TexComp

9–11 September
2026
Bristol, UK

Abstracts

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3D Textile Architecture: Process and Product 1

SIMULATION-CALIBRATED ANALYTICAL METHOD FOR FAILURE LOAD PREDICTION IN 3D WOVEN COMPOSITE L-SECTIONS

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An analytical method was developed to predict failure loads in L-shaped 3D composite sections subjected to vertical loading. Based on finite element simulations and limited testing, the approach presents a closed-form analytical expression suitable for use in early-stage design.

FE analyses showed that corner unfolding is the dominant failure mode, driven by radial tensile stress at the inner radius with contributions from out-of-plane shear. The corner was modeled using plane-strain curved-beam elasticity [1] to obtain radial and shear stresses, and failure initiation was evaluated using the Soni–Kim interlaminar criterion.

Fourteen ABAQUS™ simulations covering multiple thicknesses and radii all exhibited unfolding, with failure defined at roughly 50% propagation across the section width. Nonlinear shear behavior typical of 3D woven composites was included. The calibrated method enabled creation of carpet plots showing corrected failure loads across wide geometric ranges, aligning well with simulations and available test data as illustrated by Figure 1.

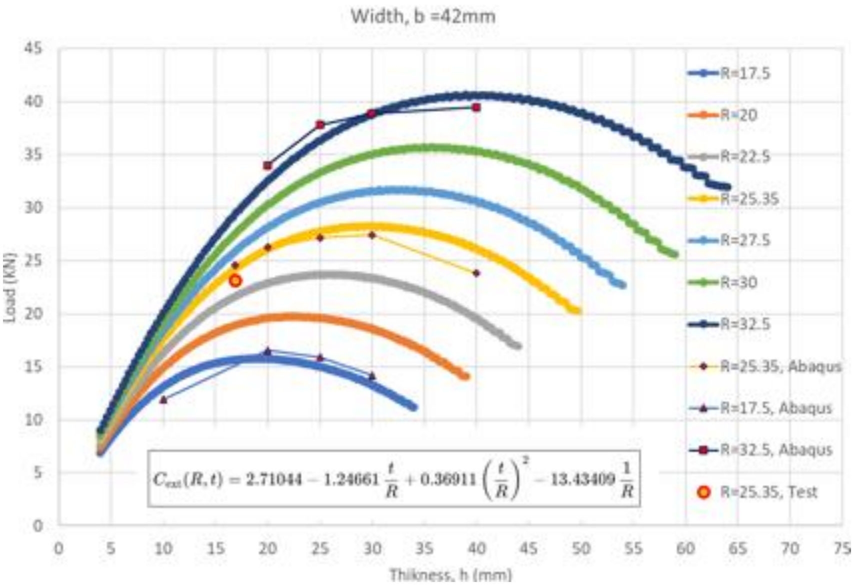

Figure 1: Carpet plot of corrected failure loads for 42mm wide specimens, obtained using the extended correction factor

Overall, the method offers an efficient method for early-stage design of L-section composites, capturing essential mechanics and providing accurate load predictions without requiring FE modelling.

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TOWARD A COMPREHENSIVE AND EFFICIENT STRUCTURAL DEFINITION OF 3D WARP-INTERLOCK WOVEN FABRICS FOR ENHANCED DESIGN

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This study addresses the increasing interest in three-dimensional warp interlock woven fabrics (3D WIFs), which show strong potential for advanced technical and industrial applications. However, their development and broader adoption have been limited by the lack of a precise, comprehensive, and standardized structural definition. Inconsistent terminology, ambiguous structural concepts, and differing interpretations among researchers and industry professionals have created confusion and hindered effective communication and innovation. The main objective of this research is therefore to refine the structural definition of 3D WIFs, eliminate inconsistencies, and establish a universal framework that supports design and industrial implementation.

To achieve this, the study proposes several key advancements. Warp yarn categories are redefined, considering surface warp yarns as regular warp yarns when they bind a single layer, regardless of their position. New structural parameters are introduced to enhance design flexibility, including the number of weft yarns per column to allow variable layer counts, along with a new index describing the elementary weaving pattern. Experimental weaving trials demonstrate that the order of weft insertion significantly influences the final fabric architecture, leading to the introduction of a novel {Z} index to specify weft insertion order. The refined definition also integrates denting diagrams to clearly define warp yarn positioning per dent and describes the evolution of binding, regular, and stuffer warp yarns within the structure [1].

For instance, considering the representation of 3D WIF Orthogonal Layer to layer (O-L) architecture with binding, stuffer, and regular warp yarns, having an irregular distribution of weft yarns per column (Rwp = 10; Rwf = 15) in figure 1; the structural definition can be written as:

$$O - L\,\{4-3-2-1-2-3\}_1\{iN\}\begin{bmatrix} Binding & \begin{bmatrix} \begin{pmatrix}1\\2\end{pmatrix}\begin{pmatrix}0-2-0-1-0-2\\1-3-1-1-1-3\end{pmatrix}\\ \begin{pmatrix}7\\8\end{pmatrix}\begin{pmatrix}3-0-1-0-1-0\\4-1-2-0-2-1\end{pmatrix}\end{bmatrix}\\ Regular & \begin{bmatrix} \begin{pmatrix}3\\4\end{pmatrix}\begin{pmatrix}0-1-0-1-0-1\\3-3-1-1-1-3\end{pmatrix}\\ \begin{pmatrix}9\\10\end{pmatrix}\begin{pmatrix}1-0-1-0-1-0\\4-2-2-0-2-2\end{pmatrix}\end{bmatrix}\\ Stuffer & \begin{bmatrix} \begin{pmatrix}5\\6\end{pmatrix}\begin{pmatrix}2-1-1-0-1-1\\2-2-1-1-1-2\end{pmatrix}\end{bmatrix}\end{bmatrix}$$

Where :

1. O is equivalent to Orthogonal and L for Layer-to-layer binding of warp yarns,
2. $\{4-3-2-1-2-3\}_1$

corresponds to the irregular number of weft yarns per column repeated one time,

3. {iN} indicates the evolution of weft yarns inside the 3D woven architecture
4. Binding, Regular, Stuffer represent respectively the different evolutions of the binding, regular and stuffer warp yarns inside the 3D WIFs.

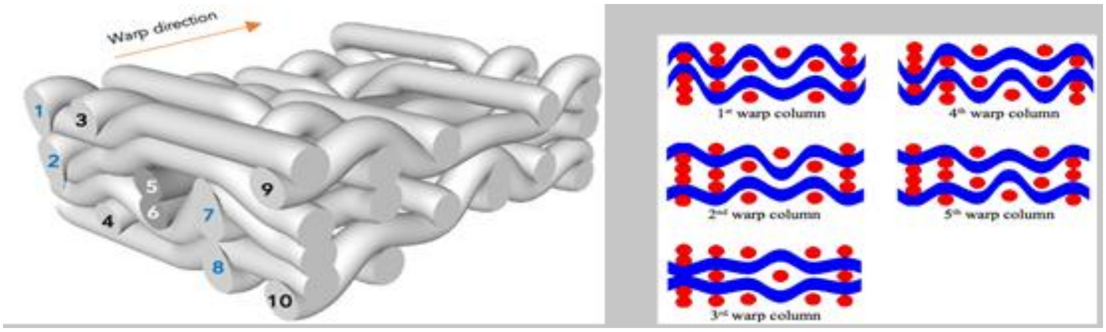

Figure 1 (a) Geometrical and (b) schematic representations of 3D WIF Orthogonal Layer-to-layer (O-L) architecture with binding, stuffer, and regular warp yarns, having an irregular distribution of weft yarns per column (Rwp = 10; Rwf = 15).

Together, these advances establish a robust, universal framework for designing innovative 3D woven architectures, including irregular layer structures and clearly defined yarn roles. By improving communication, design control, and compatibility with existing manufacturing and advanced yarn technologies, the proposed definition supports broader adoption of 3D WIFs across composite textiles applications.

Overall, this work advances standardization and is expected to promote wider adoption, interdisciplinary collaboration, and sustainable innovation in 3D woven fabric design and production.

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MANUFACTURING OF TEXTILE-BASED COMPOSITE STRUCTURES FOR HIGH-RATE AEROSPACE APPLICATIONS – AN INDUSTRIAL FRAMEWORK

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Manufacturing of textile-based composites has evolved in response to increasing demand for lightweight, high-performance structures across the aerospace sector. Two dominant trends have emerged: the production of larger integrated aerostructures and the development of smaller, structurally demanding components manufactured at significantly higher volumes. The latter is particularly relevant for emerging aerospace markets such as Advanced Air Mobility (AAM) and next-generation single-aisle aircraft, where scalability and cost efficiency are key design drivers. Textile reinforcement systems combined with liquid moulding processes such as Resin Transfer Moulding (RTM) are increasingly attractive for high-rate structural production due to their near-net-shape capability, dimensional control and compatibility with a wide range of textile architectures including non-crimp fabrics, braided preforms and tailored fibre placements [1–4].
Tailored reinforcement technologies such as Tailored Fibre Placement (TFP) further enhance this approach by enabling fibres to be aligned with principal load paths while maintaining manufacturable tow trajectories and controlled stabilisation through stitching [5,6]. The work illustrates these concepts through case studies from the HiRACOS programme, including a composite rotor blade for Advanced Air Mobility and a composite aircraft nose wheel, with examples of the components and processes shown in Figure 1.

Figure 1: Manufacturing methods and components geared towards high-rate manufacturing.

This work examines manufacturing strategies that enable high-rate production of textile-based composite structures while maintaining aerospace structural performance. The study focuses on the interaction between material architecture, preforming technologies and liquid moulding processes, and how these factors influence manufacturability, cycle time and structural efficiency. As a representative case, non-crimp fabrics (NCFs) and braided preforms are examined to evaluate trade-offs between manufacturability and structural performance, with particular focus on draping and forming behaviour and their impact on product quality and production rate.
The novelty of this work lies in demonstrating how the coupled optimisation of process, material architecture and manufacturing cycle time can enable scalable production of structurally efficient textile composite aerospace components. The work also outlines key research and development directions required to enable the next generation of high-rate composite aerospace structures, including advances in textile architectures, preforming and stabilisation methods, liquid moulding processes and digital manufacturing tools.

Acknowledgements: This work was carried out within the collaborative research project of HiRACOS, funded by Aerospace Technology Institute and in collaboration with Syensqo, AMRC and NCC.

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3D Textile Architecture: Process and Product 2

A SIMPLIFED IMAGE BASED ANALYSIS OF 3D WOVEN COMPOSITES WITH BINDER ARCHITECTURES

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Abstract

Due to the through-thickness binder reinforcements, 3D woven composites have outstanding out-of-plane mechanical properties in terms of damage tolerance and delamination resistance [1]. However, this improvement in through-thickness properties often comes with a compromise in the in-plane properties and depends on the weave structures of the reinforcements [2]. As the Z binder is the primary element to hold the 3D woven structures, a variation in its architecture can significantly affect the ultimate mechanical properties and failure modes [3]. One of the common observations from previous research is that, by reducing the tow waviness and crimp%, in-plane properties can be significantly improved [4]. This research aims to investigate the influence of the Z-binder weave architectures on the tensile behaviours of three-dimensional (3D) woven carbon/epoxy composites by reducing tow crimp sequentially. Composites are manufactured with four binder weave architectures, namely 1X1 Plain, 2X1 Twill, 2X2 Twill orthogonal weaves and an Angle Interlock weave. On-line video imaging, Digital Image Correlation (DIC) and micro-computed tomography (Micro-CT) techniques are employed to investigate the deformation and damage mechanisms in the specimens failed in in-plane tension. The experimental results show that the modulus is primarily driven by the fibre volume fraction of the composites whereas the failure strength is highly influenced by the crimp of the Z-binder and load bearing tows. Among all weaves, the Angle Interlock has the highest tensile modulus and strength due to the lowest degree of Z binder interlacements. Among the orthogonal weaves, 2X2 Twill resulted in higher tensile strength due to the fewer binder interlacements which resulted in lower crimp. Additionally, weft-way composites were found to have significantly lower tensile strength compared to warp-way due to the pinching of load bearing weft tows by the Z-binders. Industrially relevant analytical, method of computing laminate stiffness/modulus based on local tow waviness is proposed here. This numerical method considers the fibre orientation and crimp parameters in each ply and with appropriate corrections, predicts laminate properties with reasonable accuracy. A good agreement between computed and experimental results has been reported.

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CANTILEVER BENDING OF TAPERED 3D WOVEN COMPOSITES: EXPERIMENTAL INVESTIGATION AND MESOSCALE MECHANICAL MODELLING

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Abstract
Survivability under bird-strike loading is a critical design requirement for aircraft engine fan blades. 3D woven composites have demonstrated superior impact resistance compared with conventional laminated composites currently used in fan blade manufacture. Previous studies on tapered 3D woven composites have primarily focused on angle-interlock architectures [1–2]. The present study investigates the effect of taper ratio on the mechanical behaviour and meso-scale geometry of tapered 3D woven composites with orthogonal weave architecture.
3D woven preforms were manufactured on a 16-shaft table loom using 12K carbon fibre tows as stuffer yarns and 6K carbon fibre tows as binder yarns. The tapering was achieved by dropping weft yarns; excess warp stuffer yarns were manually trimmed. Composite specimens were produced via vacuum resin infusion using an epoxy matrix system. A 3D-printed tapered caul plate was used during infusion to ensure consistent tapered geometry across specimens. Mechanical characterisation was conducted using cantilever bending tests, with the thick end clamped and load applied at the thin end using a universal testing machine.
Geometries with different taper ratios were analysed and modelled in TexGen. The geometries were discretised into finite element meshes for simulation of cantilever bending in Abaqus. Figure 1a presents an example of the idealised longitudinal cross-section along a binder yarn within the tapered region generated in TexGen, corresponding to the physical composite shown in Figure 1b.
The paper will discuss a comparison of the experimental results and the FE analysis. Conclusions related to the design and manufacture of tapered 3D woven composites will be presented.

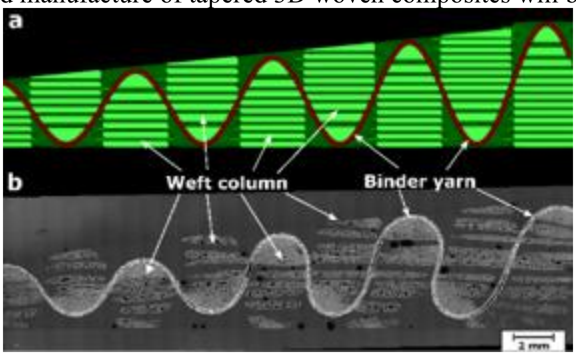

Figure 1: a – Geometric model of tapered region of orthogonal variable thickness 3D woven composite (taper ratio 1:10), b – microscopy of tapered region of orthogonal variable thickness 3D woven composite.

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LARGE COMPRESSION RESPONSE OF RE-ENTRANT 3D WOVEN THERMOPLASTIC AUXETIC COMPOSITES

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Auxetic materials, characterized by a negative Poisson's ratio (NPR), exhibit unique deformation mechanisms and enhanced energy absorption capabilities compared to conventional materials. While architectured auxetic structures have attracted increasing attention [1], textile-based reinforcements remain relatively underexplored despite their strong potential for advanced mechanical performance [2].

In this work, 3D woven thermoplastic auxetic composites are developed using a manual weaving loom. The multilayer reinforcement is produced from a twisted hybrid yarn combining aramid fibers and thermoplastic filaments. A one-piece woven preform is first manufactured, then shaped into a re-entrant hexagonal architecture and consolidated through a thermocompression process.

The mechanical response under quasi-static compression is primarily governed by the architectured geometry, exhibiting a characteristic lateral contraction induced by the re-entrant configuration. The force-displacement curve displays three distinct regimes: an initial elastic phase, followed by a plateau associated with progressive structural deformation and energy absorption, and finally a densification phase marked by an increase in stiffness. The NPR effect is particularly pronounced during the initial linear phase and is clearly observed through digital image correlation measurements.

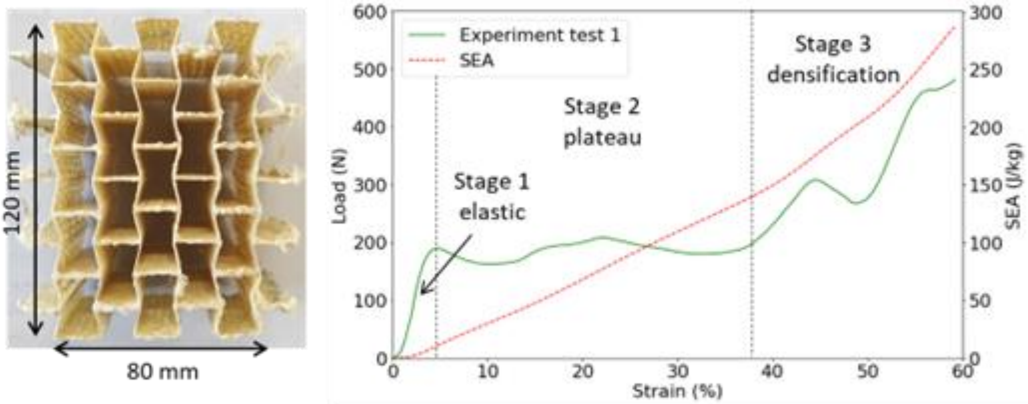

Figure 1: 3D woven reinforced composite and its associated mechanical response curves.

These results highlight the potential of combining textile-based 3D reinforcements with auxetic architectures for the design of advanced composite materials dedicated to lightweight structural and engineering applications.

This study has been funded by the French Defense Innovation Agency (AID) as part of the RAPID framework for the CORPLAUX project (reference number 2022 29 0959).

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NUMERICAL MODELLING OF WOVEN 3D PET TEXTILES

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Abstract
Spacer fabrics offer an alternative to conventional sandwich cores due to their through-thickness connectivity, eliminating the need for bonding adhesives and reducing the risk of skin–core delamination. The highly porous core also enables the possibility for fluid flow between the skin layers which opens the door to new engineering applications.
This study presents a numerical modelling approach in Simcenter 3D for predicting the compressive behaviour of unimpregnated woven spacer fabrics. Unlike the work of Lupu et al. [1] on warp-knitted spacer fabrics, the emphasis is placed on accurately capturing the initial two stages of the compression process.
Two modelling workflows are explored for generating a representative CAD unit cell of the produced woven spacer fabric. The first relies on built-in geometric extraction tools, such as cylinder correlation, to derive yarn paths directly from µCT data. The second method defines the textile as a set of parameters which are then manually determined by performing measurements on both µCT images as well as images made using an optical profilometer.
The applicability of the resulting numerical model is assessed by validating it against newly produced spacer structures. Finally, the model is used to perform a sensitivity analysis on material properties of the monofilaments, providing insight into how respective property variations influence the global compression behaviour.

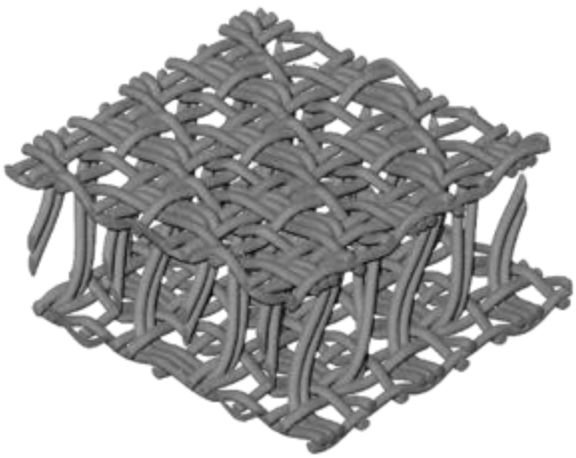

Figure 1: µCT-scan image of 3D textile

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Fatigue of Textile Composites

FATIGUE LIFE PREVISION MODEL FOR A 3D WOVEN PMC BASED ON THE NON-LINEAR CYCLIC BEHAVIOR AT A MESO-SCALE

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3D woven polymer matrix composite (PMC) are ideal candidates to design turbofan blades. Despite their performance under impact, 3D woven PMC fatigue behavior remains a challenge for numerical prediction, especially under complex multi-directional loading. Therefore, a thermodynamically admissible macroscopic life expectancy forecast model (*MOSCA*) is being developed by the collaborators *ONERA* and *Safran* [1, 2]. *MOSCA* is based on continuum damage mechanics approach and integrates an incremental damage formulation $\dot{d}$ which includes static and fatigue phenomena:

$$\dot{d}_{(i)} = \frac{\partial d_{(i)}}{\partial t} = \left(d_{(i)}^{\infty} - d_{(i)}\right) \frac{p_{(i)}^{s}+1}{s_{(i)}^{s}} \left[\frac{\left\langle \varepsilon_i^{eqm} - \varepsilon_{(i)}^{0,s}\right\rangle_+}{s_{(i)}^{s}}\right]^{p_{(i)}^{s}} \frac{\partial \varepsilon_i^{eqm}}{\partial t} \Bigg\} \text{static contribution}$$

Among improvements needed for *MOSCA*, residual deformations and fatigue load ratio effects under cyclic loading are considered in this work. To this end, the proposed methodology tackles the problem at the inner-structure scale (Figure 1a). Indeed, a mesoscale approach enables to use and tune non-linear behavior at constituent scale, evaluating their influences on a meso-representative cell under cyclic loading (Figure 1b). A comprehensive meso-models library will be used, from idealized and parametrizable to high fidelity image-based models [3] (Figure 1a). The aim of this study is to analyze the effect of meso-scale features on cyclic behavior of 3D woven PMC. Ultimately, this mesoscopic framework will serve to overcome the lack of experimental data and integrate complex phenomena to *MOSCA*.

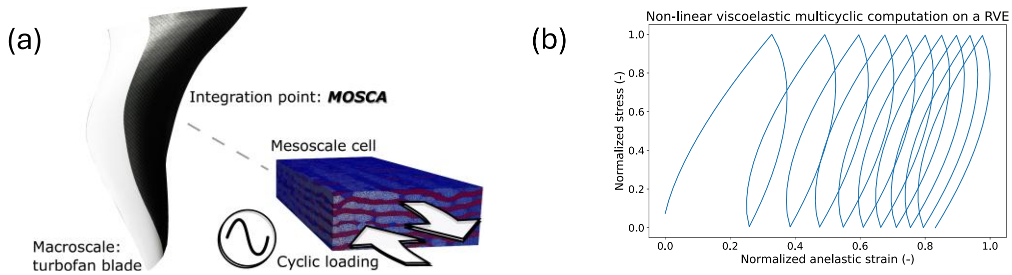

Figure 1: Overview of the proposed framework with (a) a description of the meso-scale approach and (b) the material response to cyclic loading at meso-scale.

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PHYSICS-INFORMED MACHINE LEARNING FOR FATIGUE DELAMINATION WITH FIBRE BRIDGING RETARDATION IN COMPOSITES

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Text: Fatigue delamination growth (FDG) is one of the most important causes of failure in composite structures. The presence of fibre bridging can have significant retardation effects on FDG behavior [1]. Models based on machine learning (ML) have been developed to determine fatigue properties (i.e. fatigue life and crack propagation) of metals and composites in the last decade [2-3]. There is sufficient evidence that the use of ML can have great capacity in materials' fatigue life prediction and crack evaluation. However, the use of ML without physical constraint takes disadvantages of black-box and lack of physical interpretation, which sometimes can result in fatigue determination violating physics. Physics-informed neural networks (PINNs) incorporates physical principles recently therefore have been proposed and employed to improve the interpretability and prediction accuracy of ML [4].

The objective of this study is to propose a physics-informed ML strategy for developing a reliable model that can accurately represent FDG with fibre bridging retardation under different stress ratios, based on our previous work in this field [5]. Particularly, a self-consistent physics-informed ML prediction framework, consisting of two connected physics-informed ML models, is proposed in the present study. The first ML model employs experimental data to predict the strain energy release rate (*SERR*) during fatigue delamination under different stress ratios. The *SERR* predictions from the first ML model, as a function of the crack propagation length a-a_0, are utilized to train the second physics-informed ML model to estimate the fatigue crack growth rate *da/dN* under different stress ratios. The Bayesian optimization (BO) is adopted during the ML training to ensure that all hyperparameters of each ML model are self-optimizing, thus eliminating the need for manual tuning.

After training, the model is able to predict FDG behavior under different stress ratios as a function of the *SERR*. Its robustness is verified via a cross validation. Furthermore, the proposed physics-informed ML framework is found to be superior to non-physics-informed ML models as well as the theoretical model, and exhibited reliable performance in terms of prediction accuracy, interpretability, generalization and extrapolation.

