Bristol Composites Institute Postgraduate Research and Training Showcase 2021: Poster Booklet

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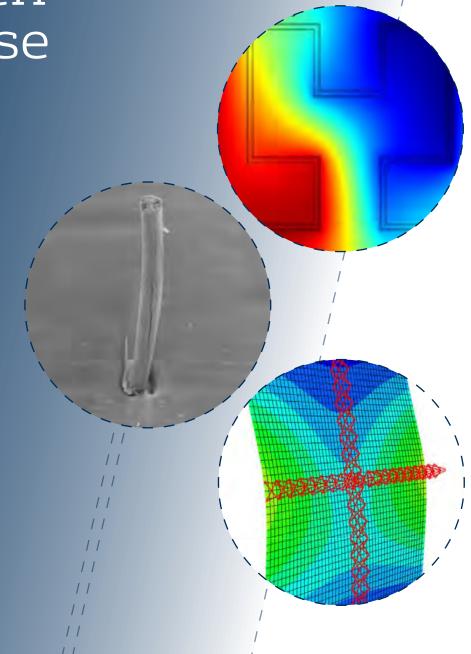EPSRC Centre for Doctoral Training in Advanced Composites for Innovation and Science

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EPSRC Centre for Doctoral Training in Composites Science, Engineering and Manufacturing

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Contents

Manufacturing and design

Prosthetic socket design: development of functional requirements.

Kevin Alarcón, Eric Kim, Elena Seminati

Specialism: Design and Manufacturing

A transtibial prosthesis aims to partially restore the function of a lower leg. They are often abandoned by their users. The reason for this is a poor socket design that is not in synergy with the residual limb. The lack of effective design might be the difficulty in holistically understanding and solving the design challenges as this requires multidisciplinary knowledge across biology, biomechanics, mechanical and manufacturing engineering, clinical knowledge, and experience. This work aims to use a holistic approach for the design of a prosthetic socket of a mature residual limb of a transtibial amputee and assess current designs from a holistic perspective. The literature was used to derive a set of design requirements to maintain a healthy limb. These requirements were used to analyse current socket designs. It was found that designs often focused on the pressure and shear distribution but failed at maintaining good temperature and moisture balance, which in turn significantly weakens the skin and hampers its functions. These findings present demand for materials and manufacturing techniques that can satisfy a diverse range of requirements. And thus, provides a unique opportunity for the development of composite materials.
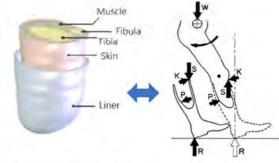
The socket is the component of a prosthetic that interfaces with the residual limb.
A complex system composed
- Dynamics of everyday movement
- Limb composition and response
- socket properties and response

A successful socket must
- Transfer moments and loads
- Be controllable
- Not damage the limb

Ottobock UK, 2020

Meulenbelt, Arch. Phys. Med. Rehabil, 2009
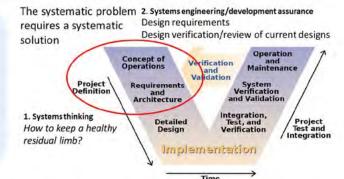
Jin, Biosurface and biotribology, 2016
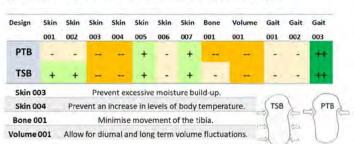
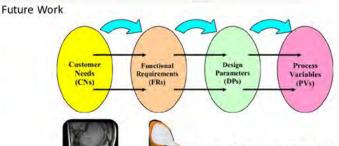Sanders, Pressure Ulcer Research, 2005

Current designs lead to:
- Skin lesion in over 65% of users.
- Abandon rate of around 25 – 57%

Therefore there is significant room for improvement in prosthetic socket design.

Highsmith, Journal of the American Academy of Pas, 2007

The systematic problem requires a systematic solution

2. Systems engineering/development assurance
Design requirements
Design verification/review of current designs

Concept of Operations
Verification and Validation
Operation and Maintenance
Project Definition
Requirements and Architecture
System Verification and Validation

1. Systems thinking
How to keep a healthy residual limb?

Detailed Design
Integration, Test, and Verification
Project Test and Integration

Implementation

Time

Qualitative requirement analysis of classic socket designs

Design	Skin 001	Skin 002	Skin 003	Skin 004	Skin 005	Skin 006	Skin 007	Bone 001	Volume 001	Gait 001	Gait 002	Gait 003
PTB	-	-	--	--	+	-	+	--	--	-	-	++
TSB	+	+	--	--	+	-	+	-	--	-	-	++

Skin 003	Prevent excessive moisture build-up.
Skin 004	Prevent an increase in levels of body temperature.
Bone 001	Minimise movement of the tibia.
Volume 001	Allow for diurnal and long term volume fluctuations.

TSB — PTB

Future Work

Customer Needs (CNs) → Functional Requirements (FRs) → Design Parameters (DPs) → Process Variables (PVs)

- Composite materials
- Finite element analysis
- Development of manufacture method

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Manufacturing and design

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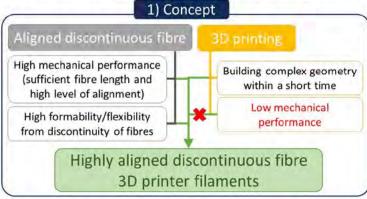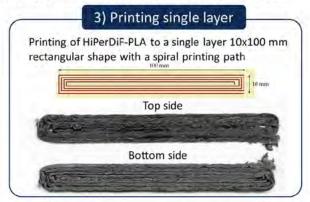
HiPerDiF
High Performance Discontinuous Fibre
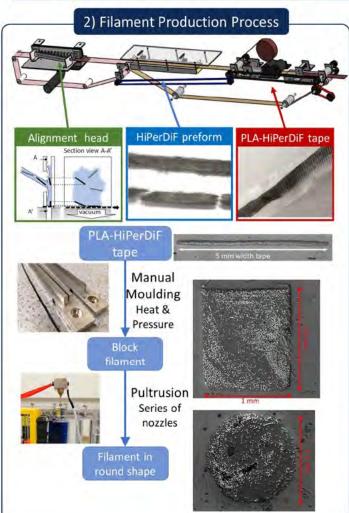
University of BRISTOL
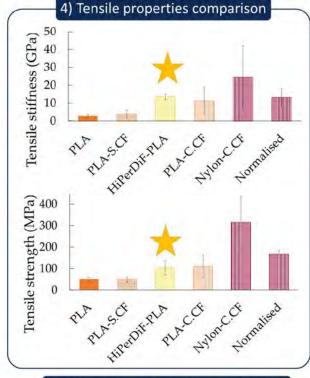EPSRC Centre for Doctoral Training in Advanced Composites for Innovation and Science

Highly aligned discontinuous fibre composite filaments for fused deposition modelling: production and characterisation

Narongkorn Krajangsawasdi, Marco L. Longana, Ian Hamerton, Benjamin K.S. Woods, and Dmitry S. Ivanov

1) Concept

Aligned discontinuous fibre

High mechanical performance (sufficient fibre length and high level of alignment)

High formability/flexibility from discontinuity of fibres

3D printing

Building complex geometry within a short time

Low mechanical performance

Highly aligned discontinuous fibre 3D printer filaments

2) Filament Production Process

Alignment head — Section view A-A' — vacuum

HiPerDiF preform

PLA-HiPerDiF tape

PLA-HiPerDiF tape — 5 mm width tape

Manual Moulding Heat & Pressure

Block filament

Pultrusion Series of nozzles

Filament in round shape

1 mm

3) Printing single layer

Printing of HiPerDiF-PLA to a single layer 10x100 mm rectangular shape with a spiral printing path

100 mm

10 mm

Top side

Bottom side

4) Tensile properties comparison

Tensile stiffness (GPa): PLA, PLA-S.CF, HiPerDiF-PLA ★, PLA-C.CF, Nylon-C.CF, Normalised

Tensile strength (MPa): PLA, PLA-S.CF, HiPerDiF-PLA ★, PLA-C.CF, Nylon-C.CF, Normalised

5) Next step: Continuous production

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HiPerDiF
High Performance Discontinuous Fibre

SOLVAY

UKRI

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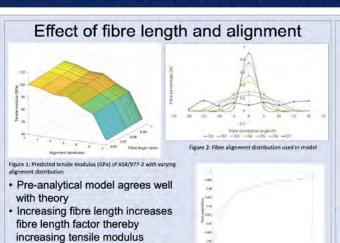EPSRC Centre for Doctoral Training in Composites Science, Engineering and Manufacturing

Investigating the scale up of the HiPerDiF process

Chantal Lewis, Marco Longana, Carwyn Ward, Ian Hamerton

Research Aims:

- Explore the effects of fibre length, orientation and process parameters on the tensile performance of aligned discontinuous fibre composites
- Understand the requirements and concerns of industry when considering the quality of carbon fibre preform through a commercial management survey
- Identify measurement systems and techniques suitable for inline inspection to monitor material quality

Effect of fibre length and alignment

Figure 1: Predicted tensile modulus (GPa) of AS4/977-2 with varying alignment distribution

Figure 2: Fibre alignment distribution used in model

- Pre-analytical model agrees well with theory
- Increasing fibre length increases fibre length factor thereby increasing tensile modulus
- Highly aligned fibres exhibit better tensile properties (104.28 GPa @ D1, 10mm fibre length)

Figure 3: Effect of fibre length (1 – 10mm) on fibre length factor

Effect of processing length

Figure 4: Comparison of HiPerDiF alignment results from open literature [1, 2, 3]

HiPerDiF Technology	Pl (mm)
1G	0.5
2G	0.7

- Alignment quality increases as the ratio of fibre length (fl) to processing length (pl) increases
- Processing length is the width of the alignment plate gap

Commercial management survey

Q13: How important are these parameters when determining the quality of your material?

Quantitative analysis

- Self administered questionnaire
- Descriptive and correlative analysis using Excel
- Large group of participants

Qualitative analysis

- 1-1 Interviews
- Thematic analysis using NVivo 12
- Smaller sample size – drilling down

Measurement techniques

	Air coupled Ultrasound	Eddy current	CCD Camera	Optical laser line scanner
Scan speed	~600 mm/s	~500 mm/s	~600mm/s	100-500m/s
Inspection parameters	Presence of defect & areal weight only	Areal weight, alignment, presence of defect	All	All
Resolution	1 – 2mm	0.1 – 1mm	0.1– 1mm	1 – 12 μm
Accuracy	Medium	High	Medium	High
Cost	££	£££	£	££££
Comments	Access to both sides required	Several different sensors and software might be required. Susceptible to carbon dust	Processing can be optimised to improve images & increase accuracy	High sensitivity

- Techniques with the capability of monitoring the preform manufacturing process in-line, with good resolution and accuracy
- In-line monitoring can improve process control by capturing 100% real time quality data and reduce defects
- Production time lost to offline inspections can be reduced

Conclusions:

- Highly aligned fibres with length 6 – 10mm exhibit better tensile properties than shorter fibres
- Data from previous HiPerDiF studies suggest a relationship between alignment quality, fibre length and plate gap dimensions
- Optical laser line scanner preferred, however a high resolution CCD camera with improved processing would reduce costs
- Survey confirms quality monitoring of ADFRC manufacturing process and material is important to meet customer needs

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1. H. Yu, K. D. Potter, M. R. Wisnom, A novel manufacturing method for aligned discontinuous fibre composites (High Performance-Discontinuous Fibre method), Composites Part A: Applied Science and Manufacturing 65 (2014) 175–185 doi:10.1016/j.compositesa.2014.06.005.-1
2. H. Yu, K. D. Potter, M. R. Wisnom, A novel manufacturing method for aligned short fibre composite in: Proceedings of ECCM15-15th European conference on composite materials. Venice, Italy (2012), 15th European conference on composite materials (2012) 24–28
3. S. Huntley, T. Rendall, M. Longana, T. Pozegic, K. Potter & I. Hamerton (2021) Smooth Particle Hydrodynamics (SPH) Simulation for Short Fibre Recycling Using Water Jet Alignment, International Journal of Computational Fluid Dynamics, DOI: 10.1080/10618562.2021.1876227

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Modelling steering-induced defects in automated fibre placement

S. Mahapatra, Y. Wang, J.P.H. Belnoue, J. Kratz, D. Ivanov and S.R. Hallett

The term Manufacturing 4.0 is becoming ever more common in the composite industry, referring to a concept in which machines are augmented with sensors in a system that intelligently controls and adapts production. One of the most common machines used for the manufacture of high value composites is automated fibre placement (AFP). In this study a finite element platform for the prediction of as-manufactured geometry of a preform deposited by AFP is developed. It is envisaged that, longer term, the proposed framework could be coupled with in-process sensing to allow on-line adaptation and optimisation of the process parameters to mitigate the formation of defects and increase productivity. As opposed to similar models, the proposed numerical scheme takes into account the viscoelastic nature of the contact behaviour of prepreg and also the in-plane shear behaviour that have been identified as two of the main drivers of out-of-plane defects generated during manufacture.

