusing on several local and global stochastic quantities of interest. Particular attention is devoted to random geometries and random cracks (position and length) within the hydrophilic matrix. Finally, the impact of uncertainties associated with input parameters on the output responses is discussed for each case study.

#1682

# Autonomous Thermal Management in Flexible Conductive Polymer Composites for Wearable Systems and Battery Safety

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Flexible thermal management materials are increasingly required for wearable electronics and electrified transport, where heating must be lightweight, conformable, energy-efficient, and intrinsically safe. Conductive polymer composites (CPCs) enable Joule heating and sensing via percolated conductive networks, yet conventional CPCs often exhibit high switching temperatures governed by semicrystalline matrix transitions, limiting suitability for body-contact devices. In parallel, lithium-ion batteries require passive thermal protection to mitigate overheating without adding significant weight or system complexity.

This work presents an autonomous thermal management strategy based on two complementary flexible polymer composite platforms: (i) self-regulating CPCs exploiting the positive temperature coefficient (PTC) effect for wearable heating and temperature sensing, and (ii) flexible phase change composites (PCCs) for passive thermal buffering in battery safety applications. For the wearable CPC platform, styrene-ethylene-butylene-styrene (SEBS) elastomer was combined with graphene nanoplatelets (GNPs) to form a flexible conductive network, while lauric acid (LA) was introduced as a biodegradable functional component to enhance PTC behaviour within the wearable-relevant temperature window. Temperature-dependent resistivity measurements demonstrate a pronounced increase in PTC intensity upon LA incorporation, with an optimised SEBS/LA ratio yielding the strongest switching response between 20-50 °C. Hot-stage optical microscopy reveals thermally induced microstructural evolution consistent with conductive network disruption and recovery, supporting a morphology-driven PTC enhancement mechanism. The resulting CPC films maintain compliance under bending and twisting and exhibit high temperature sensitivity around physiological temperatures, enabling body-temperature monitoring.

For battery thermal protection, flexible PCCs based on polycaprolactone (PCL) and polyethylene glycol (PEG) were developed to absorb excess heat through latent heat storage near 55 °C. Infrared thermography under electrical loading shows reduced peak temperature and delayed temperature rise when PCC layers are applied, confirming effective passive thermal buffering.

#1683

# Influence of Fiber Architecture on the Mechanical and Acoustic Behavior of Hybrid Composite Laminates

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In this study, hybrid composite laminates combining different fiber types (carbon, glass, natural fibers etc..) and textile architectures were produced using a manufacturing process employing a combination of hand lay-up and vacuum bagging methods. The matrix system was kept constant in all samples, aiming to directly assess the effect on the mechanical and vibro-acoustic behavior of the composites based on fiber properties and architecture. Within the scope of the study, laminates with different stacking arrangements and fiber orientations were designed using woven fabrics, unidirectional (UD) fibers, stitched textile structures, and felt-like fiber forms.

The mechanical behavior of the produced hybrid composites was evaluated using tensile and bending tests. Furthermore, the effects of fiber arrangement, orientation angle, stacking order, and stitching threads in textile structures on mechanical performance were investigated in detail. In addition to mechanical tests, sound transmission coefficient measurements were performed to evaluate the vibro-acoustic performance of the composite structures. These measurements analyzed the role of fiber architecture and textile structure on sound transmission behavior.

The study aims to reveal how different fiber forms and textile architectures affect both the mechanical and acoustic properties of composite materials under the same matrix system. The aim is for the findings to provide a fundamental knowledge base for hybrid composite design in applications where structural performance and sound and vibration control are both important.

#1684

# Development of a Lightweight, Impact-Resistant, and Innovative Composite Photovoltaic Module for Vehicle-Integrated Applications

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This study focuses on the fabrication, integration, and characterization of a lightweight, innovative composite photovoltaic (PV) module system for vehicle-integrated photovoltaic (VIPV) applications. Transparency on the front surface is achieved using a glass fiber–reinforced polymeric composite instead of traditional glass, while the impact resistance of the structure is increased, resulting in greater resistance to hail and similar hazards. This higher impact resistance also provides a significant weight reduction. To take advantage of the high thermal conductivity of carbon fiber, the back protective layer is designed using carbon fiber–reinforced polymer (CFRP) sandwich structures. The sandwich structure provides advantages such as impact absorption and plays a significant role in reducing the weight of the structure. This lightweight, innovative PV structure provides more than a 50% weight reduction compared to traditional structures. The innovative composite PV structures can be produced directly using a vacuum infusion method and integrated into vehicles. This production method allows the integration of innovative PV composite modules into curved and angled surfaces. To examine the resistance of this innovative PV composite module, developed as an alternative to traditional PV structures, to impacts such as hail and mechanical loads, ice drop tests and bending tests were conducted. Light transmittance tests were performed to examine the transparency of the front surface, and DSC tests were conducted to characterize the surface. The interface was examined with an optical microscope after the vacuum infusion process. The findings reveal that this innovative PV composite is promising due to its superior advantages, such as high durability and lightness, in addition to providing the desired transparency.

#1685

# On the development of wood plastic composites with reclaimed raw materials employing 3D printing and injection molding

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Wood plastic composites (WPCs) are widely promoted as sustainable materials for construction applications. However, their production still relies predominantly on primary polymers and high-quality, well-defined wood resources. In parallel, large amounts of construction and demolition wood waste remain underutilised. In Norway alone, more than 90% of wood waste is currently incinerated, whereas only a limited fraction is considered suitable for material recycling.

Recent research increasingly focuses on using bio-based or recycled polymers and various wood waste sources as WPC matrices and fillers. Despite these advances, the industrial implementation of circular WPC concepts remains limited. Key challenges include the lack of harmonised international classification systems for wood waste, the limited availability of consistently defined secondary raw materials, and the predominance of high-grade recycled polymers and wood fractions.

This study addresses the challenge of producing industrially relevant WPCs from mixed construction wood waste and recycled polymers without compromising material performance, processability, or economic feasibility. The objective is to develop a scalable and standardised formulation and processing approach that enables consistent material properties despite fluctuating raw material characteristics.

The methodological approach focuses on the development and evaluation of WPC formulations compatible with both injection molding and extrusion-based additive manufacturing. The formulation parameters are selected to enable processing using both manufacturing methods, enabling a comparative assessment.

Material performance is evaluated using standardised test methods relevant to industrial WPC applications. Various mechanical and physical properties, including the modulus of elasticity (MOE), the modulus of rupture (MOR), and water absorption behaviour, are evaluated in accordance with international standards.

This provides a benchmark for assessing the industrial applicability of WPCs based on secondary raw materials and bio-based polymer matrices. This standards-oriented evaluation enables direct comparison of processing methods and provides a basis for identifying formulation- and process-related limitations for industrial implementation.

#1686

# Forward-thinking sustainability for composites

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Sustainability in composite materials requires a holistic, lifecycle-driven approach rather than isolated initiatives. Considering the full value chain, from raw material sourcing and manufacturing to product use and end-of-life, is essential for making informed decisions and enabling long-term progress toward circularity.

In this keynote, Kim Sjödahl emphasizes that no single company can achieve circularity alone. Meaningful progress depends on collaboration across the value chain, from regulators to customers via researchers, suppliers, and recycling partners. The composites industry has the capability to become significantly more sustainable by aligning efforts, sharing challenges, and embracing openness.

The presentation highlights the importance of allowing multiple recycling and recovery pathways to coexist. No single solution fits all composite applications, and progress comes from coordination rather than competition between technologies.

Transparency is identified as a key enabler of trust and collaboration. Openly sharing data on emissions, waste, and sustainability performance accelerates learning and strengthens collective responsibility across the industry.

Leveraging industrial experience at Exel Composites, Sjödahl demonstrates how principles of circularity are actively being integrated into composite manufacturing processes. Through a review of multiple case studies, Sjödahl highlights the practical challenges and driving motivations behind these efforts, while identifying actionable strategies and priorities - particularly in advancing circular design within the industry.

By aligning industry and academic efforts, composite materials can continue to deliver high performance while evolving toward a more sustainable and responsible future.

#1688

# Sustainable and recyclable thermosets for the automotive, aerospace sectors and beyond

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Thermoset composites allow for lightweight tailored physical-chemical properties, providing multi-functionality and high performance, even in extreme condition applications, across different industrial sectors. Introducing biobased components, developing more efficient processes, exploring reuse and recycling technologies are some of the most innovative routes explored in the field.

The Horizon Europe project REPOXYBLE (www.repoxyble.eu, GA 101091891) applies the Safe and Sustainable by Design concept to develop a new generation of multifunctional epoxy-based components for applications in aerospace and automotive sectors, in use cases such as novel lightweight cars and high speed aircraft. To achieve this, REPOXYBLE consortium includes partners from across the entire material value chain: raw material suppliers, chemical and composite manufacturers, end-users in the automotive and aerospace industries, chemical recycling experts to address end of life issues.

Our contribution will showcase advances in material and process innovations, and circular design approaches such as the chemical recycling of the composites developed (patent pending). REPOXYBLE has driven its research actions in two aspects: 1) new processing additives, models, and an "out-of-autoclave" manufacturing technique reducing the energy for thermoforming more than 80%, in comparison to traditional process; 2) a chemically recyclable depolymerizable epoxy resin system (DLCE), addressing the recycling challenges associated with traditional thermosets usually used for waste-to-energy. REPOXYBLE DLCE makes possible the recovery of reactive building blocks coming from the cleavage of the resins and the carbon fibers reinforcement, to be used in a second life composite, without milling. The reuse of carbon fiber in its full length opens the door to high performance structural applications in a second life, contributing to reducing product environmental footprint.

In summary, we will present a novel methodology for infrared-assisted curing and an optimized epoxy depolymerization process, including a strategy for solvent recovery and reuse.

#1689

# Environmentally Friendly Sustainable Thermoset Vitrimer-Containing Polyrotaxane

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Durable green plastics with extended lifespans have self-healing properties and shape memory andare chemically recyclable and marine biodegradable. These plastics are attracting attention in applications such as adhesives and carbon fiber composite materials. Vitrimers satisfy many of these requirements, interms of reprocessability and self-healing. Herein, we report significant improvements in the properties of vitrimers induced by the ester-exchange reaction between polyester-grafted polyrotaxane (PR) and the ester bonds of epoxy resin vitrimer to achieve the uniform molecular dispersion of PR. The optimal epoxy resin vitrimer incorporated with PR (VPR) exhibited enhanced toughness, with an elongation at break 5.3 timesgreater than that of a vitrimer devoid of PR; it also showed self-healing properties, was chemically recycled 10times faster, and was recovered twice as fast. These results can be ascribed to the sliding diffusion motion of the PR, which lowers the energy required for transesterification. Furthermore, VPR showed 25 wt% biodegradation following exposure to seawater for 30 days. These findings may lead to the development of environmentally friendly plastics that exhibit most of the properties required for a circular economy.

#1691

# Fracture response of 3D printed polyether-ether-ketone through energy-partitioning concept of EWF technique

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3D printing of polyether-ether-ketone (PEEK) PEEK polymer using the Fused deposition modeling (FDM) technique has gained tremendous attention recently due to its several applications in the automotive, biomedical and aerospace sectors. However, several process variables involved with the FDM technique mandate ascertaining the structural integrity of 3D printed PEEK in terms of fusion bonding between deposited filaments. In this direction, the essential work of fracture (EWF) is a novel methodology for characterizing the ductile fracture resistance of thin ductile polymeric sheets using the energy separation principle. Henceforth, the present study is focused on determining the effect of raster orientation on the fracture characteristics of 3D printed PEEK by employing the energy partitioning based EWF approach. Double edge notch tensile (DENT) specimens having a constant thickness and varying lay-ups are subjected to in-plane stress loading and EWF-related parameters are obtained by employing the yielding-based energy partitioning concept. Fracture initiation resistance is highest for 0o raster angle (loading direction parallel to polymer deposition path) followed by +45°/–45° raster angle (loading direction at +45°/–45° to polymer deposition path). The EWF-based parameters establish the influence of raster orientation over fracture initiation energy. Additionally, crack opening displacement (COD) and energy dissipation rate (R∞) parameters are also assessed, and their comparisons are substantiated by obtained EWF results indicating a direct coherence between all the fracture parameters. The present comprehensive analysis prescribes a reliable, feasible, and cost-effective way of investigating the fracture characteristics of 3D printed PEEK for practical employment.