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A NEURAL NETWORK FOR FATIGUE LIFE PREDICTION OF TEXTILE COMPOSITES

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Textile-reinforced polymer composite components are frequently subjected to cyclic loading throughout their service life. Due to the inherent complex yarn architectures, these materials may undergo mechanical performance degradation, which can ultimately result in unexpected and catastrophic fatigue failure. Over the past decades, significant research efforts have been devoted to understanding the fatigue behavior of textile composites, focusing on experimental characterization, microstructural observations, and predictive modeling [1].

Experimental investigations remain indispensable for capturing the intricate fatigue mechanisms in textile composites. However, fatigue testing is inherently time-consuming and resource-intensive, particularly for textile composites where the interplay of fiber orientation and weave pattern creates a vast design space. It is therefore impractical to experimentally cover all possible load levels and conditions for any textile reinforcement architecture. Consequently, approaches that reduce experimental effort while still providing reliable fatigue life predictions for design purposes are urgently needed.

In this context, the present work introduces a physics-informed neural network (PINN) framework for fatigue life estimation based on a limited set of experimental data. The methodology integrates a Basquin/Walker-type fatigue law with a shallow residual artificial neural network (ANN). The model learns systematic deviations arising from the damage progression as connected to the stiffness degradation during loading. The governing fatigue relations are embedded in the training objective through physics-based constraints, such as monotonic fatigue life reduction with increasing stress range, consistent mean-stress (R-ratio) effects and smoothness constraints on frequency dependence. Additionally, run-out tests are treated as right-censored observations via a survival-type loss, while Gaussian priors are imposed on the Basquin/Walker parameters to regularize learning under data scarcity. A multi-stage training strategy is adopted: first calibrating the physics parameters, then progressively introducing the data-driven residual while tightening the physics constraints.

The resulting ANN framework was adopted to predict the fatigue life curve of a 3D orthogonal weave glass textile composite and a glass plain weave textile composite subjected to uniaxial cyclic tensile loading in the warp and fill directions [2].

The PINN demonstrated improved robustness and generalization compared to purely data-driven baselines, particularly in sparsely sampled regions of the loading space. Remarkably, reliable fatigue life predictions can be achieved with only a minimal number of fatigue tests, making the approach highly attractive for textile composites where experimental campaigns are costly and complex.

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FATIGUE DAMAGE OF TEXTILE CORD–ELASTOMER COMPOSITES UNDER COMPRESSION–TENSION LOADING

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Compression-tension fatigue significantly damages textile cord-elastomer composites used in industrial products. However, conventional fatigue test methods only allow limited control over these conditions. This work introduces the new Extension-Compression-Uniaxial (ECU) fatigue test (Figure 1) [1]. This test allows for strict uniaxial loading with separate control over tensile and compressive strain amplitudes, while keeping a specimen design that reflects industrial applications. The ECU test is validated through a comparative fatigue study on textile cords made from different filament materials, cord constructions, and elastomer matrices. These cords were subjected to pure tension, pure compression, and combined compression-tension loading. The experiments reveal clear differences in damage development across loading modes. Combined loading leads to the most significant drop in mechanical performance. In contrast, pure compression affects mainly the elastomer matrix, while tensile loading highlights damage growth within the cord. Temperature and number of cycles greatly influence fatigue progression. Variations in elastomer stiffness have a limited impact within the investigated range. Post-mortem X-ray tomography and scanning electron microscopy highlight the multiscale damage processes triggered by different loading scenarios, revealing distinct failure mechanisms at the filament level. The results show that the ECU test is a useful tool for isolating and studying fatigue damage mechanisms in reinforced elastomer systems under complex loading conditions.

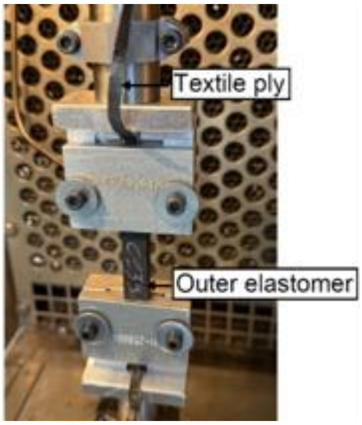

Figure 1: ECU test setup [1].

This project has received funding in the framework of Conventions Industrielles de Formation par la Recherche (CIFRE), managed by the ANRT (Association Nationale de la Recherche et de la Technologie) and supported by the French tire manufacturer Michelin.

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Life-Cycle Assessment (LCA) and Sustainable Composites

LCI/LCIA of Carbon Fibres: *an update… and a breakthrough.*

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More than 50 years ago, the industrial production of (continuous) carbon fibres started almost simultaneously, first in Japan, then in UK and USA. Since then, the production process has been optimised, not only to improve the properties, but also to reduce cost. Because energy consumption represents an important share in the production cost of carbon fibres, these cost reduction and efficiency improvement efforts have also led to a reduction of the total embedded energy (CED) and greenhouse warming potential (GWP and CO_2 emission) of carbon fibres.

During Texcomp-15 in Leuven (2024), an analysis was presented of the very different life cycle inventory and impact analysis data (LCI/LCIA) that have been published over the past decades. For instance, the cumulative energy demand (CED) varies from 200 to 1200 MJ/kg. We have investigated the reasons behind this discrepancy.

After careful comparison of the different published data, it could be concluded that the differences between LCIA data (CED, GWP) is most probably due to large differences in the input data for LCI : primary data from industrial plants seem to be most reliable (for instance, provided by JCMA, *Japanese Carbon fibre Manufacturers Association*), while lab-scale and pilot plant data, up to literature data or data based on theoretical assumptions are gradually less reliable.

However, still these hugely different data exist, and are being used by researchers and engineers in the composites industry. An additional problem was that the JCMA data only present four impact indicators, namely CED, GWP,NOX and, SOX, and hence neither a complete LCI data set nor a full list of (~15) impact indicators was available.

The authors have attempted, over the past few years, to set up discussions amongst two major players, namely JCMA and EUCIA *(European Composites Industry Association)*, who had been publishing in their Eco Impact Calculator much higher data than JCMA . These discussions have now finally resulted in a breakthrough: JCMA will publish, by July 2026, a full LCI data set, based on recent (2022) industrial measurements. These data will then be used in the SIMAPRO software to create a full impact indicators list (according to European standards) and will later be included in EcoInvent's database. EUCIA will further collaborate with JCMA, and eventually refer in their Eco Impact Calculator to the JCMA/EcoInvent data for carbon fibres.

DYNAMIC MODELLING OF EMISSIONS, MASS FLOWS, AND CAPEX IN THE CARBON FIBER INDUSTRY IN THE TRANSITION TO NETZERO 2050

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Carbon-fibre (CF) composites are central to lightweight transport, energy and infrastructure, but rapid market growth can offset improvements in unit CF kgCO2e/kg intensity. This work presents a scenario-based decision model that links market growth, dynamic material flow analysis (D-MFA), CAPEX, and supply-chain decarbonisation levers for dry CF and downstream CFRP value chains from 1980 to 2050. Demand is segmented by sector and sub-sector and mapped to P10/P50/P90 pathways aligned with 1.5, 2.1 and 2.7°C climate futures. The framework couples historical demand reconstruction, lifetime-dependent in-use stocks, end-of-life recovery, virgin/recycled fibre substitution and the adoption of decarbonization enablers as shown below.

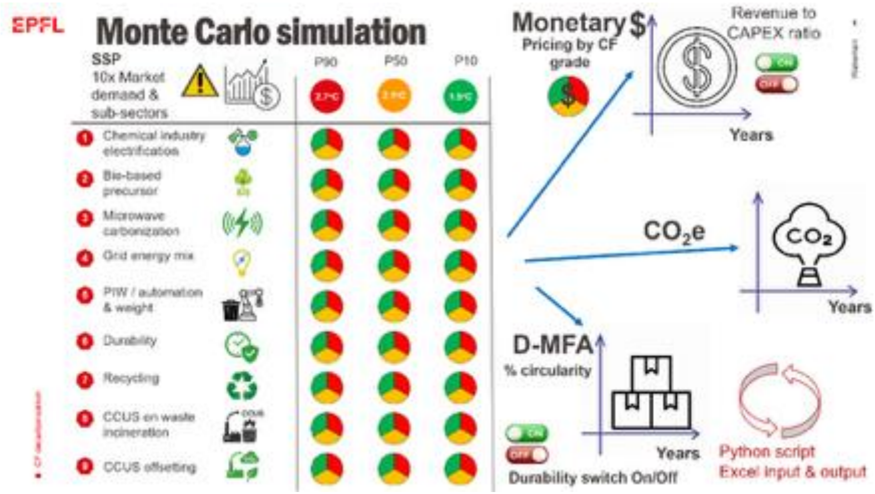

Figure 1: Dynamic Monte Carlo simulation of carbon fiber 1980 to 2050

Preliminary model outputs indicate that strong demand growth can keep absolute sector emissions high even when kgCO2e/kg CF declines substantially; accordingly, no single lever is sufficient and a systemic and collaborative approach is required. The largest reductions arise from combined action upstream on precursor/feedstock emissions, together with manufacturing waste reduction and accelerated circular recovery. Recycling improves system performance, but its contribution is constrained by application-specific quality requirements. CAPEX planning ahead of waste streams is required with traceable reverse logistics critical. The model provides a quantitative basis to compare decarbonisation roadmaps, circularity strategies and investment timing for advanced composite value chains under deep uncertainty. The authors acknowledge seed funding from E4S and discussions with industrial partners used to pressure-test assumptions and scenario definitions.

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NATURAL FIBERS FOR COMPOSITES: LIMITATIONS AND IMPROVEMENTS

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Natural fibers, such as flax and hemp, are increasingly being used in composite materials due to their sustainability, low density, and good mechanical properties. However, their performance is often limited by structural defects, particularly **kink bands**, which concentrate stress and trigger rupture in composite [1].

Kink bands are regions within the fiber where the cellulose microfibrils are misaligned therefore reducing the fiber stiffness. These defects act as **stress concentrators** [2] (particularly in the vicinity of kink band pores), leading to reduction of tensile resistance and **premature failure** when the composite is subjected to loads. As a result, the full potential of flax and hemp fibers in composite applications is not fully used.

Recent research has shown that **applying tension** to these fibers can reduce the number and severity of structural defects [3,4]. Tension is suspected to aligns the cellulose microfibrils more uniformly, reducing kink bands severity and number.

Observations during tensile tests using **X-ray tomography at Synchrotron Soleil** have provided valuable insights into the behavior of these fibers under load. The high-resolution imaging (325 nm voxel size) revealed a significant reduction in pore sizes within kink-band defects when tension was applied. This reduction in porosity is likely to contribute to improved mechanical properties by eliminating stress concentrations at small pores and enhancing the fiber's overall integrity.

While flax and hemp fibers have inherent limitations due to structural defects such as kink bands generated during fiber extraction, applying tension during processing can mitigate these issues. The use of advanced imaging techniques, such as X-ray tomography, has confirmed that tension reduces porosity and improves fiber alignment, leading to a potential increase of mechanical performance. This understanding paves the way for optimizing natural fiber composites for a wider range of applications.

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REVITALIZING FLAX AS A SUSTAINABLE ALTERNATIVE TO FOSSIL-BASED FIBERS

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According to European Union strategies and frameworks, sustainability, bioeconomy and circular economy in textile field are of key importance. "Revitalizing Flax as a Sustainable Alternative to Fossil-Based Fibers in Baltic Region" [1] is a project that tackles the problem of how to reduce the dependence on fossil-based fibers and circularity challenges. The project is funded by Swedish Institute. In recent decades the large-scale use of flax in textiles and other industries has decreased. Since Baltic region has historical expertise in flax farming and linen production, it is essential to increase modern flax processing methods and find new innovative applications for flax as a bio-based fiber. Using flax could also tackle the microfiber problem in Baltic Sea, since synthetic textiles, packaging and fishing equipment are contributing to microplastic in the environment. Moreover, flax cultivation requires fewer chemicals and fertilizers.

Three different EUs universities are working together in this project. Firstly, the University of Borås (HB) in Sweden specializes in textile research, Tallinn University of Technology (TalTech) in Estonia focuses on recycling, testing and material development, and Kraków University of Economics (KUE) in Poland in quality testing and consumer expectations. One of the aims of this project is to identify expertise and develop co-operation with existing and new partners for future research.

It is essential to use flax in different novels and modern applications. One of the project's goals is to identify research gaps in the field of flax and its applications. The project also studies new ways to utilize, recycle, and find innovative applications for flax fibers. Materials containing virgin and recycled flax fibers are being studied and developed during the project. Different stakeholders are also involved in this project to ensure that the problem is widely recognized and focused on.

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Thermoplastic Textile Composites 1

NETWORK ANALYSIS OF ELECTRIC CONDUCTIVITY MEASUREMENTS

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Weldability is one of the inherent advantages of thermoplastic composites (TPCs), enabling fusion bonding of two parts without the need for additional materials and corresponding weight penalties. Various welding technologies have been developed over the years, and applied in current aircraft structures. The conductive properties of carbon fibres provide the possibility for inductive heating by means of an alternating electromagnetic field. This principle is applied in induction welding, where a coil is moved (typically using a robot) on the outside along the interface of two parts to be fused together.

The power dissipation in eddy currents induces the heat generation required for welding. The currents are directly related to the electric conductivity of the materials to be welded. Thus, knowledge of the conductivity provides essential input to design the welding process, rather than to develop it by trial and error. Typically, I-V measurements are performed on rectangular strips of the composite material to determine its anisotropic electric conductivities, using two [1], four [2] or six probes [3] to transfer the current (I) and measure induced voltages (V).

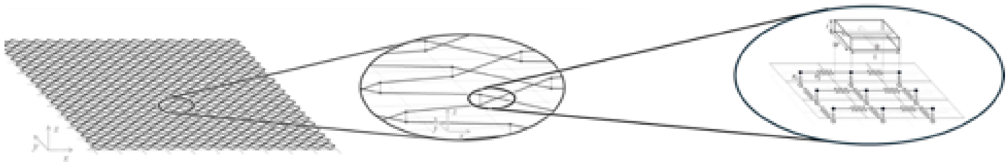

Figure 1: Resistor grid model of a conductive carbon fabric.

Following classical linear theory, the in-plane conductivities of balanced carbon fabrics (with equal conductivity in both fibre directions) should satisfy in-plane isotropy. However, conductivity measurements on carbon fabric reinforced TPCs show distinct orientation dependent results. A simple resistor network solver (consisting of in-plane fibre and through-thickness contact elements) was developed to represent the fabric's mesostructure (see Figure 1) and thus to shed some light on the meso scale phenomena underlying the homogenized response on the macroscopic level.

The simulation results confirm the orientation dependent macro scale response of the experiments. While respecting the continuum approach, this implies that the isotropic in-plane conductivity should be a (nonlinear) function of the material orientation vs the electric field strength vector. Further, such analyses enable studies on the size dependencies, leading to recommendations for test specimen dimensions for conductivity measurements.

The support of the ThermoPlastic composites Research Centre TPRC in Enschede (NL) for this work is gratefully acknowledged.

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DEVELOPMENT OF THERMOPLASTIC MULTI-MATRIX COMPOSITES WITH ADJUSTABLE STIFFNESS GRADIENTS

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The development of thermoplastic multi-matrix fiber-reinforced composites with locally adjustable anisotropic stiffness gradients offers new opportunities for lightweight structures with integrated functional zones. This contribution focuses on a simulation-based process chain for the manufacture of such composites with integrated compliant solid-state joints, enabling the targeted combination of load-bearing stiffness and localized flexibility.

The manufacturing approach is based on hybrid yarns composed of glass fibers and thermoplastic matrix materials such as polypropylene (PP) and thermoplastic polyurethane (TPU). These yarns are processed into two-dimensional and three-dimensional reinforcement preforms using textile technologies such as tailored fiber placement (TFP) and multilayer weft knitting (MLG), allowing local control of fiber orientation, matrix distribution, and stiffness transitions. After textile preforming, the structures are consolidated by hot pressing in order to realize defined matrix transition zones and integrated compliant regions within a single composite component.

Key challenges in realizing multi-matrix composite structures with locally adjustable stiffness and mobility include ensuring reliable interconnection and chemical compatibility between dissimilar matrix systems as well as precisely setting fiber orientations that correspond to the intended kinematic behavior of the composite part. This project addresses these challenges through a simulation-supported process chain that encompasses online hybrid yarn spinning with adjustable TPU fiber content, TFP and MLG for the locally defined integration of hybrid yarns into near-net-shape 2D and 3D preforms, and process as well as structural simulation to guide preform design and consolidation. By combining compliant and stiff structural regions within a single component, the approach enables the realization of fiber-reinforced composite joints with defined movement direction, targeting applications in orthoprosthetics and robotics.

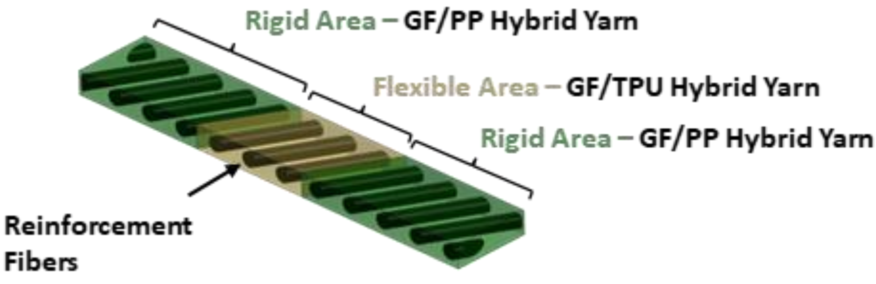

Figure 1: Multi-matrix fiber-reinforced composite with integrated solid-state joint | © IPF

FATIGUE BEHAVIOR OF WOVEN FABRIC REINFORCED THERMOPLASTIC COMPOSITE FLEXURES SUBJECTED TO LARGE DEFORMATIONS

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This paper reports on an extensive qualitative and quantitative damage development study on thin woven fabric reinforced composite curved beam subjected to large deformations. This damage development is related to fatigue tests performed at deformation levels related to the type of damage observed in the quasi-static tests. The results lead to conclusions concerning the lifetime prediction of such structures.

This study is related to the application of woven fibre reinforced thermoplastic composites for flexures used in a morphing wing application. A proposed concept by Fokker Aerostructures [1] for an active morphing winglet includes the use of flexible skin and flexures to constrain the kinematics of the movable. The reasonably complex 3D shell-like flexure has led to the use of an aerospace qualified satin weave reinforced thermoplastic composite for its enhanced formability. Besides, a glass fibre is chosen, leading to a material with a high strain to failure, necessary for the large deformations. As often with such materials, the damage development is gradual, asking for a thorough characterization to support the optimization of the design of such flexures, and to predict its lifetime under repeated loading.

In order to perform the damage development characterization in a generic way, a test geometry representing the loading conditions and the type of damage observed in the flexure was chosen. More particularly, the curved beam test allows folding and unfolding at corners, typical of the deformation patterns encountered in the flexures. For clarity, an illustration of the winglet, the flexure and the curved beam folding/unfolding setup is shown in Fig. 1.

The results of the work presented contains a qualitative and qualitative description of the damage evolution on the meso-scale, as a function of the fibre orientation and the ratio between corner radius and thickness [2]. Main techniques used include Acoustic Emission and cross-sectional microscopy. The quantitative aspect of this research leads to the definition of strains at failure initiation. These strains are used as a basis to evaluate the fatigue life of the material under these conditions. Results of these fatigue tests lead to conclusions on the lifetime prediction of such structures.

Fig. 1: From the morphing winglet movable, down to the Flexure, the curved beam test and the mesoscopic damage analysis.

The project is part of the AEROMO2 JTI-CS2-2019-CFP10-AIR-01-45 project number 887240, funded by the Clean Sky 2 Joint Undertaking.

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MECHANICAL PERFORMANCE OF COMPOSITES REINFORCED WITH ZERO-TWIST HYBRID YARNS FROM RECYCLED CARBON FIBRE

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Waste and recycled carbon fibre (rCF), increasingly available as production waste from various carbon fibre processing stages and through reclaiming from end-of-life composites, have found widespread use in industrial applications. However, the mechanical performance of composites based on these forms of waste carbon fibres or rCF remains significantly lower compared to composites made from continuous or well-aligned virgin fibres. These relatively low values are mainly attributed to poor fibre orientation, significant fibre shortening during processing, and low fibre content, all of which limit the mechanical performance of the composite. In order to overcome these limitations, a new concept of spinning process for the production of zero twist (~0 T/m) hybrid yarns from rCF and thermoplastic fibres based on thermal activation of thermoplastic fibres is developed and patented [1]. The spinning process incorporates a modified drafting (1) unit with adjustable gauges and fibre guidance elements for fibres up to 120 mm in length, combined with a thermo-module (2), false twister (3), nozzle (4), take-up rollers (5), and a winder (6) shown in Figure 1. The resulting zero twist hybrid yarns from rCF and polyamide 6 fibres with high orientation are expected to enable thermoplastic composites with high tensile strength and modulus compared to those produced from virgin carbon filament yarns, thereby unlocking the potential of rCF for high-performance carbon fibre reinforced composite applications. The effects of relevant spinning parameters of zero-twist yarns on mechanical properties of composite will be presented for the first time.

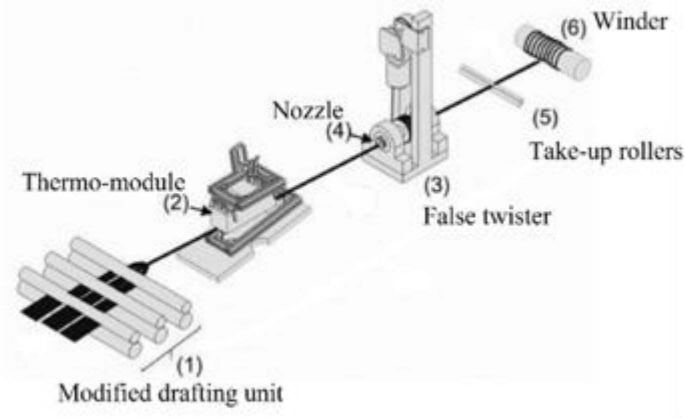

Figure 1: Process (left) for the development of zero twist hybrid yarn (right) [1]

This article presents parts of the results achieved within the Project CH 174/46-2 | GE 2525/7-2 funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – 407164652| 407164652. The funding is gratefully acknowledged.

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3D Textile Architecture: Process and Product 3

ELASTO-PLASTIC ANALYSIS OF SHEAR-OUT FAILURE IN BOLTED JOINTS OF 3D WOVEN CARBON FIBER-REINFORCED POLYMER COMPOSITES

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This study presents a predictive modeling framework for shear-out failure in straight-sided lugs manufactured from 3D woven carbon fiber-reinforced polymer (CFRP) composites, with material directions aligned relative to the pin displacement direction. The material response is represented using plasticity criterion to capture directional yielding and nonlinear deformation behavior.

While prior approaches commonly rely on elastic formulations with progressive damage evolution, such models depend on post-failure material behavior that is difficult to characterize experimentally and often requires extensive calibration. In contrast, the present work introduces a mechanistically based failure criterion that avoids reliance on post-failure assumptions and instead links failure initiation directly to measurable material response.

The model is implemented in the commercial finite element solver Abaqus/Explicit. Initial shear failure is identified by monitoring the evolution of shear strain in the warp–weft direction (ε_{12}) in the vicinity of the pin. The load corresponding to the first element reaching the material shear failure strain is defined as the onset of failure. Ultimate failure is characterized by the propagation of a shear failure band from the pin hole to the free edge of the lug, with the associated load defined as the ultimate shear-out strength.

Experimental observations of 3D woven composites under pure shear demonstrate significant plastic deformation over a broad strain range - reaching 50% or more - without noticeable softening in the stress–strain response. The global response of lugs during shear-out loading reflects this behavior through continued strain accommodation in regions that have already exceeded the shear failure threshold, progressive extension of shear bands, and eventual shear-out failure. This approach enables robust prediction of shear-out failure without reliance on post-failure calibration, providing a practical and physically grounded tool for design of 3D woven composite joints.

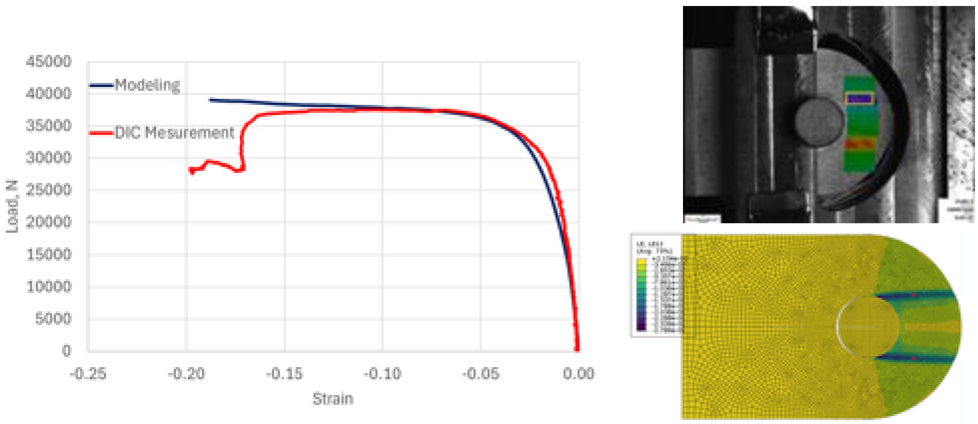

Figure 1: Comparison of load–strain response at the center of the shear band between FEM simulation and experimental measurements.