Automated Fibre Placement
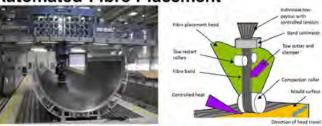
Fig.1. Schematic of the AFP layup process [1].

The process involves a robotic arm continuously depositing thin strips of prepreg onto a tool. The deposition process involves the simultaneous warming, lay-up and consolidation of prepreg consisting of multitude of process parameters. The majority of the process parameters for AFP are derived by expensive and time-consuming trial-and-error approaches to ensure part conformance, Fig. 2.

Key research points

- Minimum steering radius as a function of process parameters is tabulated to avoid the extreme cases of these process induced variabilities, such as out-of-plane wrinkling and tow pull-up.

- The primary motivation of the present work is to reduce this empirical process development through a systematic use of a digital twin of the manufacturing process, Fig. 3.

- Generating a full factorial process-quality map empirically may require upwards of 200 AFP trials, but using existing material characterisation data [2] and process modelling, the augmented approach can reduce this to less than 20 trials.

- With the addition of a compaction model [1], this capability can be extended to full preform modelling.
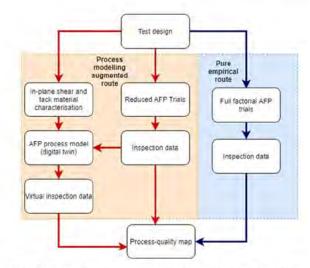
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Fig. 2. Two routes to deriving process-quality map
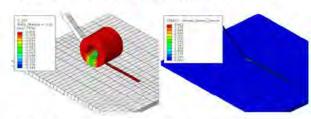
Finite element AFP model

Fig. 3. Through thickness strain (left) and contact pressure in MPa (right) of a single 6mm wide IM7/8552 tow being deposited at 325mm/s and 35° C under 100N, with a radius of 4500mm.

[1] J. P. Belnoue, O. J. Nixon-Pearson, D. Ivanov and S. R. Hallett "A novel hyper-viscoelastic model for consolidation of toughened prepregs under processing conditions". Mechanics of Materials, vol. 97, pp 118-134, 2016.

[2] Y. Wang, D. Ivanov, J. P. H. Belnoue, J, Kratz, B and S. R. Hallett "Modelling of the In-Plane Shear Behavior of Uncured Thermoset Prepreg". American Society for Composites, USA, 2019.

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Micro-Scale Analysis of Progressive Damage in Ceramic Matrix Composites
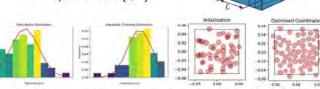
Riccardo Manno, Giuliano Allegri, Antonio Melro and Stephen Hallett

The purpose of this work is to investigate the damage behaviour of Ceramic Matrix Composites (CMCs) at the micro-scale. This level of analysis entails representative elementary volumes (RVEs) located within a single fibrous tow. An RVE generation algorithm originally developed for CMC has been adapted to CMCs, including also the presence of the compliant fibre coating that promote the toughness. A micro-scale thermo-mechanical homogenisation framework, based on Periodic Boundary Conditions (PBCs), has been implemented in Abaqus. Two user subroutines for Abaqus have been chosen to take care of the damage progression: Frictional cohesive behaviour at the interphase and a smeared crack CDM approach for matrix cracking.
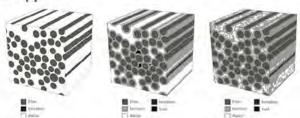
Thermo-Mechanical Homogenisation Tool
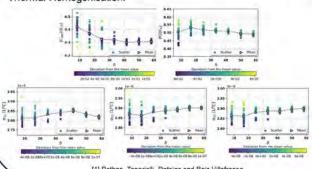
Constitutive response trend with increasing the ratio:

$$L/d = \delta \to \delta \in [0, \infty].$$

- Generation of a random normal distribution of radii and interphase thicknesses.
- Generation of random guess for fibre coordinates.
- Fibres are displaced using a *L-BFGS-B Quasi-Newton optimisation solver* [1].

- Fibre coordinates are given as an input to another algorithm which is capable of generating three different microstructures.
- Definition of *Periodic Boundary Conditions* (PBCs) for the Mechanical Homogenisation and *Thermal PBCs* (TPBCs) for the Thermal Homogenisation.
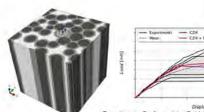
[1] Pathan, Tagarielli, Patsias and Baiz-Villafranca, *Composites Part B: Engineering*, 267-278, 2016

Damage implementation

Fibre push out: Cohesive-Frictional behaviour
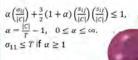Alfano [2] model has been rearranged:
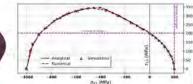- Bristol Cohesive law [3],
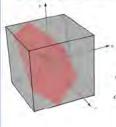- residual frictional shear,
- friction reduction.

Experiments Performed by Robin M. G. De Meyere University of Oxford

Matrix cracking : CDM technique with smeared formulation.
- Damage Initiation Criterion → *Christensen criterion*

$$\alpha \left(\frac{\sigma_{ii}}{|C|}\right) + \frac{3}{2}(1+\alpha)\left(\frac{s_{ij}}{|C|}\right)\left(\frac{s_{ij}}{|C|}\right) \leq 1,$$
$$\alpha = \frac{|C|}{T} - 1, \quad 0 \leq \alpha \leq \infty.$$
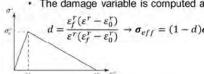$$\sigma_{11} \leq T \text{ if } \alpha \geq 1$$

- Damage Progression

- The angles maximising the failure initiation define the failure plane.
- The fracture energy is smeared over the volume element.
- The damage variable is computed as:

$$d = \frac{\varepsilon_f^r(\varepsilon^r - \varepsilon_0^r)}{\varepsilon^r(\varepsilon_f^r - \varepsilon_0^r)} \to \boldsymbol{\sigma}_{eff} = (1-d)\boldsymbol{\sigma}$$

Further Work

- Full test of the Matrix Cracking implementation.
- Couple the interphase behaviour with the CDM formulation in order simulate the stress strain response of a minicomposite.

[2] Alfano, G. and Sacco, E., 2006. *International Journal for Numerical Methods in Engineering*, 68(5), pp.542-582.
[3] Jiang, W.G., Hallett, S.R., Green, B.G. and Wisnom, M.R., 2007. *International journal for numerical methods in engineering*, 69(9), pp.1982-1995.

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Manufacturing and design

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Infusion of integrated structures with semi-cured elements

Michael O'Leary

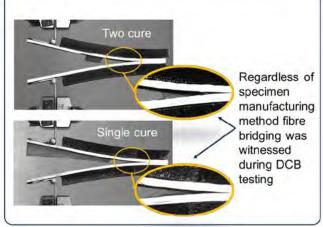Industrial Supervisors: Jon Price, Turlough McMahon.   Academic Supervisors: James Kratz, Dmitry Ivanov.

Introduction:

Post cure joining operations and complex preform integration prior to resin infusion processes are two challenges facing manufactures as they can lead to delays in production and additional process verification. A multistage cure process is seen as having the potential to alleviate both issues. In this PhD project, a simple structure containing elements which were semi-cured prior to a final infusion and curing has been created for the purpose of investigating the effect of integrating these semi cured elements within composite structures and the subsequent effect on interfacial properties. Feasibility study results indicate that the addition of a semi-cured element slightly lowers the interfacial mode 1 fracture toughness. The research will develop over the coming years to close the performance gap and reduce manufacturing risk.

Manufacture & Testing

Two stage infusion & oven cure process:
- 1st cure @ 140°C for X min (semi cure) cure achieving DoC's from 0.2-0.9
- 2nd cure @ 180°C for 150 min (final cure) cure achieves T_g ~ 165C and DoC ~ 1

Comparative panel:
- Single infusion & cure @ 180 for 150 min

DCB specimens machined from panels and tested.

Two cure

Single cure

Regardless of specimen manufacturing method fibre bridging was witnessed during DCB testing

Future Work:

1. Evaluation of remaining DoC's to determine optimal DoC for real world manufacturing conditions
2. Exploration of the effect of cure path on neat resin properties.
3. Process modelling to optimize the manufacturing window

Initial Results

15% reduction in G_{ic} and **12%** reduction in G_{ip} experienced in panels undergoing two cure process with initial DoC of ~0.7 in the semi-cured element

Average G_{Ic} and G_{Ip} Values for Both Cure Cycles

G_I [J/m²]

-12%

-15%

Single Cure GIc — Single Cure GIp — Two Cure GIc — Two Cure GIp

Single cured specimen. Crack propagating through the ply

Twice cured specimen showing crack propagating through the semi cured portion

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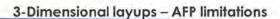EPSRC Centre for Doctoral Training in Advanced Composites for Innovation and Science

Advanced Continuous Tow Shearing process

Michelle Rautmann, Dr. Dmitry Ivanov, Dr. Byung Chul Eric Kim

By utilising in-plane shear deformation, the **C**ontinuous **T**ow **S**hearing (**CTS**) process allows **defect free fibre steering for 1D angle variation** composite lay-ups. The CTS technology **eliminates tow gaps or overlaps**, induced by conventionally used Automated Fibre Placement (AFP) processes, when producing a curved fibre composite and exhibits **no coupling between the tape width and the minimum steering radius**.

However, laying up on a complex 3D surface is to date challenging, as triangular gaps with fibre discontinuities and resin rich areas are induced that lead to high stress concentration and areas of failure initiation. Therefore, a **novel concept** is being developed to allow the production of **defect-free 3-Dimensional composite lay-ups**.
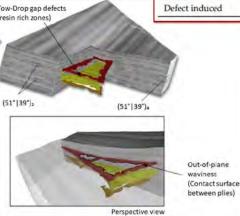
3-Dimensional layups – AFP limitations

Specimen configurations	Analytical result (MPa)	Experimental result (MPa)
Un-notched test:		
Baseline	357.5	389.2
Defect induced	312.5 — 12.59	303.1 — 22.12
Open hole test:		
Baseline	219.2	225.6
Defect induced	199.2 — 9.12	214.7 — 4.83

Strength reduction in %

Table 1: Comparison of tensile test results between defect free specimens, and un-notched and notched specimens containing resin rich areas. [2]

AFP induced triangular shaped gaps on 3-dimensional surface. [1]

Electroimpact Proprietary

Tow-Drop gap defects (resin rich zones)

$(51°|39°)_2$

$(51°|39°)_4$

Out-of-plane waviness (Contact surfaces between plies)

Perspective view

X-ray computed tomography of specimens. [2]

Geometry induced defects:
Resin rich areas and fibre discontinuities

High stress concentration

Areas of failure initiation

AFP layup with resin pockets.

TWiC Concept idea

Aim

Improve the current CTS technology by eliminating geometry induced defects to enable complex layups.

- Constant fibre volume fraction
- Production of complex shaped 3-Dimensional structures without tow gaps and overlaps
- No geometry induced defects ➡ No fibre discontinuities and resin rich areas (hot spots for damage initiation)
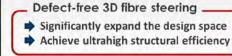
'Defect-free' TWiC layup.

CTS/TWIC layup.

Scanned CTS/TWIC layup.
x=100   x=300

Defect-free 3D fibre steering
- ➡ Significantly expand the design space
- ➡ Achieve ultrahigh structural efficiency

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[1] https://www.youtube.com/watch?v=xK4gMDduHgA
[2] Test specimens with induced tow drops, resulting in triangular shaped resin rich areas for un-notched and notched tensile tests by Falcó et al.

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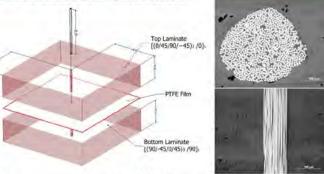
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Influence of matrix ductility on the delamination bridging behaviour of Z-pins

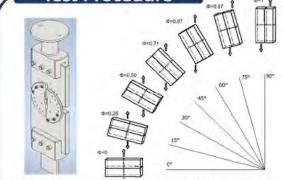### E. Santana de Vega, G. Allegri, B. Zhang, I. Hamerton and S. R. Hallett

Z-pinning is an effective method for embedding through-thickness reinforcement in composite laminates. Z-pins are typically manufactured employing carbon fibres combined with a bismaleimide (BMI) resin. The toughness improvement they provide decreases dramatically as the delamination mode ratio of Mode I to Mode II decreases, due to the inherent brittleness of this material combination. In this study, novel carbon-fibre Z-pin rod-stocks were successfully manufactured considering alternative matrix formulations to BMI. A ductile epoxy resin exhibited the most promising performance, showing extensive bending deformation and pin fibrillation. Z-pins based on this resin exhibited superior apparent delamination toughness throughout the full mode-mixity range.