#1692

# Reprocessability of cryogenically aged basalt fiber reinforced polyamide matrix composites used for hydrogen storage in aircrafts

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Reprocessability of cryogenically aged basalt fiber reinforced polyamide matrix composites used for hydrogen storage in aircrafts

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The reprocessability of fiber-reinforced polymer composites after service exposure remains a critical challenge for circular design. In this study, the reprocessability of an additively manufactured basalt fiber reinforced polyamide matrix composite (BFRP), developed for aircraft hydrogen storage applications, is investigated, employing mechanical recycling and simulated lab-based service aging. Two reprocessing routes were followed: (i) direct reprocessing of as-produced material and (ii) reprocessing after cryogenic conditioning.

Following aging and/or reprocessing, the mechanical, viscoelastic, and chemical properties were evaluated by means of tensile testing, Dynamic Mechanical Analysis (DMA), Fourier Transform Infrared Spectroscopy (FTIR) spectroscopy and microscopy. It was found that mechanical recycling led to a pronounced loss of tensile stiffness and strength (up to ~80% loss), whereas FTIR testing revealed minimal chemical degradation, indicating that recycling-induced damage is not governed by macromolecular oxidation or chain scission. Viscoelastic testing showed a moderate reduction in the glass transition temperature values, accompanied by increased damping properties, indicating interfacial weakening and a loss of load-transfer efficiency. Interestingly, cryogenic conditioning prior to recycling partially mitigated the mechanical property loss, while revealing similar chemical signature to the non-conditioned material, highlighting the need to account for service-life-induced damage when designing recycling strategies for structural composites.

Keywords: basalt fiber reinforced polyamide matrix composites, cryogenic aging, additive manufacturing, durability, reprocessing, degradation

#1693

# Closed-form Analytical Modelling of Thick-walled Cylindrical Composite Pressure Vessels with Variable Dome Curvature

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Composite-overwrapped pressure vessels are essential for high-pressure hydrogen storage in the automotive and energy sectors, yet achieving safe and cost-effective storage remains a primary engineering challenge. To accelerate preliminary development, analytical models capable of determining comprehensive stress fields are vital for design optimization and parametric studies. The prevailing technical netting theory, based solely on membrane stresses, is often inadequate as it neglects the critical discontinuity stresses occurring at the cylinder-dome junction. In Type IV pressure vessels, these localised loads can exceed their membrane counterparts, potentially compromising the structural integrity.

This contribution introduces a novel closed-form analytical methodology for predicting stress concentrations due to geometric discontinuities at the junction of thick-walled, laminated composite vessels. Formulated within a layerwise framework, the model is applicable to arbitrary laminate layups and captures the complex interlaminar stress distributions in thick composite shells. By idealizing the vessel as a coupled system subjected to uniform internal pressure and localized edge loads, the framework establishes far-field solutions via layerwise stress functions. The localized stress gradients at the junction are represented by a characteristic decay formulation, where the decay parameters are similarly derived from the material properties of each individual layer.

Unlike existing models that are often restricted to specific regions or symmetric layups, this methodology provides complete 3D stress and displacement fields for generic layup sequences. Comparisons with finite element simulations show excellent agreement across all field variables. For an internal pressure load of 70 MPa, the model identifies transverse shear stresses reaching critical values of up to 60 MPa at the junction, demonstrating the necessity of accounting for bending stresses to ensure reliable prediction of mechanical behaviour.

#1695

# High-performance, conductive and sustainable PA6-based filaments for 3D printing with reclaimed carbon fibres and conductive fillers

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Developing electrically conductive, dimensionally stable polyamide 6 (PA6) filaments from recycled carbon fibres addresses both sustainability and performance demands in advanced polymer composites. Such materials offer a route to valorise end-of-life carbon fibre waste while meeting the growing need for lightweight, conductive components in applications where weight, cost and environmental impact are critical. Conductive, dimensionally stable filaments are particularly relevant for additive manufacturing (Fused Deposition Modelling), electromagnetic interference shielding, embedded sensors and structural electronics, where reliable electrical pathways and low thermal deformation under service conditions are both required. Our goal was to produce an electrically conductive, dimensionally stable polyamide 6 (PA6) filament using reclaimed carbon fibres as the primary reinforcement. The filaments were prepared from PA6 loaded with reclaimed carbon fibres (CF) only, CF combined with carbon nanotubes (CNT), and CF combined with CNT and carbon black (CB). The filament containing only recycled CF exhibited poor electrical conduction. Incorporation of CNT alongside CF markedly improved conductivity, reaching approximately 0.015 S/m. The ternary filler system (CF + CNT + CB) exhibited the best performance, with electrical conductivity of 21 S/m, several orders of magnitude lower than the CF-only formulation and substantially lower than the CF+CNT formulation. Thermomechanical measurements revealed that thermal expansion decreased in parallel with the conductivity in the temperature range of our study. SEM imaging supported these findings by showing a homogeneous distribution of fillers within the PA6 matrix and good adhesion between the fillers and the polymer, indicating effective percolation pathways and mechanical coupling that explain both the electrical and thermomechanical improvements. Combining reclaimed carbon fibres with multi-scale conductive additives yields a PA6 filament with significantly enhanced electrical conductivity and dimensional stability compared with CF-only formulations. The promising results indicate a route for producing value-added, sustainable conductive 3D printing filaments from reclaimed carbon fibres.

#1696

# Environmental trade-offs between durability- and recyclability-oriented composite components for an aircraft hydrogen storage tank

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Aviation contributes approximately 2.5% of the global CO2 emissions and is expected to double or quadruple by 2050. As a response to this, the aviation industry is now shifting towards battery-electric or hydrogen-powered aircrafts. For hydrogen-powered aircraft, a strong and lightweight storage tank is essential. Therefore, the industry is currently researching the use of multilayered composite structures for this purpose.

The aim of this study is to assess the environmental trade-off when designing for sustainability or designing for recycling using life cycle assessment (LCA). A representative component of a composite hydrogen storage tank has been selected for the study. Two design strategies will be compared: a durability-oriented design where material properties were maximized, and an environmentally oriented design where the material is recyclable and considered more environmentally friendly.

The material properties and necessary conditions for this component will be used to create the functional unit of the study. The study will consider the full life cycle to see where the different scenarios will have the largest impacts and how they affect the total life cycle phases. Emphasis will be placed on the material selection, manufacturing process, and end-of-life scenarios. From this, the trade-offs between durability-oriented and recycling-oriented scenarios can be identified.

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#1697

# Data-Driven Optimisation of Composite Laminates Using Multi-Objective Bayesian Optimisation (MOBO)

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The challenge when designing composite structures is often there are competing performance objectives governing structural behaviour. This behaviour is complex and computationally expensive to run numerous nonlinear finite element simulations. This work presents a data-efficient, physics-informed Bayesian optimisation framework for the design of Carbon Fibre Reinforced Polymer (CFRP) laminates, with a focus on capturing both peak load capacity and post-failure stability. High-fidelity finite element simulations were conducted in Abaqus to model the mechanical response of symmetric CFRP laminates under short beam shear loading, with reaction forces extracted to characterise structural performance. Two performance metrics were defined: (i) peak load prior to failure, and (ii) load drop following peak, used as a proxy for damage tolerance and stability. These objectives are inherently competing, motivating a multi-objective optimisation approach. A physics-guided feature engineering strategy was adopted, encoding laminate layups using domain-relevant descriptors such as ply orientation fractions, interface transitions, and surface ply angles. Gaussian process surrogate models were trained on a limited initial dataset, of 20 random layups, enabling accurate prediction of laminate performance with quantified uncertainty. Multi-Objective Bayesian Optimisation was then implemented using Expected Hypervolume Improvement (EHVI) to efficiently explore the design space and propose batches of high-value candidate layups to simulate next. The framework successfully identifies Pareto-optimal laminate configurations, demonstrating the ability to simultaneously maximise load capacity while minimising post-failure degradation. Results show strong agreement between surrogate predictions and finite element simulations, despite the small training dataset, highlighting the data efficiency of the approach. This work establishes a scalable foundation for the optimisation of more complex composite structures, such as corrugated sandwich panels under impact loading, and illustrates the potential of Bayesian, physics-informed machine learning for accelerating composite material design.

Keywords: Composite laminate design; Finite element simulation; Physics-informed Bayesian optimisation; Gaussian Process surrogate modelling; Multi-objective optimisation.

#1699

# Effects of polymer molecular weight on the performance of overmoulded parts

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Thermoplastic composites (TPCs) are increasingly replacing metal parts because of their high strength-to-weight ratio, formability, and recyclability, making them well suited to high-volume production. A key challenge emerges when moving from individual components to integrated assemblies. Overmoulding, which combines thermoforming and injection moulding, enables large-scale manufacture of multi-material structures. However, achieving strong interfacial strength, governed by fusion bonding, is critical; understanding the process is therefore essential to produce reliable, high-performance components.

Investigating the factors that influence bond strength is necessary to deliver robust and accurate manufacturing predictions. Previous work established a methodology to evaluate interfacial bond strength in an industrially relevant 450 mm overmoulded ribbed beam. The present study builds on this approach by examining in detail the effects of interface temperature and polymer grade, specifically fibre content and molecular weight, on bond strength. Molecular weight, or chain length, controls both the rheological behaviour and mechanical performance of the melt, but often introduces a trade-off between processability and structural properties. De Gennes showed that even small variations in molecular weight can markedly alter healing rates, while reductions in chain length are also associated with lower strength and toughness.

To investigate these effects, a comprehensive study is performed using a bio-based polyamide PA410 resin (EcoPaXX®) supplied by Envalior (Netherlands). Injection-moulding compounds with two molecular weights (32MW and 43MW) and two glass fibre contents (30 wt% and 50 wt%) are examined. The insert consists of unidirectional tape with 60 wt% glass fibre. A full-factorial design of experiments is used to assess the influence of interface temperature, molecular weight, and fibre content. Bond strength is measured using T-rib pull-off specimens using a bespoke clamping fixture in addition, microscopic analysis is performed to identify dominant failure modes.

#1700

# Bridging Numerical Simulations and Non-Destructive Inspection with Image Processing Analysis: A Paradigm of a Certification by Analysis Procedure for Thermoplastic Composite Fuselage Panel

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Certification by Analysis (CbA) methodology has gained ground lately towards the development of large composite structures, while reducing design and manufacturing costs with the replacement of robust numerical modelling calibrated from base experimental procedures. The Finite Element (FE) technique is quite common for numerical description of materials and structures, whilst Non-Destructive Inspection (NDI) enables the investigation of damaged footprint upon testing. Although these two methodologies co-exist in CbA approaches, they are not straightly connected, and engineers only phenomenologically compare FE results with NDI evidence, with screenshots that deviate per color palettes, scales and characteristics, which makes the comparison tough and arbitrary.

Towards this mismatch, two novel mathematical indicators to quantitative compare FE results to Digital Image Correlation (DIC) displacement fields and Acoustic Emission (AE) damage propagation indices are developed using Image Processing Analysis algorithms with RGB filtering. Specifically, a Root Mean Square Error variable stores the average of the difference of displacement value encrypted in each pixel of the displacement field of the two cases (FE and DIC) which are categorized from the color scale. Then, a damage density function, calculated from the damaged elements in each step of FE analysis divided by the total damaged elements in the last step, is straightly compared to the normalized AE event counts.

Several paradigms are extracted from a completed Certification by Analysis procedure of a novel Carbon Fiber Low Melt PolyArylEtherKetone (CF-LMPAEK) thermoplastic composite fuselage panel design process and specifically from three group of tests: skin to stiffener joint, skin to stiffener and frame and final multistiffened fuselage panel under compression loads. It is also shown that these indicators can work as design variables if used in the material characterization level of the material, since they provide important information towards the calibration of material models.

#1701

# Smart and repeatable easy-repairing composites enabled by thermoplastic interleaves

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Fibre-reinforced polymer composites are increasingly adopted in lightweight structural applications due to their high specific strength and stiffness. However, their susceptibility to barely visible impact damage and interlaminar delamination remains a major limitation, often leading to conservative design, costly inspection, and premature component replacement. Conventional repair strategies are labour-intensive, irreversible, and difficult to automate, highlighting an urgent need for smart composite systems that enable efficient, reliable, and repeatable repair while preserving structural performance.

In this work, we present a class of smart and repeatable easy-repairing composite laminates enabled by thermoplastic interleaving strategies. Building on a series of studies using thermoplastics for damage-tolerant and easily repairable composites, we develope a new generation of interleaved laminates capable of repeatable self-healing after delamination failure. Thin thermoplastic interleaves are strategically introduced at selected ply interfaces within fibre-reinforced epoxy laminates, forming a responsive interphase that can be reactivated through controlled thermal stimuli.