LIGHTNING STRIKE TESTING OF 3D WOVEN COMPOSITE MATERIALS

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This paper investigates the lightning strike behaviour of advanced carbon/epoxy composite architectures intended for structural applications in the fan module of aero-engines, with a focus on fan cases and fan blades. While conventional two-dimensional laminated composites are now widely used in such structures, their inherent sensitivity to interlaminar damage under out-of-plane loading raises questions regarding their robustness when subjected to lightning strikes. Three-dimensional (3D) interlock woven composites, featuring through-thickness reinforcement, are a promising alternative to enhance damage tolerance and maintain structural integrity in service after such extreme events.

The study presents a direct experimental comparison between a reference 2D carbon/epoxy laminate and a 3D carbon/epoxy interlock woven composite of comparable thickness, in order to isolate the effect of the through-thickness architecture. Flat plates of each material were tested in a specialized laboratory using representative high-current lightning strike simulations. The specimens were rigidly clamped on a metallic fixture to reproduce constrained boundary conditions typical of engine structures. For each configuration, the surface burn pattern, the depth of the thermally and electrically affected zone, the extent of internal delamination, and the residual mechanical performance after impact were assessed and compared.

The results highlight a clear change in damage mechanisms induced by the 3D architecture. For a given lightning strike severity, the depth of the burnt or eroded region remains of the same order for both materials, indicating similar exposure to the thermal and electrical fluxes. However, the 3D interlock composite exhibits a significantly reduced delaminated area and a strong limitation of through-thickness crack propagation and perforation, owing to the mechanical stitching effect of the interlock tows. This improved damage containment translates into markedly enhanced post-impact behaviour and residual strength capability, supporting the ability of 3D composites to ensure safe continued operation after a lightning event.

These findings demonstrate the potential of 3D interlock woven composites to increase in-service robustness and flight safety for fan module structures exposed to lightning, and provide experimental evidence to support their consideration in future aero-engine design and certification strategies.

YARN DEGRADATION DURING WEAVING: POST-MOTION INTERACTIONS IMPACT

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Context

Woven composite reinforcements exhibit high and specific mechanical performances. Nevertheless, the weaving process can induce damage to warp tows, particularly due to the flexural and frictional sensitivity of materials such as carbon and glass fibers, especially at high warp densities. This issue is critical, as defects including filament breakage, material loss, or bonding imperfections can lead to a degradation of mechanical properties, often resulting in conservative, oversized reinforcement designs. While yarn-to-yarn friction has received increasing attention in recent years, existing studies predominantly focus on shedding conditions where yarns are crossing at the shedding center plane [1].

The objective of the present work is to investigate the influence of weave pattern on yarns arrangement between two successive shedding phases, and to assess its impact on yarn-to-yarn friction at the initiation and termination of shedding.

Methods

Basic weave patterns are used to generate simple cases of yarn-to-yarn interactions. Then, a yarn prepositioning concept is developed on a UNIVAL 100 motorized Jacquard from Staubli, in order to place yarns in precise positions before shedding to evaluate the influence of yarn crossing a) at the end of the motion, by avoiding yarn friction at the beginning and during motion and b) at the beginning of the motion, by avoiding any other yarn-to-yarn friction. The tension of a studied yarn is measured and images from a high-speed camera for yarn position monitoring complete the study.

Discussions and conclusions

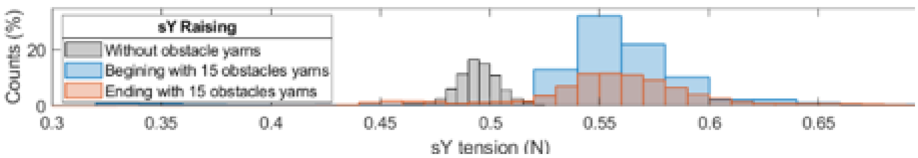

Figure 1: Distribution histogram without obstacle yarn and with 15 obstacles yarns.

Increasing the number of crossed yarns, called obstacles yarns, at the beginning of the shedding motion results in a wider distribution of yarn tension, indicating increased variability in load sharing between yarns (Figure 1). This suggests that yarn interactions become more heterogeneous as the number of crossings increases. At the end of the shedding motion, tension distribution remains spread and shifts toward higher tension values when the number of crossed yarns increases. This trend points to enhanced frictional effects accumulated during yarn displacement.

These results indicate that the number of crossed yarns significantly affects both tension levels and dispersion during shedding, which may contribute to increased local stress concentrations and a higher risk of yarn damage due to weaving process.

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INFLUENCE OF THE 3D WEAVING PROCESS ON THE DEGRADATION OF PARA-ARAMID YARN

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3D warp interlock fabric can provide a monolithic woven structure thanks to the binding warp yarns that help to maintain the whole fibrous architecture. These architectures enhance mechanical performance, particularly regarding dynamic response, ballistic resistance, and protection against knife or spike threats [1]. Beyond protection, they offer improvements in flexibility and wearer comfort [2]. In composite applications, 3D woven preforms are highly valued for their ability to suppress delamination under mechanical loading. However, the compaction of the different types of yarns inside the 3D woven structure is the result of an optimized combination between the warp and weft linear densities of yarns, the end and pick densities of the fabric and its 3D woven architecture. This compaction leads to the definition of the fiber volume fraction of the 3D warp interlock fabric. While beneficial for the final mechanical properties, the increase of the end and pick densities poses challenges during the weaving process. Increased friction between yarns often leads to fibrillation—the degradation and loss of individual filaments. This phenomenon ultimately degrades the mechanical integrity of both the yarn and the resulting fabric. By applying a step-by-step scientific approach, different types of yarns (binding and stuffer warp yarns) have been chosen according to their specific locations inside the 3D woven architecture and extracted at different steps of the weaving process (from the bobbin to the 3D woven fabric) to be finally characterized their tensile strength properties and loss of weight. Based on this investigation, it appears that the stuffer warp yarns have been more damaged than the binding warp yarns, which is mainly due to their interply position subjected to more yarn-to-yarn friction during the weaving process.

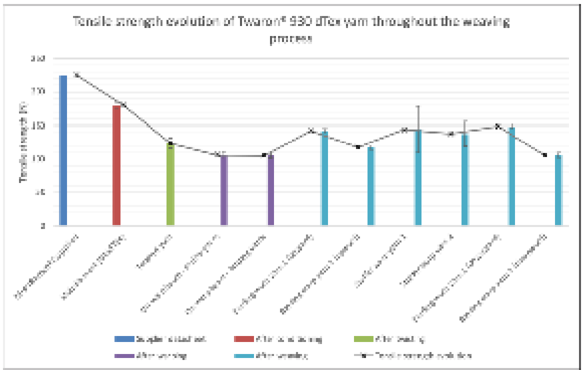

Figure 1: Twaron® 930 dTex yarn breaking force evolution: from raw multifilament to 3D woven fabric

The authors declare no conflict of interest regarding the use of Twaron® fibers provided by Teijin Aramid for this research.

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Thermoplastic Textile Composites 2

STRUCTURAL ARCHITECTURE AND THERMAL BONDING DESIGN IN RECYCLED-FIBRE NONWOVENS

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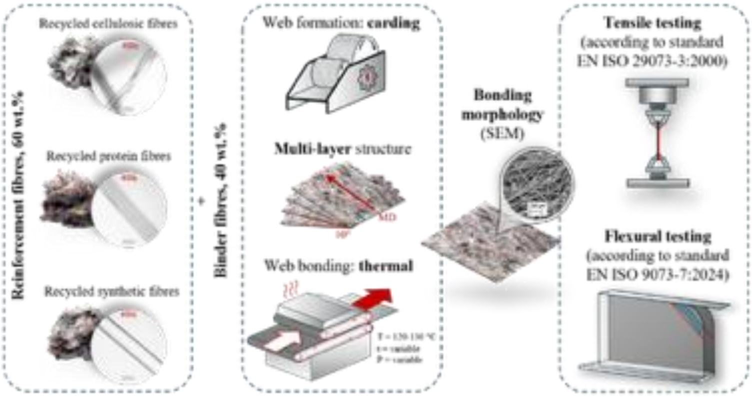

Figure 1: Structural design and characterization workflow for thermally bonded recycled-fibre nonwovens.

The increasing demand for circular material solutions has accelerated interest in recycled fibre-based textile reinforcements for lightweight composite structures and resource-efficient interior applications. Thermally bonded nonwoven structures offer a low-energy manufacturing route; however, their mechanical performance remains strongly governed by fibre structure bonding morphology, and anisotropic web structure.

This study explores the influence of fibre type, multilayer architecture, and thermal bonding conditions on the mechanical behaviour of carded nonwoven reinforcements produced without mechanical entanglement. Mechanically recycled cellulosic, protein-based and synthetic fibres were analyzed to evaluate intrinsic fibre morphology and influence bond formation and load transfer mechanisms.

Webs were produced using semi-industrial carding followed by controlled thermal bonding under varying temperature, pressure, and dwell time conditions. Structure of the nonwovens were analysed by optical microscopy and scanning electron microscopy (SEM) to characterize fibre orientation, bonding area formation, and inter-fibre fusion morphology. Multilayer assemblies were introduced to modify fibre distribution through thickness and to reduce directional anisotropy. Mechanical performance was evaluated using tensile and flexural testing in machine (MD) and cross-machine directions (CMD).

The work aims to establish experimentally grounded process–structure–property relationships linking fibre characteristics, bonding physics, and macroscopic performance, providing guidance for designing recycled fibre nonwovens suitable for lightweight composite structures and durable interior textile products. The presented approach supports scalable manufacturing strategies combining material circularity with engineered structural performance.

The authors would like to acknowledge The Centre of Excellence in Circular Economy of Strategic Mineral and Carbon-based Resources (SOURCES) for their financial support.

3D-PRINTED BIO-BASED TEXTILE COMPOSITES FOR RESOURCE OPTIMISATION AND ENHANCED TEXTILE DURABILITY

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Textile composites, as one of the key areas in advanced textiles development, play an important role in enhancing the performance, durability, and lifespan of textiles. However, the high consumption of raw materials and the generation of waste in conventional manufacturing methods for these composites have posed significant environmental challenges. In this regard, 3D printing as an additive manufacturing technology enables the creation of targeted, localised reinforcement structures on textiles, helping to improve performance and extend durability by reducing material consumption. This approach, especially in the development of sustainable textile composites, offers great potential to optimise resource use and reduce waste. In this study, a biobased polymer composite comprising bacterial cellulose, pectin, and polylactic acid is used to create localised reinforcing structures on textiles. This approach enables improvement in the fabric's functional and mechanical properties without significantly increasing weight or material consumption. Also, the use of natural polymers that can be extracted from renewable resources and biowastes offers an effective approach to reduce dependence on virgin raw materials and promote a circular economy in textile composites. Finally, the physical and mechanical properties of the composite, along with the adhesion and stability of the printed structures under different conditions are evaluated.

The Engineering and Physical Sciences Research Council (EPSRC) is acknowledged for supporting this research through a doctoral (PhD) studentship awarded to Aida Fadakarsarkandi [Project Reference: EP/W524396/1: EPSRC 2945174].

SELF-REINFOCED PLA WOVEN REINFORCED THERMOPLASTIC BIOCOMPOSITES

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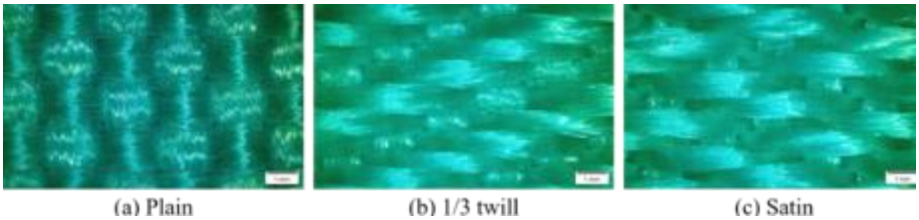
Biopolymers development has garnered growing interest in recent years as an alternative to petroleum-based materials in a context of sustainable development. Among them, polylactide (PLA) is biobased, biocompatible and compostable under industrial conditions [1], and accounts for more than 31% of the global biopolymer production. Despite its widespread use in the biomedical and packaging fields [2], its low glass transition temperature (60°C) and weak elongation at break (2-6%) remain a limitation for sustainable applications. Therefore, PLA is increasingly used in blends with other thermoplastic polymers [3] and as matrices in composite materials in order to improve its thermomechanical properties [2][3]. Recent works have highlighted the interest in producing PLLA matrix composites reinforced with glass fiber or flax via thermoplastic-resin transfer moulding (TP-RTM) process [4], with molar masses reaching above 140,000 g/mol. TP-RTM process allows the production of composites via *in situ* polymerisation of the matrix around the reinforcement. The present objective is to produce all thermoplastic self-reinforced PLLA biocomposites via TP-RTM to reach recyclable materials.

This work presents the production and characterisation of PLLA thermoplastic woven reinforcements for the manufacture of self-reinforced PLLA biocomposites. PLLA is first blended with poly(ε-caprolactone) (PCL) via twin-screw extrusion to improve its ductility. Blends with various proportions of PCL (from 10 to 40 wt.% PCL, in increments of 10 wt.%) are processed and optimised PLLA/PCL immiscible polymer blends multifilaments are obtained via melt spinning process. Scanning electron microscopy observations are conducted on multifilaments of different ratio and their mechanical properties are examined as well via tensile testing. Different weave patterns (Fig 1) are realised and their mechanical properties and compatibility with the TP-RTM are characterised. Thermoplastic biocomposites are produced with each structure (2 to 4 plies depending on the weave pattern) to assess their influence on the properties of the composites. It is shown that weft yarn density affects the reinforcement porosity and thus influence the composite impregnation quality. A comparison with similar all-PLLA structures is also made.



(a) Plain (b) 1/3 twill (c) Satin

Figure 1: PLLA/PCL woven reinforcements.

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Braided Composites

DEMONSTRATION CUSTOMIZABLE 3D BRAIDING STRUCTURES USING A RADIAL BRAIDER BASED ON THE CHAIN AND SPROCKET DESIGN

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Current products made from composite braids can rarely take advantage of their full mechanical potential because of the limitations of traditional two-dimensional and fixed geometry braiders [1]. Assi et al. proposed a 3D hexagonal braider relying on the so-called chain and sprocket mechanism [2]. The horngears (HG), i.e., the sprockets, were installed on a flat horizontal bedplate arranged in a hexagonal compact layout. [2]. The carrier had a chain shape that was moved by the HG. Since all HGs are individually controlled by independent motors, this design allowed the individual control of the yarn carrier paths to achieve tailorable and evolutive braided structures. We present here a redesign of the chain and sprocket 3D braider in a radial configuration with an improve one-link chain carrier design. The objective was to demonstrate the customization ability of the 3D braider by manufacturing a braided hockey stick shaft with an evolving textile structure. The shaft had a multilayer braid section, followed by a multilayer braid interlock section and finished by a filament winding section. Figure 1 a) shows the braiding of a hockey stick, with the braid (in blue) being braided over the mandrel (in pink). The HGs were arranged in a radial braider configuration, formed by a 48-sided polygon. It had seven axial layers of HGs, with 24 HGs on each circumferential layer, for a total of 168 HGs. The center of each HG was a tube to allow the passage of an axial yarn. Figure b) shows the hexagonal compact layout of the HGs on six of these angled plates. Figure c) shows the relation between the carrier (in green), the HGs (in grey) and the guiding track (in white).

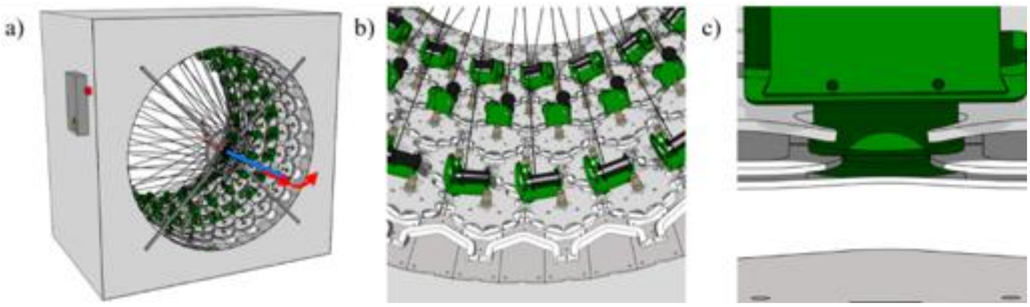

Figure 1: a) Braiding of a hockey stick showing new braider layout. b) Hexagonal compact layout of the HGs on six of the angled plates. c) Carrier (green), HGs (grey) and track (white)

The full-scale braider was built. A Human-Machine-Interaction software was developed to program the rotations of HGs to produce a 3-layer tubular braid, followed by a 3-layer 3D interlock braid, followed by a 6-layer filament winding layup. With this prototype, the radial redesign of the chain and sprocket braider was proven.

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ACQUISITION OF PRESSURE AND STRAIN MAPS DURING UNIAXIAL COMPRESSION OF A THREE-DIMENSIONAL SEALING BRAID

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Sealing braids, as seen in Figure 1, are key dynamic sealing elements in rotary units. Installed in the stuffing box around the shaft, their role is to control leakage while limiting friction and wear. During operation, axial tightening by the gland follower compresses the packing rings, induces radial expansion of the braided architecture, and generates contact pressure at both the shaft and stuffing-box-housing interfaces, which directly governs sealing performance.

This PhD work aims to characterize the mechanical response of three-dimensional sealing braid architectures, develop a structural representation consistent with LATTY manufacturing constraints, and identify its constitutive law. To this end, it adopts a yarn-scale modeling strategy equivalent to that developed for interlock textiles in a previous study [1], and aims to adapt this method to three-dimensional braided textile structures. In doing so, the central challenge is to link the real textile geometry to a robust geometrical and mechanical description, which requires instrumented tests for model validation.

In scientific literature, experimental studies on the transverse response of textile structures remain limited. Most available works focus on resin-based composites and typically stop at the onset of matrix cracking [2]. In the present case, the sealing braid structure is matrix-free which enables investigation beyond this damage threshold. In this first study, we focus on analyzing the transverse compression response of the sealing braid. Therefore, an imaging-assisted uniaxial compression test was developed on a representative braided sample. Contact pressure is mapped at the lower interface with pressure measurement film while out-of-plane lateral deformation is quantified from time-resolved 3D profilometry point clouds. The resulting coupled pressure and displacement maps characterize the braid mechanical response under quasi-static loading and provide reference data for validating a future yarn-scale numerical model.

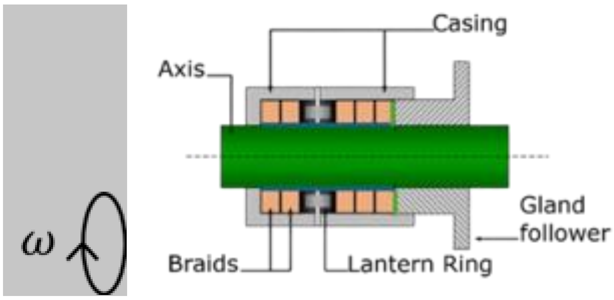

Figure 1: Schematic of a braided packing

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MATERIAL DEVELOPMENT OF CF/PPS COMMINGLED FIBRE FOR THE BRAIDING MANUFACTURING PROCESS

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An increasing demand for thermoplastic composites across various engineering sectors due to rapid processing times, ability to be reprocessed and excellent impact resistance has resulted in an increase in range of commercially available commingled material systems. This refers to a material system in which carbon fibres and thermoplastic polymer in multifilament format are combined prior to manufacture to produce a commingled tow. Commingled material has successfully been used with the braiding process to manufacture composite components [1] [2]. Much of the work focuses on small scale braiding machine with low carrier numbers this reduces the impact of interyarn friction. Interyarn friction is a significant concern when manufacturing with a high carrier number and processing adjustments are required to manufacture a braided preform.

This work builds on existing work by investigating the development of a material system that is suitable for large scale braiding through changing commingling parameters including percentage sizing and the inclusion of an additional twist during the rewinding process. Carbon fibre commingled with polyphenylene sulphide (PPS), CF/PPS material, supplied and developed by Coats for the braiding process, is used in this study. The material supplier developed different iterations of the CF/PPS to enable a comparison of material parameters.

Braiding materials require sufficient bundle integrity to minimise filamentisation and ensure good processability during manufacturing. This can be enhanced either by increasing the size applied to fibres or by introducing an additional twist during the rewinding process. However, a high sizing content can adversely affect downstream processing and significantly increase friction within the braid cone. In contrast, incorporating an extra twist during rewinding can improve bundle cohesion whilst reducing potential drawbacks.

Figure 1 CF/PPS Triaxial Braid at NCC

This work highlights the successful development of a commingled material system suitable for braiding on large braiding machines through minimizing % sizing content and including an additional twist during rewinding. The work demonstrates a material development framework which can be applied to commingled material systems with different polymers to enable more rapid product development for large scale braiding machines. This offers the potential to expand the application of thermoplastic braiding across sectors for larger component geometries.

Acknowledgement: This work was carried out as part of the Capability Development Program at the NCC with collaboration from Coats.

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SIMULATION OF OVERBRAIDED PRODUCTS AT DIFFERENT LEVEL OF FIDELITY

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Braided products are widely used for broad set of applications, such as ropes, medical stents, filters, sealings, composites. In the past, different software tools were developed and presented for simulation of braided products [1, 2]. In the most cases the braided strings are represented as single tube (Fig. 1a), and if modelled as multifilament structure (Fig. 1b), then the contact between these elements is normally not included in the simulation of the commercial products. Several researchers reports such contact simulations with specialized software [3], or general purpose FEM software, but these remains until now applicable mainly for research institutions with high qualified personal.

This work presents next-generation simulations of braided products at filament level, with additional option for simulation of ovebraided axial symmetry mandrels (Fig. 1c). Option for randomization of the position of the single filaments (demonstrated on the blue rowing Fig. 1d) increases the fidelity of the models. These generated geometrical model are after that passed to high performance algorithms for contact computation of the fiber to fiber contact simulations.

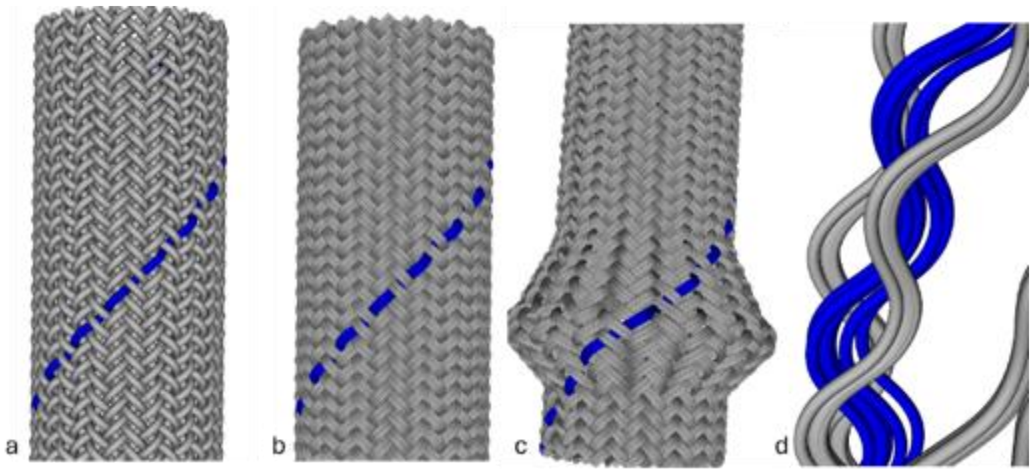

Figure 1: Different models of braids a)one tube per rowing, b) multiple filaments per rowing, c) multiple filaments per rowing over axial symmetric profile d) filament position randomisation

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Experimental Characterisation Of Textile Reinforcements 1

MEASUREMENT OF RECYCLED CARBON FIBRE WEB CHARACTERISTICS BY IMAGE ANALYSIS

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The growing demand for carbon fibre (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].

A route to reprocess recycled carbon fibres (rCF) is through new textile architectures. Fibre continuity is lost from the onset of the initial part manufacturing, and further length reduction may occur to enable recycling. Textile technology adapted to staple fibres are therefore required to manufacture rCF reinforcements. One candidate is the carding process, which is an old process initially developed for cotton and wool, that consists in aligning and separating fibres to individualize them and produce a continuous web or sliver suitable for subsequent processing. By optimizing this process, the rCF can be reprocessed first in a web and finally into nonwovens. The carding produces nonwovens with anisotropic behaviour and features linked to the favoured fibre orientation.