Coupon Preparation

Top Laminate [(0/45/90/−45)₃ /0]ₛ
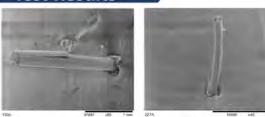PTFE Film
Bottom Laminate [(90/−45/0/45)₃ /90]ₛ

Test coupon configuration (left). Micrographs showing the microstructural features of LTG pins within a E-glass/epoxy laminate after the insertion and curing (right).
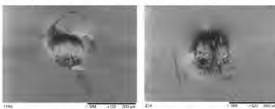
Test Procedure

Test configuration using arcan rig (left), diagram depicting the test angles and load mode-mixity ratios (right).

Test Results

SEM images of BMI (left) and LTG (right) Z-pins pulled out at load mode-mixity ratio of 0.2.

SEM images of BMI (left) and LTG (right) Z-pins which ruptured at load mode-mixity ratio of 0.5.

Apparent delamination toughness of the BMI and LTG pins throughout the full load mode-mixity range, normalised for an aerial density of 0.2%.
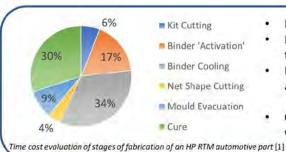
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Transportation Shells for High Volume Preforming: The Clamshell Project

Mr Kirk Willicombe, Professor Ian Hamerton, Dr Carwyn Ward

The ever-increasing need for environmentally friendly methods of mass transportation has led to an increased demand for lightweight vehicles, and in turn increased interest in high volume composite manufacture for the automotive industry. As such, the development of new manufacturing methods and practices is an area of significant interest. This project investigates a method by which this can be achieved, saving time in the preforming process by utilising thermoplastic shells to transport the preforms and hold their shape, as opposed to the traditional, time-consuming approach using binder materials. This shell can then be heated and compressed to form the matrix of the final part. An initial feasibility study has been undertaken, assessing the viability of achieving acceptable fibre impregnation and wet-out using this method, and further refinement in both processing characteristics and material selection is underway.

WHY

- Kit Cutting — 6%
- Binder 'Activation' — 17%
- Binder Cooling — 34%
- Net Shape Cutting — 4%
- Mould Evacuation — 9%
- Cure — 30%

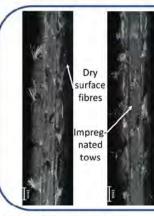*Time cost evaluation of stages of fabrication of an HP RTM automotive part [1]*

- Preforming important for final part quality
- Binder used to ensure preform holds shape; this allows transportation and prevents geometric defects etc.
- Binder shown to account for over 50% of the time cost of a typical HP RTM automotive part

- **Corollary: Removing binder from the preform process will significantly reduce manufacture cycle time**

HOW

- Thermoplastic outer '**clamshell**' to replace binder
- Shell provides preform shape
- Shell matched to tool; heated and compressed to form final part matrix
- Shell benefits:
    - **Protects** preform
    - **Prevents defects**
    - Allows easier **transportation**
    - Maintains **geometric tolerances**
    - **Recyclable** thermoplastics used

Compaction force applied to upper tooling

Heated closed mould tooling to contain shell

Thermoplastic "clamshell" to contain preform

Preform held inside thermoplastic shell

RESULTS

Dry surface fibres

Impregnated tows

- Trial samples manufactured of 6 ply UD Carbon and PLA shell over a range of compaction loads
- Manufactured samples show good **inter-tow** and **intra-tow impregnation**
- Feasibility study **successful**
- **Bespoke rig** designed to test engineering TPs
- **Further work**
    - Parameter **refinement**
    - **Nylon, Polycarbonate,** Adaptive thermosets
    - Mechanical **testing** and **analysis**

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Materials
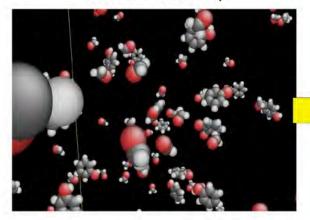
Molecular Modelling for Materials Science

Matthew A. Bone, Terence Macquart, Brendan J. Howlin, Ian Hamerton

Introduction

Materials science is steadily adopting computational modelling simulations to accelerate and enhance the materials discovery process. Use of molecular dynamics (MD) is a core technique supporting this effort. MD allows the user to model chemical structures at an atomistic (1×10^{-10} m) scale. Polymeric materials, nanofillers, and composites can all be modelled and analysed to determine physical, mechanical, and chemical properties. Integrating high throughput modelling with data science techniques, such as machine learning, enables rapid testing and optimisation of new materials. As materials become more complex, computer simulation becomes the only feasible way to fully explore the design space; simultaneously increasing the scope of potential materials whilst reducing development costs.
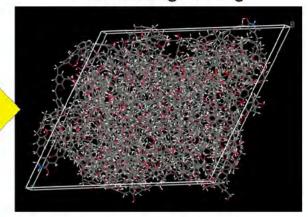
Virtual Chemistry

Chemical processes or experiments that can be modelled in MD:

- Atomistic Structure of Composites
- Polymerisation
- Chemical Reactions
- Solvation
- Crystallography
- Diffusion
- Chemical Potential

Practical Engineering

Example material properties that can be characterised from MD simulation:

- Glass Transition Temperature (T_g)
- Density and Free Volume
- Degree of Crosslinking
- Coefficient of Thermal Expansion (CTE)
- Young's Modulus
- Shear Modulus
- Poisson's Ratio

Multi-scale Modelling

The next stage in computational materials science is incorporating simulation data across a range of modelling scales. Material properties can be generated with MD simulations, then fed into further finite element models, allowing for rapid testing of new materials in existing structures. Alternatively, MD can enable development of structures that are designed and optimised from an atomic level, a task infeasible for laboratory based development cycles.

Bone, M.A.; Macquart, T.; Hamerton, I.; Howlin, B.J., *Polymers* **2020**, *12*, 926.
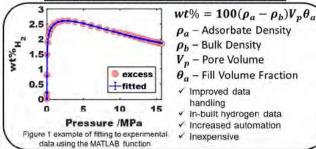
Materials

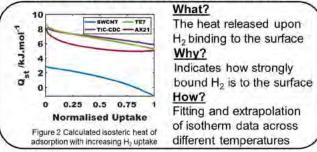# Semi-empirical Modelling of Hydrogen Sorption Isotherms

Mr Charles Brewster, Dr Sebastien Rochat, Dr Mi Tian, Dr Lui Terry, Prof. Valeska Ting

Solid-state hydrogen storage is the **key to environmentally-friendly fuel economy**. Several reports have demonstrated adsorption within **micropores can densify hydrogen past the solid phase** [1] moving the field closer to practical hydrogen storage. However, determination of adsorbate hydrogen density is **difficult, expensive and time-consuming**. Semi-empirical modelling can provide an estimate of density from gas sorption isotherms. To simplify/automate this process, two MATLAB functions were developed to calculate the adsorbate density and heat of adsorption directly from gas sorption data. These were used to identify material properties leading to greater hydrogen density to facilitate the rational design of **microporous carbon materials for nano-composite hydrogen storage vessels**.

Fitting of Experimental Hydrogen Uptakes

Figure 1 example of fitting to experimental data using the MATLAB function

$$wt\% = 100(\rho_a - \rho_b)V_p\theta_a$$

ρ_a – Adsorbate Density
ρ_b – Bulk Density
V_p – Pore Volume
θ_a – Fill Volume Fraction

✓ Improved data handling
✓ In-built hydrogen data
✓ Increased automation
✓ Inexpensive

Calculation of Isosteric Heat of Adsorption

Figure 2 Calculated isosteric heat of adsorption with increasing H_2 uptake

What?
The heat released upon H_2 binding to the surface

Why?
Indicates how strongly bound H_2 is to the surface

How?
Fitting and extrapolation of isotherm data across different temperatures

Results

❖ Higher Heat of Adsorption = Higher Density

❖ Disordered porous networks beneficial for Hydrogen densification

❖ More micropores (< 2 nm) and ultra-micropores (< 0.7 nm) better for densification
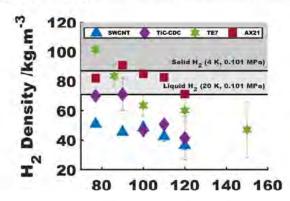
Conclusion

❖ Fitting function adequately fits all data for all materials at any temperature

❖ Values from fitting can be passed directly to the second function to calculate the heat of adsorption

❖ Chemical modification or optimisation of pore geometry may increase heat of adsorption

Porous Carbon Materials

Material (pore geometry)	BET SSA /m². g⁻¹	Total V_p /cm³.g⁻¹	Pore Size /nm
SWCNTs (cylindrical)	945	0.89	0.58, 0.95 and 1.16
TiC-CDC (slit)	1107	0.46	0.66
TE7 (disordered)	1234	1.33	0.68, 1.2 and 1.5
AX21 (disordered)	2524	1.82	1.3 and 1.5-5

Figure 3 Plot showing the effect of temperature versus adsorbate density determined through used of the MATLAB (AX21 90-120 K inclusive are taken from Bimbo et al.)[2]

References

1. Ting VP, Ramirez-Cuesta AJ, Bimbo N, Sharpe JE, Noguera-Diaz A, Presser V, et al. Direct evidence for solid-like hydrogen in a nanoporous carbon hydrogen storage material at supercritical temperatures. ACS nano. 2015;9(8):8249-54.
2. Bimbo, N., et al., *Isosteric enthalpies for hydrogen adsorbed on nanoporous materials at high pressures.* Adsorption, 2014. **20**(2-3): p. 373-384.
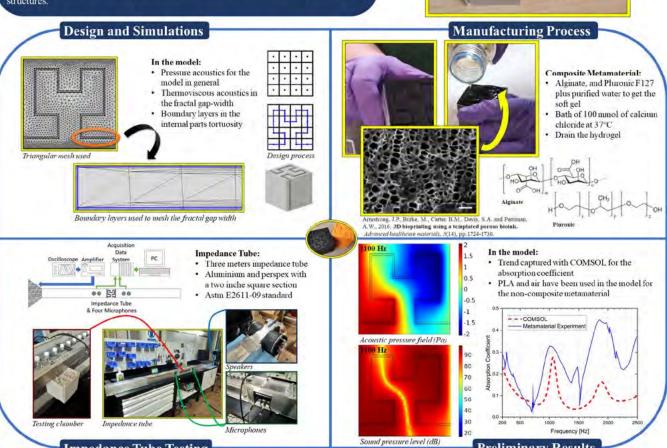
Materials

PLA-HYDROGEL FRACTAL ACOUSTIC COMPOSITE METAMATERIAL FOR SOUND INSULATION

Gianni Comandini, Fabrizio Scarpa, Mahdi Azarpeyvand, Valeska Ting

Introduction

Noise can be a severe threat to human health. The mitigation of this type of pollution is not trivial but essential towards improving the collective quality of life. For mechanical, civil, and aerospace engineering applications, one of the common ways to deal with unwanted sound is to exploit the mass law or utilise thick layers of absorbing materials. However, that is not always possible due to weight or space restraints, and new solutions and technologies are needed. Composite metamaterials can be part of the answer. In this work COMSOL Multiphysics simulations and experiments were performed on metamaterials with fractal geometries and hydrogel fillers. The results show key features which affect the meta-behaviour of these structures.

Design and Simulations

In the model:
- Pressure acoustics for the model in general
- Thermoviscous acoustics in the fractal gap-width
- Boundary layers in the internal parts tortuosity

Triangular mesh used

Design process

Boundary layers used to mesh the fractal gap width

Manufacturing Process

Composite Metamaterial:
- Alginate, and Pluronic F127 plus purified water to get the soft gel
- Bath of 100 mmol of calcium chloride at 37°C
- Drain the hydrogel

Alginate

Pluronic

Armstrong, J.P., Burke, M., Carter B.M., Davis, S.A. and Perriman, A.W., 2016. 3D bioprinting using a templated porous bioink. *Advanced healthcare materials*, 5(14), pp.1724-1730.

Impedance Tube Testing

Impedance Tube:
- Three meters impedance tube
- Aluminium and perspex with a two inche square section
- Astm E2611-09 standard

Impedance Tube & Four Microphones

Testing chamber *Impedance tube* *Speakers* *Microphones*

Preliminary Results

In the model:
- Trend captured with COMSOL for the absorption coefficient
- PLA and air have been used in the model for the non-composite metamaterial

100 Hz
Acoustic pressure field (Pa)

100 Hz
Sound pressure level (dB)

COMSOL
Metamaterial Experiment

Absorption Coefficient — Frequency [Hz]

Conclusions

- The COMSOL model of the metamaterial without hydrogel captures broadly the trend in terms of absorption coefficient.

