CIMComp
EPSRC
Future Composites Manufacturing Research Hub

2020/2021

ANNUAL REPORT

Underpinning the development of next generation composites manufacturing processes

University of Bath
University of Bristol
Brunel University London
University of Cambridge
Cranfield Manufacturing
The University of Edinburgh
University of Glasgow
Imperial College London
Manchester 1824 The University of Manchester
University of Nottingham UK | China | Malaysia
The University Of Sheffield.
University of Southampton
Ulster University
Warwick The University of Warwick
Prifysgol Glyndŵr Wrecsam
Wrexham Glyndŵr University

UKRI
Engineering and Physical Sciences Research Council

Contents

1 Executive Summary

"Welcome to the Hub's fourth Annual Report. As we pass the mid-term point, we are starting to see a real impact from our investments despite the challenges of this year and the disruption caused by COVID-19. I am extremely grateful to all our stakeholders for the dedication and commitment shown in support of the Hub, without which we would not be able to achieve our vision and goals."

Prof Nick Warrior
Hub Director

As our research portfolio has expanded, the Hub has continued to improve quality by reinforcing synergies between project teams and by building on other UKRI research investments across materials, design, characterisation and manufacturing for composites. Our cohort size has grown to 36 PhDs, 46 EngDs and 26 postdoctoral researchers, based within 15 UK universities. This expansion includes a consortium of 37 industrial companies and partnerships with four High Value Manufacturing (HVM) Catapult Centres, across a wide range of industrial sectors.

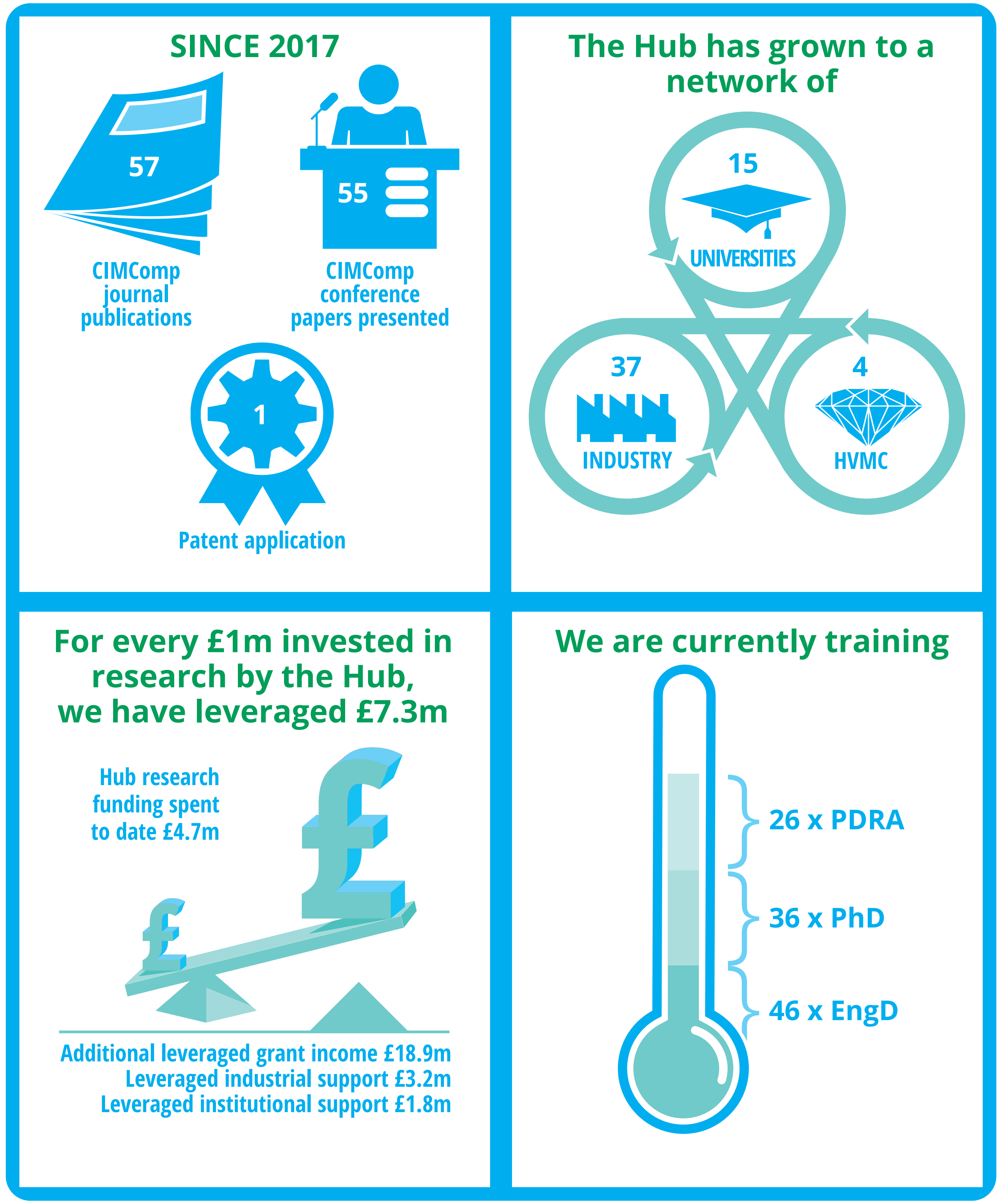
The Hub's research portfolio currently consists of 34 past and present projects including 6 Core Projects, 19 Feasibility Studies, 4 Fellowships, and 5 Synergy projects. £4.7m has so far been committed to fund collaborative research activities within the Hub, from a total research budget of £7.3m. Future funded projects will be aligned with emerging and increasing industrial interest in thermoplastic processing technologies and sustainability. We launched our latest Feasibility Study Call in May 2021 with funding allocated for 5 new projects.