The highly heterogeneous microstructure of carded rCF webs, characterized by presence of fibre bundles, entangled regions, and strong local anisotropy variations makes their quantitative characterization particularly challenging. This work proposes an optical image analysis framework dedicated to the robust characterization of fibre orientation and distribution in carded rCF webs. The approach is designed to handle the specific complexity of these materials, where classical fibre detection methods fail due to fibre clustering and the presence of disordered regions.

The method relies on a multi-step segmentation strategy combining: a multi-scale tubular enhancement filter to detect elongated fibre-like structures, a structure tensor-based coherence map to quantify local orientation consistency, and a physically motivated scoring function integrating tubular response, coherence, and local fibre density. This enables the classification of the image into three regimes: well-individualised fibres, fibre bundles (aligned but not individually separable), and disordered fibre clusters. As a perspective, authors want to link fibre properties and carding parameters to the resulting web, and the web characteristics to the resulting nonwoven properties such as compressibility, permeability and ultimately mechanical properties of the composites.

This research is part of the DUCHESS project, which aims to establish an industrial scale process of recycling and remanufacturing carbon fibres from various sources [3]. This project is funded by the French State as part of France 2030, operated by ADEME.

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FULL-FIELD EXPERIMENTAL CHARACTERIZATION AND MULTI-SCALE DIGITAL TWIN OF A 3D WOVEN COMPOSITE FAN BLADE SPECIMEN

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The inherent complexity of 3D woven composites textile architecture makes the experimental characterization and the numerical prediction of their mechanical response particularly challenging, especially at the mesoscale.

This work presents a comprehensive experimental and numerical study conducted on a technological dovetail specimen directly sampled from a full-scale 3D woven composite fan blade. The specimen geometry and boundary conditions are representative of an in-service structural configuration, enabling a direct confrontation between experiments and multi-scale simulations.
On the experimental side, a multi-camera Digital Image Correlation (DIC) system [1] of four synchronized cameras was deployed to capture the full 3D displacement fields over the four upper faces of the specimen simultaneously, while a monovision camera provided complementary 2D measurements in the dovetail region. This multi-camera DIC setup was specifically developed to handle the complex, non-planar geometry inherent to textile composite specimens under multiaxial loading. Acoustic Emission (AE) was monitored in-situ to detect and localize the onset of damage within the woven architecture [2], while X-ray micro-computed tomography (μ-CT) was performed ex-situ to characterize the internal textile morphology and to identify damage patterns at the mesoscale [3].

On the numerical side, the 3D full-field displacement data from DIC were used as boundary conditions for the macroscopic Finite Element Model (FEM), ensuring a physically consistent loading of the specimen. A structural zoom strategy was then applied: the macroscopic displacement fields were transferred to drive a local mesoscale FEM, in which the actual textile geometry was reconstructed from μ-CT data.

The crosschecking of DIC, AE and μ-CT data with both macro and meso simulations provides a consistent and powerful framework to describe the initiation and progression of damage within the 3D woven architecture under multiaxial and gradient stress states. This fully closed-loop digital twin methodology demonstrates the added value of combining advanced full-field measurements with textile-informed mesoscale modelling for the structural assessment of woven composite components. Ongoing work aims to extend this approach to fatigue loading conditions and to other blade locations.

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MANUFACTURING AND MATERIAL CHARACTERISATION OF PRE-SHEARED 2D WOVEN CFRP

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As a 2D woven fabric is formed over a doubly curved geometry, the tows rotate away from their perpendicular position and become locked in the cured composite component. This in-plane shear alters the fibre orientation and significantly affects its directional material properties. To investigate this, pre-sheared carbon fibre reinforced plastic (CFRP) coupons with varying shear angles were manufactured and subjected to tensile tests [1] in different loading directions, with full-field strain measurements captured using digital image correlation (DIC) [2].

The material system used in this study is a rapid-cure 2x2 twill woven carbon fibre epoxy prepreg system [3]. The plies were sheared individually using a picture frame, and the laminate was formed by consolidating 6 pre-sheared plies in a hot press.

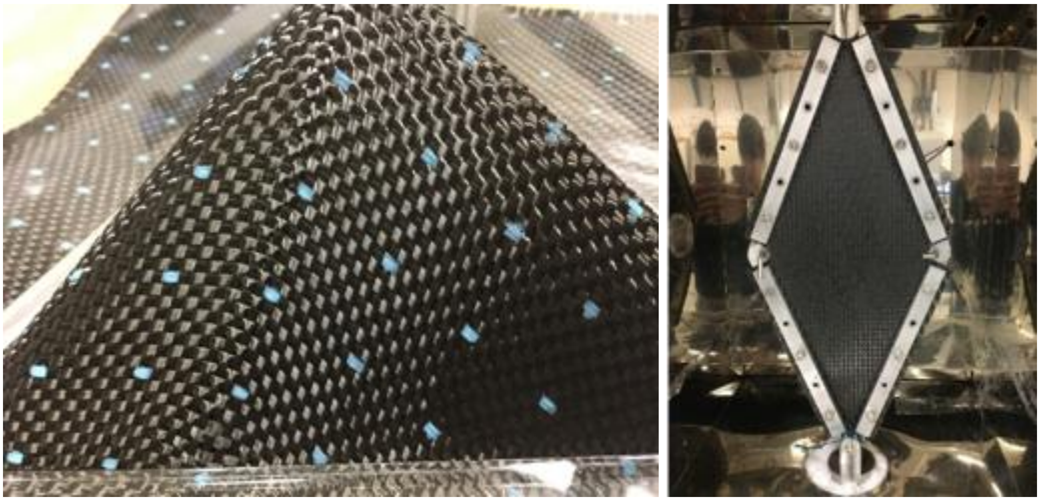

Figure 1: (Left) In-plane shear deformation in the fabric induced by forming over a tetrahedral tool. (Right) A prepreg ply sheared in a picture frame.

This presentation addresses two main aspects: First, the manufacturing challenges, such as shearing and layup of individual plies, temperature control of a rapid-cure system, and laminate quality assessment using surface scanning and X-ray computed tomography (CT) imaging; and second, the mechanical behaviour, including stress–strain response, DIC strain field analysis, and the implications for composite design.

The combined effects of shear angle and loading direction lead to dramatic anisotropy, with Young's modulus varying from 11 GPa to 63 GPa and ultimate strength ranging from 85 MPa to 990 MPa.

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DEVELOPMENT AND CHARACTERIZATION OF RECYCLED CARBON FIBER WEBS AND ROVINGS FOR COMPOSITE REINFORCEMENTS

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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 [1]. 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 [2–4]

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.

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 through a multi-scale approach. At the microscopic scale, the mechanical and morphological properties of the fibres are characterized to quantify fibre degradation. At the macroscopic scale, the structural characteristics of the reinforcements produced are examined, with particular emphasis on fibre orientation at each processing stage. The impact of resizing the recycled carbon fibres is also investigated, since the recovered fibres are free of sizing. Furthermore, the effect of blending carbon fibres with thermoplastic fibres prior to carding is assessed, in response to the growing interest in manufacturing thermoplastic carbon fibre composites [5].

This work is part of the DUCHESS project [6], 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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Emerging Composite Processing Technologies 1

Asphaltene-Derived Carbon Fibers and Nonwovens: Processing, Performance, and Multifunctional Applications

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Asphaltenes—an abundant, low-value byproduct of petroleum refining—offer a low-cost alternative to conventional PAN precursors, enabling more affordable carbon fiber products while valorizing an underutilized refinery stream. This presentation shows carbon fiber products derived from asphaltenes, manufactured using two distinct processing methods: melt spinning, which produces continuous, aligned fibers, and melt blowing, which results in nonwoven mats. The routes differ in fiber formation, producing distinct fiber diameter, morphology, and properties. Melt-spun fibers offer the tensile strength and stiffness needed for structural reinforcement, while melt-blown nonwovens provide fine diameter, high surface area, and conductivity suited to functional applications. These properties suggest to distinct markets: melt-spun fibers target structural composites for transportation, aerospace, and other industrial sectors, benchmarked against PAN- and pitch-based fibers; melt-blown nonwovens target energy storage applications, including electrode substrates and current collectors for supercapacitors and batteries. This presentation connects processing to resulting properties and performance, benchmarks against commercial alternatives, and highlights asphaltene valorization as a route to cost-advantaged, multifunctional carbon fiber products across composite and energy storage markets.

INTERLAMINAR TOUGHENING OF CARBON FIBRE/EPOXY LAMINATES USING ASPHALTENE-BASED CARBON NANOFIBRE INTERLEAVES

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Delamination is one of the major failure modes in fibre-reinforced polymer composites, arising from the relatively weak, matrix-rich interlaminar regions between plies [1]. To increase resistance to delamination and improve the composite's performance in structural and safety-critical applications, interleaving is an effective technique, typically achieved by inserting a discrete layer in the resin-rich areas between plies [2]. Carbon fibres as interleaves offer advantages such as interlaminar toughening, retention of other mechanical properties, and improved functionality [3,4]. In this study, the interlaminar fracture toughness behaviour of interleaved carbon/epoxy was investigated, using melt-blown carbon nanofibre mats developed from a cost-effective and naturally abundant feedstock, Alberta Oilsands Asphaltene (AOA). Asphaltene-derived carbon fibres have been shown to offer significantly lower production cost and up to 68% lower carbon footprint compared to conventional polyacrylonitrile-based carbon fibres [5]. Carbon nanofibre mats in varying areal density ranges (up to 40 gsm) were used as interleaves to establish a relationship between interleaf areal density and its interlaminar toughening performance. Both non-interleaved and interleaved carbon/epoxy were tested according to ASTM D5528 and D7905 for mode I and mode II fracture toughness. Results show that the carbon nanomat interleaves increase the non-precracked G_{Ic} by over 30%, and both non-precracked and pre-cracked G_{IIc} by more than 110%. Scanning electron microscopy was used to examine the fracture surfaces. For both modes, interleaf/epoxy debonding and interleaf fibre fracture were observed, which have enhanced the composite's resistance to delamination. For mode II fracture toughness specifically, crack deflection through the interleaf layer significantly contributes to the interlaminar toughening of interleaved carbon/epoxy under shear loadings. This study demonstrates the potential of AOA-derived melt-blown carbon nanofibre mats as a cost-effective and sustainable interleaving material for improving the delamination resistance of structural composite laminates.

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DESIGN AND VALIDATION OF PASSIVELY FUNCTIONALIZED SHELL COMPOSITE STRUCTURES MANUFACTURED BY TAILORED FIBER PLACEMENT PROCESS

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Composite materials are increasingly employed in structural components due to their high specific stiffness and strength. Manufacturing techniques such as Tailored Fiber Placement (TFP) offer not only a high degree of freedom in design since the fiber orientation can be chosen freely, but also the integration of functional behavior directly into the part. A notable application is the hydrofoil, where hydrodynamic performance can be enhanced if the structure adapts its shape to varying load conditions across different navigation modes. Passive functionalization, which enables deformation under applied loads without actuators or mechanical assemblies, offers an attractive approach for such adaptive designs.

This work focuses on the design and validation of passively functionalized shell laminated composites produced via the TFP process. A density-based topology optimization strategy is employed to simultaneously optimize the material distribution and fiber orientation, using an objective function formulated to generate specific deformation under given load. To ensure manufacturability, a fiber path generation method compatible with TFP is integrated directly into the design workflow. The 3D shell element is modeled by SB8 solid-shell element and a reduced constitutive tensor from the work of M. Dia [1]. SB8 element allows to model shell elements behavior rapidly and correctly while the implementation of its cinematics is easier as it's based only on displacements.

The proposed methodology is demonstrated through two numerical case studies. The first involves a cantilever-type benchmark from the work of Papapetrou et al. [2], where the optimized topology is reproduced to validate the effectiveness of SB8 elements with transversely isotropic material. The second examines a four-layer composite shell laminate under distributed bending load, illustrating how targeted deformation can be induced through passive functionalization. In both cases, numerical simulations confirm that the optimized structures meet the design objectives while remaining compatible with TFP manufacturing constraints.

These results highlight the potential of integrating topology optimization and fiber path generation for the practical design of passively functionalized composite structures. The approach provides a pathway for improving structural performance in real-world applications, reducing the need for complex assemblies and active control systems, and demonstrating the feasibility of adaptive composite components produced through modern automated fiber placement techniques.

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CONTINUOUS CARBON FIBER PLACEMENT WITH LOW-POWER INFRARED HEATING ON CURVED SURFACES: FEEDRATE OPTIMIZATION BASED ON TRANSIENT THERMAL MODELING

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Short Summary:
This differentiable thermal model predicts transient temperature evolution on curved geometries, enabling feedrate optimization for consistent automated fiber placement.

Abstract:
Continuous carbon fiber placement on curved surfaces using low-power infrared heating poses significant challenges in temperature regulation, as the inherently distributed and transient thermal footprint of the heat source interacts strongly with local surface geometry and feedrate [1-3].

In this work, we achieve consistent temperature control at the contact point during point-focused infrared heating through feedrate optimization enabled by a transient thermal field modeling framework formulated for curved surfaces. A data-driven approach is employed to identify path-dependent coefficient functions in the thermal model, and an efficient backtracking algorithm is developed to provide robust initial guesses for the feedrate optimization. Together, these contributions enable quality-controlled desktop continuous carbon fiber placement using low-power infrared heating. The effectiveness of the proposed method is validated through physical experiments conducted on a robotic system equipped with a prototype desktop carbon fiber placement hardware.

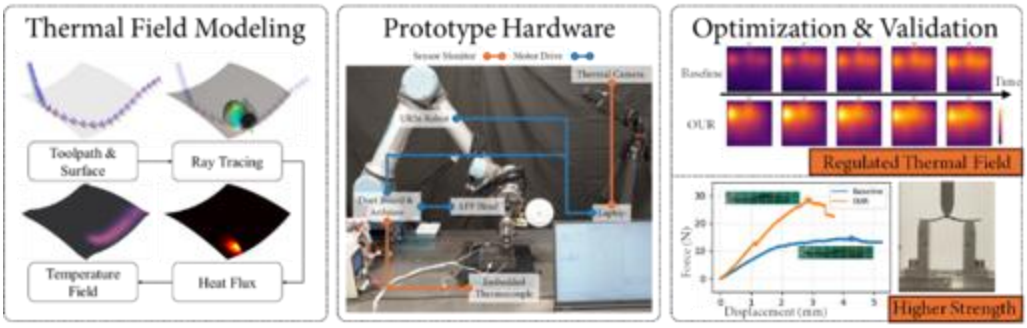

Figure 1: Overview of the proposed thermal-aware manufacturing framework. Experiments validate that thermal field regulation through feedrate optimization significantly enhances mechanical strength compared to the baseline configuration employing a uniform feedrate.

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3D Textile Architecture: Process and Product 4

GEOMETRIC SCALING AS MEANS OF ENABLING THE DESIGN OF 3D WOVEN COMPOSITES

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Geometric scaling has been defined as a special type of variation of woven architecture that produces composite configuration having identical, or very similar, effective elastic properties. Existence of such configurations has not been discussed, let alone proven to date. Scaling rule has been derived explicitly for 3D layer-to layer angle interlock composites under condition that the key geometric properties of the weave: the interlocking angle, global fibre volume fraction and weft to warp tow volume ratio, should not be affected by changes in geometry of the composite due to scaling.

The role of tow sizes as designable parameters directly associated with scaling has been established for the first time. With scaling method in place, design of 3D woven composites has been defined as a two-stage process, where the effective elastic properties are varied via systematic variation of tow densities [1,2], while scaling is applied at a post-processing stage to ensure the practicality of design [3]. The design process is comprehensive in a sense that it involves all the designable parameters, explicitly defining their roles and contribution. The roles of two groups of designable parameters is schematically shown in Figure 1, where variation of the interlocking angle and the tow ratio is realised via variation of tow densities [2], while systematic scaling, controlled by the tow sizes, keeps these properties constant, at the same time causing no changes in the effective weft stiffness (Fig. 1(a)), and resulting in moderate systematic changes in the effective warp stiffness (Fig. 1(b)).

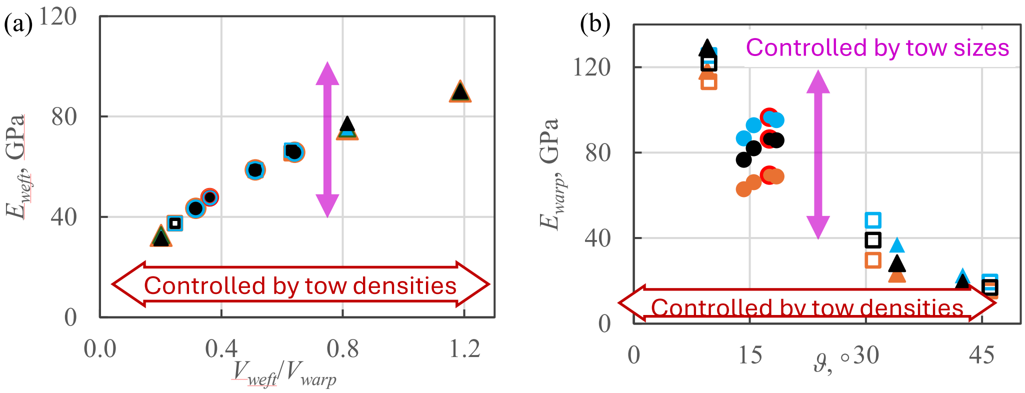

Figure 1: Variation of the effective elastic modulus (a) in the weft direction relative to tow ratio; (b) in the warp direction relative to the interlocking angle

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STUDY ON TENSION-DRIVEN DEFORMATION COMPENSATION FOR FLEXIBLE ORIENTED THREE-DIMENSIONAL WOVEN COMPOSITE PREFORMS

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Text: As a critical forming parameter in the fabrication of three-dimensional woven composite preforms, fiber tension plays a significant role in both the forming process and the structural integrity of the preform[1]. In this study, based on the flexible oriented three-dimensional woven technique[2], the effects of pre-needle fiber tension and weaving speed on post-needle fiber tension were investigated, and a digital control model for fiber tension regulation was established. A tension-driven analytical model describing the deformation of the guide array under multi-structural weaving paths was developed. A polynomial regression method was fitted to describe the relationship among pre-needle fiber tension, weaving speed, and post-needle fiber tension, with a MSE of 2.11 and a R^2 of 0.993. Additionally, a machine vision-based method for detecting tension-driven deformation of the guide array was proposed, with a maximum deviation of 25.56% between the model predictions and experimental measurements. A compensation method (Figure 1) for guide array deformation was further introduced based on parameter inversion, and its effectiveness was experimentally validated—the maximum deviation between the compensated and pre-weaving positions of the guide bars was 0.192 mm. The deformation reduction ratio reaching up to 93.77%. Furthermore, a tension-regulated forming method for gradient fiber volume fraction preforms was proposed. Under the selected process parameters, the local fiber volume fraction was tuned finely, within the range of 34.64% to 36.20%. This work was supported by national natural science foundation of China (52505338)

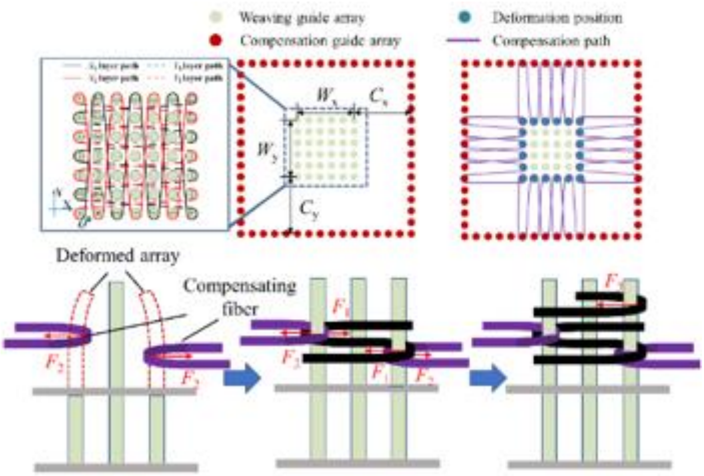

Figure 1: Schematic of guide array deformation compensation

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ADVANCED AUXETIC COMPOSITE MATERIALS BEHAVIOUR UNDER DIFFERENT TENSILE STRAIN SPEEDS FOR AERONAUTICAL APPLICATIONS

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Composite materials are increasingly used in the aeronautic industry, particularly for their lightness and their ability to combine the mechanical properties of the materials that make very performant versus weight. In addition, during flight, the fuselage, leading edges and radome of commercial aircraft can be subject to impacts from birds, debris and blade fragments. There is therefore a real need to develop a lightweight composite material that can absorb the maximum amount of impact energy and allow its dissipation without total breakage of the structure.

A previous thesis, conducted by Eloi FACON [1] (ONERA/GEMTEX, 2022–2025) has investigated the development and characterization of a para-aramid/polypropylene auxetic composite. Auxetic materials have many interesting mechanical properties, including the ability to densify during impact [2].
This auxetic behaviour is provided by the 3D re-entrant hexagonal that have the shape of an hour glass architecture made with commingled thermoplastic and para-aramid yarns and then manufactured by thermoforming. This material was studied under monotonic tension (along Y axis – warp direction) using a stereo digital image correlation equipment (see Figure 1.a). Stereo DIC is used to study the displacement and deformation (in-plane and out-of-plane) of this 3D woven composite materials under mechanical stress under two tensile speeds: 5 mm/min and 100 mm/min. Figure 1.b shows the out-of-plane variations (ΔZ) of walls for one cell (cell 22) from the 100 mm/min test as a function of axial strain and it reveals different height variations with the respect to the load and transverse directions.

The aim of this study is to deepen our understanding of this specific 3D woven composite material under different speeds of elongation. New tensile tests on the same material (same size, architecture and fibrous materials) have been done at 5 mm/min and then 500 mm/min in order to compare the material behaviour results with those obtained in the previous thesis. The material quality has been studied, as well as the impact of loading rate on the mechanical response of the material.

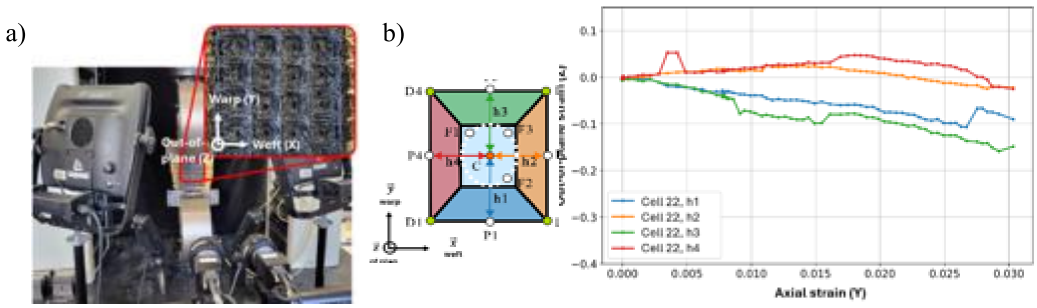

Figure 2 : DIC equipment (a) and representation of out-of-plane strain (along Z) as a function of the axial strain (along Y) of one cell (cell 22) for the tensile test at 100 mm/min (b). [1]

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DESIGN OF SANDWICH PANEL CORES AS A PERIODIC NETWORK OF TUFTED THREADS

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Sandwich panels (Figure 1a), modeled as two thin and stiff skins (typically made from glass or carbon-FRP) bonded to a thick and compliant core, are key structural parts owing to their high bending modulus. The core's shear stiffness gives the panel its strength by preventing the skins plies from slipping.

Although commercial designs (featuring cores made of PVC/PET foams, honeycomb, balsa, ...) result in significant weight savings, they remain insufficiently stiff given the stringent requirements of the aerospace industry.

In this work, we show that cores produced from a network of carbon tufted threads inclined at 45° (Figure 1b) exhibit shear stiffnesses outperforming those of cores made from PVC foams [1][2]. The major gain results from the fact that the strands mainly bear tensile stresses. Furthermore, due to their topology (structures with numerous voids), these cores score high lightweight.

Another benefit of such core designs is related to an explicit assessment of their homogenized stiffness through an asymptotic periodic expansion [1][3]. So, this article presents a simple and effective model and compares it with real-world test data to demonstrate the model's quality.