Mechanical testing shows that interlaminar fracture toughness and residual mechanical properties can be substantially recovered after consecutive damage cycles, with healing efficiencies maintained almost 100% over multiple damage-repair cycles. Microscopic and electrical characterisation reveal that the healing mechanism is governed by thermoplastic softening, inter-diffusion, and re-establishment of interfacial load transfer, without compromising laminate integrity. Importantly, the repair process is rapid, localised, and compatible with scalable heating approaches, offering clear advantages over traditional bonded or patch-based repairs.

The results demonstrate a viable pathway towards smart, reusable, and sustainable composite structures, where damage tolerance and repairability are designed into the laminate architecture. This approach opens new opportunities for extending component lifetime, reducing maintenance costs, and supporting circular design strategies in high-value composite applications.

#1702

# Mechanical Characterization of Sheet Moulding Compounds: Effects of Strain Gauge Width and Strain Rate

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Sheet Moulding Compound (SMC) composites offer high specific strength, stiffness, energy absorption, and exceptional design flexibility, making them highly promising for electric vehicle (EV) components such as battery enclosures, crash structures, and underbody panels. These advantages contribute to significant structural weight reduction while maintaining mechanical performance. Despite their industrial relevance, the complex microstructure of SMC composites, characterized by random fibre orientation, fibre length variability, fibre curvature, and fibre bundling, poses significant challenges for accurate representation in constitutive material models and reliable structural simulations.

The primary objective of this study is to advance the constitutive characterization and model calibration of high-performance glass fibre-reinforced SMC composites for energy absorbing structures through systematic mechanical testing under quasi-static and intermediate strain-rate conditions, while also assessing the influence of specimen size on the measured mechanical response. An initial experimental study was conducted to evaluate the effect of coupon geometry and gauge width on tensile stiffness, strength, and failure mode, providing insight into size-dependent behavior and representativeness of the material response.

Tensile tests were then performed at two strain-rate regimes: quasi-static (0.001 $s^{-1}$) and intermediate (0.1–10 $s^{-1}$), using servo-hydraulic test frames. These experiments enable the assessment of strain rate-dependent stiffness, strength, and failure mechanisms across loading conditions relevant to automotive crash and service scenarios.

Full-field deformation measurements were obtained using Digital Image Correlation (DIC) coupled with high-speed optical imaging. A Photron SA-Z camera system, operating at frame rates up to 240,000 fps, was used to capture strain localization, damage initiation, crack propagation, and fracture evolution.

The experimental data generated in this work provides a robust foundation for developing and validating size and rate-dependent constitutive models for SMC composites. Ultimately, this study contributes to improved predictive capabilities for the structural design and optimization of lightweight EV components.

#1703

# Orthogonal Cutting of Unidirectional CFRP Composites: Experimental Data and Numerical Modelling

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Composite materials such as Carbon Fiber Reinforced Polymers (CFRPs) are increasingly adopted in the aerospace and automotive industries due to their excellent specific mechanical properties. However, the machining of CFRPs remains a major technological challenge due to their heterogeneous microstructure, anisotropy and the complex damage mechanisms generated during cutting. In this study, an integrated experimental–numerical approach is proposed to investigate and predict damage mechanisms during the orthogonal cutting of unidirectional carbon/epoxy composite laminates. Orthogonal cutting is employed as a simplified and representative configuration of drilling operations, allowing a clearer analysis of tool–material interactions and associated mechanical phenomena. The experiments were conducted under various cutting conditions, including different depths of cut, feed rates, and fiber orientations, providing valuable insights into cutting forces and damage patterns. Based on the experimental results, a three-dimensional finite element model is developed using Abaqus/Explicit. A user-defined material subroutine (VUMAT) is implemented to capture the progressive damage behavior of the composite material. Damage initiation is governed by the Hashin failure criteria, accounting for fiber tension, fiber compression, matrix tension and matrix compression modes. Damage evolution is described using an energy-based exponential softening law, enabling a realistic representation of stiffness degradation and material removal during machining processes under cutting conditions. Numerical results show good agreement with experimental data and clearly highlight the significant influence of fiber orientation on cutting forces and damage mechanisms. Overall, the proposed VUMAT-based approach demonstrates strong predictive capabilities and provides valuable insights for optimizing cutting parameters and improving the modelling of tool–material interaction in composite machining.

#1706

# Smart Composites that Heal and Sense: Intrinsic Multi-Cycle Self-Healing with Damage Mapping

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This work presents the development of advanced smart multifunctional composite materials with intrinsic multiple self-healing cycles and self-sensing damage-mapping capabilities. The main objective was to design composite systems capable of autonomously recovering damage while simultaneously monitoring their structural integrity through electrical sensing methods. An intrinsic self-healing approach was adopted through the fabrication of polymeric films based on bismaleimides (BMI) with three distinct molecular weights, enabling systematic investigation of the influence of molecular architecture on healing efficiency and functional performance. To enhance compatibility and performance within composite structures, the BMI-based polymeric films were further optimized through nano-modification. This strategy facilitated their effective integration into quasi-isotropic fiber-reinforced composite materials, allowing for the simultaneous recovery of mechanical properties and electrical properties after damage and healing. The two functionalities of the developed composite systems were quantitatively assessed through repeated low-velocity impact tests followed by controlled healing procedures. Impedance spectroscopy was employed to study the electrical behavior of the materials and to assess changes associated with damage and subsequent three healing cycles. Structural characterization and damage identification were conducted using Infrared thermography (IR-T) and phased array C-scan inspection, allowing for non-destructive evaluation of damage, healing quality assurance, and structural changes identification after the healing cycles.

#1710

# Direct Integration of Electrospun Nanofibers in FDM-Printed Filter Structures

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This study demonstrates an automated manufacturing approach for functional filtration structures by integrating electrospinning with 3D FDM printing. PAN nanofibers are electrospun onto PLA structures during printing using a custom mounting fixture, creating self-supporting filter geometries in a continuous process. To analyse mechanical properties, a tensile test was conducted according to ISO 527-2 shows that neat PLA achieves 52 MPa tensile strength and 2.1 GPa Young's modulus, while PLA with integrated nanofibers reaches 75 MPa strength and 2.9 GPa modulus, representing 44.2% and 45% improvements. SEM analysis confirms complete nanofiber-matrix integration with adequate interfacial bonding. Prototype filters demonstrate the feasibility of producing complex geometries with integrated nanofiber membranes in a single automated process, eliminating manual nanofiber membrane handling and assembly. This approach enables rapid fabrication of custom filter designs with controlled frame geometry and membrane placement for various filtration applications.

#1711

# Design and Qualification of Large-Scale Composite Aquaculture Structures for Offshore Marine Environments

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The Aquafarm NEOM project represents a significant advancement in the design and qualification of large-scale closed aquaculture systems utilizing composite materials. Building upon the Neptun 4.0 (N4) concept, the updated Aquafarm (AF) design introduces structural simplifications, modular outfitting, and enhanced material specifications, while maintaining comparable dimensions and biomass capacity. This paper outlines the design basis and qualification strategy developed to ensure compliance with several standards, including NS 9415:2021, NYTEK23, and DNV-ST-C501, with particular emphasis on glass-reinforced plastic (GRP) components.

The AF structure is classified within Reliability Class 3 and Safety Class High, reflecting its operational exposure and criticality. A comprehensive qualification plan was implemented to address documentation gaps between N4 and AF, encompassing metocean analysis, structural and hydrodynamic assessments, material and joint testing . FEM-based evaluations of static, dynamic, and buckling behaviour were conducted using updated ANSYS models, incorporating harmonic equivalent wave responses derived from environmental contour methods.

Key elements of the work include employing both dry and fully saturated material properties for composite failure assessment, integrating updated slamming load models, and coupling frequency-domain hydrodynamic data computed using linear radiation–diffraction theory with structural simulations. The AF design also introduces a roof structure and revised inlet configurations, requiring additional local capacity checks and mooring analyses.

This work demonstrates a robust methodology for qualifying composite aquaculture structures under demanding marine conditions, supporting future deployment in both the Red Sea and Norwegian waters. The approach ensures structural integrity, escape prevention, and regulatory compliance, setting a precedent for the next generation of large sustainable aquaculture infrastructure.

#1712

# Development of Flax Fiber Composites Fabricated Using Preforms Prepared via TuFF (Tailored Universal Feedstock for Forming)

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The use of natural fibers (e.g., flax, hemp, and jute) as reinforcement in composite materials has increased significantly in recent years due to their competitive specific properties, good damping behavior, and renewable production cycle. Despite these advantages, several limitations still restrict their broader application, including the intrinsic discontinuity of the fibers and difficulty in achieving consistent fiber properties. In order to convert natural fibers into a composite preform, it is common for fibers to be spun into yarns that can be used for further processing into woven fabrics. The yarn structure can reduce the packing efficiency of the fibers, introduce local misorientation, and affect resin impregnation into the fabric.

In the study, the Tailored Universal Feedstock for Forming (TuFF) process was employed to align discontinuous natural fibers and fabricate preforms with tailored architectures suitable for further composite processing, without first converting the fibers into yarns. The use of discontinuous short fibers provides enhanced formability, as the fibers can reorient and conform within the polymer matrix. By leveraging the TuFF alignment process, various types of aligned discontinuous flax fiber–based preforms were produced.

Epoxy-based polymer composites were subsequently manufactured from the prepared preforms using a modified Resin Transfer Molding (RTM) technique. The microstructural and mechanical properties of the resulting composite structures were characterized using appropriate microscopy and mechanical testing methods. The results indicate that the aligned discontinuous flax fiber/epoxy composites exhibit improved tensile performance compared to non-aligned configurations, demonstrating the effectiveness of the TuFF process in controlling fiber architecture. The microstructural features and mechanical behavior of the developed composites are discussed.

#1713

# Graphene-enhanced Thermoplastic and Elastomer Nanocomposite Systems for High-end Solvent and Gas Barrier Applications

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Fluoropolymers, such as polytetrafluoroethylene (PTFE) and fluoroelastomer (FKM), offer exceptional barrier properties in high-performance sealant applications. However, current health-related legislation in the UK and the EU restricts the use of most fluoropolymers. In this study, we synthesized two distinct types of highly segregated nanocomposites as potential replacements for PTFE and FKMs, respectively: (i) ultrahigh molecular weight polyethylene (UHMWPE) and graphene nanoplatelet (GNP) nanocomposites, and (ii) nitrile butadiene rubber (NBR)/GNP nanocomposites, incorporating different GNP concentrations (between 0.5 and 10 wt.%).

To investigate the microstructure of the nanocomposites, a comprehensive micro-CT analysis and AI-assisted segmentation of scanning electron microscopy (SEM) images were performed. The physical and chemical properties of the nanocomposites were characterized using FTIR, DSC, and XRD. Mechanical performance was analyzed via DMA and tensile testing. Barrier properties were evaluated through toluene solvent uptake tests, while gas permeability was investigated using $CO_2$ in a custom low-pressure apparatus.

The results revealed that mechanical and barrier properties depended more strongly on the fractional GNP coverage of the UHMWPE particles than on the bulk concentration, and on the homogenous dispersion of the GNPs in the NBR nanocomposites. Furthermore, the controlled dispersion of GNPs on the surface of polymer particles led to substantial improvements in properties, even at low GNP concentrations. For instance, the diffusion coefficient for toluene and xylene uptakes decreased by up to 25% in both systems, and $CO_2$ permeability was reduced by up to 30% with a loading of only 1 wt.% GNPs. This enhanced performance was attributed primarily to high fractional GNP coverage on individual polymer granules in the UHMWPE/GNP nanocomposites and to homogeneous dispersion within the NBR systems. Consequently, the results demonstrate significant potential for these nanocomposites in sealant applications as potential replacements for PTFE and FKM.

#1715

# Biobased Epoxy Resins for High Temperature Application: Machine Learning-Guided Design of Biobased Resins

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Biobased Epoxy Resins for High Temperature Application: Machine Learning-Guided Design of Biobased Resins

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Epoxy resins are essential in modern polymer science due to their excellent mechanical strength, adhesion and versatility in high performance composites. However, most commercial epoxies are derived from Bisphenol A (BPA), a compound associated with negative environmental and toxicological concerns. To address these issues, this work adopts a green-by-design approach to develop bio-based epoxy resins from renewable and environmentally benign precursors while targeting thermomechanical performance comparable to BPA-based resins.