- Even if more tests are needed, the composite Hilbert fractal metamaterial with hydrogel, seems to have high values of absorption coefficient in the low frequency range (below 500 Hz), showing interesting properties in terms of energy dissipation.

Future Work

- A poroelastic COMSOL model of the hydrogel inside the metamaterial.
- Understand the physic behind this high energy dissipation in the low frequency range.
- Evaluate how the manufacturing process of the hydrogels influence the acoustic performances.

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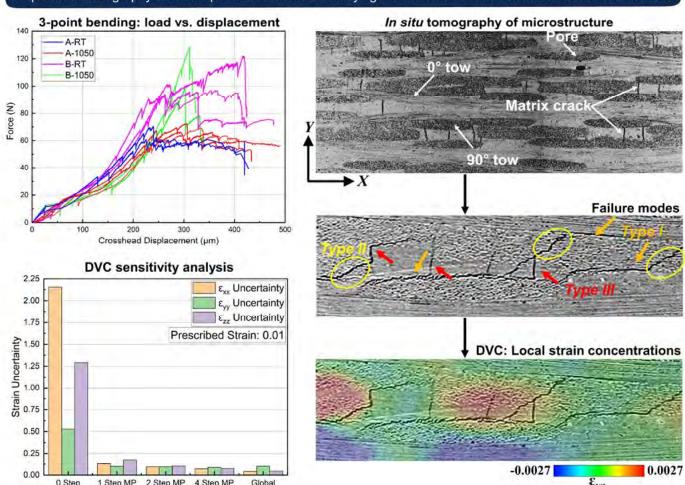
University of BRISTOL
EPSRC Centre for Doctoral Training in Advanced Composites for Innovation and Science

In situ full-field characterisation of oxide-oxide ceramic-matrix composites using X-ray computed micro-tomography and digital volume correlation

J. Paul Forna-Kreutzer, Jon Ell, Harold Barnard, Talha J. Pirzada, Robert O. Ritchie, Dong Liu

In situ synchrotron X-ray computed micro-tomography and digital volume correlation (DVC) were utilised to understand the failure mechanisms at room temperature and 1050°C of two types of Nextel™720/alumina oxide-oxide ceramic-matrix composites (CMCs) - termed materials A and B – differing only in their sintering temperatures. Under three-point bending, strengths of ~55-58 MPa were found for material A and ~94-100 MPa for material B. Damage was associated with three primary types of cracks: (I) interfacial delamination; (II) inclined cracks within fibre tows; (III) opening of existing matrix shrinkage cracks. Material A exhibited higher shrinkage crack propagation, whereas material B displayed more pronounced diagonal matrix microcracking. At 1050°C, both systems showed less microcracking but more pronounced delamination. Such damage characterisation was rationalised in terms of the corresponding 3D DVC displacement/strain fields. Specifically, global DVC was utilised and maximum principal strain locations prior to failure, which varied from 0.05 to 0.1, correlated well to the fracture initiation sites. Further, abrupt positive to negative transitions of shear strain components were observed and were attributed to the different bonding strengths between 0°/90° fibres and the matrix. The current study demonstrates that *in situ* high-temperature tomography/DVC is a powerful method for studying the deformation and fracture of oxide-oxide CMCs.
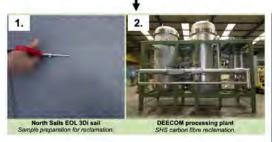
3-point bending: load vs. displacement

In situ tomography of microstructure

Failure modes

DVC sensitivity analysis

DVC: Local strain concentrations

Materials

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End-of-life composite sails as a feedstock for circular manufacturing
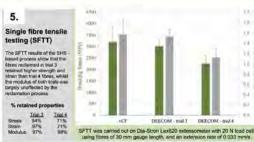
Marcelle Hecker, Marco L. Longana, Ole Thomsen, Ian Hamerton
In collaboration with North Sails

www.northsails.com/sailing/en/sails/materials/3di/raw

Reclamation with DEECOM (SHS-based process)

1.

2.

North Sails EOL 3Di sail
Sample preparation for reclamation.

DEECOM processing plant
SHS carbon fibre reclamation.

3.

4.

Reclaimed carbon fibres
from DEECOM – trial 3.

SEM of single carbon fibre
from DEECOM – trial 3.

5.

Single fibre tensile testing (SFTT)

The SFTT results of the SHS - based process show that the fibres reclaimed in trial 3 retained higher strength and strain than trial 4 fibres, whilst the modulus of both trials was largely unaffected by the reclamation process.

% retained properties

	Trial 3	Trial 4
Stress	94%	71%
Strain	97%	71%
Modulus	97%	98%

SFTT was carried out on Dia-Stron Lex820 extensometer with 20 N load cell, using fibres of 30 mm gauge length, and an extension rate of 0.033 mm/s.

Research aim + objectives

The aim of this project is to explore end-of-life (EOL) 3Di composite sails as a feedstock for circular manufacturing, by investigating environmentally benign recycling routes for these sails.

Objectives:

1. To investigate existing fibre reclamation processes and assess their ability to recover high quality carbon fibres and matrix degradation products from a North Sails 3Di sail.
2. To remanufacture the successfully recovered fibres into secondary composite products. Initially with our in-house HiPerDiF manufacturing process.
3. To quantify and compare the environmental impact of each recycling scenario, using life-cycle assessment methods.
4. To build a demonstrator following the most successful recycling technique.

EOL 3Di sail → Reclamation → rCF → Remanufacture → CFRP composite

Reclamation

Three reclamation processes were chosen based on a number of requirements: the processes should represent a range of the main reclamation technologies which exist; the processes should be developed beyond the lab-scale; and whilst the real environmental impact of each process will be investigated as part of this project, their operating conditions or any additional materials required for operation should not pose obvious environmental threats.

Reclamation processes/companies

❖ **Superheated steam (SHS) - based**
A range of processing temperatures trialled.

❖ **Pyrolysis - based**
A range of processing temperatures trialled.

❖ **Solvolysis - based**
A range of processing temperatures, times, solvents trialled.

Assessing reclamation

- Reclaimed carbon fibre quality/properties → SEM, SFTT.
- Possibility for reuse of matrix degradation products → GC-MS.
- Environmental impact of reclamation → LCA.
- Format of waste which can be processed.

Future work

- The carbon fibres with the highest retained mechanical properties will be used to manufacture composite coupons using our in-house discontinuous fibre alignment machine - **HiPerDiF**.
- For the SHS - based process shown (left), the 'trial 3' fibres will be used.
- The fibres reclaimed using the pyrolysis and solvolysis based processes are yet to be tested.

Materials

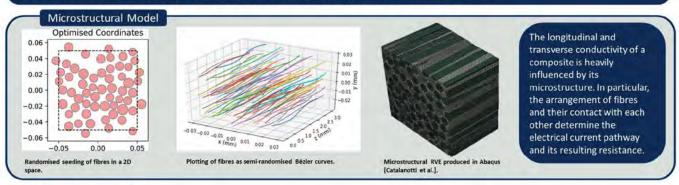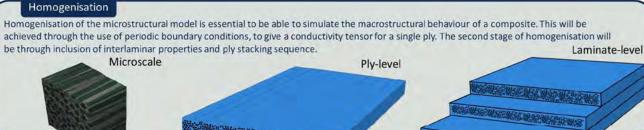Bristol Composites Institute (ACCIS)

EPSRC Centre for Doctoral Training in Advanced Composites for Innovation and Science

Modelling multifunctional composites for further aircraft electrification
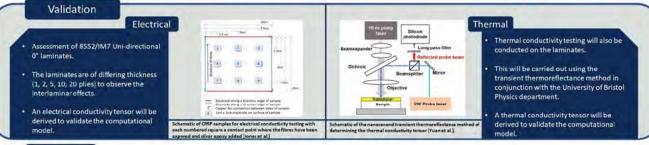
Callum Hill, Richard Trask, Ian Hamerton, Jason Yon and Giuliano Allegri

The electrification of aircraft requires significant improvements in thermal management, weight reduction, energy storage and electrical distribution. The use of multifunctional composites is essential in these endeavours and provides an effective way to eliminate the mass of components by using existing structural elements to perform the same function. In fibre-reinforced composites, the mechanical and physical properties are highly anisotropic – with superior tensile strength, stiffness, thermal and electrical conductivities occurring in the in-plane fibre direction rather than in the out-of-plane direction. However, the electrical and thermal behaviours of composites are poorly understood, particularly for complex geometries with different stacking sequences. To more fully understand this behaviour, a multi-physics model will be produced to characterise the directional electrical and thermal conductivity of fibre-reinforced composites.

Microstructural Model

Optimised Coordinates

Randomised seeding of fibres in a 2D space.

Plotting of fibres as semi-randomised Bézier curves.

Microstructural RVE produced in Abaqus [Catalanotti et al.].

The longitudinal and transverse conductivity of a composite is heavily influenced by its microstructure. In particular, the arrangement of fibres and their contact with each other determine the electrical current pathway and its resulting resistance.

Homogenisation

Homogenisation of the microstructural model is essential to be able to simulate the macrostructural behaviour of a composite. This will be achieved through the use of periodic boundary conditions, to give a conductivity tensor for a single ply. The second stage of homogenisation will be through inclusion of interlaminar properties and ply stacking sequence.

Microscale

Ply-level

Laminate-level

Homogenisation

Validation

Electrical

- Assessment of 8552/IM7 Uni-directional 0° laminates.
- The laminates are of differing thickness (1, 2, 5, 10, 20 plies) to observe the interlaminar effects.
- An electrical conductivity tensor will be derived to validate the computational model.

Schematic of CFRP samples for electrical conductivity testing with each numbered square a contact point where the fibres have been exposed and silver epoxy added [Jones et al.]

Thermal

- Thermal conductivity testing will also be conducted on the laminates.
- This will be carried out using the transient thermoreflectance method in conjunction with the University of Bristol Physics department.
- A thermal conductivity tensor will be derived to validate the computational model.

Schematic of the nanosecond transient thermoreflectance method of determining the thermal conductivity tensor [Yuan et al.].

Future work

To provide experimental validation, 8552/IM7 laminates will be produced. Thermal and electrical conductivity measurements will be taken in-plane, transversely and through-thickness. These data will be compared to modelling results for the same material. A validated Multiphysics model will enable precise multifunctional design to optimise the array of properties desired of a structure, hereby minimising mass and volume. Through this, it is hoped the new generation of electric aviation is realised.

References
[Catalanotti et al.]: An algorithm for the generation of three-dimensional statistically Representative Volume Elements of unidirectional fibre-reinforced plastics:Focusing on the fibres waviness
[Jones et al.] C. E. Jones, "Electrical and Thermal Effects of Fault Currents in Aircraft Electrical Power Systems With Composite Aerostructures," IEEE Transactions on Transportation Electrification, vol. 4, pp. 660–670, 9 2018.
[Yuan et al.]: C. Yuan, W. M. Waller, and M. Kuball, "Nanosecond transient thermoreflectance method forcharacterizing anisotropic thermal conductivity,"Rev. Sci. Instrum. vol. 90, p. 114903, 2019.
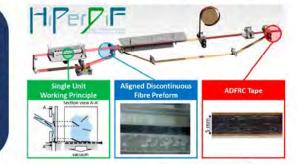
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Aligned Discontinuous Natural Fibre Epoxy Composites Produced with the HiPerDiF Method

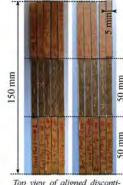Presenter: Ali Kandemir (CDT18)   Supervisors: Marco L. Longana, Ian Hamerton, Stephen J. Eichhorn

Introduction

This work aims at developing discontinuous Natural Fibre (NF) composites to address the current environmental concerns by delivering sustainable fibre reinforced polymer (FRP) materials for light-weighting design solutions. The High Performance Discontinuous Fibre (HiPerDiF) method is a high throughput, low environmental impact, water-based manufacturing process to produce high-performance, highly aligned discontinuous fibre composites. It was demonstrated that NFs can be processed into high performance FRPs with the HiPerDiF method, despite their hydrophilic nature. The suitability of various natural fibres as constituent for discontinuous FRPs was evaluated in previous works. In this work, curaua, flax (Polish{cu}and French{ft}origin), and jute fibres are used as a reinforcement for an epoxy matrix to produce highly aligned discontinuous FRPs with the HiPerDiF method. The mechanical and physical properties of discontinuous NF composites are investigated.