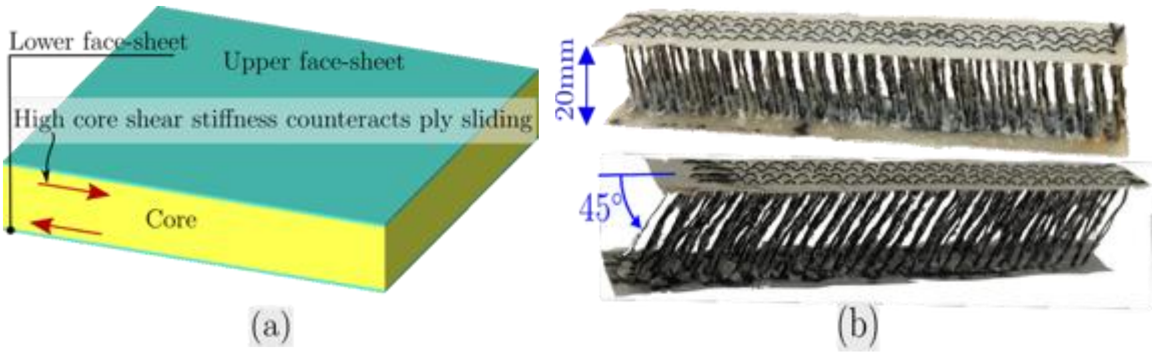

Figure 1: (a) Typical foam core sandwich – (b) Core sandwich resulting from thread stitching

This simple model is designed to determine the optimal tuft density based on mechanical requirements. Also, this model should facilitate the wider adoption of the simple and effective technology call tufting.

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AI Applications in Textile Composites

A LSTM-FEA INTEGRATED APPROACH TO PREDICT CURING-INDUCED DEFORMATION IN WOVEN THERMOSET COMPOSITE

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In industrial practice, the prepreg compression molding (PCM) process that is widely used for manufacturing complex woven parts involves a preforming stage that inherently induces spatially varying yarn orientations. This geometric non-uniformity is inherited by the parts, resulting in location-dependent material properties during curing. Consequently, high-fidelity prediction of curing-induced deformation (CID) demands a multiscale simulation capable of capturing the complex interplay among local yarn orientations, viscoelastic resin behavior and global structural response. However, traditional FE^2 approaches are usually computationally intractable for large and non-uniform woven CFRP structures.

To address this computation bottleneck, this study developed an integrated Long Short-Term Memory (LSTM) – Finite Element Analysis (FEA) framework. An LSTM network is first trained on a high-fidelity virtual dataset, generated from mesoscale FEA for Representative Volume Elements (RVE) across a wide range of conditions, including yarn angles, degrees of cure, temperatures and time. Subsequently, the trained network is decomposed and deployed into the chemical-thermal-mechanical coupled FEA via user subroutines for curing modeling. These subroutines written in Fortran are input into the commercial FEA solver ABAQUS/Implicit. This integration enables the LSTM to interact with relevant material models through state variables, which facilitates the fully automated update of the relaxation modulus at every time increment and eliminates the requirement for intervention to enable external software switch. Validation on doubly curved woven CFRP parts demonstrates that this LSTM-FEA integrated modeling approach can achieve excellent prediction accuracy of above 92%. At the same time, this approach is approximated to realize computational speedup of 2~4 orders of magnitude compared to conventional FE^2 methods.

This work establishes a practical AI-enhanced FEA modeling to virtually optimize manufacturing processes and reduce reliance on physical prototyping for composite parts, representing an important advancement toward intelligent manufacturing of high-performance and lightweight structures.

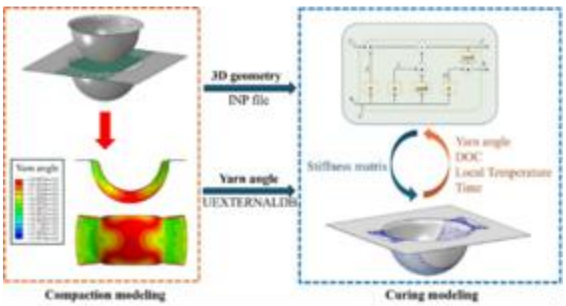

Figure 1. Flowchart of the integrated LSTM-FEA modeling approach.

A PHYSICS-ENHANCED DEEP LEARNING FRAMEWORK FOR FABRIC DEFORMATION AND STRESS PREDICTION IN PREFORM FORMING

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The accurate and efficient prediction of deformation and stress fields in fabric preforming is critical for process optimization and defect identification. While deep learning has shown promise compared with finite element simulations, existing models often suffer from limited spatial awareness and poor physical consistency when capturing nonlinear and coupled physical fields. To address these challenges, we propose Forming-Net, a physics-enhanced multi-task deep learning framework based on the U-Net architecture. The primary innovation is the integration of multi-task learning and physics-based constraints. This combination can capture the intrinsic coupling between fabric deformation and stress fields while preserving physical consistency. Specifically, to overcome spatial amnesia, a shared encoder integrated with explicit coordinate channels is designed to learn coupled feature representations, while a pre-trained physics-informed network is incorporated to enforce material constitutive laws through additional loss constraints. Benchmark comparisons demonstrate the applicability of Forming-Net across varying geometries. Quantitative comparisons with representative baseline models show that the coefficient of determination (R^2) for stress field prediction increases from 86.62% to 94.93%, while the mean absolute error (MAE) decreases by nearly 30% compared to baselines. These results indicate that the proposed approach provides an effective tool for rapid process design and offers new insights into data-driven modeling of complex coupled physical fields in fabric forming.

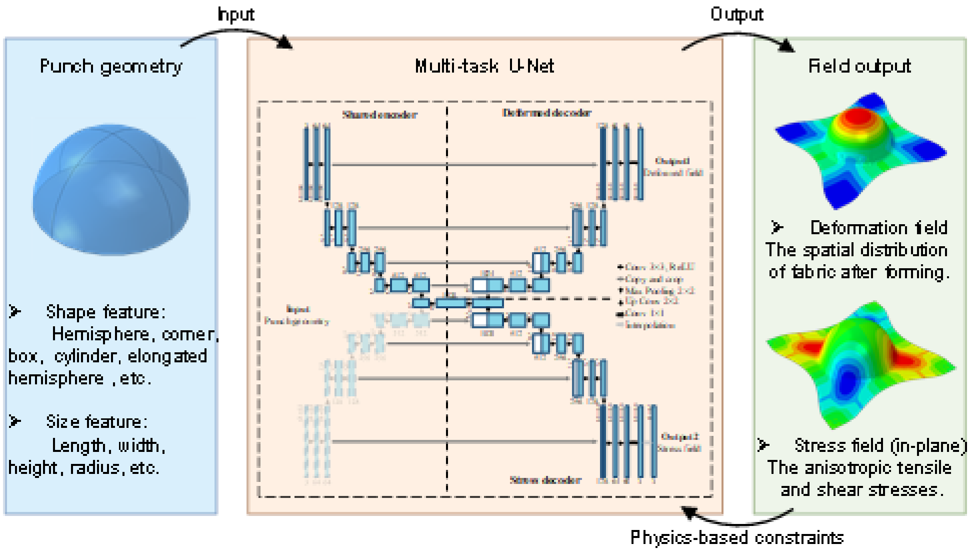

Figure 1: Schematic illustration of the overall Forming-Net framework.
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FROM IMAGING TO SIMULATION: AUTOMATED X-RAY CT–DRIVEN MESOSCALE MODELING OF AS-MANUFACTURED TEXTILE COMPOSITES

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The mechanical behaviour of textile composites is governed not only by the properties of their individual constituents, but also by the architecture of the textile reinforcement. This architecture is characterised by parameters such as fibre type, tow size, and weave pattern, as well as by manufacturing variables including draping extent, resin injection flow rates, and compaction levels. As a result, mechanical performance may differ between components of identical geometry and even across different regions within a single component. Reliable prediction of the properties of as-manufactured composites therefore demands a thorough understanding of the underlying mesoscale geometry.

In this work, we introduce a fully automated, open-source framework for generating digital finite element twins of as-manufactured 3D-woven composite materials. The process begins with large field-of-view CT scans of composite specimens, which are automatically segmented using a machine learning model. The segmented data are subsequently converted into finite element models incorporating spatially varying tow orientations and fibre volume fractions. A central element of the workflow is the segmentation model, which is trained exclusively on synthetic data derived from virtual scans of artificially generated mesoscale geometries. The performance of the framework has been demonstrated through accurate predictions of elastic properties, with discrepancies of less than 6.5% relative to experimentally measured engineering constants.

Following validation of the pipeline's capability to predict elastic behaviour, future work will focus on investigating the response of as-manufactured 3D-woven composites under more demanding loading scenarios, including the effects of tow reorientation, (visco)plastic deformation, and progressive damage evolution.

ADAPTIVE RESIN INFUSION CONTROL USING DEEP REINFORCEMENT LEARNING: NUMERICAL AND EXPERIMENTAL DEVELOPMENT

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Resin infusion processes in composite manufacturing are sensitive to intrinsic variability that can alter the intended flow front progression, leading to dry spot entrapment at the end of the infusion. Traditional process engineering relies on pre-determined infusion strategies that cannot respond to such in-process disturbances. This work presents a real-time adaptive control approach in which autonomous Agents, trained with Deep Reinforcement Learning (DRL), continuously adapt the infusion strategy to steer the outcome of the infusion towards the expected result.

To demonstrate the approach, a toy problem is proposed: the infusion scenario is a two-dimensional square domain (1m × 1m), bounded by four independent line inlets (Figure 1). At each control step (every 30 seconds of infusion time), the Agent observes the infusion state and assigns an open/closed state to every inlet, which affects the velocity field in the fluid domain. The objective is to steer the flow front closure towards an arbitrarily prescribed vent location on the domain. To that extent, two different Agents were developed that deal with different input types: the first Agent (Agent A) receives the current centroid of the unfilled region and the target vent position. The second Agent (Agent B) receives a synthetic-generated image of the infusion domain, where the filled region, dry region and target position are marked with different colors. Training was carried out in simulated environments built on top of the open-source Lizzy resin infusion simulation package [1]: Agent A was trained on a standard workstation; Agent B was trained on the Isambard-AI supercomputer [2]. Both Agents were able to learn effective control policies, with Agent A slightly outperforming Agent B (Figure 1).

To validate the performance of the control model experimentally, trained Agent A was deployed on a physical infusion setup identical to its numerical training environment. Results showed consistency with the learned policy, and at the same time highlighted limitations in the idealized simulated conditions. This work focused on detailing the full workflow and pitfalls encountered to produce ML-based control Agents for infusion: future work will aim at extending the approach to more complex geometries and image-based Agents operating directly on in-process video feed.

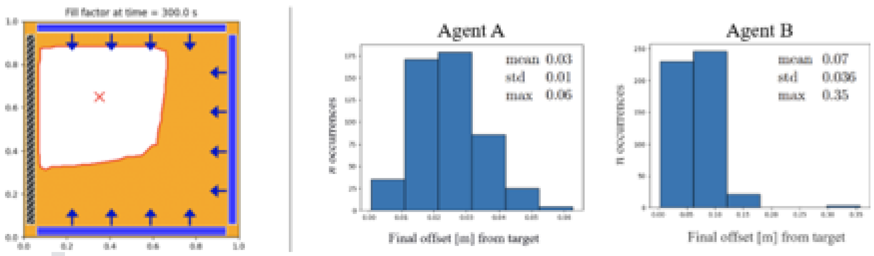

Figure 1: Infusion scenario (left) and performance evaluation of trained Agents (right)

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FULL-FIELD RESIN INFUSION RECONSTRUCTION USING GAUSSIAN PROCESS SURROGATE MODELS ON SPARSE SENSOR DATA

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Resin Infusion of dry fabric based manufacturing is of growing interest in many industries to help achieve sustainability goals, driven by increasingly complex, large, and high rate parts [1]. However, factors such as: atmospheric pressure, ambient temperature, fabric permeability, and resin viscosity can vary significantly between production cycles, causing premature gelation, dry spots, and Resin Rich Regions. Active Control methods have been investigated to correct defects before they can fully form through various effectors [2, 3]. These have not yet been scaled to wider industry use and one challenge is getting accurate low-latency information on the progress and form of the flow front during infusion. Several projects have successfully tested control algorithms but rely upon either a very high sensor density or full-field vision systems, both difficult to enact in an industrial setting.

This work, building upon previous research by the author and others at Bristol Composite Institute [4, 5, 6], implements a new surrogate model based method of reconstructing the full-field state of pressure and fill across a part based on sensor readings. This surrogate model involves combining a smart-sampled Deep Gaussian Process Model and a more conventional Encoder-Decoder structure. By combining these approaches, an accurate reconstruction of the full-field can be created without incurring the usual high computational cost and training problems associated with traditional machine learning approaches. Training data for this model are provided through both the use of conventional commercial software (LMAT) simulations and a Forward Sparse Variational Gaussian Model developed by this author. Multiple test cases are used to showcase the models abilities including both a simple 1mx1m flat panel and a more complex flanged-web; with variations in several global parameters such as resin viscosity and more local parameters such as racetracking.

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Emerging Composite Processing Technologies 2

ENHANCED RESISTANCE WELDING OF THERMOSET COMPOSITES VIA PRECONSOLIDATED HEATING ELEMENTS

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Resistance welding is a promising novel approach for joining thermoset and thermoplastic 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 customised 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. Preconsolidated 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.

Acknowledgments
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REGENERATED CELLULOSE FIBRES FROM ALL-CELLULOSE COMPOSITES

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All-Cellulose Composites (ACCs) are innovative materials composed of cellulose-based textiles, where ionic liquids have been used to facilitate the dissolution of cellulose. These sustainable composites offer a promising alternative to conventional, fossil fuel-derived materials, presenting potential applications such as packaging, automotive, and biomedical industries. In addition, these materials are comprised of renewable cellulosic resources ACCs can also utilise post-consumer textiles (which may otherwise have been landfilled or incinerated) as the raw material. The key advantage of ACCs compared with plastics lies in their biodegradability, renewability, and lower environmental footprint, offering a more sustainable material solution.

Within this research, a plain weave mercerised cotton has been used as the primary material due to its high cellulose content. Cotton typically is comprised of around 95% cellulose, in addition to being the most widely used natural textile fibre globally. The process of forming ACCs typically involves partially dissolving cellulose-based fabrics, enabling the matrix and reinforcing phases to originate from the same material, eliminating the need for additional polymers or synthetic binders. This study employs the ionic liquid 1-ethyl-3-methylimidazolium acetate (EMIMAc) and the cosolvent dimethyl sulfoxide (DMSO) for the production of the cellulosic composites.

One potential route to recycle ACCs includes regenerating the materials in novel cellulosic fibres, where ACCs are used as the source of cellulose within the spinning dope. Based on the Ioncell process, EMIMAc has been combined with DMSO at a ratio of 20:80 and combined with the mechanically shredded ACCs, which has successfully produced single monofilaments. These filaments demonstrate the feasibility of recycling cellulose-based composites into new fibre forms, and hopefully the creation of new textile and material technologies. Future efforts are directed towards exploring post-consumer (second-hand) textiles, which represent one of the most complex waste streams globally, as at present, only 1% of all clothing is recycled. The end goal of this research is to enable a closed-loop recycling system for cellulosic textiles, whilst further developing concepts surrounding the production of ACCs and the wet-spinning of fibres using ILs.

DEVELOPMENT OF A MODEL TO PREDICT THE BREAKAGE OF CARBON FIBER IN THE COMPOUNDING PROCESS USING A TWIN-SCREW EXTRUDER

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Fiber breakage is unavoidable during the compounding process with thermoplastic polymers in a twin-screw extruder, which makes controlling the optimal fiber length difficult. Previous studies, primarily focusing on glass-fiber-reinforced plastics, have reported that longer fiber lengths enhance the reinforcing effect and improve mechanical properties. Therefore, the residual fiber length is also considered a crucial factor in governing the mechanical properties of carbon fiber-reinforced thermoplastics (CFRTPs).

However, an accurate model capable of reproducing the progression of fiber breakage, including the effect of residence time conditions, has not yet been sufficiently established. The objective of this study was therefore to develop a model to predict the fiber breakage during the compounding of polypropylene and carbon fibers in a twin-screw extruder.

The model assumes that fiber breakage is governed by shear stress. A fiber breakage criterion was derived based on the shear stress data obtained from the experiments. Next, the shear stress distribution within the kneading section was calculated through particle tracking analysis using Ansys Polyflow. A model predicting the fiber breakage was then constructed by incorporating the derived criterion.

To reproduce the complex kneading flow occurring in the kneading section, a testing apparatus capable of generating a simple shear flow was fabricated, and fundamental experiments were conducted.

Validation of the initial model revealed that, although it could reproduce the trend in average fiber length under long residence time conditions, significant discrepancies from the experimental results occurred under short residence time conditions. To address this issue, this study examined the impact of initial fiber length and the time-dependent nature of the breakage progression. As an original validation approach, the kneading block of the actual twin-screw extruder was divided axially and fibers were sampled from multiple positions within a single block to evaluate the progression of the breakage behavior in detail. The results showed that time dependency must be included in the model, and an improved model incorporating an exponential decay term was proposed.

The improved model made it possible to reproduce the trend of average fiber length under short residence time conditions, and it also achieved a good agreement for long residence time conditions, with a difference of less than 0.1 mm to the experimental average fibre lengths for all kneading block configurations, as shown in Figure 1.

In conclusion, the time-dependent fiber breakage model proposed in this study is an effective approach for improving the prediction accuracy of fiber length variation during twin-screw compounding, and it serves as a design tool for controlling residual fiber length in the CFRTP manufacturing process.

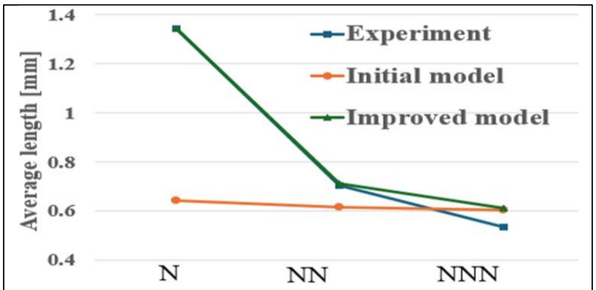

Figure 1: Experimental and predicted average fiber lengths under various residence time conditions.

FEM–MPS MULTISCALE ANALYSIS OF FIBER ORIENTATION IN INJECTION-MOLDED SHORT-FIBER REINFORCED THERMOPLASTICS

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Injection molding of short-fiber reinforced thermoplastics (SFRTPs) produces components with heterogeneous fiber orientation distributions governed by complex flow conditions. Accurate representation of fiber orientation in injection-molded parts is essential for robust process–structure relationships. Conventional models based on orientation tensor, such as the Folgar–Tucker formulation [1], rely on phenomenological interaction terms and may exhibit reduced predictive capability under high fiber volume fractions.

This study presents a one-way coupled multiscale analysis integrating a global finite element method (FEM) flow simulation with a local Moving Particle Simulation (MPS) framework. Particle-based approaches have been applied to fiber orientation analysis in injection molding [2], however, their integration within a coupled FEM–MPS framework remains limited. Macroscopic velocity and temperature fields from the FEM analysis are transferred to a local particle domain, while the global fiber orientation field is imposed as an inflow boundary condition. Within the MPS domain, individual fiber motions are resolved to represent fiber–fiber interactions and concentration effects.

The framework in Figure 1 was applied to a rib-structured mold in which a characteristic five-layer orientation pattern was observed experimentally. A T-shaped local domain extracted from the plate-to-rib transition was analyzed using MPS with FEM-derived inflow conditions. The analysis captured the layered orientation structure and reproduced injection-speed-dependent changes. FEM results indicated that these variations are associated with differences in extensional flow behavior near the gate region.

The proposed multiscale framework provides a mechanism-based understanding of fiber orientation formation and offers a basis for future structural analysis of injection-molded components.

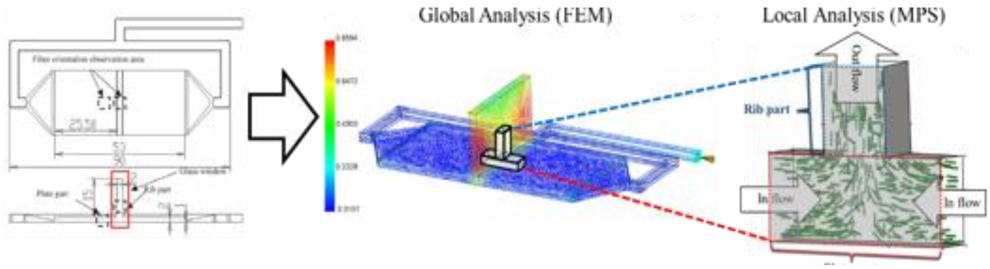

Figure 1: Conceptual diagram of FEM-MPS multiscale analysis

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MECHANCIAL PROPERTIES OF CARBON FIBER COMPOSITE HONEYCOMB FABRICATED BY FOLD-CUTTING METHOD

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Honeycomb materials, as typical cellular materials, are widely used in automotive, marine, construction, and aerospace industries due to their high specific strength, high specific stiffness, and impact resistance. Combining carbon fiber reinforced polymer (CFRP) composite, which possess superior mechanical properties and thermal stability, with honeycomb structures can further enhance the overall performance of the honeycomb material. Among the key technologies, the fabrication method of composite honeycomb is fundamental and critical. Unlike the stretching process used for aluminum honeycombs or the resin impregnation process for aramid paper honeycombs, the fabrication of composite honeycombs primarily addresses how to integrate the topological characteristics of cellular materials with composite molding methods. To this end, this study proposes a fabrication method based on a fold-cutting design concept [1]. By establishing a mapping relationship between the two-dimensional planar geometry and the three-dimensional honeycomb structure, planar material is cut along predetermined paths and then folded into a three-dimensional configuration. Hexagonal molds are embedded to maintain the honeycomb shape during hot pressing. This method enables the formation of thin-walled composite honeycombs with various configurations through pre-designed patterns, offering potential for standardized and industrial production.

Based on the composite honeycomb fabricated by the fold-cutting method, this study further investigates the mechanical performance of composite honeycomb sandwich structures under typical loads. The possible failure modes under out-of-plane compression, shear, bending [2], and in-plane compression are analyzed, and corresponding theoretical prediction models are established. Three-dimensional failure mechanism maps governed by key geometric parameters of the honeycomb are developed. Experimental tests under different loading conditions validate the observed failure modes. Through dimensionless treatment of structural parameters, total mass, and load equations, contour maps of the load-to-mass ratio are plotted, and geometric relationship equations for the optimal design route of the composite honeycomb sandwich structure are obtained. Combined with low-velocity impact tests and finite element simulations, the mechanical response, failure modes, and energy absorption mechanisms of the composite honeycomb sandwich structures under different damage states are studied [3]. Parameterized analysis of the honeycomb geometry yields methods to enhance structural impact resistance. This research provides a reference for the large-scale fabrication and industrial application of composite honeycombs.

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Special Technical
Textile Products

INFLUENCE OF CONSTRICTION ON THE LOAD-BEARING CAPACITY OF BURY SPLICES OF BRAIDED SYNTHETIC ROPES

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Floating offshore wind turbines require suitable mooring systems to withstand wind and wave loads. Mooring lines are typically composed of chain~~s~~ at the ends and a synthetic fiber rope in the central section. One of the most critical points of such assembly is the fiber rope termination. Splicing is the most widespread and effective method for terminating braided synthetic ropes [1]. One splicing method called bury splice consists of forming a closed loop in which the rope is reinserted into itself, generating, under tension, a tightening of the outer braid around the inner one. This tightening, related to the constriction effect inherent to braided ropes, ensures that the loop is held in place by friction. The relationship between this constriction effect, the relative sliding between the components of the spliced region and its mechanical performance remains poorly documented in the literature.

The objective of this study is to develop experimental methods and numerical models dedicated to understanding the mechanisms taking place within the splice when mechanical tension is applied, with particular emphasis on the constriction effect.

A tensile testing setup coupled with a scanner was developed to observe elongations as well as relative displacements between the internal and external parts of the splice (Figure 1). At the beginning of the test, markers are inserted along the splice within both the inner and outer braids, and measurements are then performed at each load increment. The results highlight non-uniform relative sliding between these braids; this sliding can subsequently be analyzed to infer the mechanical behavior of the different parts of the splice during the various loading phases.

The experimental data demonstrate the capability of the proposed protocol to capture information that cannot be observed using conventional methods. They provide reference data for finite element modeling and pave the way towards criteria for assessing proper splice design.

Figure 1: Tensile testing setup combines with scanner measurement

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SELF-SENSING ZNO NANOWIRE-ENHANCED TEXTILE COMPOSITES FOR STRUCTURAL HEALTH MONITORING

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Embedding sensing functionality directly into structural composites offers a transformative route toward real-time structural health monitoring in aerospace, automotive, wind turbine blade, and protective systems. This study presents a scalable strategy for integrating zinc oxide nanowires (ZnO NWs) into textile reinforcement, enabling multifunctional composites capable of simultaneous load bearing and intrinsic damage sensing.