Aromatic biobased pre-cursors are particularly promising, as their rigid structures can yield glass transition temperatures similar to petroleum-derived epoxies. To accelerate material development, machine learning(ML) is employed to predict the Tg direct from molecular structure. A curated dataset of experimentally reported epoxy systems is used to train models such as Random Forest Regression, enabling identification of key structural features influencing thermal properties.

Initial predictions indicate that epoxy systems incorporating moieties containing anhydride and phenolic components exhibit high Tg values of 137$^{o}$C and 133,53$^{o}$C, respectively, when cured with anhydride based hardeners. While the results are derived from secondary datasets focused primarily on Tg, ongoing works aims to improve model accuracy by expanding the datasets and transitioning toward Gaussian process models. Overall, this study demonstrates the potential of integrating data-driven modelling with experimental in the design of high-performance, sustainable epoxy resins.

References

[1] Zhang Y., Xu X.: Machine learning glass transition temperature of polymers, Heliyon, Vol. 6, No. 10, 2020, e05055.

[2] Tao L., Varshney V., Li Y.: Benchmarking Machine Learning Models for Polymer Informatics: An Example of Glass Transition Temperature, Journal of Chemical Information and Modeling, Vol. 61, No. 11, 2021, 5395-5413.

#1716

# Adaptive Divergence-Guided Multi-Head and Multi-Task Learning for Efficient Photometric Stereo–Based Carbon Fiber Defect Inspection

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Carbon fiber materials (CFMs) are increasingly adopted across high-performance industries due to their exceptional stiffness-to-weight ratio and directional mechanical properties. However, manufacturing defects and deviations in fiber orientation can significantly degrade structural performance, making reliable inspection essential. Despite advances in automated inspection, industrial quality control still largely relies on manual visual assessment, owing to the anisotropic reflectance of CFMs and the low contrast between defects and surrounding material.

Photometric stereo, which estimates surface normals using multi-directional illumination and a single camera, has emerged as a powerful tool for CFM inspection by enabling dense fiber orientation estimation. However, deploying deep learning models for automated analysis introduces challenges, including domain and distributional shifts across manufacturing conditions. While attention-based architectures—global, local, or self-attention—have been proposed to address these issues, they often yield marginal accuracy gains at the cost of increased computational complexity and reduced inference speed, limiting real-time industrial deployment.

To address these constraints, this work proposes a lightweight multi-head convolutional neural network for industrial CFM inspection with an adaptive focal loss. The key contribution is an adaptive focus parameter ($\gamma$), dynamically computed from similarity measures between the probability mass functions (PMFs) of each classification head. Jensen–Shannon divergence quantifies inter-head agreement and guides loss re-weighting, encouraging complementary learning without expensive attention mechanisms.

The proposed framework is extensively validated on a publicly available CFM inspection dataset. Comparative benchmarks against prior state-of-the-art methods, including attention-augmented multi-head baselines, demonstrate an accuracy improvement exceeding 5%. Comprehensive ablation studies further evaluate alternative divergence metrics, including Kullback–Leibler divergence, Total Variation distance, Hellinger distance, and Wasserstein distance, confirming the robustness and effectiveness of the proposed approach. The results highlight a practical pathway toward accurate, efficient, and scalable AI-driven inspection systems for composite manufacturing.

#1722

# Development and Characterization of a Novel Semi-Bio-Based Thermoset System for High-Stiffness Flax Composites.

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The development of sustainable structural materials requires bio-based resins that match the processing versatility and mechanical rigidity of traditional synthetic systems. This research investigates a novel thermoset system synthesized from citric acid, glutaric acid, and glycerol triglycidyl ether (GTE). A primary achievement of this formulation is its rheological suitability for composite manufacturing using resin infusion. The resin exhibits a viscosity profile that allows for successful vacuum infusion at a lower temperature with a suitable pot life, a significant advantage over many bio-based alternatives that require elevated temperatures and possibly shorter time and for effective impregnation. Thermal characterization and curing optimization identified the suitable temperature for achieving a robust cross-linked network. The post-curing stage was further analysed in two-hour increments to determine the optimal duration for maximizing the glass transition temperature (Tg) and mechanical stability. Tensile testing of the neat resin confirmed that the citric-glutaric chemistry yields a high-stiffness matrix with performance characteristics comparable to established commercial semi-bio-based epoxies, despite the significantly higher renewable content of the proposed system. The resin was utilized to manufacture composites reinforced with woven flax fabrics via vacuum-assisted resin infusion. A critical component of the study involved evaluating the fibre-matrix interface through single-fibre pull-out tests. This analysis compared the interfacial adhesion of untreated flax fibres against those subjected to an alkalization treatment. It was observed that the alkalization of the woven flax successfully improved the interfacial bonding, enhancing the compatibility between the hydrophilic lignocellulosic fibres and the organic acid-based matrix. The results demonstrate that this citric-glutaric-GTE system provides an infusion-ready, high-performance solution for natural fibre composites, offering a viable pathway for structural components in the automotive and sports-equipment sectors.

#1725

# Thermomechanical shear characterization of Flax/PP composite laminates under thermoforming conditions: from experiment to simulation

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This study aims to enhance the understanding of the formability of spread-tow woven flax fibre-reinforced polypropylene (Flax/PP) composite laminates under thermoforming conditions by investigating their in-plane shear behaviour at elevated temperatures. Natural fibre-reinforced thermoplastic composites such as Flax/PP are increasingly attractive for industrial applications, particularly in the automotive sector, owing to their environmental benefits, low density and cost effectiveness. Despite this growing interest, their thermomechanical behaviour during forming processes remains insufficiently characterised, especially under conditions relevant to thermoforming. To address this gap, a combined experimental and numerical investigation was carried out. The in-plane shear behaviour was characterised using bias-extension tests conducted at three temperatures (167, 172 and 182 °C) and three displacement rates (10, 100 and 250 mm/min). These temperature levels were selected to represent typical thermoforming conditions based on the material's melting and degradation behaviour identified through thermal analysis. A dedicated experimental fixture was designed to enable preheating within an oven and rapid specimen transfer, thereby ensuring consistent thermal conditions during testing. Full-field strain and deformation measurements were obtained using three-dimensional digital image correlation, allowing accurate evaluation of local shear deformation across the specimens. To complement the experimental programme, a finite element model incorporating a temperature- and rate-dependent hypo-elastic shear formulation was developed. The material parameters were identified by minimising the least-squares error between experimental and numerical force–shear angle responses. The calibrated material model was subsequently implemented in ABAQUS/Explicit via a VUMAT user subroutine to simulate the bias-extension tests. The results indicate that temperature has a markedly greater influence on the in-plane shear response of the Flax/PP laminates than the applied displacement rate. Good agreement between the experimental measurements and numerical predictions demonstrates the capability of the proposed model to accurately capture the thermomechanical shear behaviour of the material during thermoforming.

#1728

# Manufacturing CF/PEEK composites by laser-assisted tape placement with elevated tool temperature for crystallinity and interphase control

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The optimisation of process parameters in laser-assisted tape placement (LATP) for CF/PEEK composites has been widely studied; however, controlling the final composite properties, including crystallinity and the fibre–matrix interphase, remains challenging because of the inherently rapid heating and cooling rates. In this work, we demonstrate the feasibility of using a heated tool to regulate crystalline morphology and the associated properties by maintaining the tool temperature within the crystallisation range of the matrix. Increasing the tool temperature to 200 °C enlarged the average spherulite size from approximately 1.5 μm to 3.2 μm and increased crystallinity by about 10%. The study also shows that, in LATP without a heated tool, the tape surface temperature can drop by up to 100 °C between the nip point and the exit of roller compaction. By contrast, when the tool temperature was set to 200 °C, the temperature drop was limited to approximately 35 °C, owing to the reduced temperature difference between the incoming tape and the substrate prior to the nip point. This improved thermal profile promoted polymer diffusion, reduced interlaminar void content, and enhanced crystallisation. Transmission electron microscopy further confirmed the formation of a distinct diffusion region at the elevated tool temperature (200 °C), characterised by intermediate oxygen and carbon concentrations between the fibre and matrix, showing similar charactersitics compared with the autoclave processed composites. These microstructural changes in crystalline morphology, void distribution, and fibre–matrix interphase substantially increased the interlaminar shear strength of the CF/PEEK composites.Overall, these findings provide new insights into improving the performance of CF/PEEK composites manufactured by LATP through microstructure control. In particular, introducing a heated tool offers an additional energy input that mitigates the effects of rapid heating and cooling without requiring major modifications to the LATP process.

#1730

# A novel approach for equivalence of Quad-DD laminates

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Composite laminates have been exploited for many practical engineering applications due to their lightweight and high strength and stiffness capabilities. One of the most important design issues is the laminate stacking sequence. Over the last decades, the quadriaxial (QUAD) layup has been dominant for composite structures, which one can have plies oriented at 0º, ±45º, and 90º, and follows the well-known ten percent rule. Despite the undeniable importance of QUAD for composite popularity, some drawbacks have been pointed out regarding the design methodologies adopted for this family of laminates. Alternatively, a new family of laminates named Double-Double (DD) was recently proposed with promising advantages when compared with traditional QUAD, mainly regarding homogenization and optimization [2]. DD are constituted of double-helix plies, ±ϕ and ±ψ, where these angles are continuous variables that range between 0º and 90º. In the present study, a novel approach is derived to demonstrate that QUAD and DD can have exactly the same inplane stiffness (based on the V1*-V2* domain) and flexure stifness (based on the W1*-W2* domain) for most cases, independently of the material properties. For hard laminates, when the QUAD has at least 50% of the plies orientated at 0º or 90º, the inplane stiffness equivalence is approximate. The failure envelopes in the normal strain space are also obtained using the Tsai-Wu failure criterion, demonstrating that DD have a higher strength than QUAD for both CFRP and GFRP.

#1733

# Depolymerized biorefinery lignin as a sustainable precursor for epoxy thermosets

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The shift to a circular economy has intensified global interest in lignocellulosic biomass as a sustainable alternative to fossil-based polymers. Finland produces large volumes of technical lignin as a by-product of pulp and biorefinery operations. However, its value is always underestimated due to its complex structure and heterogeneity. As the second most abundant biopolymer, lignin offers significant potential in material chemistry and polymer science. In this study, industrial Oat husk and spruce lignins were investigated as renewable feedstocks for epoxy thermoset systems. Catalytical depolymerization and solvent fractionation were applied to reduce its complexity and improve functional uniformity. The tailored lignin fractions exhibited an increased phenolic OH content and a lower molecular weight (Mw) compared to unfractionated lignin, as confirmed via quantitative 31P NMR and high-performance size exclusion chromatography (HPSEC). Epoxy matrices were prepared via optimised glycidylation reaction applied to lignin fractions, with optimal reaction conditions to minimise the use of complicated chemicals while controlling adverse effects. The epoxy functionalized lignin fractions were characterised using 31P NMR, 1H NMR, 13C NMR and HPSEC. Thermal curing was performed using Jeffamine D-430, and the thermomechanical performance of cured epoxy resins was evaluated by thermogravimetric analysis (TGA), differential scanning calorimetry (DSC), and tensile testing. The results demonstrate that fractionated and depolymerised lignins show improved epoxy content, curing behavior and enhanced thermomechanical performance compared to unfractionated lignin-based systems. These findings highlight the potential of tailored industrial lignin streams as sustainable epoxy components for advanced thermoset applications.

#1734

# Influence of Lattice Designs on the Microstructure of Additively Manufactured Precipitation hardeneable Al-Cu-Li Alloys.

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The geometrical freedom of the Laser powder bed fusion (PBF/LB-M) process enables the printing of lightweight engineered lattices such as strut-based lattices (e.g., FCC, BCC derived) and triply periodic minimal surface (TPMS) lattices (e.g., gyroid and diamond). These provide high stiffness to weight ratio, tailorable energy absorption, and permeability while reducing material usage. Among the materials available for PBF/LB-M lattice manufacturing, Al–Cu–Li alloys are attractive for high strength and lightweight applications. The high strength property is derived from precipitation strengthening contributions from phases such as T1(Al2CuLi), TB (Al7.5Cu4Li) or S(Al2CuMg). Current studies on PBF/LB-M manufactured lattices have primarily focused on macroscopic properties and geometric fidelity and have been limited to a few alloys such as Al-Si and Ti-based alloys. Since the localized thermal behaviour is strongly geometry dependent (strut inclination, node mass, and TPMS curvature), heat flow, melt-pool stability, as well as cooling/reheating cycles could produce location specific precipitation microstructure and grain morphology. Lattice architectured design could therefore be used to control and tailor microstructure formation in lightweight and precipitation hardenable alloys such as Al–Cu–Li alloys. This work presents a comparative microstructure study where the influence of PBF/LB-M produced lattice structures (FCC and TPMS) on the microstructure of two precipitation hardenable Al–Cu–Li alloys is investigated. The influence of uniform and varying strut thickness, strut inclinations of different angles (60°, 65°, 70°) and TPMS geometries on the microstructure is presented alongside with analysis of characterized precipitation microstructure as correlated with varying Cu/Li ratio, Zr content of the investigated alloys.