HiPerDiF
Single Unit Working Principle | Aligned Discontinuous Fibre Preform | ADFRC Tape
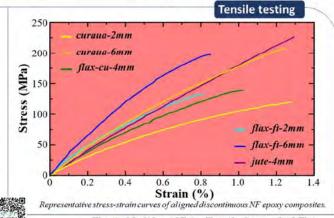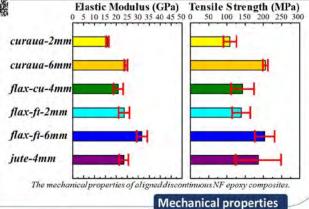
NF preforms & coupons

curaua   flax-cu   flax-ft   jute
Top view of aligned discontinuous NF preforms processed by the HiPerDiF method before matrix impregnation.

Top view of aligned discontinuous NF epoxy composites.

Tensile testing

curaua-2mm
curaua-6mm
flax-cu-4mm
flax-fi-2mm
flax-fi-6mm
jute-4mm

Representative stress-strain curves of aligned discontinuous NF epoxy composites.

Cross-sectional optical microscope and fracture area scanning electron microscope images of the 6 mm flax-ft aligned discontinuous NF epoxy composites.

O & SE micrographs

Mechanical properties

Elastic Modulus (GPa)   Tensile Strength (MPa)

curaua-2mm
curaua-6mm
flax-cu-4mm
flax-ft-2mm
flax-ft-6mm
jute-4mm

The mechanical properties of aligned discontinuous NF epoxy composites.

Conclusion

- flax-ft-6mm is the stiffest (~32 GPa) among all fibre types.
- curaua-6mm is the strongest (~205 MPa), the 2nd strongest is flax-ft-6mm (~200 MPa).
- curaua-2mm has the lowest strength and stiffness, which was expected since in our previous study we found that the critical fibre length for curaua is higher than 2 mm.

Among the studied fibres, flax fibres were found to be the most promising candidate owing to their mechanical performance in the composites and current market status for sustainability.

Future Work

- The development of fully sustainable NF composites will continue considering renewable, recyclable and reusable matrices.
- Aligned discontinuous fibre composites with combinations of promising constituents will be manufactured with theHiPerDiF technology and characterised.

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Numerical Study of the Effective Elastic Properties of Bi-phase Honeycombs

Athina Kontopoulou, Fabrizio Scarpa and Giuliano Allegri

We investigate the effective elastic properties of bi-material hexagonal honeycombs. Key variables considered here are the geometry of the honeycombs and the specific stiffness of the materials. The engineering elastic constants of bi-phase honeycombs are here characterised as functions of the internal cell angle θ (from conventional (θ=30°) to re-entrant (θ=-30°) configurations). The elastic properties are computed via a 3D high-fidelity FE framework that involves the homogenisation of Representative Volume Elements (RVEs) under Periodic Boundary Conditions (PBCs) using Abaqus. We demonstrate how the elastic properties of hexagonal honeycombs, in particular the through-thickness (i.e. out-of-plane) shear moduli and in-plane Poisson's ratio, can be tailored by adopting bi-phase architectures. The FE results are in good agreement with classical analytical expressions derived from Gibson & Ashby formulations [1].
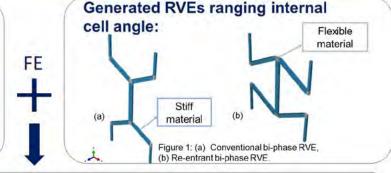
Computational approach:

- The stiffness matrix is populated assigning six independent components of the strain tensor (loading cases):

$$\{\varepsilon\} = \{\boldsymbol{C}\}\{\sigma\}$$

- The strain components are applied through strain-controlled PBCs [2]:

$$u(x_\beta) - u(x_\alpha) = \varepsilon \cdot (x_\beta - x_\alpha) \quad \forall\, x \in \partial\Omega$$

FE +

Generated RVEs ranging internal cell angle:

Figure 1: (a) Conventional bi-phase RVE, (b) Re-entrant bi-phase RVE.

Results:

Legend:
- $E_s/E_f=1.0$
- $E_s/E_f=1.5$
- $E_s/E_f=2.0$
- $E_s/E_f=2.9$
- $E_s/E_f=4.4$
- $E_s/E_f=5.7$
- $E_s/E_f=154.0$
- $E_s/E_f=425.5$
- Gibson & Ashby
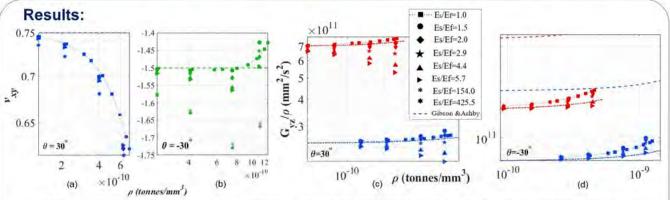
Figure 2: Elastic properties against density compared to the analytical formulations of Gibson & Ashby (dashed lines) with FE results (markers) for bi-material honeycombs: (a) Poisson's ratio v_{xy} for the conventional RVE, (b) Poisson's ratio v_{xy} for the re-entrant RVE, (c) Specific shear modulus G_{yz}/ρ for high-specific-stiffness baseline material (red colour) and low-specific-stiffness baseline material (blue colour) in the conventional RVE, (d) Specific shear modulus G_{yz}/ρ for high-specific-stiffness baseline material (red colour) and low-specific-stiffness baseline material (blue colour) in the re-entrant RVE.

Conclusions:

- In auxetic configuration, the introduction of flexible joints allows increasing the magnitude of auxeticity up to 15% when the flexible material has a Young's modulus ~400 times lower than that of the baseline material.
- The out-of-plane specific shear stiffness G_{yz}/ρ can be enhanced up to 7% in bi-phase re-entrant RVE when the baseline material has relatively low specific stiffness, and the flexible joints have Young's modulus approximately 2/3 that of the baseline.

Future work:

- Manufacturing and testing of bi-phase honeycombs to compare with the numerical results.
- Numerical and experimental investigation of the effect of different types of hinges & multi-phase architectures on the mechanical performance in 3D open-cell lattices.

bristol.ac.uk/composites

[1] L. J. Gibson, M. F. Ashby, Cellular Solids, Cambridge University Press, 1997.
[2] A. R. Melro, R. Manno, Microscale representative volume element: generation and statistical characterization, Multi-Scale Continuum Mechanics Modelling of Fibre-Reinforced Polymer Composites, 2021.

Materials

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The Impact of Viscoelasticity on Wind Turbine Blade Leading Edge Protection

Imad Ouachan[1]*, Kirsten Dyer[2], Ian Hamerton[1], Carwyn Ward[1]

Bristol Composites Institute[1], Offshore Renewable Energy Catapult[2], *Imad.Ouachan@bristol.ac.uk

Introduction
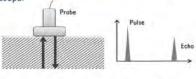
- Offshore wind turbine blades are expected to remain in operation with minimal maintenance for a **service life of 25 years**.

- For the European offshore wind industry, degradation caused by rain erosion is a significant cost ;

  - Reduction of aerodynamic performance (**€56m - €75m annually**).

  - Maintenance and downtime (**€56m annually**).

- Understanding of failure mechanisms for rain erosion is limited, particularly the **viscoelastic material properties** and **high strain rates** caused by raindrop impacts.

Objectives

- Measurement of the speed of sound of a commercial coating using the standard ultrasonic method.

- Prediction of the speed of sound using novel method utilising Dynamic Mechanical Thermal Analysis.

- Comparison of coating lifetime prediction between the two methods using the Springer equation.

Methods

- Commercial polyurethane based coatings were cast into 1 cm³ blocks and tested using an Olympus Panametrics NDT 5 MHZ/0.25" transducer, Olympus pulser/receiver and Keysight Infiniivison Digital oscilloscope.

Figure 1 – Schematic representation of the current standard (DNVGL-RP-0573) utilises a pulse echo technique to measure the speed of waves propagating through a medium.

- Dynamic properties were obtained using DMTA in a dual cantilever setup with he TTS principle (Fig. 2) used to predict material responses in at high strain rates associated with rain droplet impact.
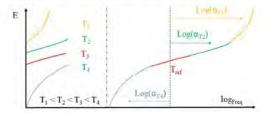
Figure 2 – Schematic representation of the Time Temperature Superposition Principle

$$C_{DMA} = \sqrt{\frac{|E^*|}{\rho}} \sec\frac{\delta}{2}$$

$C = Speed\ of\ Sound$
$E^* = Complex\ Modulus$
$\rho = Density$
$\delta = Loss\ Angle$

Equation 1 – Calculation of Speed of sound from dynamic data obtained from DMTA

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Results

- Dynamic moduli of coating material obtain via DMTA and TTS method shown below (Fig. 3).
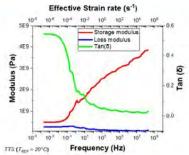
Figure 3 – Dynamic moduli obtained via DMTA and TTS approximation to extended the range of frequencies.

- Dynamic moduli were used in combination with Equation 1 to predict speed of sound values (Fig 4).

- Using the Springer Lifetime Prediction Equation the effect of speed of sound differences on the number of impacts is displayed (Fig. 4).
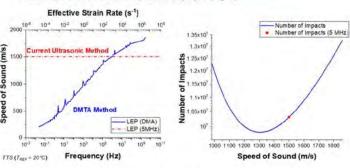

Figure 4 – Left: Comparison of speed of sound values between standard ultrasonic method and novel DMTA method. Right: Comparison of resulting predicted material lifetime of standard ultrasonic method and DMTA method using the Springer equation.

- Using the Springer Equation the effect of speed of sound differences on the number of impacts at a reference temperature of 20 °C.

- New DMTA method shows lifetime could be **5.1% lower or 22.4% higher** than the current ultrasonic method predicts accounting for viscoelastic material effects induced by strain-rate.

Conclusions

- Leading Edge Erosion is one the **biggest problems** the offshore wind market needs to overcome.

- **Modern coating solutions are viscoelastic** and as result dependant on strain, strain-rate and temperature. These **effects are commonly not considered**.

- Demonstrated a **new method of predicting material properties** using DMTA that captures the effect of strain rate and quantified its **effect on the lifetime** of a commercial material.

- This work is part of developing a selection of tests to provide a **predictive capacity** to **understand material failure** and **facilitate rapid product development**.

Acknowledgements
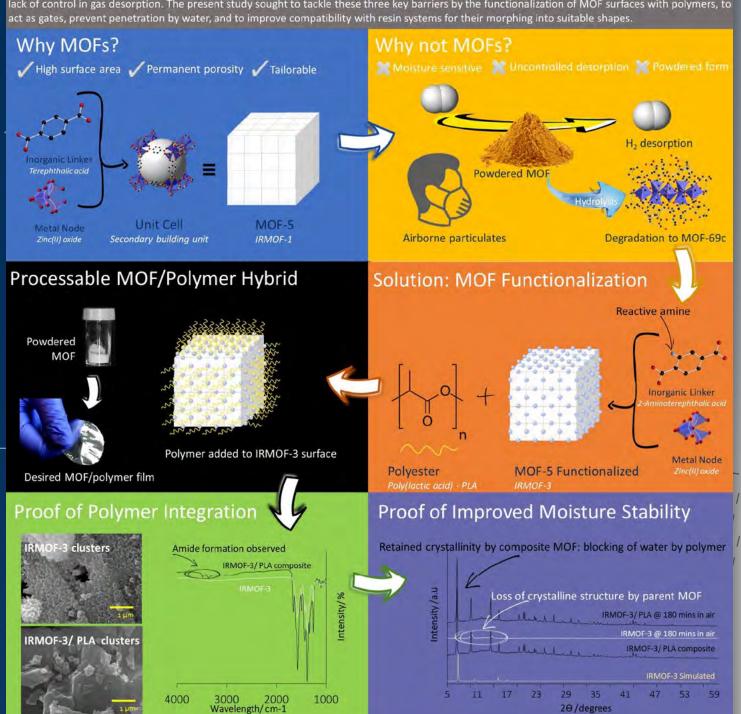
Nanocomposite MOF/Polymer Hybrids with Improved Processability

Chiara Petrillo, Prof. Adam Perriman, Prof. Ian Hamerton, Prof. Valeska Ting

The use of metal-organic frameworks (MOFs) in hydrogen storage is currently limited by their inherently powdered form, instability to humidity, and the lack of control in gas desorption. The present study sought to tackle these three key barriers by the functionalization of MOF surfaces with polymers, to act as gates, prevent penetration by water, and to improve compatibility with resin systems for their morphing into suitable shapes.

Why MOFs?