ZnO NWs were hydrothermally grown directly onto dry fabrics prior to composite fabrication, ensuring compatibility with conventional vacuum-assisted resin infusion processes. By optimising nanowire length, a continuous and stable piezoelectric sensing network was achieved without compromising mechanical properties.

Under three-point bending, the ZnO-functionalised composites generated reproducible electrical signals that correlated directly with mechanical loading and damage evolution. The optimized nanowire configuration enabled clear detection of crack initiation and progressive failure, demonstrating reliable self-monitoring capability without external sensors or additional power supply. Importantly, moderate nanowire integration enhanced flexural stiffness through improved fibre–matrix bonding, while excessive growth negatively affected resin infiltration and mechanical strength. A controlled growth window therefore provides the optimal balance between sensitivity and structural integrity.

This study demonstrates a practical and controllable platform for producing self-sensing composite laminates using industry-compatible processing routes. The work provides quantitative insight into multifunctional optimisation in hierarchical composites, paving the way for structurally integrated sensing systems applicable to advanced lightweight engineering components.

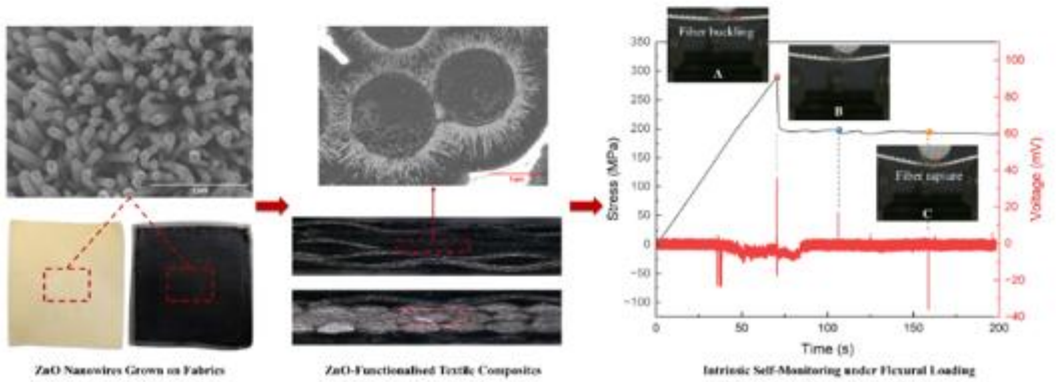

Fig 1: Scalable fabrication and intrinsic self-monitoring of ZnO-functionalised textile composites

The author acknowledges the financial support from the Engineering & Physical Sciences Research Council (EPSRC, EP/W524372/1) and technical support from Leeds Electron Microscopy and Spectroscopy Centre (LEMAS).

SUSTAINABLE FIBER-RINFORCED COMPOSITES FOR HIGH-PERFORMANCE DRONE COMPONENTS

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This work investigates the potential of sustainable natural fiber-reinforced composites (NFRCs) for high-performance drone components, addressing the growing demand for lightweight, strong, and environmentally responsible materials in unmanned aerial vehicle (UAV) applications. Natural fibers such as wool and flax offer advantages including low density, biodegradability, and reduced environmental footprint compared to conventional carbon and glass fiber composites [1,2]. However, challenges such as mechanical performance and flammability must be mitigated for broader adoption. Wool fiber, known for its natural flame-retardant and self-extinguishing properties, has been widely used in the textile industry to produce apparel, but its use in composite production has been limited. In Europe, approximately 75% of the wool produced by sheep farms is also unsuitable for use in the textile industry. This wool is classified as special waste and requires sterilization before it can be disposed of. Each year, around 150 million tons of this unused wool is generated, and this amount increases when adding wool from other end-of-life products, such as carpets, as well as waste from the textile industry [4,3]. Wool, despite being abundant and naturally flame-retardant, remains underutilized in composite manufacturing. This research explores the feasibility of valorizing such wool waste as reinforcement in bio-based composite systems. In this study, wool-woven fabrics and flax fibers were used as reinforcement materials, combined with a bio-based epoxy resin. Drone engine cover components were produced using resin infusion technology, while moulds were fabricated using fused deposition modelling (FDM). Mechanical tests, including tensile strength, three-point bending, interlaminar shear, and thermal insulation analysis, were conducted to assess structural performance. The findings demonstrate that wool fiber composites exhibit promising thermal insulation and fire-resistant behavior, whereas flax fiber improves stiffness and load-bearing capability. The hybridization of wool and flax fibers, therefore, presents a viable pathway toward sustainable, high-performance drone structures.
The authors acknowledge the projects “Sustainable Industrial Design of Textile Structures for Composites,” which is funded by the European Union. Grant Agreement no. 101079009 Call: HORIZON-WIDERA-2021-ACCESS-03/Twinning. Acronym: SustDesignTex, and “Sustainable design of hybrid (textile–polymer) active conductive structures of frequency selective surfaces (FSS) with a dominant absorption coefficient of the incident wave or capabilities for steering the reflected beam,” funded by the Polish National Science Center under Grant Agreement no. UMO-2024/53/B/ST11/01140”

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LOW-COST PRECURSORS FOR CARBON FIBER: BREAKDOWNS AND BREAKTHROUGHS

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Carbon fiber materials play an important role in high-performance composites in clean technology. Applications include the substitution of metal to reduce the weight of passenger vehicles thereby improving gas mileage, material for construction of hydrogen storage tanks for fuel cell vehicles, the use within composites for wind turbine blades, and functional applications such as carbon-based electrodes. These fibers are chosen because their specific strength and stiffness far outperform all other materials due to their relatively low density. Yet, the high cost of the fiber prevents widespread adoption of the material in many applications limiting demand to the 200 kiloton scale. The majority of this fiber is sourced from polyacrylonitrile (PAN) with pitch fiber making up nearly the rest of the market, with limited production of specialty rayon-based carbon fiber.

PAN production is expensive and requires wet spinning, while pitch is only derived from a specific petroleum or coal cut with further chemical treatment to make high mesophase content compounds. To address this high-cost issue, high-carbon content precursors for carbon fiber production have been explored extensively in the academic literature, such as asphaltenes, recycled plastic and technical lignin, resulting with mixed success. Many academic studies are limited with the inability to control the fiber diameter in the production of green fiber below 10 microns, while furnace temperatures are typically on the order of 800-1200 ºC. In contrast, commercial high performance carbon fiber are typically heated above 1600 ºC with fiber diameters in the single digit micrometer range. The continuous nature of the process also helps to control orientation of graphitic structures to enhance the properties, making it difficult for academic laboratories to achieve high performance in batch processes. This talk will highlight efforts of converting potential low-cost carbon fiber precursors [1-2] by melt-spinning into filaments, highlighting issues that surround thermo-oxidative stabilization and carbonization. Further, we provide insight into lab-based methods for controlled drawing of the fiber and the impact on the resulting tensile mechanical properties. The results show a potential pathway towards melt-spun, low-cost precursors with small diameter fibers having strengths on the gigapascal scale and modulus on the 100's of gigapascal scale.

The authors would like to acknowledge Alberta Innovates and Emissions Reduction Alberta for funding support through the Carbon Fibre Grand Challenge program.

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DESIGN AND MODELLING OF WOVEN FLAX/BIO-EPOXY TEXTILE COMPOSITE LAMINATES FOR BRIDGE DECKS

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Pedestrian and cycle bridges constructed from concrete and steel pose sustainability challenges due to their high carbon emissions, susceptibility to corrosion, and high maintenance demands [1]. Textile fibre-reinforced polymer (FRP) composites provide lightweight, corrosion-resistant alternatives. Natural textile fibre-reinforced polymer (NFRP) composites further promote sustainability by using renewable fibres and reducing environmental impact. Their controllable textile architecture enables the tailoring of structural performance through laminate design and manufacturing. However, the structural behaviour of woven flax textile-reinforced bio-epoxy composites remains underexplored for bridge deck applications. This study evaluates the design and finite element modelling (FEM) of woven flax/bio-epoxy textile composite laminates for pedestrian and cycle bridge decks.

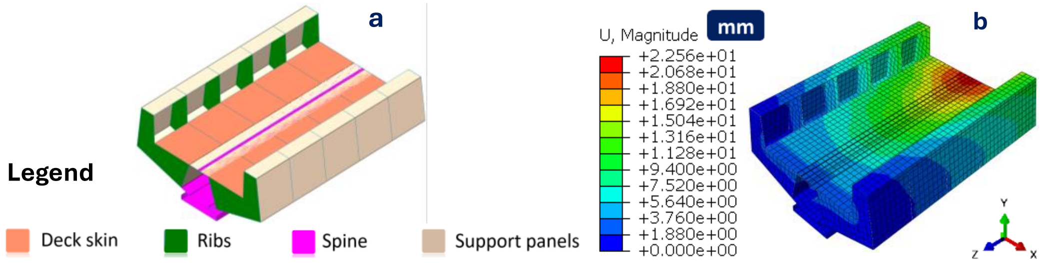

Figure 1: Bridge section: **(a)** design model; **(b)** FEM of the woven flax/bio-epoxy laminates.

The bridge design was inspired by the UK Network Rail Modular FRP FLOW Bridge [2]. A 3-D CAD model was developed in SolidWorks and analysed in Abaqus. Shell-based S4R element modelling with orthotropic material properties and hourglass control was employed. Symmetric $[0/90]_n$ woven laminate lay-ups and woven-faced sandwich structures were investigated. A 2.5 kN/m² load with safety factors was applied in accordance with serviceability conditions [3]. The 32-layer trial laminate exhibited over-engineered stiffness, resulting in a mid-span displacement of $U_{max} \approx 4.53$ mm. The optimized 16-layer $[0/90]_8$ laminate (≈ 21.4 mm) offered a better stiffness-weight ratio ($U_{max} \approx 18.44$ mm; stress ≈ 15.74 MPa). A sandwich structure with 10 woven layers (≈ 13.4 mm) and a 9.5 mm balsa core exhibited a maximum displacement of $U_{max} \approx 22.6$ mm while remaining within serviceability limits (≈ 22 mm) [3]. Hourglass energy remained below 1.3%, confirming model stability. Sensitivity analysis showed that mesh size and applied pressure load were the most significant factors in the structural behaviour. This study presents new design data for woven flax/bio-epoxy textile composite laminates, a material system rarely reported in the literature for bridge applications. This will inform the current and future experimental approaches.

The authors gratefully acknowledge the financial support of the Engineering and Physical Sciences Research Council (EPSRC) under grant reference EP/S021728/1.

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Yarn and Fibre Scale Modelling 1

TEXGEN – 20 YEARS OF OPEN-SOURCE DEVELOPMENT

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The geometry of textile reinforcement, including its architecture and parameters, define the effective properties of textile composites. Multi-scale modelling approaches enable separation of length scales, where fibre bundles are typically represented as solid yarns at the meso-scale [1]. Creating complex geometric models of textiles poses several challenges e.g. many individual yarns need to be defined for complex textiles, the yarns should not overlap and they should have defined local orientation according to the fibre direction. Textile pre-processors, such as TexGen and WiseTex, can significantly simplify the problem.

TexGen, an open-source textile pre-processor, has been widely used for modelling textile reinforcements at the meso-scale, with over 78,000 downloads worldwide as of March 2026. Over the past two decades, it has evolved to support woven, braided, and knitted structures through an intuitive graphical user interface [2]. It has been also integrated into other software packages, such as PolyTex, an open-source package for image-based modelling of textile composites [3].

This work presents recent developments in TexGen for creating complex textile geometries. These include new classes for generating 3D woven structures with decoupled binders yarns, as well as support for prismatic domains and tapered sections. In addition, extended boundary condition definitions have been implemented to enable faster analysis of mechanical properties using finite element solvers. These developments further strengthen TexGen as a versatile platform for meso-scale modelling and simulation of advanced textile composites.

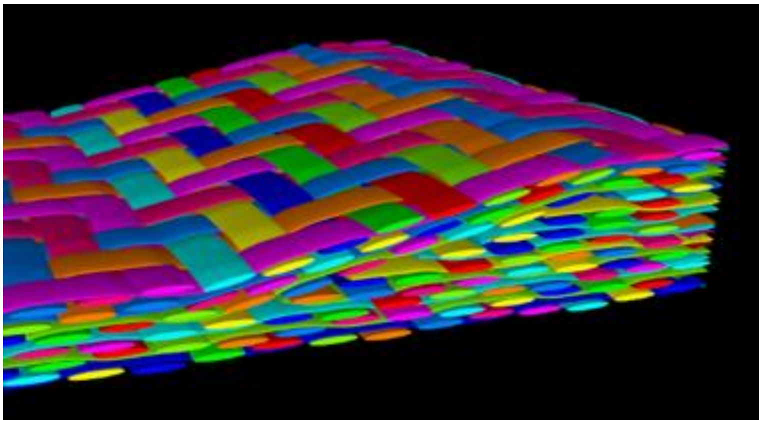

Figure 1: Geometric model of tapered composite manufactured using the ply drop technique.

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SIMTEX: TEXTILE MANUFACTURING SIMULATION AT SCALE

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Variability in composites manufacturing processes is a crucial consideration for the design and characterization of composite material products, but one that has remained difficult to address with physics-based tools like finite element (FE) analysis. Whilst great strides have been made with the development of sophisticated material and element formulations in commercial FE solvers, simulating at large scales, either in terms of single model size or number of simulation runs, remains unfeasible due to prohibitive computational costs.

The Bristol Composites Institute has been developing the SimTex finite element solver since 2014, leveraging the computational efficiency of its very fast contact algorithm initially to solve for accurate 3D woven fabric yarn geometries [1], and in recent years, a wider range of composites manufacturing processes such as braiding and forming. The application of the solver to these dynamic processes has been instructive for the continued refinement of the solver to more accurately simulate yarn movement. These improvements can be most seen in explorations of filament winding, braiding, coreless winding and weaving with SimTex.

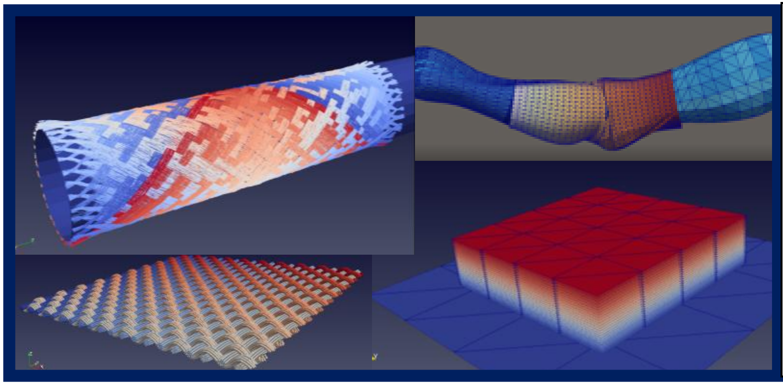

Figure 1: SimTex simulation outputs for (clockwise from top left) a): yarn coverage of a braided cylinder, b): fitting of a textile sleeve to a model arm, c) compression of a stack of tri-meshed textile plies, d) a 10x10 tiling of 2x2 plain

More robust contact calculations and constitutive models have made tri-element based meso-scale models more viable for forming processes, while additional improvements to parallelization of the solver has allowed for the simulation of increasingly large components at yarn-level resolution. This acceleration is set to improve further, with early development of GPU utilization reporting substantial reductions in runtime for contact-dominated simulations. Additional explorations of fabric modelling for technical textiles for sport and models of weaving processes in the loom have shown promising results and spurred further feature development in the solver to aid usability and flexibility.

Between these usability improvements, efficiency gains and an expanding material and element library, SimTex aims to develop into a compelling manufacturing simulation platform for textiles, composites, and beyond.

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FIBRE-SCALE ANALYSES OF MULTI-LAYER WOVEN CARBON-FIBRE REINFORCEMENTS USING NUMERICAL AND EXPERIMENTAL METHODS

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The forming process plays a pivotal role in the manufacturing of textile composites, as it shapes the textile preform into its final curved, three-dimensional geometry. This stage is critical because it determines the fibre orientations and structural integrity of the preform, which directly influence the mechanical performance of the final composite part [1]. This process involves a complex interplay between the textile architecture, the geometry of the component, and the boundary conditions of the forming process [2]. However, the draping process can also introduce distortions into the textile structure, which may compromise the quality of the final composite. In woven fabrics, deformations primarily occur through in-plane shear, as the interlacing points between warp and weft yarns allow rotational movement. As the shear angle increases, the yarn cross-sections deform, altering the contact areas at the binding points and increasing frictional forces [3]. Additionally, membrane tensions generated during forming amplify the friction at the crossing points due to the increased normal loads between intersecting warp and weft yarns. These frictional forces, combined with the inherent stiffness of the textile, can lead to defects such as wrinkling, fiber misalignment, or gaps, particularly when forming complex geometries with double curvatures.

The microstructure of multi-layer woven carbon-fibre (CF) reinforcements has been studied both in their undeformed state and during the forming process, with a particular focus on changes in roving cross-sections and undulation. These microstructural features undergo significant variations under the tensile and shear deformations experienced during draping, which, in turn, influence the overall deformation behaviour of the fabric. To gain deeper insights into these changes, robot-assisted high-frequency eddy current testing technology is being further developed to accurately record and reconstruct the complete thread paths of preforms made from multi-layer woven fabrics. This advanced eddy current testing, combined with fibre orientation measurements, provides fundamentally new perspectives on the deformation behaviour of multi-layer woven fabrics. By capturing detailed information about fibre paths and structural changes, this approach enables a more comprehensive understanding of the draping process and its impact on the final composite structure. Furthermore, a fibre-scale simulation model is used to investigate the fabrics micro structure during deformation. In particular, the influence of the out-of-plane undulation of the fibre course caused by the crimp of the weft and warp yarns is analysed on the tensile and shear properties. Forming simulations of double curved geometries using the developed fibre scale model are performed and compared to a meso-macro approach giving insights into the deformation behaviour of the textile during preforming. The gained insights are critical for optimising the forming process and improving the performance of textile composites in advanced applications.

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A MESOSCALE EMBEDDED-FIBRE APPROACH FOR MODELLING THE NON-LINEAR BEHAVIOUR IN WOVEN CERAMIC-MATRIX COMPOSITES

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Ceramic-matrix composites (CMCs) are critical for enabling higher service temperatures in aircraft engines. However, their complex non-linear behaviour, which is driven by multi-scale interactions between microscale damage and mesoscale load transfer, remains challenging to predict. Traditional multiscale homogenisation methods struggle to capture the entire damage process due to limited scale separation and inherent material variability.

To address this challenge, we propose an integrated approach that simultaneously models constituents, damage mechanisms, and load transfer at a unified scale. Our method combines discrete element concepts with mesh superposition technique: fibres are represented as trusses embedded in a quasi-brittle matrix, while a novel non-linear interface user-element ensures kinematic coupling and introduces interfacial damage and friction. This extends classical embedded-fibre methods to complex non-linear regimes.

When applied to woven SiC/SiC composites, our approach accurately reproduces the macroscopic mechanical response up to failure, with characteristic CMC behaviour features emerging naturally without the need for additional fitting parameters. It also enables monitoring microscale damage evolution, including matrix cracking, fibre/matrix interface debonding, and fibre breakage, as validated against fully instrumented tensile tests. These results underscore the method's potential for advancing both the understanding and optimisation of woven CMC materials.

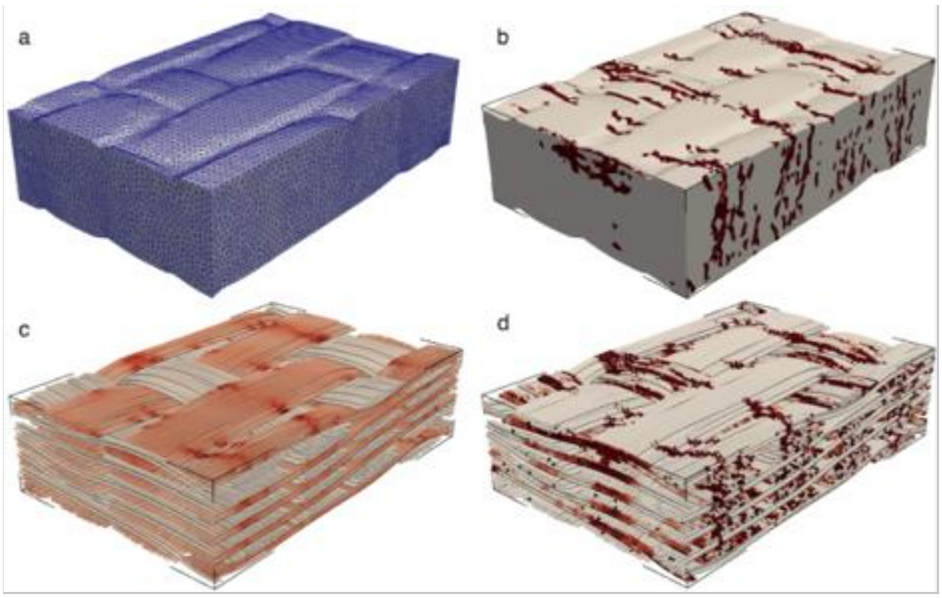

Figure 1: 3D visualisation of damage in a woven CMC under tensile loading, as predicted by our embedded-fibre approach: (a) finite element mesh, (b) matrix cracking, (c) fibre stress and (d) interface damage.

Yarn and Fibre Scale Modelling 2

THEORETICAL-NUMERICAL INTEGRATED MULTI-SCALE MODEL FOR FAST PREDICTION OF IMPACT DAMAGE IN TEXTILE COMPOSITES

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This study proposes a theoretical-numerical integrated multi-scale simulation approach [1], and employs various forms of experimental results and numerical predictions to demonstrate the model's applicability and efficiency. As depicted in Fig. 1, this multi-scale simulation approach encompasses two main parts: the theoretical analysis model and the FE model. The analytical model is based on previous work [2], comprising simulations at micro-, meso-, and macro-scale, while the FE model includes only the meso-scale and macro-scale. As illustrated in Fig. 1(b), the real-time interaction of the mechanical response and damage information in the theoretical analysis model and the FE model can be realized by formulating the theoretical model as a subroutine and implementing it in finite element software.

The proposed approach is utilized to predict the mechanical responses and failure behaviors of different types of two-dimensional triaxial braided composites specimens: straight-sided tension/compression, tube and notched specimens. Additionally, the failure behavior of two-dimensional triaxial braided composites under high-speed impact was simulated using the established multi-scale model. The predictions show good agreement with both the meso-scale finite element simulations and the experimental results, while reducing the computational time by more than 10 times as compared to the meso-scale model. Overall, the theoretical-numerical integrated multi-scale model provides a fast and reliable solution for modeling the progressive failure behavior of textile composite structures under various loading conditions.

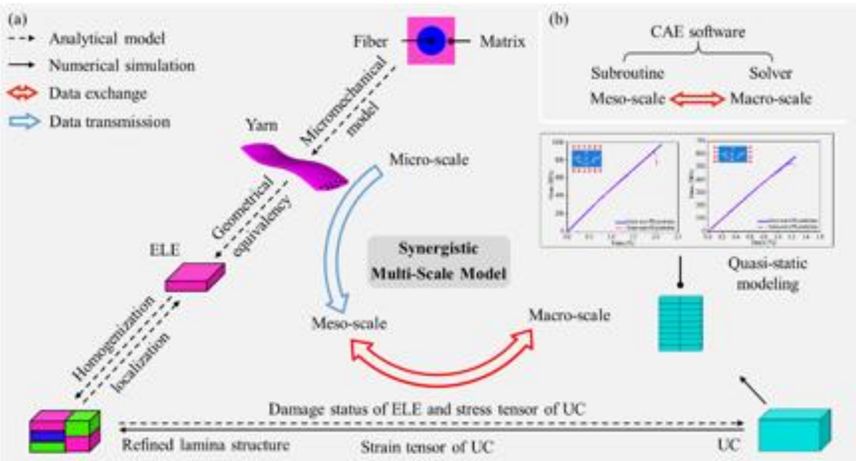

Figure 1: Scheme for the synergistic multi-scale modeling framework

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FINITE ELEMENT ANALYSIS OF LOW-VELOCITY IMPACT (LVI) DAMAGE IN BIO-INSPIRED HELICOIDAL CFRP LAMINATES FOR THIN- AND THICK-WALL STRUCTURES

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Carbon fibre-reinforced polymer (CFRP) laminates are widely used in aerospace structures owing to their high specific stiffness and strength. However, the harsh in-service environment and complex loading conditions in aircraft, making these materials susceptible to low-velocity impact (LVI), which can introduce barely visible impact damage (BVID) including matrix cracking, delamination, and fibre breakage, leading to substantial reductions in residual compressive strength. In order to improve the damage tolerance of CFRPs, innovation in CFRP microstructures has become the key pathways. Bio-inspired (BI) helicoidal laminate architectures, in which fibre orientations rotate gradually through the thickness, have demonstrated potential for improved damage tolerance by promoting progressive stress redistribution and enhanced energy dissipation [1, 2].