#1735

# Recyclable and reprocessable NIPTU/MWCNTs composite

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Polyurethanes (PUs) are widely used polymers thanks to their versatility and adjustable properties. However, conventional PU synthesis relies heavily on toxic isocyanates, raising significant environmental and health concerns. Isocyanate-free polyurethanes (NIPUs), which are obtained from the reaction between cyclic carbonates and amines, have therefore emerged as a sustainable alternative. When cyclic thiocarbonates react with amines, they yield an isocyanate-free polythiourethane (NIPTU) containing a thiol group.

Alongside the search for environmentally friendly synthesis routes, the development of reusable and recyclable polymer networks has become a key focus in the field of sustainable materials research. Adaptive covalent networks (CANs), which incorporate dynamic covalent bonds that enable self-repair and remodeling while ensuring the material is fully recyclable, have attracted considerable attention. In particular, thiol-containing polymers crosslinked by disulfide bonds offer a robust and reversible mechanism for network reorganization under thermal or chemical stimuli without significant loss of mechanical or thermal properties.

Incorporating multi-walled carbon nanotubes (MWCNTs) improves the mechanical properties of materials while introducing advanced functionalities, such as electrical conductivity and thermal stability. This combination of mechanical strength and electrical conductivity is particularly important in fields such as energy storage, coatings and electronics.

Therefore, this study has developed an environmentally friendly, reprocessable and recyclable composite material based on a NIPTU matrix reinforced with MWCNTs. The mechanical, electrical, and reprocessability properties of the composite have been studied in depth over several reprocessing cycles.

#1745

# Multi-scale structural analysis of pultruded carbon fiber composites using Small and Angle X-Ray Tensor Tomography

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Pultruded carbon fiber composites are high-performance, hierarchical materials widely used in sustainable energy, transportation, and structural applications. Their physical properties are directly related to the material's hierarchical structure, which is influenced by their processing parameters. A detailed understanding of the hierarchical structure and its correlation with physical properties would further enable the optimization of material processing for targeting desirable applications.

Scanning Small-Angle X-ray Scattering (sSAXS) imaging, where a sample is raster-scanned through a focused X-ray beam, is well-suited for the investigation of hierarchical composite materials, as it records a full scattering pattern at each scan position, providing statistically representative information on the nanostructure. When combined with a tomographic acquisition (scanning images taken at different rotations and tilts), this approach gives rise to Small Angle X-ray Scattering Tensor Tomography (SASTT).

In this work, synchrotron SASTT is employed to retrieve the material's structure across different length scales. The tensor reconstruction in each volume unit (voxel) enables the representation of the reciprocal space map and retrieves 3D structural orientation throughout the entire sample volume [1,2]. Thus, making SASTT an ideal method for 3D analysis of composite hierarchical structures, such as the density of fibers, porosity, defects, alignments, and polymer matrix.

Two pultruded carbon fiber composite samples, manufactured under different processing conditions, were characterized at the cSAXS beamline at the Swiss Light Source. The reconstructions at different length scales were obtained with the Mumott software package [2,3], which results in a modelled full 3D reciprocal space map for each voxel for different length scales. Furthermore, the degree of orientation, the main orientation, and the misalignment of the scatterers throughout the full composite volume are obtained.

The hierarchical structure analysis ultimately enables the investigation of how different processing parameters influence the internal structure of the composites and thus, their performance.

#1747

# Characterising damage mechanisms of CFRP laminates under high-strain-rate loading and extreme temperatures using synchrotron X-ray imaging

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Carbon-fibre-reinforced-polymer (CFRP) laminates offer high specific stiffness and strength, favourable fatigue performance, corrosion resistance and desirable tailorability, leading to widespread adoption in aerospace structures. However, understanding and predicting their behaviour under impact remains a challenge because damage is anisotropic and the polymer matrix is strongly rate-/temperature-dependent. The present work characterises the coupled mechanical response and damage mechanisms in [±45]4s CFRP laminates subjected to high-strain-rate uniaxial compression at temperatures from 23 to -50 ℃.

An experimental setup and accompanying data analysis procedure were devised to bridge global mechanical response and local 3D strain fields with meso- to micron-scale damage processes under high-rate loading imposed using a modified split-Hopkinson pressure bar (SHPB) system. Specifically, the methodology combined in-situ X-ray phase-contrast imaging (XPCI) for time-resolved damage observation with pre-/post-loading X-ray tomography for digital volume correlation (DVC), complemented by conventional strain-gauge measurements.

It was found that, compared to room temperature, low temperatures reduce the strain to damage initiation and promote a more abrupt matrix-dominated fracture response, consistent with reduced molecular mobility and increased relaxation times in epoxy resins. Despite the difference in time scale, damage follows a similar development sequence across the tested temperatures: initiating as intra-ply cracking (first observed in surface plies) and subsequently evolving into inter-ply delamination. Importantly, DVC reveals that more pronounced through-thickness and inter-ply shear coupling at low temperatures occurs before the global apparent yield, producing shear localisation cutting through fibres. These observations imply that extracting the lamina shear behaviour from [±45]ns laminates under uniaxial loading, which is often interpreted as near-pure in-plane shear, can be misleading when high strain rates are combined with low temperatures. This can be attributed to the fact that non-uniformity and unsynchronised stress development through laminate thickness, inter-ply shear coupling, and “mixed-mode” stress/strain states contribute more significantly to the measured response.

#1748

# Magnetically Driven 3D Printed Composite Capsule for Targeted Drug Delivery

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Helicobacter pylori infection remains a major clinical challenge due to increasing antibiotic resistance and limited efficacy of conventional pharmacological treatments. Photoactivated ingestible capsules have emerged as a promising alternative, enabling localized therapy within the stomach. However, current capsule-based approaches rely on passive locomotion, which limits precise positioning and controlled therapeutic activation. Reliable magnetic actuation and navigation under low magnetic field conditions are therefore essential to enable advanced smart therapeutic capsules.

This study presents the design, development, and experimental validation of a low-field electromagnetic actuation system and a 3D printed composite magnetic capsule. This includes the fabrication methods of the magnetic capsule using a photocurable elastic resin loaded with 40w/w% neodymium–iron–boron (NdFeB) microparticles, processed via stereolithography. The capsule design is further extended to incorporate an embedded light source, enabling combined magnetic navigation and light-based therapeutic functionality.

A low-field electromagnetic actuation system for controlled navigation based on a four-electromagnet configuration driven by a Proportional–Integral (PI) closed control loop system is developed. The generating the magnetic field gradients having intensities below 100 mT are used to navigate the capsule in predefined trajectories.

Our experimental results show the closed-loop actuation of the developed magnetic capsule along predefined trajectories, including vertical, diagonal, and complex paths, with performance evaluated in terms of positional accuracy, stability, and overshoot recovery.

This work introduces a versatile electromagnetic actuation platform integrating materials design, additive manufacturing, and smart control, with potential applications in photoactivated therapy, targeted drug delivery, and reconfigurable biomedical devices.

#1749

# Long Term Performance of Injection Molded Isotactic Polypropylene containing Weld Lines in Neat and Glass Fiber Reinforced Grades.

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Although previous studies have examined various aspects of weld line phenomena in injection moulded thermoplastic materials, further research is needed to accurately predict their long-term behaviour, including creep and fatigue responses. This study investigates the thermal and structural properties of isotactic polypropylene (iPP), both unfilled and reinforced with 30% glass fiber, using standard tensile specimens specifically configured to generate frontal weld lines. The experimental work includes short-term tests aimed at characterising deformation kinetics across a wide range of strain rates ($10^{-2}$ to $10^{-6}$ $s^{-1}$) and temperatures (−20°C, 23°C, and 80°C). Long-term behaviour is assessed through creep-to-failure experiments, cyclic fatigue tests, and crack-growth measurements performed on CT specimens extracted from injection moulded plates.

Identification of the dominant failure mechanism—whether governed by plastic deformation or crack propagation—enables the application of the Eyring´s relationship to model deformation. The results demonstrate that this approach remains valid for specimens containing weld lines, allowing prediction of time-to-failure under cyclic loading based solely on creep-to-failure data. The predictions show an accuracy within factors of 3 across the temperatures investigated. When crack-growth mechanisms induce brittle failure, as observed in unfilled polypropylene at elevated temperatures, the predicted times-to-failure are consistent with those obtained from CT crack-growth tests. This agreement supports the use of linear elastic fracture mechanics (LEFM) to reliably estimate failure times under constant stress, even in materials with weld line-induced defects.

Additionally, stress-rate-controlled tensile tests provide novel insights into short and long-term performance, compared to conventional strain-rate-based experiments, particularly for iPP grades where plastic deformation governs failure. Overall, the analytical models based on stress-rate data, enable accurate prediction of creep-to-failure times for materials containing weld lines, contributing to improved understanding of their mechanical reliability in service conditions.

#1754

# Thermomechanical Performance of Aerosil–Polycarbonate Composites Produced by Additive Manufacturing under Extreme Environments

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Additive Manufacturing (AM) offers new opportunities for the development of high-performance polymer composites tailored for extreme service conditions. By incorporating functional nanofillers into thermoplastic matrices, AM enables significant improvements in mechanical and thermal properties while maintaining high design flexibility.

In this work, a new class of additively manufactured polycarbonate-based composites reinforced with ceramic nanofillers (Aerosil 300) is proposed. Aerosil was introduced at weight fractions of 1%, 2%, and 4% to enhance the mechanical performance of the polymer matrix. The mechanical behavior of the printed composites was investigated under severe thermal conditions through static compression tests conducted over a temperature range from −90 °C to 80 °C. Both out-of-plane and in-plane loading configurations were examined in order to evaluate the effect of printing orientation on the mechanical response.

Alongside the experimental investigation, a coupled numerical approach combining Digimat and Abaqus was implemented to model both the material behavior and the additive manufacturing process. A three-dimensional thermomechanical model was developed to analyze the influence of printing parameters on temperature distribution, residual stresses, deformation, and warpage of Aerosil/PC printed parts.

The results highlight a significant improvement in the mechanical and thermal performance of the composites with increasing Aerosil content, particularly under extreme temperature conditions. Moreover, the combined experimental–numerical framework demonstrates strong potential for predicting process-induced defects and guiding the optimization of additive manufacturing parameters for advanced polymer composite systems.

Keywords: Additive manufacturing, Aerosil/Polycarbonate composites, Printing parameters, Thermal environment, Digimat-Abaqus coupling.

#1755

# Automated crack detection in thin paste adhesive joints

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Adhesively bonded composite joints have been widely applied in applications such as automotive, civil engineering and energy. Adhesive joining of composite parts offer a lightweight solution without affecting structural integrity of the composite parts. Full-scale modelling of structural composite parts requires an in-depth understanding of fracture mechanisms. Most critical fracture Mode is Mode I, with the lowest energy required for crack growth. Semi and automated crack detection techniques have been developed and validated for thin film joints in Mode I testing. Nevertheless, Mode I fracture mechanisms of thin paste adhesively bonded composite joints of 2-3 mm in thickness have been less investigated in recent years.

In this work a fully automated framework is presented to monitor crack propagation using Digital Image Correlation (DIC) for thin paste joints. An accurate crack detection in case of crack path deviation, non-connected crack front and change of local material heterogeneity around the crack tip is demonstrated. Framework is established with detection of longitudinal strains around the crack tip using full field DIC data from DIC images obtained on specimen's surface. Framework starts with visual or automated identification of reference crack length. At this reference crack tip, a longitudinal strain threshold is identified with DIC data. This threshold, is then used as a criterion to identify automatically crack length for subsequent images. Previously, reference crack length identification was obtained automatically using Image Processing Technique. However, this technique is sensitive to lighting and paint contrast. In order to mitigate these issues two additional techniques are investigated.

An AI-based technique using Ilastik Open Source software is applied to identify reference crack length with minimum training data. Additionally, a technique based on characterizing adhesive and adherend strain properties around the crack tip of reference image is investigated.