✓ High surface area ✓ Permanent porosity ✓ Tailorable

Inorganic Linker
Terephthalic acid

Metal Node
Zinc(II) oxide

Unit Cell
Secondary building unit

MOF-5
IRMOF-1

Why not MOFs?

✗ Moisture sensitive ✗ Uncontrolled desorption ✗ Powdered form

Powdered MOF

H_2 desorption

Airborne particulates

Hydrolysis

Degradation to MOF-69c

Solution: MOF Functionalization

Reactive amine

Inorganic Linker
2-Aminoterephthalic acid

Metal Node
Zinc(II) oxide

Polyester
Poly(lactic acid) - PLA

MOF-5 Functionalized
IRMOF-3

Processable MOF/Polymer Hybrid

Powdered MOF

Polymer added to IRMOF-3 surface

Desired MOF/polymer film

Proof of Polymer Integration

IRMOF-3 clusters

1 μm

IRMOF-3/ PLA clusters

1 μm

Amide formation observed

IRMOF-3/ PLA composite

IRMOF-3

Intensity/%

4000   3000   2000   1000
Wavelength/ cm-1

Proof of Improved Moisture Stability

Retained crystallinity by composite MOF: blocking of water by polymer

Loss of crystalline structure by parent MOF

Intensity /a.u

IRMOF-3/ PLA @ 180 mins in air

IRMOF-3 @ 180 mins in air

IRMOF-3/ PLA composite

IRMOF-3 Simulated

5   11   17   23   29   35   41   47   53   59
2θ /degrees

Conclusions

- Method developed for functionalisation of IRMOF-3 with PLA
- Well-integrated smooth surface of MOF composite observed
- Proof-of-concept achieved for improved water stability

Future Work

- Thermal behaviour analyses for gating proof-of-concept
- Electrostatic polymer coupling to assess phase behaviour
- Synthesis of nanoMOF to increase polymer:MOF ratio

Materials
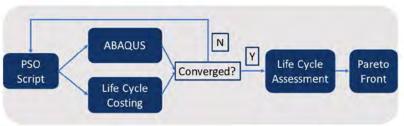
Life Cycle Engineering assessment of biocomposites

Will Proud, Richard Trask, Ian Hamerton, Marco Longana and James Blake
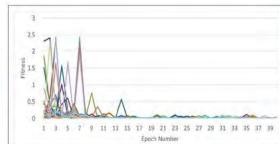
Biocomposites are a composite with either full or partial natural constituents. An increase in awareness of anthropological climate change has led to an increased use of biocomposites in applications where most often glass fibre reinforced composites are incumbents. Whilst against some environmental impact factors biocomposites have lower impacts, when considering the full life cycle biocomposites are not guaranteed to be environmentally superior to their synthetic counterparts. This research is working towards helping engineers understand how biocomposites compare to synthetic composites against technical, economic and environmental factors.

Framework Development
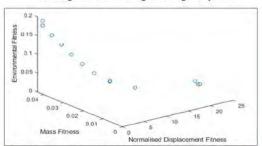
Aim – develop an adaptable optimisation framework providing data on sustainability over a full life cycle for

Convergence of swarm against Single Objective
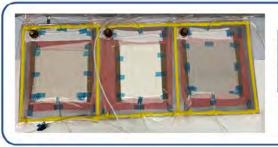
- A derivative free Particle Swarm Optimisation (PSO) has been developed using python, ABAQUS and GaBi software, numerically modelling the below case studies
    1. Open Hole Tensile Test
    2. Tensile Test
    3. Sandwich panel flexure
- Optimisation carried out with variables of ply orientation, laminate thickness and material type. Objective functions assessed: laminate mass, displacement and cost. Constraints are composite failure criteria.
- Biocomposites assessed against synthetic composites
- Validation of numerical results undertaken through analytical methods
- Pareto front generated based on concept of Pareto dominance

Results - Pareto front for Multiple Objective Optimisation

Current and Future Work

- Manufacture and test of coupons to generate mechanical data for large scale optimisation of full scale marine industry structural sandwich panel
- 9 composites being manufactured using Vacuum Assisted Resin Infusion with below constituents

Woven Basaltex	Sicomin SR8100 Epoxy
Woven Glass	Sicomin InfuGreen 810 Bio-epoxy
Woven ampliTex ® 5040 (Flax)	Arkema Elium® Resin

Optimal frame layout.

Materials

3D and 4D printing of flax fibre reinforced Poly-Lactic Acid (FFRPLA)

Charles de Kergariou, Fabrizio Scarpa, Adam Perriman, Giuliano Allegri, Antoine Le Duigou

Context

- Bilayer structures with different deformation capabilities of the two layers tend to bend when stimulated via either their environment or mechanical loading [1].

- Natural fibres such as flax expand and contract with changes in relative humidity of their environment.

- Most of the time soft discontinuous fibre composites are used to produce hygromorphs. Using stiff continuous fibre composites brings the possibility to explore a new area of the hygromorphs design space.

Example of complex 4D printed hygromorph

Problems

Control deformation of 4D printed FFRPLA:

- Predict the deformation of the hygromorph when the natural fibre expand due to change in relative humidity.

- Printing continuous FFRPLA modifies the design space compare to discontinuous fibres composites.

Objectives

- Evaluate the material properties responsible for the deformation of the hygromorph.

- Use simple specimens to understand the effect of filament path on the deformation of the hygromorph.

- Model simple fibre path to explore the design space of FFRPLA hygromorph.

- Demonstrate the possibility to produce and design complex hygromorph with the 3D printer used.

RH=9%   RH=98%   Stacking Sequence

Expected results

- Observe the influence of relative humidity on the mechanical and hygromorphic properties of FFRPLA.

- Observe the impact of fibre orientation and trajectories on the deformation of simple specimens.

- Finite Element Analysis model should be used to find new printing pattern improving the deformation capabilities of the 4D FFRPLA printed hygromorphs.

- Plant will serve as inspiration to produce complex hygromorphs with 3D printed FFRPLA.

[1] Y. S. Timoshenko, "Analysis of bi-metal thermostats,"osapublishing,no. I, pp. 233–255, 1925.

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Author email: charles.dekergariou@bristol.ac.uk

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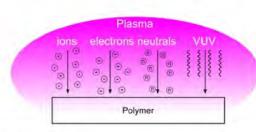
University of BRISTOL
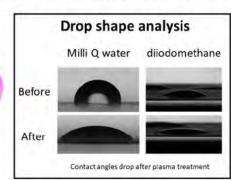EPSRC Centre for Doctoral Training in Advanced Composites for Innovation and Science

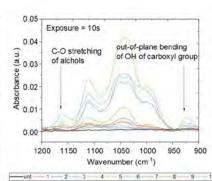# Plasma surface modification of UHMWPE and its effects on adhesion and wettability

Usman Sikander[1], Mark Hazzard[2], Michael Wisnom[1], Ian Hamerton[1]

[1]Bristol Composites Institute (BCI), Department of Aerospace Engineering, University of Bristol, Bristol, BS8 1TR, U.K.
[2]DSM Materials Science Centre, Geleen, The Netherlands.

Ultrahigh molecular weight polyethylene (UHMWPE) fibre and tapes have chemically inert surfaces and yield composites with inferior mechanical properties. In this study, plasma treatment was conducted to improve performance of UHMWPE. It was observed that after 10 s plasma exposure, oxygen functional groups were added to the surface and the total surface free energy (γ_{SV}) and its polar component (γ_{SV}^P) increased by 49% and 98%, respectively. IFSS of UHMWPE/Epoxy micro-composite also increased from 2.2 ± 0.4 MPa to 8.5 ± 1.1 MPa, which can be attributed to an increase in surface area and a drop in contact angle from 98.4° ± 1.0° to 43.7° ± 4.7° because of plasma treatment.

Plasma — ions, electrons, neutrals, VUV → Polymer

Drop shape analysis

Milli Q water — diiodomethane
Before / After
Contact angles drop after plasma treatment

Exposure = 10s
C-O stretching of alchols
out-of-plane bending of OH of carboxyl group
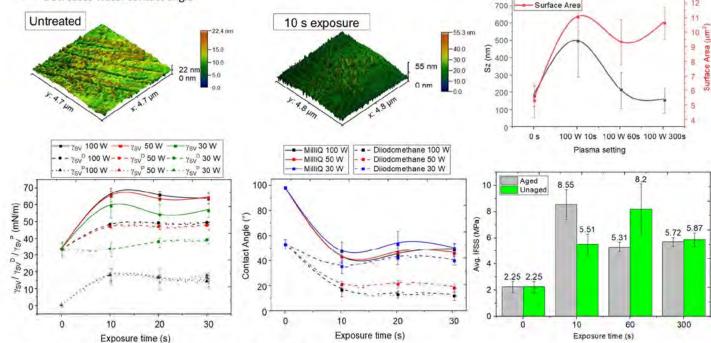
Plasma treatment
- Adds oxygenated functional groups
- Increases in magnitude of Sz (peak + valley height) and surface area
- Decreases water contact angle

Untreated — 10 s exposure

Sz / Surface Area vs Plasma setting (0 s, 100 W 10s, 100 W 60s, 100 W 300s)

γ_{SV} 100 W, γ_{SV} 50 W, γ_{SV} 30 W, γ_{SV}^D 100 W, γ_{SV}^D 50 W, γ_{SV}^D 30 W, γ_{SV}^P 100 W, γ_{SV}^P 50 W, γ_{SV}^P 30 W

MilliQ 100 W, MilliQ 50 W, MilliQ 30 W, Diiodomethane 100 W, Diiodomethane 50 W, Diiodomethane 30 W

Aged / Unaged — Avg. IFSS (MPa): 2.25, 2.25, 8.55, 5.51, 5.31, 8.2, 5.72, 5.87

- Plasma causes an increase in total SFE and its polar and dispersive components
- Surface character of fibres changes from strongly hydrophobic to mildly hydrophilic
- Contact angles with Milli Q water and diiodomethane drop significantly after plasma treatment
- IFSS increases for both aged and unaged samples, where adhesion is promoted the most at lower exposure time in aged condition
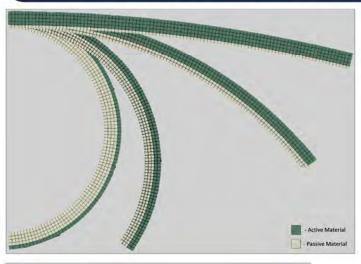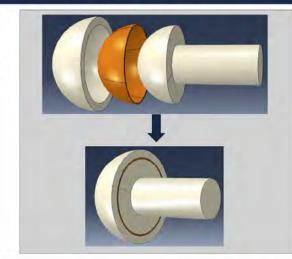
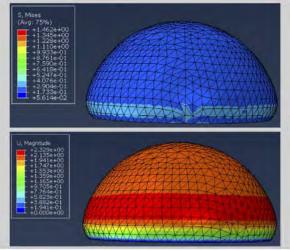# Modelling of smart composite materials for in-vivo deployment
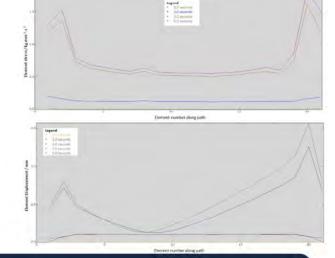
Joe Surmon[1], Richard Trask[1], Kate Robson-Brown[2]

1. Bristol Composites Institute, University of Bristol, Bristol, BS8 1TR, UK
2. Department Of Anthropology And Archaeology, University of Bristol, 43 Woodland Rd, Bristol BS8 1TH

Proof of concept 4D material models are presented. Firstly, the potential for pixel/voxel based modelling is shown in the form of programmable shape changes by altered material distribution. Secondly, initial simulations are presented for the use of 4D materials in-vivo, particularly for the treatment of osteoarthritis. Finally, Methods and arguments are proposed to open this field to non-engineers looking to design and manufacture: 4D printable, active, composite materials.

Conclusions:
- Pixel/Voxel based modelling successfully implemented in 4D material modelling
- Machine learning can be used to drive material placement for desired shape changes
- In-vivo temperatures can be used to trigger material shape changes to aid performance and support of implants
- Key stress areas identified when deploying smart composite materials in a human joint

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A smart wing based on vacuum-packed particles

David Brigido, Piotr Bartkowski, Robert Zalewski, Stephen Burrow, & Benjamin Woods

In order to help bridge this divide between nature's flying creatures and our modern rigid aircraft, this research investigates a flexible morphing wing inspired by the fish skeleton called the Fish Bone Active Camber (FishBAC). The FishBAC can change the wing shape smoothly and continuously to keep the wing shape optimal, and the flow attached like avian wings, reducing drag, noise and fuel consumption. This morphing concept has shown an increase of lift-to-drag ratio for about 25% compared to a conventional control surface.