In this study, we developed a high-fidelity finite element (FE) framework to predict LVI damage evolution in BI helicoidal CFRP laminates across two representative aerospace structural configurations: a thin-wall design (2.5 mm) and a thick-wall design (4.5 mm). For each baseline quasi-isotropic (QI) layup, we designed three alternative helicoidal counterparts to optimise the buckling and LVI performance. We built the FE models in Abaqus/Explicit using a user-defined VUMAT subroutine implementing the LaRC05 intralaminar damage model [3]. This damage model captures the dominant failure mechanisms in fibre-reinforced composites, including matrix cracking, matrix splitting, fibre tensile failure, and fibre kinking. To improve numerical robustness, we employed a sub-stacking approach with cohesive surface interactions between sub-stacks. To represent the manufacturing-induced variations, we introduced geometric imperfections derived from linear buckling analysis with appropriate scaling factors. We validated the FE predictions against experimental LVI tests conducted on thin- and thick-wall specimens manufactured using IM7/8552.

The FE model demonstrated good agreement with experimental results in terms of global load–time response and peak loads. Importantly, it captured key damage features observed experimentally, including the delayed onset of fibre-dominated failure in helicoidal configurations and characteristic matrix splitting patterns on the back surface. Through detailed FE simulations, we analysed the damage evolution in BI helicoidal structures, gaining deeper insight into how these architectures promote distributed damage through extended delamination and migrating matrix cracks. The detailed FEA setups and results will be presented at the conference.

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HIGH-FIDELITY IMAGE BASED MESO-SCALE MODELLING OF 3D WOVEN COMPOSITE

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Because of their performances, woven composites are widely used in the aerospace field. To be used for applications with complex geometry, the inner structure design grows also in complexity [1]. Predicting the mechanical behavior of such materials necessitates a detailed knowledge of their inner structure. Recent speed-up and improvements of virtual approaches [2] make them suitable for woven composite design and numerical prediction, however, virtual models remain too idealized when compared to X-ray computed microtomography (μCT). Image based approaches [3] offer the possibility of more realistic meso- models. The FE simulations using image-based models provide a reference to validate virtual ones using mechanical criteria (extending qualitative comparison to μCT).

The systematic generation of numerical models from μCT remains challenging. We proposed a variational segmentation approach that combines μCT with a prior geometric model that is iteratively improved [4]. Our method generates realistic numerical models of woven fabrics, replicating the as-manufactured weaving pattern, and are, by construction, free of interpenetration. A voxelization of the geometric model as refined as necessary is generated and the imaged based mesh generator CGAL [5] is used to build a conformed mesh of the geometry.

At ONERA, the aim is to apply this approach to 3D woven PMC and study their behavior under cyclic loading. The emphasis is put on the behavior of the resin in between yarns. A library of woven composite meso- models is used, ranging from parametrized virtual models to high-fidelity image-based models. Virtual models will allow to tune the yarns geometry and constitutive laws to understand local phenomena. The image-based model will then provide a numerical reference by simulating the behavior of a realistic meso- architecture under cyclic loading. An extension of the image-based framework (segmentation and meshing) could follow to be more suitable for cyclic loading of PMC, i.e. if representing explicitly the resin at yarns interfaces turns out to be a prerequisite.

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ROTATION-FREE SHELL ELEMENT FOR FORMING SIMULATION IN SIMTEX USING MIXED TIMESTEP INTEGRATION

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The forming process is widely recognised as one of the most efficient and cost-effective methods to manufacture textile composite parts with complex 3D geometries [1]. However, defects such as fibre misalignment and wrinkles are often introduced during forming. These defects propagate into the final product and can significantly impair its mechanical performance. To mitigate such defects, numerical modelling tools are increasingly employed to predict defect formation, enabling the implementation of appropriate countermeasures based on simulation results. Kinematic draping models can be used for rapid forming analysis, but neglecting the dynamic response of the material leads to poor accuracy. Therefore, finite element (FE) based techniques have attracted attention due to their high fidelity. However, these simulations are computationally expensive due to complex constitutive behaviour of textile composites. As a result, industry-scale simulations typically require substantial CPU/GPU resources and memory, with computations lasting for weeks. To reduce the computational cost it is essential to develop more efficient, but still accurate, simulation methods.

In this study, rotational-free shell elements with decoupled tension, shear and bending behaviour are developed. In particular, the bending force is made dependent on element curvature, which depends solely on the nodal displacement of neighbouring elements. This allows neglecting the rotational degree of freedom [2] and thereby improve computational efficiency. However, implementation within commercial FE solvers is challenging due to limited access to their core codes. Therefore, the proposed material model is implemented in SimTex, an explicit FE solver developed at Bristol Composite Institute (BCI). SimTex demonstrates inherent computational speed advantages over commercial solvers, driven by the use of a HashMap-based approach to accelerate contact detection and the implementation of efficient early-stage contact rejection criteria.

The ability to increase SimTex's computational speed further is also explored. As an explicit solver, the computational performance of SimTex is constrained by the critical timestep, which is governed by the smallest characteristic element length. To ensure accuracy in regions involving contact and high curvature, the minimum element size should remain sufficiently small, causing globally conservative timesteps and reduced efficiency. To solve this bottleneck, a mixed timestep algorithm is introduced to improve the computational speed [3]. When combined with adaptive meshing, this algorithm allows larger elements to be processed using larger timesteps in regions of a model where the small critical timestep is not required, therefore significantly reducing overall simulation time.

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Manufacturing of Textile Preforms 1

EFFECT OF BINDER STATE ON DEFORMATION AND DEFECT FORMATION DURING PREFORMING OF UNIDIRECTIONAL NON-CRIMP FABRICS

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During the preforming stage of liquid composite molding (LCM), dry textile reinforcements are shaped into three-dimensional near-net-shape preforms; however, this process involves macroscopic deformation phenomena that can introduce defects and negatively influence final part quality. Stabilizing binder is commonly introduced to the fabric to improve handleability and shape retention during preforming, while also influencing the mechanical response of the fabric [1-3]. Despite their widespread use, the effect of binder state and activation on deformation mechanisms and forming-induced defect development remains insufficiently understood, particularly for unidirectional non-crimp fabrics (UD-NCFs) [4]. In this study, a carbon fiber UD-NCF is investigated under three conditions, namely no binder, with binder, and with pre-activated binder, to quantify the influence of binder state on deformation behavior and defect formation during preforming. Experimental preforming tests are conducted using hemispherical and pyramidal punch geometries for both single- and double-layer configurations. The results show that binder state governs the forming response across all configurations. For single layer forming, the no binder fabric exhibits the lowest forming forces and smooth wrinkling of the fabric, owing to high inter-tow bending mobility. In contrast, the with binder and pre-activated binder conditions lead to increased forming forces and a transition toward distinct wrinkling deformation due to progressive restriction of tow bending mobility. For double-layer configurations with stitch-side interaction (Figure 1), the binder state governs the force–displacement response, with the no binder condition exhibiting the lowest forming force, with binder fabric showing increased resistance due to mechanical inter-layer coupling, and pre-activated binder fabric producing the highest forces as inter-layer adhesion restricts relative ply motion. The representative deformation of the pre-activated case illustrates this constrained, coupled response, confirming the progressive transition from inter-layer sliding to adhesion-dominated behavior with increasing binder constraint. Binder state and activation history should be accounted for in UD-NCF preforming process design, as changes in tow and inter-layer mobility affect forming forces, deformation mode, and the onset of wrinkling.

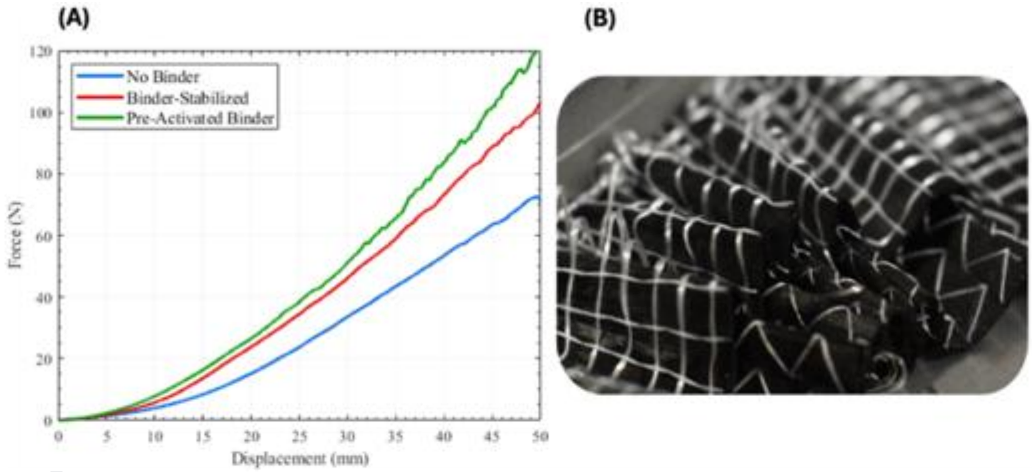

Figure 1. Effect of binder state on double-layer preforming under stitch-side interaction. (A) Force–displacement curves for no binder, with binder, and pre-activated binder conditions. (B) Representative wrinkling in the pre-activated binder case, illustrating constrained wrinkling and inter-layer deformation.

THROUGH OPTIMISED DRY FIBRE PREFORM STABILISATION

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Preform stabilisation is critical in manufacturing infused fibre-reinforced components with increased thickness and complex geometries at high production rates. The instability of carbon fibre layers during preform handling presents a significant challenge in maintaining structural integrity throughout the infusion process. This study provides a critical comparison of thermoset and thermoplastic binders, in various forms, for stabilising thick carbon fibre preforms prior to infusion.
Replacing metallic components with carbon fibre in load-bearing applications introduces challenges to manufacture parts that can withstand operational loads. A primary challenge is managing the bulk of dry fibre preforms. As additional layers are incorporated to meet strength requirements, preforms become significantly thicker. This can create difficulties during lay-up due to the preforms tendency to spring back to its original shape, and during infusion where insufficient stability may lead to fibre misalignment within the tooling. Each of these can significantly affect the quality and properties of the final part, making stabilisation a critical step for allowing high-rate production of fibre-reinforced parts.

To address these challenges, binder materials were systematically integrated into the lay-up process to stabilise fibres and enable partial consolidation prior to resin infusion. This experimental work evaluates binders based on thermoset and thermoplastic resins, assessing their effectiveness with respect to dimensional stability, geometric conformity, and handling robustness over variable radius tooling featuring both male and female radii.

The results establish a scalable stabilisation strategy for improving dimensional consistency and process reliability. This allows it to be developed into high-rate manufacturing solutions through integration into automated production environments, thereby advancing the adoption of infused carbon fibre components across high-performance industries.

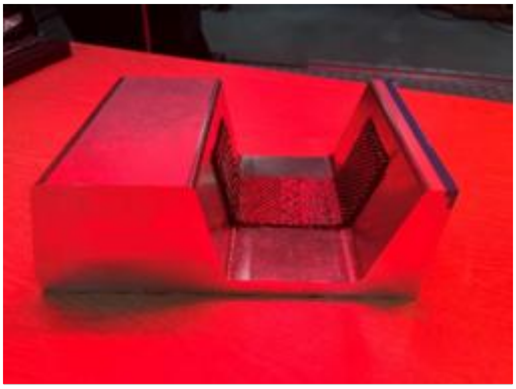

Figure 1: Preform in position on tool, under IR lamps

DEVELOPMENT OF NONWOVEN COMPOSITES FROM MECHANICALLY RECYCLED TEXTILE FIBRES

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Abstract: The growing accumulation of textile waste due to fast fashion and linear production systems presents significant environmental and resource challenges. This goal can be achieved if discarded textiles are effectively recycled, and the resulting recycled materials are used in the production of new textile products.

This study aims to determine a suitable nonwoven composite fabrication method using mechanically recycled synthetic textile fibres. To achieve the aim, composites were produced from blends of recycled synthetic fibres and low melting polyester. Nonwoven preforms were produced via carding and pre-pressing, followed by hot-pressing. Four different hot-pressing techniques that combined preform drying before hot-pressing and a 1-minute relaxation period during pressing were used. Three hot-pressing temperatures were applied. Mechanical properties were evaluated through tensile, flexural, and Charpy impact tests. The results showed that incorporating 1-minute relaxation period during hot pressing improved tensile strength by approximately 23%, flexural strength by 16%, and impact strength by 11%. The highest tensile and flexural strength values were observed at 130 °C, while the maximum impact strength was achieved at 110 °C. Drying the nonwoven preforms prior to pressing reduced tensile, flexural and impact properties.

The findings demonstrate that processing parameters affect composite properties. The developed materials show potential for semi-structural applications such as furniture components and lightweight automotive interior parts, supporting circular economy approaches in textile waste management.

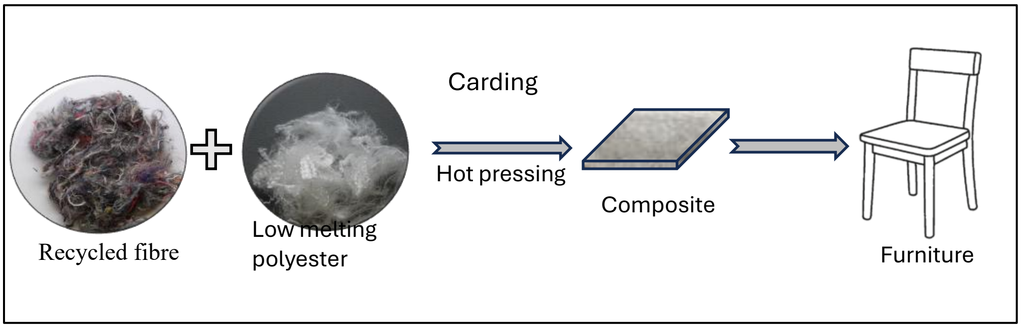

Figure 1: Graphical abstract

This work was supported by [Ministry of Education and Research] through Centre of Excellence in Circular Economy for Strategic Mineral and Carbon Resources [TK228U4].

SWAT - SYSTEMATICALLY WEAVING A DIGITAL THREAD INTO COMPOSITE PARTS

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The manufacture of 3D woven carbon fibre preforms for aerospace and high-performance applications presents significant challenges in process variability, traceability, and certification. Despite advances in textile composite architectures, structured digital integration within weaving platforms remains limited, restricting the ability to link process parameters to preform quality and downstream mechanical performance. This work presents SWaT (Systematically Weaving a Digital Thread), a framework for embedding a structured digital architecture into a 3D Jacquard weaving line to enable real-time process intelligence and lifecycle connectivity.

A 3D Jacquard weaving platform was instrumented and digitally integrated through a unified acquisition framework capable of handling high-density, high-frequency machine and process data. Machine outputs and condition data were synchronised and contextualised within a scalable data pipeline designed to ensure temporal alignment, traceability, and schema standardisation. A tiered data architecture (raw → structured → contextualised) was implemented to support robust storage, interrogation, and long-term lifecycle accessibility. Real-time visualisation interfaces were developed to enhance process transparency and enable rapid identification of anomalous machine behaviour during manufacture.

Advanced signal processing and feature extraction methodologies were applied to clean, filter, and normalise process data streams, enabling statistical correlation between machine state variables and resulting preform characteristics. Predictive modelling strategies were subsequently deployed to support process optimisation, condition monitoring, and early-stage defect identification. The resulting digital thread framework strengthens understanding of process–structure relationships in 3D woven composites, supports evidence-based process qualification, and establishes the foundation for digital passports and future digital twin implementations in textile composite manufacturing.

This work demonstrates how systematic digital integration within 3D weaving can bridge textile processing science with composite certification requirements and industrial scalability, offering a transferable framework for next-generation composite manufacturing systems.

Figure 1: Digital Thread Architecture Implemented Within a 3D Carbon Fibre Weaving Platform

Experimental Characterisation of Textile Reinforcements 2

MULTI-SCALE CHARACTERIZATION OF NATURAL FIBERS FOR TECHNICAL APPLICATIONS TO FLEXIBLE INTERMEDIATE BULK CONTAINERS (FIBCS)

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Flexible intermediate bulk containers (FIBCs) are used all over the world in various fields such as construction, storage, and freight transport. Currently, FIBCs are made of polypropylene, a synthetic fiber. They are intended for reuse, but 65% of them are used only once and then buried, incinerated, or left in the environment. Only 50% of these FIBCs are recycled, but they are never recycled to produce new FIBCs. Thus, with the AGEC law (France) and the Packaging and Packaging Waste Regulation (Europe), which aim to decrease the single-use plastics, FIBCs cannot continue to be produced as they currently are. Therefore, substituting synthetic fibers with natural fibers appears to be a viable solution. The objective is to produce FIBCs made from natural fibers so that they can be recycled at the end of their life cycle. To meet the specifications, it is essential to identify the physical and mechanical properties of the natural fiber reinforcements at different scales: fibers, yarn, and fabrics [1, 2]. The characterization of fibers and yarns will enable us to analyze the ability to produce first yarns by spinning and fabrics by weaving. The specifications for loaded FIBCs lead to different deformations in the vertical direction and around the circumference, as shown in Figure 1. Unbalanced fabrics must be considered with different yarn densities in the warp and weft directions or with different weave structures.

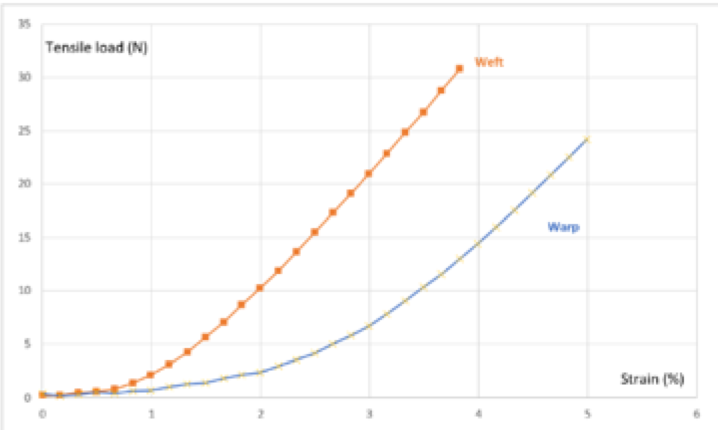

Figure 1: Tensile behavior of unbalanced fabrics

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EXPLORING THE MULTIFUNCTIONAL PROPERTIES OF FLAX FIBER/HOLLOW GLASS MICROSPHERE REINFORCED POLYURETHANE COMPOSITES

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Short summary
Polyurethane composites reinforced with flax fiber and Hollow Glass Microspheres (HGM) showed improved strength, thermal and acoustic properties. They present a promising option for sustainable engineering applications.

Abstract
The demand for sustainable, multifunctional composites has grown across sectors such as automotive, construction, and aerospace. Natural fiber–reinforced polyurethane composites with functional fillers offer great potential for these applications. Polyurethane composites are lightweight, porous materials offering easy fabrication, thermal insulation, acoustic performance, waterproofing, chemical resistance, and cost-effective single-step processing [1]. Flax is an excellent natural reinforcement due to its high cellulose content (67–80%), providing exceptional tensile strength (600–1100 MPa) and Young's modulus (27–80 GPa), comparable to E-glass fibers but with a much lower density (≈1.4–1.5 g/cm^3) [2]. Hollow Glass Microspheres (HGMs) are lightweight, hollow spherical particles known for their low density, excellent thermal insulation, fire resistance and sound insulation properties. making them promising functional fillers for construction, transportation, aerospace, and military applications [3].

In this study, flax fiber (FF) and HGMs were employed as natural reinforcement and functional fillers to develop rigid polyurethane (PU) bio-composites with enhanced mechanical, thermal, and acoustic properties. The composites were fabricated via a one-shot, one-step method by premixing chopped flax fibers (5–15 wt.%) and HGMs (2–6 wt.%) with bio-based polyol prior to the addition of isocyanate. Comprehensive characterization included apparent density, water absorption, compressive and impact strength, thermal stability, and acoustic performance. Incorporation of flax fibers improved structural rigidity and sound damping due to their fibrous morphology, while HGMs contributed to lightweighting, thermal insulation, and enhanced sound absorption through their hollow structure. Optimal mechanical performance was achieved at 5%FF–2%HGMs, while thermal and acoustic efficiency increased with moderate filler loading. SEM analysis confirmed good dispersion at lower concentrations, with some agglomeration at higher levels. The synergy between FF and HGMs demonstrates a promising pathway toward sustainable, lightweight, and acoustically efficient polyurethane composites for building, automotive, and interior applications.

This work has been completed while the presenter was a Doctoral Candidate in the Interdisciplinary Doctoral School Lodz University of Technology, Poland.

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ON THE IMPACT STRENGTH OF PINEAPPLE FIBER REINFORCED POLYPROPYLENE

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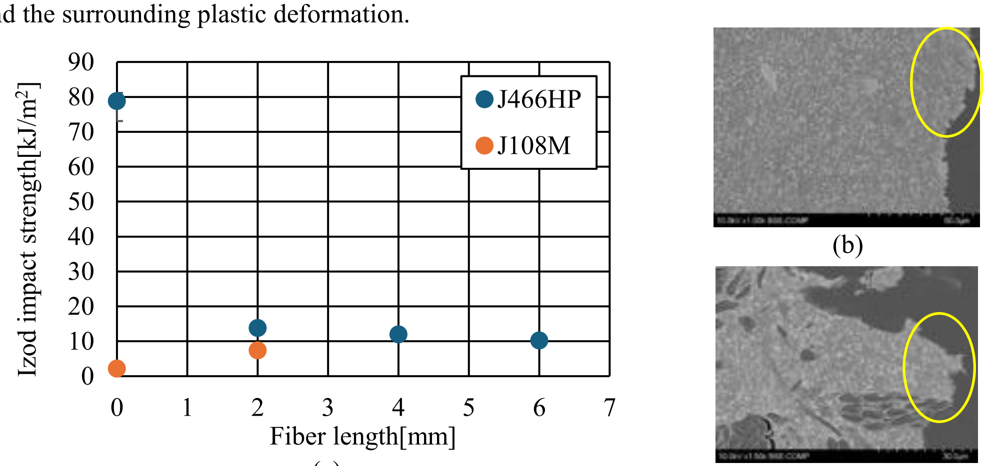
From an environmental sustainability perspective, natural fiber-reinforced thermoplastics have attracted increasing attention for several industrial applications [1]. Pineapple leaf fiber (PALF) is a renewable reinforcement material with one of the highest strengths among natural fibers. However, sufficient impact resistance is required for structural applications. Impact-modified polypropylene (PP) contains a dispersed rubber phase, typically ethylene–propylene rubber (EPR), which enhances impact resistance through deformation of the rubber phase. When fibers are incorporated, the deformation and energy absorption mechanisms of the rubber phase may be constrained.

This study aimed to clarify how fiber reinforcement influences the deformation behavior of the rubber phase and the resulting change in impact strength.The matrix materials used were a PP homopolymer (J108M) and a rubber-modified polypropylene (J466HP).

As shown in Figure 1a, the impact strength of J466HP was higher than the neat J108M. However, a significant decrease in impact strength was observed when fibers were incorporated, particularly for J466HP. Furthermore, in the impact strength of J466HP progressively decreased as the fiber length increased from 0 to 2, 4, and 6 mm (corresponding to fiber content of 30 w%).

SEM observations of fracture surfaces revealed deformation of the rubber phase in neat specimens (Figure 1b). In fiber-reinforced specimens, matrix deformation appeared to be constrained (Figure 1c). The observed decrease in impact strength with increasing fiber length suggests that deformation constraint becomes more pronounced with longer fibers. This suppresses rubber phase deformation and the surrounding plastic deformation.



(a) (b) (c)

Figure 1: (a) Izod impact strength as a function of fiber length for a PP homopolymer (J108M) and a rubber-modified PP (J466HP). SEM observation of J466HP (b) without fibers and (c) with 2 mm fibers length.

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PASSIVE VISUAL STRAIN SENSING IN WOVEN GLASS FIBRE COMPOSITES

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The ability to directly interpret strain in textile composite structures without instrumentation remains a key challenge in structural monitoring. This study introduces a bonded polymeric kirigami layer as a passive sensing approach that converts substrate strain into a visible and spatially localised deformation pattern through geometric amplification.

Woven glass fibre composite substrates were manufactured from an 8-harness satin prepreg system and tested under uniaxial tension. Kirigami ribbons based on a linear parallel slit architecture were designed with a unit cell ratio of

$$l_c/l_x = l_c/l_y = 3$$

and additively manufactured using TPU 90A. The kirigami geometry is shown in Figure 1(a), while bonded specimens with varying ribbon lengths are presented in Figure 1(b). Finite element modelling (FEM) incorporating hyperelastic material behaviour and geometric nonlinearity was used to predict deformation mechanisms and to identify an optimal ribbon thickness of 0.2 mm for enhanced strain sensitivity.