#1757

# Metal-Free Thermoelectric Nanocomposites: g-$C_3N_4$/SWCNT Hybrid Fillers in Recycled Polyamide 6 for Sustainable Waste Heat Recovery

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Approximately 63% of global energy consumption is dissipated as low-grade waste heat below 100°C, offering significant opportunities for thermoelectric energy harvesting. This study develops sustainable n-type thermoelectric polymer nanocomposites by synergistically combining graphitic carbon nitride (g-$C_3N_4$) and single-walled carbon nanotubes (SWCNT) within a chemically recycled polyamide 6 (ECONYL) matrix. The metal-free approach utilizes g-$C_3N_4$'s layered structure to enhance phonon scattering and reduce thermal conductivity, while SWCNT establishes efficient electron transport pathways. Preliminary investigations reveal an electrical percolation threshold between 0.1-0.25 wt% SWCNT, with volume resistivity decreasing from $10^{15}$ Ohm·cm (neat PA6) to $2.8\times10^{2}$ Ohm·cm at 2 wt% SWCNT loading, corresponding to an electrical conductivity of approximately 0.36 S/m. Notably, hybrid systems containing 2 wt% SWCNT with 5 wt% g-$C_3N_4$ achieve lower resistivity (77-170 Ohm·cm) than binary SWCNT composites, indicating synergistic filler interactions enhancing charge transport. Nanocomposites are fabricated using industrially scalable twin-screw melt mixing at 260°C with 250 rpm screw speed, followed by hot pressing at 240°C to produce flexible films of 100-200 µm thickness. A factorial experimental design systematically optimizes g-$C_3N_4$ (0.5-3.0 wt%) and SWCNT (0.1-2.0 wt%) concentrations. Target thermoelectric metrics include a Seebeck coefficient below -40 µV/K, an electrical conductivity exceeding 100 S/m, a thermal conductivity below 0.4 W/m · K, and ZT values of 0.05-0.1. This investigation represents the first systematic study combining g-$C_3N_4$ with SWCNT in recycled PA6 for thermoelectric applications, thereby establishing structure-property relationships for flexible energy-harvesting devices.

#1759

# Bridging the Gap Between Local TRM Mechanisms and Reliable Shear Strengthening Design: From Experimental Observations to Predictive Modelling

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Textile-Reinforced Mortar (TRM) has emerged as a promising retrofit solution for reinforced concrete (RC) structures deficient in shear resistance, yet translating the observed local strengthening mechanisms into predictive and reliable design tools remains a major scientific challenge. This work addresses this gap by coupling advanced local sensing — distributed fibre optic sensing (DFOS) and digital image correlation (DIC) — with both monotonic and cyclic four-point bending tests on asymmetrically reinforced RC beams, some retrofitted with TRM on lateral faces in the critical shear zone.

Under monotonic loading, TRM increased beam stiffness by approximately 20% and transformed the failure mode from a single dominant diagonal crack into a distributed microcracking pattern. Crack openings were reduced by 75% for bending-induced cracks and 85% for shear-induced cracks, while the load carried by existing stirrups was decreased by over 60%. Critically, DFOS revealed that the textile reinforcement does not work uniformly along the shear span: yarns closer to the load application point carry disproportionately higher strains, directly correlated with local crack density. This non-uniform load sharing is governed by the load transfer length at each crack. Under cyclic loading up to 3,000 cycles, unstrengthened beams exhibited progressive stiffness degradation leading to macroscopic damage, whereas TRM-retrofitted beams showed stiffness stabilisation after an initial loss during the first 500 cycles. Nevertheless, the critical dependence of TRM effectiveness on adequate load transfer length persists under repeated loading: without sufficient anchorage across cracks, the textile cannot mobilise its full bearing capacity.

The scientific challenge lies in developing predictive models that link crack width evolution, load transfer length, and the crack propagation behaviour of TRM under tension to the actual strengthening performance on beams under sustained or repeated shear demands. Addressing this challenge is essential for moving from empirical observations to a mechanics-based design framework for TRM shear strengthening.

#1763

# 3D modelling of magnetic alignment dynamics of an individual fibre-like reinforcing element in melt-processed soft magnetic composites

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Magnetically functionalised magnetic soft composites are increasingly used to realise programmable soft actuators and flexible mechanisms by integrating magnetic response directly into 3D-printed structures. A key step in manufacturing such components is the formation of anisotropic microstructures during processing, where fibre-like magnetic fillers can rotate and align under an external magnetic field while the soft matrix remains in a heated and low-viscosity state. This alignment governs the effective magnetisation, mechanical anisotropy, and overall actuation capability of the final printed part. In this study, a 3D multiphysics numerical model is developed to analyse the rotational dynamics and alignment behaviour of individual fibre-like magnetic fillers suspended in a viscous medium. The model couples magnetic torque, viscous drag and the rotational motion in the fluid, enabling systematic comparison with analytical expressions. The developed 3D model provides a reliable framework for predicting the magnetic alignment behaviour of individual fibre-like magnetic fillers. Its results offer direct implications for soft magnetic filament processing, including the identification of suitable processing windows that satisfy required alignment time and the establishment of a quantitative basis for the magnetic programming of soft magnetic filaments during manufacturing.

#1764

# A Bayesian Framework for Composite Design Allowables: Uncertainty Quantification and Reliability Enhancement under Data Scarcity

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The certification of primary composite structures necessitates the determination of design allowables—specifically A-basis and B-basis values—to ensure structural integrity under statistical variability. Traditionally, frequentist methodologies mandated by industry standards (e.g., CMH-17) require extensive experimental campaigns to achieve the required confidence levels. However, in the early stages of material development or for specialised high-performance laminates, such exhaustive testing is often precluded by prohibitive costs and time constraints.

This study proposes a robust Bayesian framework designed to determine design allowables under conditions of data scarcity. By shifting from point-estimation to a probabilistic inferential approach, the framework enables the systematic integration of Prior Distributions—derived from legacy databases, hierarchical multi-fidelity models, or virtual testing—with sparse experimental observations.

Central to this methodology is the rigorous Uncertainty Quantification (UQ), which distinguishes between aleatory material variability and epistemic uncertainty arising from limited sample sizes. Through the application of Monte Carlo sampling, we demonstrate that the Bayesian Posterior provides a more stable and physically consistent estimation of the lower-tail distribution than traditional frequentist estimators.

The results indicate that this approach significantly enhances reliability while reducing the number of physical coupons. This work provides a scalable mathematical foundation for accelerated material qualification, supporting the industry's transition toward digital twins and data-driven certification philosophies.

#1765

# Increasing energy efficiency and productivity in manufacturing: An AI-enhanced simulation-based multi-objective optimisation approach

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The pressure to improve energy efficiency in manufacturing is increasing due to rising energy costs and stakeholder demand for sustainable production. Economic sustainability denotes the concept that businesses conserve natural and financial resources in order to minimise negative environmental impacts while still creating long-term profits. This paper aims to support manufacturers to achieve economic sustainability with a focus on factory-level energy consumption. Therefore, this paper reviews state-of-the-art research on energy usage modelling in correlation to time-stepped operations to enhance energy efficiency, flexibility and cost performance in manufacturing. From reviewed studies, key knowledge gaps and limitations were identified. To address these gaps, a seven-step data-driven approach is proposed that integrates Discrete Event Simulation to model a complex manufacturing system with the aim to generate data for advanced optimisation algorithms and the application of Artificial Intelligence for intelligent production scheduling. The approach seeks to support holistic, multi-objective optimisation of energy consumption, manufacturing cost, and productivity of production facilities. Based on the optimisation results manufacturers can make data-driven decisions to improve their competitiveness and sustainability at the same time. The expected improvements from the proposed approach include the reduction of Specific Energy Consumption through measures like optimised production sequence, buffer size, and batch size. Furthermore, production scheduling to reduce peak energy consumption can be optimised through heuristic rules derived from advanced optimisation algorithms based on simulation generated data. Intelligent production scheduling leverages AI to optimise energy efficiency and flexibility in real-time. The proposed approach will be applied to an advanced composite manufacturing facility. Composite manufacturing has been selected as an example industry that is particularly energy and cost-intensive at the same time and thus struggles to achieve economic sustainability. This provides an ideal environment to investigate how to improve economic sustainability through the application of the proposed seven-step approach.

#1766

# Multihit capability of ceramic-composite ballistic plate against 5.56 x 45 mm (SS109) steel tip bullets: An experimental study.

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This experimental study analyzes the ballistic behavior of a hybrid bulletproof plate composed of a multi-curve Silicon Carbide (SiC) monolith, bonded with an Ultra-High Molecular Weight Polyethylene (U.H.M.W.PE) backing plate. The plate, with an area of 25 cm x 30 cm, was subjected to three projectile hits,in a vertical line from 5.56 x 45 mm (SS109) steel tip bullets,at a speed of 950m/s (±9 m/s).

The study conducted a comprehensive investigation into the interaction between a specific type of projectile and a hybrid ballistic plate using fracture mechanics analysis. The research initially focused on the interaction between the projectiles and the ceramic monolith. Subsequently, the study examined the interaction of the projectiles with the UltraU.H.M.W.PEbacking plate and the overall composition of the materials as an integrated energy absorber. The continuous degradation of the ceramic/U.H.M.W.PE composite structure throughout the sequence of impacts facilitated the analysis of penetration dynamics and the formation of radial cracks within the ceramic layer. Furthermore, the study assessed the efficacy of the energy transfer and absorption cones generated by the projectiles during the impact phases. Targeted incisions were made on the U.H.M.W.PE panel to measure the following parameters: (i) penetration depth for each impact (Depth of Penetration - DOP), (ii) deflection of the panel relative to its initial position (Back Face Deformation - BFD), (iii) modes of fiber breakage during various stages of projectile penetration, and (iv) the presence and causes of delamination.

In conclusion, the plate's capacity to absorb multiple hits (multi-hit capability) was identified as function of progressive degradation observed during experiments. The findings from this research provide a framework for the design and optimization of ceramic/U.H.M.W.PE bulletproof plates.

Keywords

Ballistic armor, Experimental study, Ceramic/composite armor, Multi hit capability, SS109 projectile

#1767

# Fracture behaviour and ballistic response of a SiC/UHMWPE plate under multi-hit impacts from 7.62×39 mm MSC projectiles. An experimental study.

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In modern protective engineering, multilayer composite armour systems are increasingly designed to withstand complex and high-energy impact scenarios, with each constituent layer tailored to address a specific damage mechanism. Within this context, the present study investigates the impact dynamics and ballistic performance of a hybrid SiC/UHMWPE armour configuration subjected to demanding loading conditions representative of real operational environments, focusing on 7.62 × 39 mm Mild Steel Core (MSC) projectiles.

The system under examination consists of a monolithic Silicon Carbide (SiC) ceramic strike face adhesively bonded to an Ultra-High Molecular Weight Polyethylene (UHMWPE) composite backing. The armour plates were experimentally tested under three consecutive impacts from 7.62 × 39 mm MSC rounds to impose severe dynamic loading and evaluate the progressive degradation of the ceramic/composite system. Post-impact characterisation included analysis of penetration behaviour, radial crack propagation, fragmentation patterns, and the formation or collapse of the ceramic energy-dispersion cone. Within the UHMWPE backing, Depth of Penetration (DOP), Back Face Deformation (BFD), fibre-failure mechanisms, and interlaminar delamination were examined to assess the energy-absorption capacity and structural integrity under multi-hit conditions.

The results are compared with those from a previously study involving three impacts from 5.56 × 45 mm SS109 projectiles at 950 m/s (±9 m/s). The combined analysis of all six impacts provides a comprehensive assessment of the hybrid plate’s multi-hit and multi-threat resistance, highlighting the dynamic failure mechanisms governing its ballistic response.

#1768

# Dispersion-Controlled Alumina-Enhanced Carbon/Phenolic Composites for Solid Rocket Nozzle Thermal Protection

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Abstract

Solid rocket motor nozzle liners face extreme thermal and erosive conditions, with gas temperatures near 3000 K.

Carbon/phenolic (C/Ph) composites provide low-density ablative protection, but oxidation starts near 643 K in air.

Because alumina response is dispersion driven, this work controls dispersion and DSC-guided curing to relate mi-

crostructure to torch ablation and back-surface temperature (BST).

A resol phenolic/IPA system was filled with bimodal Al2O3 at 0, 2, 4, and 6 wt.%. Dispersion combined cooled

high-shear mixing with intermittent probe ultrasonication, followed by hand lay-up impregnation and a DSC-guided

multistage cure.