Compliance-based morphing structures need to be soft enough to deform, but stiff enough to withstand aerodynamic forces. This reality leads to compromise - The FishBAC is currently both stiffer than desired in terms of actuation energy and softer than desired for aeroelastic effects. This research aims to remove those compromises by introducing a novel material that can actively change its stiffness. The new concept is based on the ability of granular materials to act as either a soft "liquid" or a solid depending on how tightly the grains are squeezed together.

The novel approach is to fill aircraft wings with particles, which can be squeezed together under vacuum pressure to make a stiff aircraft wing. When the vacuum is turned off, the grains unlock, and the wing becomes soft enough to be deformed into a new shape. This allows the wing to immediately adapt its shape to changing operating conditions – reducing noise, drag and therefore fuel burned. The research includes detailed mechanical modelling and experimental testing of the complex and highly non-linear behaviour of granular media, and the design, manufacturing, and testing of prototype demonstrators, which show the concept can achieve outstanding levels of stiffness adaptation.

Morphing wing concept

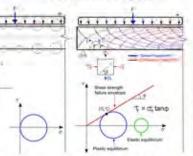PLA structure in additive manufacturing. Coffee grinds as granular media and silicone membrane

Demonstrator (3D printing wing with flexible trailing edge)

Silicone end-tabs

trailing edge with end-tab

SwitchBAC with vacuum pump

Flexural models

(a) Shear force and bending moment
(b) Transformation of stresses
(c) Principal stresses trajectories
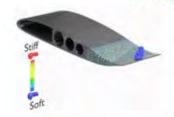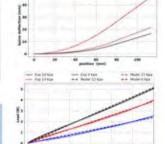
Beam model based on Mohr-Coulomb Failure criterion: 30 seconds for case (single 2 GHz and 8GB)

Plasticity model based on Von Mises yield criterion: 2 hours for case (six 2.6GHz and 64GB).

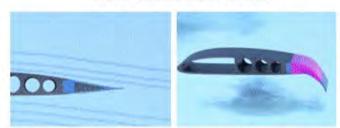## Testing and Model results comparison

Stiff

Soft

The results of experimental tests at various vacuum pressure variations were compared to the model simulation deflections. The findings revealed a good agreement.

Partnership and Funding

SABRE
Warsaw University of Technology
CONACYT

David.Brigido@bristol.ac.uk
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Fluid-Structure Interaction

The spine is deflected by the aerodynamic forces influenced by Reynolds number and angle of attack; however, this deflection can be controlled by switching the stiffness. This can result in a significant increase in the lift-to-drag ratio, leading to lower full consumption.

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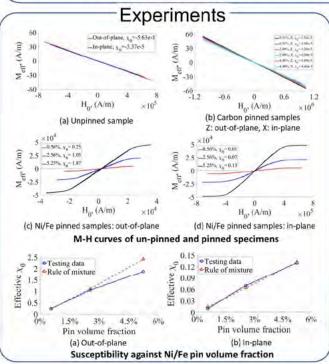EPSRC Centre for Doctoral Training in Advanced Composites for Innovation and Science

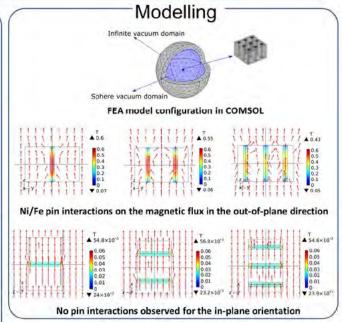# Effects of ferromagnetic & carbon-fibre Z-pins on the magnetic properties of composites

Mudan Chen[a], Bing Zhang[a], Sven Friedemann[b], Giuliano Allegri[a], Stephen R. Hallett[a]

[a] Bristol Composites Institute (ACCIS), Department of Aerospace, University of Bristol
[b] HH Wills Laboratory, Department of Physics, University of Bristol

Apart from through-thickness reinforcement, Z-pins have also proved to be effective in enhancing the electrical and thermal conductivities of composite laminates. This project investigates the effects of Z-pins on the magnetic properties of composite laminates, to provide fundamental knowledge for exploring the multifunctional applications of Z-pins. The in-plane and out-of-plane magnetic susceptibilities of IM7/8552 laminates with and without Z-pins have been measured by an MPMS®3 SQUID magnetometer. Two kinds of pin materials (T300/BMI composite and ferromagnetic Ni80/Fe20 permalloy) have been studied at three different volume fractions (nominal 0.5%, 2% and 4%). Numerical modelling in COMSOL Multiphysics® has been conducted to support the investigation of the effects of pin volume fraction on the overall magnetic susceptibility and saturation magnetisation.

Schematic of 2% Z-pinned sample

SQUID MPMS3 and sample installation

SQUID measurement principle

Experiments

(a) Unpinned sample

(b) Carbon pinned samples Z: out-of-plane, X: in-plane

(c) Ni/Fe pinned samples: out-of-plane

(d) Ni/Fe pinned samples: in-plane

M-H curves of un-pinned and pinned specimens

(a) Out-of-plane

(b) In-plane

Susceptibility against Ni/Fe pin volume fraction

Modelling

FEA model configuration in COMSOL

Ni/Fe pin interactions on the magnetic flux in the out-of-plane direction

No pin interactions observed for the in-plane orientation

Conclusions:
- Carbon-fibre Z-pins do not have large influence on the global magnetic properties of composites.
- Ni/Fe pins enhance the laminate out-of-plane and in-plane effective susceptibilities up to 1.87 and 0.13 at 5.25% volume fraction, respectively.
- The effective susceptibility of Ni/Fe pinned laminate increases with pin volume fraction nonlinearly due to pin interactions for the out-of-plane direction, but linearly for the in-plane orientation.

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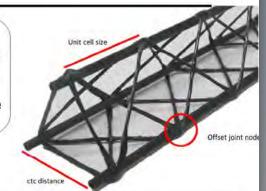EPSRC Centre for Doctoral Training in Composites Science, Engineering and Manufacturing
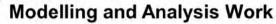
WrapToR Truss Stiffened Skin Panels for Aerospace Applications

Chris Grace, Dr Ben Woods, Dr Michael Wisnom, Dr Terence Macquart, Dr Mark Schenk

The patented Wrapped Tow Reinforced (WrapToR) truss concept has already been proven capable of producing low cost, consistent truss beam structures with a quick and simple fabrication process[1,2]. This project aims to characterise and optimise the application of the WrapToR truss concept as a reinforcement member for structural panels, to demonstrate that WrapToR stiffened skin panels can improve the mechanical performance of aerospace vehicles for a low mass budget.

Technology

- WrapToR truss technology uses an adapted filament winding method to lay down continuous carbon fibre tow as shear members

- This removes the need to assemble multiple parts and takes advantage of the high mechanical performance of composite materials.

Unit cell size

Offset joint node

ctc distance

Modelling and Analysis Work

- Determine and optimise truss design variables for different loading conditions

- Design and analyse structures of increasing complexity
    - Flat > curved/cylindrical structures

Flat panel – unit cell

Curved panel – unit cell

Real world case study

Experimental Work

- Design, build and test structures of increasing complexity
- Investigate potential fabrication issues:
    - Truss - panel adhesion
    - Truss - truss connection
- Determine fabrication procedure
- Develop worlds first curved composite panel with truss stiffeners
- Potential applications include aircraft wing or rocket fuel tanks

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1. Woods, B. K. S., Berry, B. O., and Stavnychyi, V. B., "Continuous wound composite truss structures," US Patent Application No. US20130291709 A1, May 1, 2013.
2. Hunt, C. J., Wisnom, M. R., and Woods, B. K. S., "WrapToR composite truss structures: Improved process and structural efficiency," Composite Structures, 2019, Vol. 230, p., 111467.

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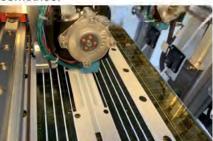
GATOR - 3D printed morphing skins

Rafael Heeb, Michael Dicker, Fabrizio Scarpa, Benjamin K. S. Woods

Morphing aircraft skins are smooth compliant wing surfaces, which directly interact with airflow and that undergo large shape changes without yielding. GATOR morphing skins seek to solve the problem of contradicting low in-plane stiffness to reduce actuation energy and high out-of-plane stiffness to resist aerodynamic loads requirements. This is achieved by taking advantage of multi-material additive manufacturing methods and thermoplastic elastomers of different stiffnesses, allowing strategic placement of stiffness and compliance, taking advantage of geometric anisotropy and design scaling laws.

The competing requirements for morphing skins

Geometrically Anisotropic ThemOplastic Rubber morphing skin design principles

Thermoplastic Elastomers
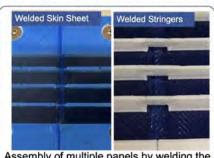which can be printed into complex geometries.

Multi-Material 3D Printing
of different stiffness materials in a single component to locally tailor stiff and flexible features.

Exploiting Geometric and Structural Scaling Laws
to help decouple morphing design constraints.

Skin Sheet

Core

Morphing Skin Panel

Morphing Wing Section

Proof of concept: GATOR skins on a FishBAC morphing wing

SABRE

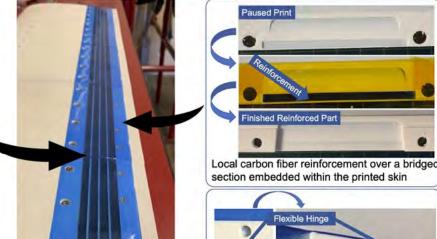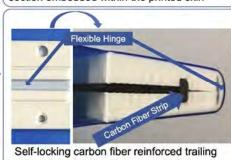Welded Skin Sheet | Welded Stringers

Assembly of multiple panels by welding the individual skin panels into one skin section

Detachable skin design – Stitching of stringers to the spine using aramid thread. Channels and holes in the stringer are needed to accommodate the thread

Paused Print

Reinforcement

Finished Reinforced Part

Local carbon fiber reinforcement over a bridged section embedded within the printed skin

Flexible Hinge

Carbon Fiber Strip

Self-locking carbon fiber reinforced trailing edge with a flexible hinge connecting upper and lower skin to constrain the skin panel

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iCOMAT

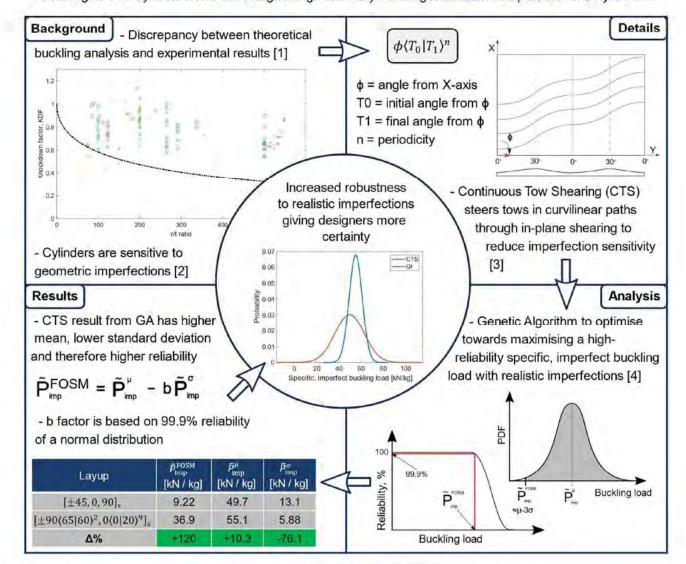University of BRISTOL
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Optimisation of variable-stiffness cylinders under axial compression with realistic imperfections

Mr Reece Lincoln, Prof. Paul Weaver, Dr Alberto Pirrera, Dr Rainer Groh

Thin-walled cylinders under axial compression are sensitive to geometric imperfections, leading designers to use overly conservative guidelines that result in cost- and weight-inefficient structures. To overcome this conservatism, a Bristol-based manufacturing technique offers an opportunity to reduce the sensitivity of thin-walled cylinders – Continuous Tow Shearing (CTS). CTS places composite tows in curvilinear paths, creating variable-stiffness cylinders. Variable stiffness cylinders break the axisymmetric nature of cylinder buckling by tailoring the stiffness circumferentially and axially. Previous work has found that the imperfection insensitivity of thin-walled cylinders can be improved through CTS. To improve the robustness of this imperfection insensitivity, a novel reliability-based optimisation is performed. The optimisation assumes a normal distribution of buckling loads and estimates a nonlinear Monte-Carlo analysis with realistic imperfections through six buckling analyses. The results show that the converged CTS cylinder has a 120% higher high-reliability buckling load when compared to a QI cylinders.