When bonded to the composite substrate, the kirigami layer exhibited characteristic in, and out-of-plane deformation driven by slit opening and ligament rotation. The deformation response showed good agreement with finite element predictions, as illustrated in Figure 1(c). A parametric study demonstrated that ribbon length strongly influences deformation localisation, with shorter bonded ribbons producing concentrated and visually distinct strain patterns, while longer ribbons resulted in more distributed responses. These findings indicate that the effectiveness of the kirigami layer is governed not only by strain amplification but also by the spatial resolution and clarity of the deformation field.

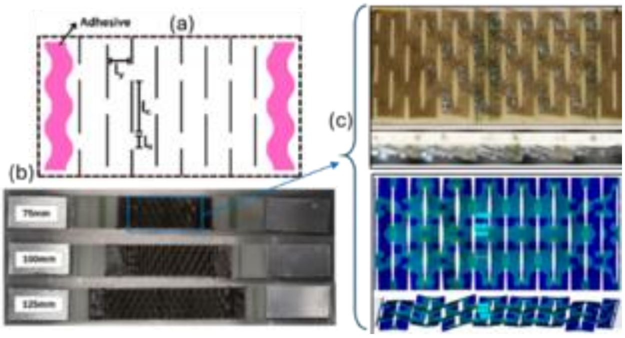

Figure 1: (a) Kirigami ribbon geometry; (b) bonded composite specimens with different ribbon lengths; (c) Experiment and FEM deformation response of 75 mm ribbon.

The proposed approach enables strain to be mapped into an interpretable visual pattern through structural geometry alone, eliminating the need for embedded sensors, wiring, or data acquisition systems. This establishes bonded kirigami as a viable, low-cost strategy for passive strain indication in textile composite structures, with potential applications in real-time inspection and structural health monitoring.

Manufacturing of Textile Preforms 2

FULL FIELD QUANTITATIVE CORRELATION OF OUT OF PLANE DEFECTS IN VIRTUAL AND EXPERIMENTAL COMPOSITE PLY FORMING DATA

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A methodology for full field quantitative correlation of Out of Plane (OoP) defects in virtual and experimental composite ply forming data is presented. The methodology is demonstrated via Manufacturing Process Simulation (MPS) research tools. The tools facilitate validation of virtual testing via Non-Linear Finite Element Analysis (NLFEA) of composite ply forming. This validation supports evaluation of a developed end to end automated forming analysis capability for industrial application on next-generation composite aerospace structures.

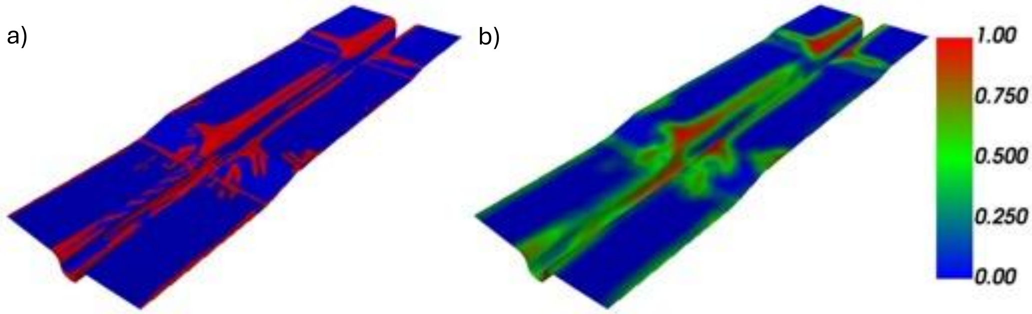

Figure 1: a) OoP defects indicated in red. b) Defect density estimate filter, filter radius 20mm.

A robust quantitative framework for classification of OoP defects is desirable for simulation validation and application of advanced methods such as optimization [1]. A second order differential geometry method is applied to classification of OoP defects such as wrinkling and bridging/ply thinning (see fig. 1a). The method conducts a local pointwise comparison of actual and expected geometry via the polar arc deviation test, developed in a forthcoming doctoral thesis [2]. Three candidate correlation indices are investigated: Pearson Correlation Coefficient, Lin's Concordance Correlation Coefficient, and Cohen's Kappa. A defect density estimate filter transforms discrete classification data into continuous data, and permits control of sensitivity to error in predicted wrinkle location for validation applications (see fig. 1b). The significance of computational performance of software implementation is evidenced.

This work was undertaken within the Airbus led, Composite Smart Industrial Control (CoSInC) programme, funded by the Aerospace Technology Institute. This work was a collaboration between the Airbus Operations MPS team and the University of Bristol, Bristol Composites Institute.

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COMPARATIVE STUDY ON BENDING STIFFNESS AND DRAPABILITY OF COATED CARBON TEXTILE REINFORCEMENTS FOR ARCHITECTURAL TEXTILE REINFORCED CONCRETE ELEMENTS

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Textile reinforced concrete (TRC) enables the production of thin, lightweight, and corrosion-free façade or structural elements. In recent years, the development of tessellated TRC geometries has opened new possibilities for architectural design and prefabrication. However, the formability and mechanical reliability of textile reinforcements remain key challenges when producing such complex shapes. [1] This study investigates the mechanical and drapability characteristics of four textile preform types—Tailored Fiber Placement (TFP), warp-knitted fabrics, woven fabrics, and automated tape layup (ATL)—all manufactured from the same 24K carbon roving and impregnated with different coating systems (epoxy, SBR, and thermoplastic acrylate).

A comprehensive test series was carried out to evaluate bending stiffness, tensile strip strength, and drapeability using standardized and adapted test methods. The epoxy-impregnated textiles exhibited the highest bending stiffness and tensile strength, whereas SBR coatings resulted in the weakest performance. TFP textiles were too stiff for conventional cantilever bending tests and required an analytical approach using the bending line of a cantilever beam. Drapability assessment on hemispherical and tessellated molds revealed that the suitability of each textile type strongly depends on geometry: while woven and TFP textiles performed moderately well on hemispherical forms, their formability on tessellated structures was limited. In contrast, warp-knitted fabrics showed consistent draping performance across both geometries, making them the most suitable reinforcement for tessellated TRC components.

The inverse correlation between bending stiffness and drapability was confirmed as a decisive design factor for textile selection. A central evaluation matrix combining mechanical and formability parameters identified the warp-knitted structure as "suitable," while ATL and TFP were classified as "rather unsuitable" for tessellated shapes. Future work will focus on validating these findings with industry scale demonstrators and explore the influence of pre-activation of thermoplastic and thermoset matrices during draping.

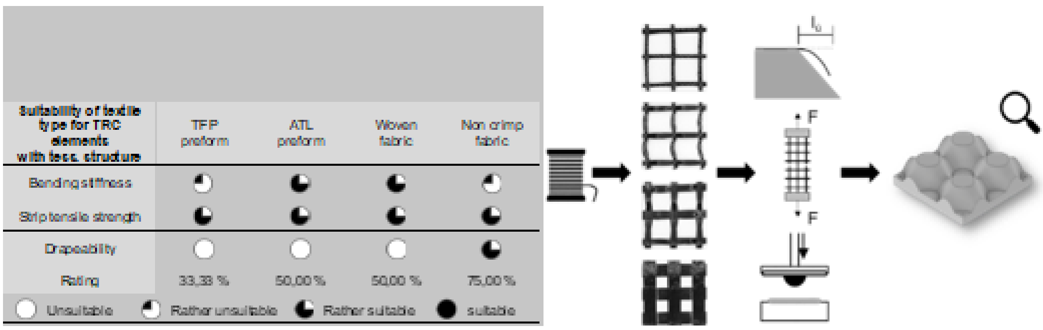

Figure 1: Central evaluation matrix of the mechanical characteristics of the tested textile types

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A SOLID-SHELL FE FOR FORMING SIMULATION OF MULTI-PLY DRY TEXTILE MATERIALS

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Liquid Composite Moulding (LCM) [1] consists of a family of processes that produces composite structures consisting of initially dry textiles with a resin. In its early stages, the dry textile undergoes large deformations, changing the fibre orientation and possibly creating some defects. Proper numerical tools replace expensive trial-and-error tests in the design phase, predicting the feasibility of complex shapes.

The behaviour of dry-textile materials is a multi-scale phenomenon: millions of fibres at the microscale form a yarn; various yarns at the mesoscale are interlaced in a given pattern forming a fabric; the fabric is draped at the macroscale to produce the desired structural part. At the latter scale, the deformation is driven by the quasi-inextensibility of the fibres, alongside the bending, shearing and sliding of the yarns [2]. These behaviours can be uncoupled from each other. Continuous models offer a balance between accuracy and computational cost for the tensile and in-plane shear behaviours, neglecting yarn sliding. The material is modelled as a hyperelastic material. As for the bending behaviour, the material is assumed elastic. The curvature in one ply is obtained from the Kirchhoff-Love model.

When stacked, the deformation incompatible with traditional shell models (Figure 1b) [3]: as plies can slide and the fibres are quasi-inextensible, initially perpendicular lines (material directors) rotate accordingly to the plies high tensile stiffness the thickness of the stack changes.

To this end, we propose an equivalent-single layer model (ED1) consisting of a top and bottom surface. Their relative movement yields the stack thickness and the material directors orientations. Each surface is modelled as a single-ply where tensile, in-plane and bending behaviours occur independently. The transverse normal strain links these two surfaces. The model is then approximated through a 6-node solid-shell FE (Figure 1b). The element is validated through a cantilever test and experimental tests from the literature. At last, forming simulation is presented.

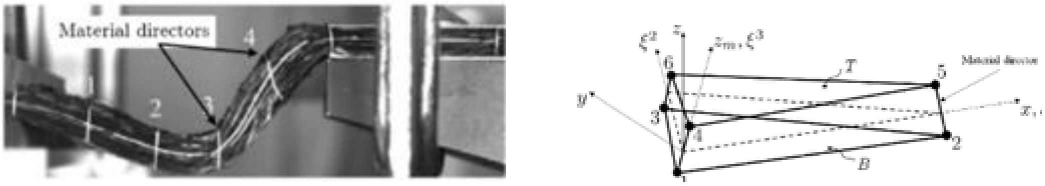

Figure 1: (a) Deformation of a multi-ply dry textile reinforcement (b) Solid-shell FE

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FAST AND ACCURATE FORMING SIMULATION OF UNIDIRECTIONAL NON-CRIMP FABRICS USING A NEW KINEMATIC APPROACH

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Simulating the forming of non-crimp fabric (NCF) preforms is essential for reducing the cost and time in manufacturing composite structures for wind energy, automotive, and aerospace applications. While high-fidelity finite element models can predict forming behaviour accurately [1], their computational cost makes them impractical for large-scale design optimisation, which is an increasingly critical need in industrial development cycles. Kinematic forming models offer a faster alternative, enabling efficient optimisation workflows. However, conventional kinematic fabric models rely on pure-shear assumptions with inextensible warp and weft yarns rotating freely at crossover points (trellis shear). These models perform reasonably for woven fabrics and biaxial NCFs at low to moderate shear, but they fail to capture the deformation mechanisms dominant in unidirectional (UD-) NCFs. Kinematic models based on simple-shear assumptions, where fibres are inextensible along the warp direction and maintain uniform spacing, provide a better foundation for UD-NCFs. Yet such models cannot represent the transverse in-plane strains that are essential for accurately predicting UD-NCF deformation [2].

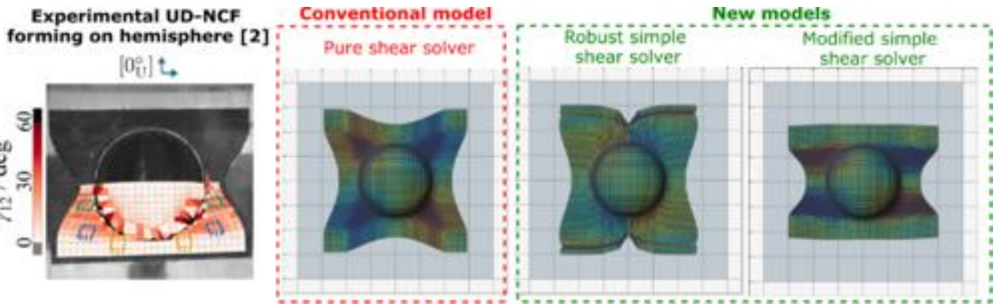

Figure 1: Experimental UD-NCF forming on hemisphere compared with new model predictions.

To address these limitations, we introduce a new, modified simple-shear kinematic model that allows fibre spacing to vary with the local shear angle. This refinement significantly improves predictions of shear angles, in-plane strain, and overall deformation, marking a substantial step forward toward fast, accurate, and industrially viable preform simulation, as shown in Figure 1. At the conference, we will additionally present use cases of the model and demonstrate extensions that incorporate multilayered preforms with transverse shear predictions.

This method was developed as part of the MADE4WIND research project funded by the European Commission with project ID 101136096 from the HORIZON Europe programme.

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ESTABLISHING DEFECT CLASSIFICATION CRITERIA FOR WET-LAID RCF NONWOVENS THROUGH MULTIMODAL INLINE SENSING

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Wet-laid processing offers a scalable and cost-effective route to recycled carbon fibre (rCF) nonwoven preforms; however, inconsistent product quality and the absence of standardised defect criteria continue to limit adoption in structurally demanding applications [1]. Whilst synthetic nonwovens benefit from well-established defect classification and inline inspection frameworks [2], no equivalent taxonomy exists for wet-laid rCF materials. These materials exhibit a distinct defect landscape, including fibre bundles and logs arising from incompletely opened tows, rope-like structures associated with vortex effects, as well as thin spots and areal weight streaking, which have not been systematically defined or quantified [1,3].

This work presents the development of a defect classification framework for wet-laid rCF nonwovens, supported by a multimodal inline sensing approach. High-speed surface imaging, combined with through-thickness areal weight sensing adapted from commercial nonwoven inspection systems, is used to detect, localise, and categorise both surface and bulk anomalies during manufacture. Defect classes are defined across three categories: surface features (e.g. thin spots, inclusions, contamination), structural features (e.g. fibre flocculation, orientation streaks, density gradients), and hybrid features requiring combined sensing modalities for identification.

To further characterise internal material variability, anisotropic eddy-current sensing is being explored as a pathway toward inline quantification of local areal weight and fibre orientation distribution within the moving web. Building on previously demonstrated offline approaches, this technique has the potential to enable real-time detection and closed-loop process control of subsurface defects and material inhomogeneity [4].

This work forms part of an ongoing programme within the Remake Value Retention Centre (RVRC), supported by Innovate UK and the UK High Value Manufacturing Catapult.

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Yarn and Fibre Scale Modelling 3

IMPROVING THE SIMULATION ACCURACY AND EFFICIENCY OF CORELESS FILAMENT WINDING PROCESS WITH SIMTEX

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Coreless filament winding (CFW) enables mould-free, robotically wound large-scale fibre architectures with high design flexibility and minimum material wastage. However, the final geometry of the lattice structure manufactured by CFW is initially undetermined and largely affected by the fibre interactions in space. Large-scale application of this process demands fast, reliable simulation to guide design and fabrication and to reduce over-dimensioning and wastage. SimTex is an explicit finite element solver developed by the Bristol Composites Institute with a focus on fast composites process modelling. As shown in Figure 1 (a), the direct or continuous winding models developed in SimTex uses multiple virtual fibres to represent the real tow cross-section and contact behaviour during the winding process, which can produce accurate prediction but becomes computationally expensive for large parts. In the indirect approach (Figure 1 (b)), overlapped multiple filaments representing the virtual tow in a defined winding path, interact with each other and expand into the deformed shape. Leveraging fast contact formulations, this approach has demonstrated its capability to generate realistic deformed cross-section of the structure with reduced computational expenditure in the previous study [1]. With recent development in contact and damping formulations in SimTex, improved solver efficiency enables the simulation parameter optimisation to be performed on a larger and more representative baseline model. This study develops an efficiency-optimised tow discretisation strategy for both direct and indirect approaches for SimTex that preserve the validated geometric accuracy for CFW parts. Simulation parameters such as virtual yarn parameters, contact and discretisation settings are varied and optimised to the experimental measured datasets from [2].

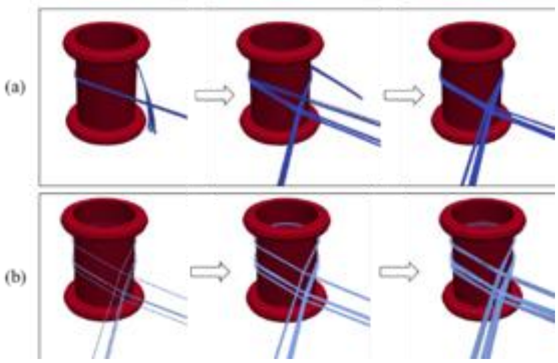

Figure 1: SimTex CFW process simulation with (a) direct and (b) indirect approach

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EXPERIMENTAL AND NUMERICAL CHARACTERISATION OF 5-HARNESS SATIN WEAVE COMPOSITES WITH VOID DEFECTS USING ANN AND MONTE CARLO SIMULATION

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Abstract: This study presents the development of a unit cell-based finite element micromechanical model that integrates post-cured fabric geometry and in-situ material properties extracted from X-ray microtomography analysis, as shown in figure 1. Void defects at both inter and intra-yarn levels are explicitly modelled to predict the thermo-mechanical properties of 5-harness satin weave composites (SWC). Mechanical constants obtained from experimental tests were used to validate the efficacy of the proposed numerical framework. A comprehensive set of numerical simulations were carried out, and generated data to train and validate an Artificial Neural Network (ANN) model, which showed strong agreement with both numerical prediction and experimental measurements. Furthermore, the influence of void content, ranging from 0 to 8\%, on the thermo-mechanical properties of 5-harness SWC was systematically investigated. Monte Carlo simulations (MCS) were also performed to evaluate the sensitivity of the thermo-mechanical constants to void-induced variability. An FE-based RVE model incorporating voids (assigned zero stiffness) [1] was developed and analysed using a two-step homogenization approach [2]. The predicted effective properties of the 5-harness SWC were compared with experimental and ANN results to validate the efficacy of the FE model. Based on the observation from the results, the predicted FE results showed good agreement with experimental results, confirming the accuracy of the developed model. The results demonstrate significant impact of void defects on composite performance and confirm the robustness and predictive capability of the developed multiscale modelling approach.

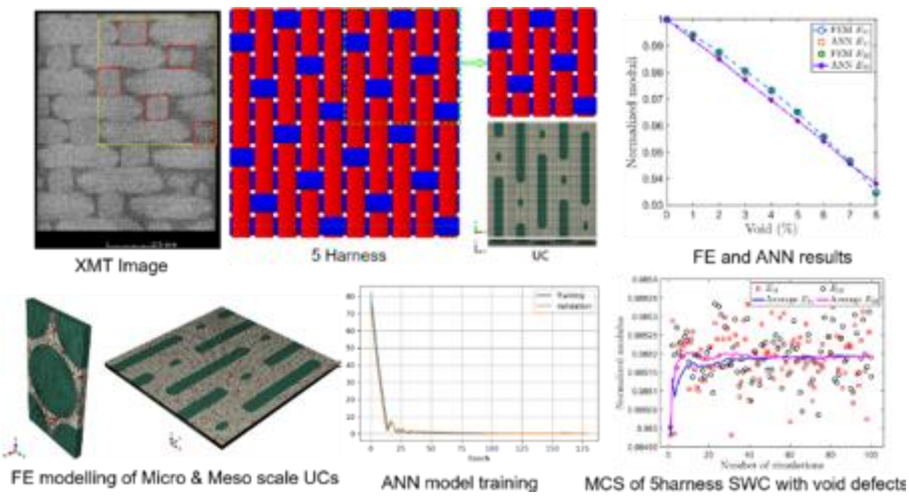

Figure 1: Overview of textile composite modelling, including UC identification, FE modelling, ANN, and MCS of 5-harness satin woven composites based on X-ray microtomography analysis.

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A FULLY VIRTUAL PIPELINE FOR TEXTILE PERMEABILITY PREDICTIONS

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Resin transfer moulding (RTM) has become increasingly popular in composites manufacturing. This is largely attributed to the absence of freezer storage requirements and its lower material costs compared to prepreg processes. As its use continues to grow, the need for accurate modelling has become essential.

A key parameter in RTM simulations is the permeability of the fibre preform. Permeability can be obtained either through experimental measurements or virtual permeability testing. Virtual approaches are attractive as they provide a method of investigating the permeability of different textile architectures without the need for extensive experimental campaigns. However, many virtual permeability studies rely on idealised fibre architecture, meaning that deformation effects during forming are not captured in the test geometry. Other studies employ the use of CT scans. However, this approach requires access to specialised equipment and the purchase of materials, which is not always practical during early fibre architecture investigations.

In this work a pipeline is developed, from textile architecture simulation in the University of Bristol SimTex software [1] to the LMAT ACCS RTM flow solver [2], enabling permeability predictions based on realistic fibre architectures. Finite Element (FE) meshes at the RVE level are created by SimTex. These meshes are generated directly from forming simulation results rather than from idealised geometries. These meshes are then imported into the LMAT ACCS RTM Solver, where cavity channels are modelled as Stokes flow domains and fibre yarns are represented as Darcy domains.

The material used in this study is Hexcel G0986 D1200 Carbon fabric. Mesoscopic models are generated with varying number of layers represented within the RVE. The influence of layer nesting on the predicted permeability is also investigated. Resulting values are compared and evaluated against the second international permeability benchmark exercise performed in 2014 [3]. The proposed workflow demonstrates a practical approach for incorporating forming induced texture architectures into RTM simulations, enabling permeability predictions on more realistic fibre geometries.

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MODELING OF THE MECHANICAL RESPONSE OF POLYMER MOORING ROPES TO INVESTIGATE THE CONSTRUCTION EFFECTS

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Polymer-based mooring lines offer significant potential to enhance mooring reliability and robustness by extending component lifetime and reducing peak loads, thereby enabling rope downsizing and cost reduction. These challenges are addressed within the Enhancing Shared mOoring system design for floating Offshore wind faRms (ESOMOOR) project of the CETPartnership.

Polymer ropes, such as polyamide and polyethylene terephthalate ropes, are attractive candidates owing to their high compliance and durability. However, their mechanical behavior is highly complex, as it is governed not only by the intrinsic properties of the filaments but also by the hierarchical rope construction, including parameters such as the number of sub-elements, twist angles, and lay lengths [1].

The present work investigates the influence of these construction parameters on the mechanical response of polymer mooring ropes under large deformation. To this end, a mesoscopic-scale finite element model is developed, in which a sub-rope is described as an assembly of strands in mutual contact. The strands are modeled as continuum media. Material nonlinearity is taken into account through an equivalent homogeneous hyperelastic constitutive law designed to capture the anisotropic behavior of the rope-yarn bundles composing the strands [2]. This constitutive model incorporates essential mechanisms such as fiber stretching, inter-fiber sliding, and compaction.

Explicit modeling of several lay lengths leads to highly demanding computational costs [3], which limits the feasibility of extensive parametric studies. To overcome this limitation, a reduced-order model is proposed, based on geometric and kinematic considerations, representing only a fraction of a lay length while preserving the essential coupling of degrees of freedom characteristic of the full rope.

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A STEPWISE SECANT COHESIVE LAW FOR EFFICIENT REPRESENTATION OF MATRIX DAMAGE IN FIBER-REINFORCED COMPOSITES

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Progressive matrix damage in fiber-reinforced polymer composites is characterized by gradual stiffness degradation governed by fracture energy dissipation. Conventional continuum damage mechanics formulations typically model this process using linear softening laws, which require iterative equilibrium enforcement and repeated damage variable updates, resulting in high computational cost for large or multiscale simulations. The proposed approach discretizes a mixed-mode linear softening law into a finite set of precomputed damage states represented by sequential, linear elastic secant stiffnesses. These states are constructed within a conformal envelope that enforces energy equivalence with the original softening law, prevents stress overshoot beyond the nominal strength, ensures complete stiffness loss at the failure strain, and approaches the original, linear formulation as the number of secant stiffness (zig zag) steps increases. Damage evolution is thus represented by a finite set of precomputed stiffness states, reducing the number of possible configurations through which an element or sub-volume can pass during the damage process. Preliminary trials have shown that this method can ease global equilibrium convergence and reduce total run time. The number of secant stiffness (zig-zag) steps provides an intuitive control over model fidelity, enabling an explicit trade-off between accuracy and efficiency. The formulation is particularly well suited for matrix-dominated intralaminar damage in multiscale composite analyses, where it can offer reductions in computational cost while preserving fidelity.

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