SEM/EDS before ablation showed uniform dispersion at 2 wt.% with particles along the fiber–resin interface;

4 wt.% showed resin-deficient zones and clustering; 6 wt.% showed more even spacing with alumina bridging resin

and fibers without obvious voids.

Oxy-acetylene torch ablation testing (ASTM E285, n = 5) with continuous back-surface temperature (BST) monitoring compared carbon/phenolic laminates containing 0–6 wt.% alumina. The unfilled laminate showed localized

penetration with frayed tows and cracking, giving the highest recession and BST. At 2 wt.% alumina, ceramic residue

and a more uniform char reduced ablation and lowered peak BST by ∼35%. At 4 wt.%, non-uniform char and ag-

glomeration limited the BST benefit (∼4%) and increased ablation relative to 2 wt.%. At 6 wt.%, a more continuous

ceramic-rich char layer formed, with minimal spallation and alumina deposits at fiber crossovers, giving the lowest

ablation and the largest peak BST reduction (∼54%). These trends are part of ongoing work and indicate that thermal

protection depends on ceramic loading together with dispersion state and char continuity, rather than loading alone.

Keywords: Carbon/phenolic composites; Solid rocket nozzle liners; Ablative thermal protection; Alumina dispersion; Extreme thermal environments

#1769

# Natural Biomass-Reinforced Biodegradable Polymer Composites for Sustainable Thermal Applications

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The growing emphasis on bio-derived and sustainable composites has intensified efforts to develop biodegradable polymer systems reinforced with renewable natural resources. In this study, we processed and powdered Prosopis cineraria, a regionally abundant lignocellulosic biomass, was incorporated into a biodegradable polymer matrix (PLA) to investigate its influence on compressive strength, flexural strength, and thermal insulation performance. Composites with varying filler loadings were fabricated through melt blending followed by injection molding to ensure uniform dispersion. Compressive strength increased progressively with Prosopis cineraria content, reaching an enhancement of approximately 45% at 15 wt% compared to the neat polymer. This improvement was accompanied by higher stiffness, indicating improved interfacial interaction and efficient stress transfer between the polymer matrix and rigid biomass particles. The enhancement demonstrates that the bio-filler effectively restricts matrix deformation under compressive loading. Flexural strength exhibited an optimum behavior, with a maximum increase of approximately 18% at 10 wt%, while at 15 wt% the improvement remained moderate (8%). This trend indicates that moderate filler incorporation enhances bending resistance, whereas excessive loading may introduce localized stress concentrations or reduced matrix continuity. Thermal insulation performance improved consistently with increasing biomass content, achieving an enhancement of approximately 65% at 15 wt% relative to the unfilled polymer. The improvement is attributed to the low intrinsic thermal conductivity of lignocellulosic constituents and the development of internal microstructural barriers that impede heat transfer. The enhancement of mechanical strength and thermal insulation demonstrates the multifunctional capability of Prosopis cineraria in bio-derived composite systems, supporting the development of lightweight, low-carbon materials for sustainable thermal applications.

#1772

# Design of Biphasic Structural Battery Electrolytes and Their Thermo-Mechanical Characterization

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Structural batteries offer a promising route toward multifunctional materials capable of carrying mechanical loads while simultaneously storing electrical energy. The performance of such systems is strongly governed by the properties of the structural battery electrolyte (SBE), which must provide sufficient ionic transport without compromising mechanical integrity. In this work, phase-separated SBEs were fabricated via thermally initiated polymerization-induced phase separation (PIPS), with particular emphasis on the role of monomer selection in controlling structure–property relationships.

A base system consisting of Bisphenol A ethoxylated dimethacrylate was modified by incorporating varying amounts of diurethane dimethacrylate (DUDMA). The influence of DUDMA content on curing behavior, microstructural evolution, ionic conductivity, and thermo-mechanical performance was systematically examined. Microscopic observations indicated that increasing the DUDMA concentration resulted in a more compact polymer framework with smaller phase-separated domains. This morphological refinement limited liquid electrolyte uptake, leading to a gradual reduction in ionic conductivity; however, conductivity values remained within a functional range suitable for structural battery applications.

Mechanical characterization revealed a notable improvement in stiffness and strength with increasing DUDMA content, attributed to enhanced crosslink density and the presence of urethane-based intermolecular interactions. An optimized composition demonstrated a favorable balance between mechanical performance and electrochemical functionality, achieving ionic conductivity on the order of $10^{-4}$ S·cm$^{-1}$ alongside a substantially increased storage modulus. Additional thermal curing further improved mechanical stability with minimal impact on ion transport.

The results demonstrate that diurethane dimethacrylate is an effective modifier for tuning the competing requirements of mechanical robustness and ionic conductivity in SBEs. This study provides practical insights for the design of structurally efficient and electrochemically functional battery-enabled composites.

#1773

# Deep Learning–Based Surrogate Modeling and Inverse Design of Temperature Fields in Induction Welding of Composite Joints

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Induction welding of fiber-reinforced polymer composites is attractive for fast and clean joining. However, achieving uniform temperature fields is challenging because many coupled process parameters interact in a highly nonlinear way. Conventional trial-and-error experiments and low-fidelity analytical models provide limited guidance for designing coil and process conditions. In this study, we develop a deep learning–based surrogate model to predict spatial temperature distributions in induction-heated composite joints and to enable inverse design of process parameters. A convolutional neural network is trained on validated numerical simulations of induction heating that systematically vary coil geometry, power, frequency, and dwell time. The trained model accurately reconstructs temperature fields and key metrics such as average temperature, heating rate, and a temperature uniformity index. By coupling the surrogate model with a multi-objective optimization scheme, we identify process windows that achieve high target temperatures, rapid heating, and improved uniformity while limiting overheating of the adherends. The optimized conditions are compared with baseline process settings and show enhanced joint-region temperature uniformity and reduced heating time. The proposed framework demonstrates that deep learning can significantly accelerate process design for induction welding and is readily extendable to studies involving susceptors or EMI-shielding structures for further control of heat generation.

#1776

# Electrospun polyacrylonitrile/TEMPO Nanofiber Electrodes: Dual Charge Storage Mechanism for Supercapacitor Applications

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Electrode materials suitable for asymmetric supercapacitor applications were developed using nanofibers produced by electrospinning a blend of polyacrylonitrile (PAN) and 2,2,6,6-tetramethylpiperidine-1-oxyl (TEMPO). Fourier-transform infrared (FTIR) analysis confirmed the characteristic nitrile groups of PAN and verified the successful incorporation of TEMPO via its nitroxide functional groups. X-ray diffraction (XRD) patterns showed that introducing TEMPO led to sharper and more intense diffraction peaks, suggesting enhanced structural ordering and stronger π–π interactions. Morphological examination revealed that adding TEMPO generated rough, interconnected PAN/TEMPO fiber networks, whereas pure PAN nanofibers exhibited uniform, smooth cylindrical shapes. Raman spectroscopy indicated the appearance of additional modes near 600 and 771 $cm^{-1}$, implying defect generation and modification of surface functionalities.Electrochemical measurements demonstrated that the composite electrodes stored charge through a combined mechanism involving both electrochemical double-layer capacitance and pseudocapacitive contributions. The PAN/TEMPO electrode exhibited a specific capacitance of 115 F $g^{-1}$ at a scan rate of 5 mV $s^{-1}$, while delivering an energy density of 10.67 Wh $kg^{-1}$ and a power density of 250 W $kg^{-1}$ at 0.5 A $g^{-1}$ in 0.1 M $H_2SO_4$. When assembled into an asymmetric supercapacitor device, the system achieved a capacitance of 80 F $g^{-1}$ at 5 mV $s^{-1}$, yielding 7.71 Wh $kg^{-1}$ energy density and 365 W $kg^{-1}$ power density at 0.25 A $g^{-1}$ under the same electrolyte conditions. Overall, the synergistic combination of EDLC and pseudocapacitive behavior in PAN/TEMPO nanofibers highlights their strong potential for high-efficiency supercapacitor technologies.

#1777

# Optimization of cure cycles of self-polymerizing mold encapsulation for electronic packaging

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Semiconductor packages are mainly manufactured using epoxy molding compound (EMC), which plays an important role in protecting semiconductor components from the surrounding environment such as moisture and mechanical shock, and dissipating the heat generated during chip operation. However, warpage in semiconductor packages has been critical issue during the semiconductor packaging process as multilayer semiconductor structures become thinner. Warpage is caused by mismatch of coefficient of thermal expansion (CTE) of the semiconductor components, and the residual stress induced by EMC curing process as well. This leads to reliability problems such as delamination and crack, thereby reducing production rate yield.

In this study, the curing behavior of EMC was first analyzed with respect to the cure cycle using differential scanning calorimetry (DSC), and the bonding temperature was calculated from the curvature of the EMC/Cu bi-layer package. Through curvature data with respect to modified cure cycle including initial heating rate, rapid cooling temperature and heating rate, a machine-learning model was trained using curvature data with respect to modified cure cycle for predicting the warpage and modified cure cycle. The degree of cure at which interfacial bonding occurs was analyzed by comparing the degree of cure measured by DSC and the warpage of the bi-layer package with respect to heating rates. The effective degree of cure for bonding was approximately 0.52. Based on the autoencoder-based machine learning model, the encoder and the autoencoder achieved accuracies of 95% and 94%, respectively. Using the trained model, this bi-directional prediction model can be used to predict curvature and the modified cure cycle required to achieve the desired curvature. These results demonstrate that the production efficiency was improved by reducing the semiconductor package's warpage and predicting the manufacture process for the warpage required in subsequent process.

Keywords: Semiconductor package, EMC(Epoxy molding compound), Bonding temperature, Cure cycle, Machine learning.

#1779

# Influence of Accelerated Moisture Absorption on Thermo-Mechanical Behaviour of Carbon Fibre Composites

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Advancements in composite materials for aerospace applications necessitate a thorough understanding of their behaviour under varying environmental conditions, particularly moisture ingress. Current standardised test methods for saturation, such as through an Environmental Chamber (EC) or submersed in liquid, require a long time to attain sufficient moisture saturation levels. A limited number of studies indicate the use of a pressure vessel to reduce this process to a matter of days from months. In this work, the effect of various accelerated moisture absorption methods on the thermo-mechanical behaviour of carbon fibre composites was investigated using Dynamic Mechanical Analysis (DMA). Furthermore, the chemical structural transformation and the surface morphological variations with respect to various moisture saturation methods were studied. The results indicate a dramatic decrease in Tg properties with increasing moisture absorption, consistent with prior literature. Interestingly, samples subjected to higher temperatures and pressures in the autoclave exhibited a similar Tg to EC saturated samples to the same mass increase. Despite the similarity, the Tan Delta showed a distinct separation of peaks not present in the EC samples, suggesting uneven moisture distribution within the composite. Moreover, the samples exposed to 135 °C for 48 hours developed extensive microcracks in the matrix and inter-ply region, as confirmed by Scanning Electron Microscopy (SEM). These microcracks were largely absent in samples exposed to lower temperatures or shorter durations. Fourier-Transform Infrared Spectroscopy (FTIR) analysis indicated no substantial changes in the peaks associated with epoxy or thermoplastic tougheners, although a decrease in the peak at 1700 $cm^{-1}$ was observed, indicating the chain scission and chemical structure disruption in the epoxy networks. This research highlights the complex interplay between moisture absorption, thermal exposure, and mechanical degradation in composite materials, underscoring the need to consider both environmental conditions and exposure duration when designing carbon fibre composites for aerospace structures.

#1784

# Enhancement of Mechanical Properties in Recycled Polypropylene Composites via Polypropylene Fiber-Induced Transcrystalline Layer

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With increasing environmental concerns and plastic waste accumulation, the effective recycling of polymers has become a critical issue. However, recycled polypropylene (rPP) suffers from strength deterioration and embrittlement due to chain scission during repeated processing, which limits its application in structural composites. In this study, a self-reinforced composite strategy is proposed to enhance the mechanical performance of rPP by incorporating polypropylene (PP) fibers and pine cone powder (PCP) within an optimized recycled–virgin PP matrix.

The matrix was prepared by blending rPP (six extrusion cycles) with virgin PP (30R/70P) and modified with maleic anhydride grafted polypropylene (MAPP) to improve interfacial compatibility and control the melting temperature. PP fibers were introduced as reinforcement, while PCP (15 wt%) was used as a bio-based nucleating agent. The composites were fabricated via twin-screw extrusion and injection molding, followed by structural, thermal, and mechanical characterization.