Background

- Discrepancy between theoretical buckling analysis and experimental results [1]

- Cylinders are sensitive to geometric imperfections [2]

Details

$$\phi\langle T_0 | T_1 \rangle^n$$

ϕ = angle from X-axis
$T0$ = initial angle from ϕ
$T1$ = final angle from ϕ
n = periodicity

- Continuous Tow Shearing (CTS) steers tows in curvilinear paths through in-plane shearing to reduce imperfection sensitivity [3]

Increased robustness to realistic imperfections giving designers more certainty

Results

- CTS result from GA has higher mean, lower standard deviation and therefore higher reliability

$$\tilde{P}_{imp}^{FOSM} = \tilde{P}_{imp}^{\mu} - b\tilde{P}_{imp}^{\sigma}$$

- b factor is based on 99.9% reliability of a normal distribution

Analysis

- Genetic Algorithm to optimise towards maximising a high-reliability specific, imperfect buckling load with realistic imperfections [4]

Layup	$\tilde{P}_{imp}^{FOSM}$ [kN / kg]	$\tilde{P}_{imp}^{\mu}$ [kN / kg]	$\tilde{P}_{imp}^{\sigma}$ [kN / kg]
$[\pm 45, 0, 90]_s$	9.22	49.7	13.1
$[\pm 90\langle 65|60\rangle^2, 0\langle 0|20\rangle^9]_s$	36.9	55.1	5.88
$\Delta\%$	+120	+10.3	-76.1

[1] Wagner, Int. J. Mech. Sci., 2018
[2] Koiter, Tech. rep., NASA TT-F-10833, 1967
[3] Lincoln, Compos. Struct. 2019
[4] Wagner, Thin Wall. Struct. 2020
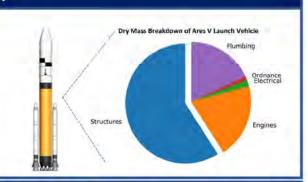
Structures

Dynamic Tuning of Thin-Walled Cylinders by Continuous Tow Shearing

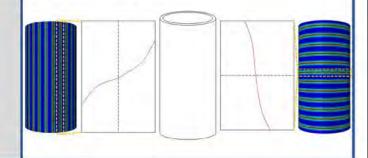Calum McInnes, Alberto Pirrera, Byung Chul Kim, Rainer Groh

Motivation

- Lightweighting identified as key enabling technology for next generation launch vehicles
- Improved structural mass efficiencies allows for larger payload capacity
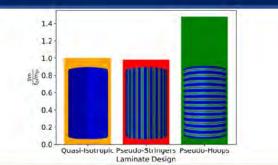- Excessive vibrations may cause payload damage or vehicle loss

Dry Mass Breakdown of Ares V Launch Vehicle

Continuous Tow Sheared Cylinder Design

- Continuous Tow Shearing (CTS) process material deformation mechanism causes orientation-thickness coupling
- Tows can be sheared axially or circumferentially to embed pseudo-hoops or pseudo-stringers into structure

Results

- Cylinders subject to free vibration only
- Resonance dominated by radial deformations
- Axial shearing of tows improves structural performance by 40%
- Pseudo-hoops increase circumferential stiffness components of structure

Conclusions

- CTS process can be used to increase structural performance
- Preferred steering direction can be inferred from mode shapes

Future Work

- Grid-stiffened structures for realistic load cases
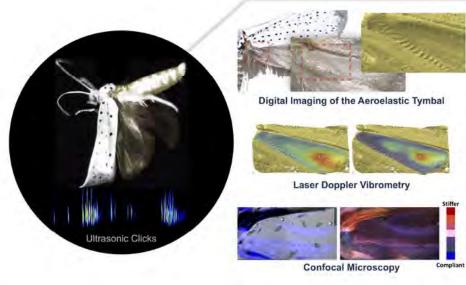- Design optimisation
- Manufacture and test demonstrator

Structures

Bioinspired Engineering — Sound Production through Elastic Instabilities

Hernaldo Mendoza Nava, Marc Holderied, Alberto Pirrera, Rainer Groh

Ermine moths employ their Aeroelastic Tymbals to produce anti-bat sounds

Ultrasonic Clicks

Digital Imaging of the Aeroelastic Tymbal

Laser Doppler Vibrometry

Confocal Microscopy

Aeroelastic tymbals are doubly curved **striated regions** on the wings membranes, their complex structure buckles due to the deformation of the wings.

- Buckling propagates as **individual snaps** at each striation.
- Snapping excites the **resonant frequencies** of the tymbal.

Experimental dynamic tests show the **modes of vibration** of the tymbal. The peak displacements of the resonant modes occur throughout the smooth region of the tymbal. Exciting the resonant frequencies leads to the production of a**coustic waves**.

Confocal microscopy of the tymbal reveals the **graded cuticular properties** of the wing membrane. Bluish areas correspond to compliant regions, while red correspond to stiffer regions.

Bioinspired Model

Multi-Striae Model

An **idealised model** with controlled parameters inherits the **doubly-curved** morphological characteristics of aeroelastic tymbals.

A simplified approach to study the **localised stability behaviour** is carried out on a **single stria**.

- A surface curvature analysis shows a transition between positive to negative **Gaussian curvature** along the shape of the ridge.
- When loaded under **displacement control** at the edge of the stria, the resultant moment-angular displacement diagram shows a **snap-down instability**.
- The instability produces a dimple on the region of larger radius of curvature.

The acoustic response is studied on a **structural-acoustic coupled model**, where the dynamic resonances of the multi-striae model are excited under a prescribed harmonic excitation. The acoustic field of the fundamental mode is shown.

Simplified Model — Single Stria

Gaussian Curvature

Acoustic Pressure Field

Snap-Down Instability

Quasi-static and Dynamic Analyses

Harmonic Response

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Structures

Continuous Extrusion of large Ultra-Efficient Truss Structures

Francescogiuseppe Morabito, Dr. Benjamin King Sutton Woods, Dr. Terence Macquart, Dr. Mark Schenk and Dr Alberto Pirrera

This work introduces a new design approach for ultra-efficient truss lattice structures. It builds on previous work on the Wrapped tow reinforced (WrapToR) composite truss technology, which has so far shown very high levels of structural efficiency in conjunction with a versatile and straightforward winding-based manufacturing process. To achieve rapid manufacturing of hybrid metal-composite large lattice spaceframes, the PhD project concern the synergic development of a new high throughput continuous manufacturing equipment for WrapToRs, together with an *ad-hoc* design optimization tool. On the one hand, the proposed prototype concept TrussBot aims to move away from batch manufacturing methods and develop a continuous technique such as pultrusion and braiding, but with less complexity involved. On the other, the optimal design tool under development allows the optimal sizing of the WrapToR members involved in a target layout.
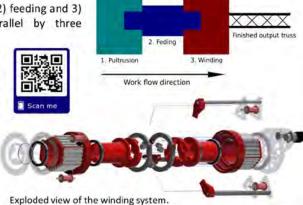
Processes involved

Three main processes: 1) pultrusion, 2) feeding and 3) winding that can be run in parallel by three interconnected subsystems.

TrussBot concept n.1 *(follow QR to video)*
The initial TrussBot concept focused on proving the viability of the proposed winding approach performing dry-filament winding on a truss-shaped mandrel/rail.
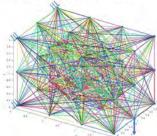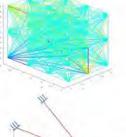
TrussBot concept n.2
A new vertical rig (tall-side figure) to test the epoxy resins production with TrussBot is currently under development.

1. Pultrusion   2. Feding   3. Winding   Finished output truss

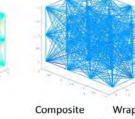Work flow direction

Exploded view of the winding system.

Layout optimization and WrapToR members sizing of large hybrid lattice space frames

GSM (Ground Structure Method) for frames layout opt. followed by further sizing of the hybrid metal-composite lattice counterpart.
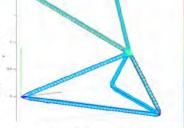

Composite WrapToR members and metal 3D printed lattice joints.

Optimal frame layout.

Large WrapToR spaceframe after sizing.

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Topological Optimization of Large, Additively Manufactured Composite Structures with a Graded Lattice Core

Alex Moss, Dr Ajit Panesar, Dr Terence Macquart, Dr Alberto Pirrera, Dr Peter Greaves, Dr Mark Forrest

Large structures require strong and stiff components to resist the primary loads imposed upon them. For instance, unidirectional carbon fibre composites are used in many large structural applications. Additively manufactured short fibre composites cannot be used to replace these components, however their value lies in providing the opportunity to combine traditional composite laminates with high-performance graded lattice architectures, which, in synergy, will provide improved structural performance and manufacturability. To design these large structures, modified SIMP density-based topology optimisation is an ideal tool to produce solutions where the solid regions represent the irreplaceable composite laminates and the graded regions represent the cellular lattice architectures. 3-dimensional topology optimisation solutions are used to demonstrate this concept on a simple composite beam, similar to a sandwich panel design. This proof-of-concept directs further study of the topic.
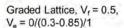
Background

Source: Buckney Thesis 2013

Minimum Compliance, Volume Constraint = 12.5%

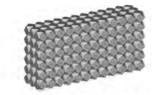Minimum Volume, Stress Constraint = 0.4% strain

Topology optimisation has been proven as a design method by solutions providing features which are now commonplace in wind blade design

Source: Strategies for functionally graded lattice structures derived using topology optimisation for additive manufacturing - Panesar et al. 2017
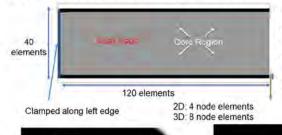

Graded Lattice, $V_f = 0.5$, $V_e = 0/(0.3-0.85)/1$

Uniform Lattice, $V_f = 0.5$, $V_e = 0.5$

Converting density distributions from topology optimisation solutions into an additively manufacturable self-supporting graded lattice improves compliance by 50% over a uniform lattice of the same volume fraction
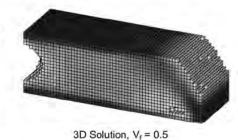
Topology Optimisation Study

Initial research involved optimising a sandwich panel type design, with the spar caps made from variable thickness laminates and the core region representing a graded lattice based on the density of the solutions. A cantilever beam problem was imposed and the optimal distribution of material was found.

40 elements

120 elements

Clamped along left edge

2D: 4 node elements
3D: 8 node elements

The spar cap regions were given an isotropic stiffness property 10x that of the core region. Penalisation factor (p) and volume fraction was varied.

3D Solution, $V_f = 0.5$

2D Solution, p = 1

2DSolution, p = 3

3D Solution, $V_f = 0.25$

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Modelling soft body impact with higher order adaptive cohesive segments

Jagan Selvaraj, Luiz F. Kawashita, Giuliano Allegri and Stephen R. Hallett

Discretisation errors involved in the use of linear displacement functions across crack surfaces result in insufficient resolution of the numerical cohesive zone. In such cases, a very fine mesh is required to model damage propagation. A methodology for modelling the cohesive zone with fewer finite elements is proposed. The use of cohesive elements with rotational degrees of freedom gives the ability to introduce multiple integration points across crack surfaces. The energy release rate associated with an integration point in a cohesive element with rotation is reduced, compared to a linear cohesive segment with four integration points. A stable solution for damage progression can thereby be obtained, even when using significantly lower mesh resolution. An approximation technique is also proposed to define the transfer of moments across the continua during damage initiation and propagation. This element formulation is coupled with the 'on-the-fly' delamination method, Adaptive Mesh Segmentation (AMS).
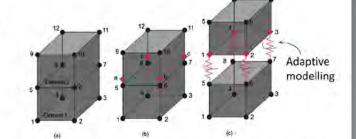
Proposed cohesive element formulation
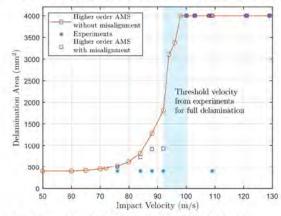
- Corner nodes of cohesive element with rotations
- Mid-side nodes calculated through transformation matrix

Adaptive Mesh Segmentation (AMS)

Modelling discontinuity on continuum meshes according to physically based criteria and without direct user intervention.
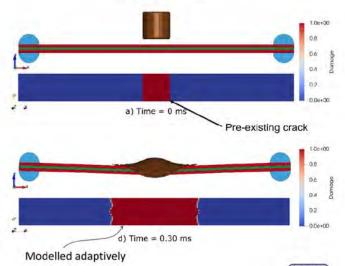

Adaptive modelling

Threshold velocity – minimum impact velocity that induces complete delamination between plies

Threshold velocity from experiments for full delamination

Experimental setup showing 88 m/s test

Demonstration with proposed cohesive element to model damage propagation at various time instants at an impact velocity of 88 m/s

a) Time = 0 ms
Pre-existing crack

d) Time = 0.30 ms
Modelled adaptively

Structures

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