The optimized composite exhibited significant improvements in mechanical properties, with tensile strength of ~35 MPa and modulus of ~1.9 GPa, and flexural strength and modulus of ~59 MPa and ~2.6 GPa, respectively. These enhancements are attributed to the formation of a transcrystalline layer (TCL) at the fiber–matrix interface. Polarized optical microscopy confirmed interfacial nucleation and oriented crystal growth, while XRD results showed increased crystallinity without changes in the α-PP crystal structure. SEM observations revealed improved interfacial bonding and reduced fiber pull-out. The TCL enhances stress transfer, reduces stress concentration, and delays crack initiation.

This study demonstrates that TCL-driven reinforcement combined with crystallinity engineering provides an effective and scalable strategy for upgrading recycled polypropylene into high-performance, fully recyclable composites.

#1787

# Study of chemical treatment on flax fibers for moisture repulsion and hydrophobic properties

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The usage of the bio fibers composites, as an alternative for synthetic glass and carbon fibers in the polymer composite manufacturing industry for numerous engineering applications have led to a serious challenge of finding solutions for the hydrophilic behavior of the natural fiber-reinforced composites (NFRCs), in environments exposed to moisture and extreme weathering conditions. This research work broadly explores the moisture resistance treatments for natural fiber-reinforced composites (NFRCs), for effective utilization and avoid high water and moisture absorption, swelling of the fibers, limited wettability etc., The HDPE pellets of various thickness starting from of 1.5 mm to 3 mm thickness will be compression molded to along with chemically treated flax fiber mats of varying (W%) of the flax starting from 14% to 16% in steps of 0.5% and are sandwiched between two HDPE thin films to make the final composite plate of the desired thickness. Both the chemically treated and untreated flax fiber-based composites would then be subjected to tensile testing prior to exposing them to accelerated ageing which includes the immersion of both the chemically treated and untreated fibers in water for certain number of hours (h) in accordance with ASTM G154-23 standards. Subsequently post exposed samples will then be subjected to tensile testing and Fourier transform infrared spectroscopy (FTIR). The hydrophilic, moisture absorption behavior and rate of degradation in their material-properties under accelerated ageing for both the chemically treated and untreated flax fiber-based composites are studied and compared to understand the effect of alkaline treatment on the elastic modulus of the NFRC in correlation with the embrittlement under extreme weathering conditions. The interfacial adhesion of the polymer with respect to the fibers and the toughness of the treated NFRC would also be studied and Morphological analysis would be conducted using scanning electron microscopy (SEM) to support the conclusions.

#1791

# Development of structural supercapacitors for integrated energy storage in composite materials

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The integration of energy storage functionality into load-bearing composite materials represents a key enabling technology for next-generation lightweight systems in aerospace, transportation, and wearable applications. Within this context, the Nano-SuperCaps project focuses on the development of structural supercapacitors based on carbon fiber-reinforced polymer (CFRP) architectures, aiming to achieve simultaneous mechanical integrity and electrochemical performance.

The proposed concept relies on a multifunctional laminate configuration in which carbon fibers act both as the primary load-bearing reinforcement and as structural electrodes within the device. Electrospun nanofibrous membranes are introduced between the carbon fiber plies as multifunctional interlayers, providing high surface area, controlled porosity and interconnected pathways that facilitate efficient ion transport while also potentially improving interlaminar bonding within the composite structure. The laminate incorporates a solid-state electrolyte system based on hybrid epoxy/ionic liquid/lithium salt matrices, engineered to simultaneously deliver ionic conductivity and mechanical stiffness. In addition, graphene nanoplatelets are integrated within the nanofibrous membranes, acting as reinforcing and conductive network that to further enhance ion transport, strengthen interlaminar adhesion and improve the overall electrochemical and mechanical performance of the multifunctional composite.

Two distinct formulation strategies are investigated: (i) resin-dominant systems prioritizing structural integrity, and (ii) ionic liquid-dominant systems targeting enhanced electrochemical behavior. A combined experimental and computational methodology is adopted, including electrospinning-based nanofiber fabrication, composite laminate manufacturing, and in-silico modeling of ionic transport and matrix behavior.

Prototype multilayer CFRP supercapacitor laminates are developed and evaluated in terms of their structural, thermal and electrochemical response. Emphasis is placed on understanding the interplay between matrix composition, nanofiber morphology, and multifunctional performance.

The outcomes of this work demonstrate the feasibility of integrating energy storage within structural composites, offering a pathway toward reduced system weight, improved space utilization and increased functional integration in advanced engineering applications.

#1804

# Numerical prediction and experimental analysis of the buckling loads of smpc cylindrical shells and its application in pyrotechnics vibration attenuation

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At present, the applications of shape memory polymers (SMPs) and shape memory polymer composites (SMPCs) in the aerospace field mainly include space deployable hinges, trusses and antennas. Most of these structures are SMPC plates; SMPC cylindrical shells, which are excellent load-bearing structures, have not been widely used. The reason for their lack of use is that the structure and external load conditions of the SMPC cylindrical shells are relatively more complex than those of the SMPC plates, which makes it difficult to analyze the load-bearing capacity (the buckling load). In addition, as a temperature-sensitive material, the mechanical properties of SMPCs will change dramatically with temperature, so the buckling behaviors of SMPC cylindrical shells are quite different from those of general fiber reinforced polymer composite cylindrical shells.

The first-order shear deformation theory is used to calculate the critical buckling loads of shape memory polymer composite (SMPC) cylindrical shells. The Single and Multiple Perturbation Load Approaches are used to calculate the knock-down factor (KDF) at different temperatures. At low temperature, the SMPC cylindrical shell will be crushed before buckling, while the simulation results coincident well with experimental data at high temperature. Finally, repeated experiments on the shape recovery process of a buckled SMPC cylindrical shell are performed, and an assumption of its potential application is also proposed.

#1805

# Impact dynamics properties of woven hemp/epoxy composites

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Natural fibre-reinforced bio-composites are environmentally sound and less dependent on fossil fuels which are widely applied in automotive, construction and aerospace industries. Moisture sensitive natural fibres lead to a sharp decrease in the mechanical performance of whole composite structures when immersed in water. The current research on natural fibre composites is limited to macro mechanical testing and the internal microstructure mechanism analysis is still challenging. This study prepared two woven hemp/epoxy composites, systematically investigating their impact dynamics properties with varying moisture content. A multi-scale model was established to evaluate moisture's hydroplastic effect and the composite's dynamic response under impact. It helps clarify moisture diffusion and moisture-regulated impact mechanism, providing theoretical guidance for anti-impact woven hemp/epoxy composite design and optimization.

Keywords: natural fibre composites; Impact dynamics; microstructure analysis

#1808

# Multi-Scale Modeling of Peri-Hole Damage Evolution During Dynamic Installation of Interference Bushings in CFRP

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The dynamic installation of metal interference bushings has demonstrated significant potential for improving the fatigue performance of carbon fiber reinforced polymer (CFRP) joints. Compared to traditional static methods, dynamic installation achieves an interference fit at elevated strain rates; however, the underlying mechanisms governing this fatigue life enhancement remain insufficiently understood.

This study employs a top-down multi-scale modeling approach to elucidate this mechanism. A full-scale macroscopic model is coupled with a microscopic damage model to evaluate the influence of varying dynamic installation speeds on peri-hole damage. Macroscopically, a multi-rate dynamic installation model is developed to simulate progressive damage evolution and the final structural response. Microscopically, a representative volume element (RVE) model is utilized, applying macroscopic strain fields as boundary conditions to precisely capture localized damage mechanics. The proposed framework is experimentally validated using cross-sectional micrographs.

The multi-scale analysis reveals three key findings: (1) high-speed installation induces localized damage—specifically matrix cracking, fiber kinking, and fiber breakage—at both the inlet and outlet of the CFRP hole; (2) the damage distribution is axially non-uniform, with the outlet exhibiting markedly more severe degradation than the inlet; and (3) three installation speeds were set (13 m/s, 24 m/s, and 40 m/s) in this study, among which the speed of 40 m/s promote a more uniform expansion of the hole diameter, significantly mitigating peri-hole damage at the outlet. Consequently, higher installation velocities yield superior interference uniformity and a more balanced axial damage profile, fundamentally contributing to the enhanced fatigue performance of CFRP structures under cyclic loading.

#1811

# Quantifying the Effect of Interlayer Shifting on Local and Effective In-Plane Permeability of Multilayer Woven Preforms

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Interlayer shifting between adjacent fabric plies is difficult to avoid during the lay-up of multilayer woven preforms and can significantly affect permeability in liquid composite molding processes. This work investigates the influence of two-dimensional interlayer shifting on the local and effective in-plane permeability of a six-layer E-glass plain weave preform. A meso-scale numerical workflow was used to generate compacted textile geometries with prescribed shifting vectors, voxelize the deformed structures, and calculate the local warp and weft direction permeabilities using steady Stokes–Darcy flow simulations. A total of 256 shifting configurations were considered to construct local permeability maps. The results show that interlayer shifting strongly affects the compaction state of the preform, with the compacted fiber volume fraction varying from 42.5% to 54.7%. The corresponding local in-plane permeability changes by more than one order of magnitude, demonstrating that local flow resistance is highly sensitive to the relative in-plane position of adjacent layers. Clear symmetry and diagonal repeatability are observed in the permeability maps, suggesting that the full shifting-domain response can be reconstructed from a reduced number of simulations. Experimentally measured shifting statistics were further combined with the numerical maps through Monte Carlo analysis. The predicted mean permeabilities and anisotropy ratio agreed well with radial-flow experiments, while the predicted coefficients of variation are lower than the measured values, indicating that interlayer shifting explains an important but not exclusive part of the experimental scatter. The proposed permeability mapping strategy provides a quantitative link between interlayer shifting, local pore structure, and effective in-plane permeability, and can support permeability prediction and variability analysis in LCM processes.

#1858

# Development of a novel adhesion system between metal and rubber compound

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Zinc borate serves as an effective adhesion promoter for rubber-to-metal bonds, significantly enhancing long-term stability under humid conditions. Although it marginally reduces initial post-cure adhesion, an optimal loading stabilizes the adhesion interphase by regulating copper migration. The specific findings are summarized as follows:

The incorporation of zinc borate initially led to a slight reduction in the adhesion stability between the rubber compound and the brass-plated steel cord immediately following the curing process.

Adhesion retention was significantly improved with zinc borate loadings particularly during extended humidity aging (up to 15 days). AES analysis demonstrated that an optimal zinc borate concentration yielded a more stable interphase depth profile. By effectively moderating copper migration, zinc borate facilitated the formation of controlled amounts of copper sulfide and zinc oxide, thereby enhancing overall adhesion durability. Excessive zinc borate concentrations triggered the overgrowth of copper sulfide and zinc oxide layers during humidity aging. Consequently, precise control of zinc borate loading is critical to ensuring robust long-term adhesion performance under hostile environmental conditions.

A novel adhesion system utilizing cobalt salt and zinc borate was developed for rubber-to-metal bonding, offering superior durability and overcoming the limitations of conventional resinous bonding systems. Analysis indicated that this new system requires high sulfur loading to maintain robust adhesion under humidity aging, with AES depth profiling revealing a more stable adhesion interphase. The findings suggest that the zinc borate-based system enhances adhesion retention through improved interfacial stability.

#1859

# Polymer Eco-Filler Composite Materials: Advanced Materials for a Sustainable Future

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The automotive industry is facing increasing pressure to reduce carbon emissions and comply with stringent environmental regulations. Traditional fossil fuel-based polymers, such as polypropylene (PP) and talc composites, while offering reliable performance, contribute significantly to the carbon emissions. This work presents the development of Polymer Eco-Filler Composites as a sustainable alternative.

Our research focuses on utilizing renewable materials to create composites with mechanical properties comparable to conventional materials while supporting a circular economy. By incorporating a fast-growing bamboo into PP matrix, we achieve up to a 50% reduction in carbon footprint compared to traditional PP/talc composites while improving the environmental profile of automotive components. Bamboo's favorable mechanical properties, fiber structure and high carbon sequestration (4x than wood) has enabled the development of eco-composite with properties better than traditional PP/talc for demanding applications. Moisture absorption is a known challenge for all eco-filler-based composites, and while we have found that moisture absorption is not a concern under ambient conditions, we are developing formulations that improve resistance to water absorption at elevated temperatures while maintaining acceptable mechanical properties. This work highlights the key challenges, technical developments, and potential benefits of eco-filler composite materials into driving sustainability in the automotive sector.

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