There have been significant outputs this year across the whole portfolio with the publication of 16 papers, taking our total journal publications to 57. Wider dissemination of Hub research has taken place in the form of Hub and project webinars which have proved extremely popular. We will continue to host these throughout the year given the interest generated, with each webinar focussing on one of the Hub Work Streams.

I am pleased to see the impact generated from some completed and ongoing Hub Investments. Congratulations to Professor Emile Greenhalgh, Principal Investigator on the Multifunctional Core Project. Emile has been awarded a Chair in Emerging Technologies by the Royal Academy of Engineering. This is a very prestigious award and recognises Emile's international reputation in the field of structural power composites. Furthermore, the low-cost thermoplastic fibre-metal laminate technology, developed by the University of Edinburgh during a previous Hub funded Feasibility Study has received support from the Offshore Renewable Energy Catapult. This technology has great potential in the renewable energy sector and the Hub is pleased to hear this work is continuing.

I hope you enjoy reading our latest report, and look forward to working with you all in the foreseeable future.

2 Headline Achievements



3 Hub Vision and Objectives

The Hub vision is founded on two industry inspired Grand Challenges:

- Improving existing composites manufacturing processes
- Developing new technologies

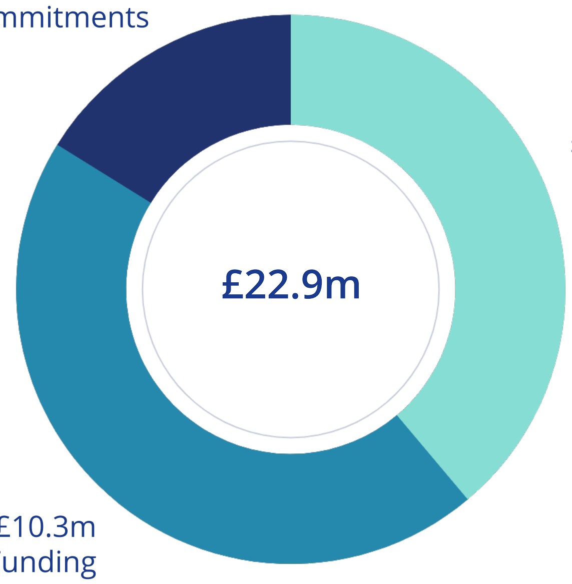
Since 2017, the Hub has built on the success of the EPSRC Centre for Innovative Manufacturing in Composites (CIMComp; EP/I033513/1), with a vision to develop a national centre of excellence in fundamental research for composites manufacturing – delivering research advances in cost reduction and production rate increase, whilst improving quality and sustainability.

Our aim is to underpin the growth potential of the UK composite sector by developing the underlying manufacturing process science and technology needed by industry, whilst enabling rapid dissemination of that knowledge into the UK industrial base.

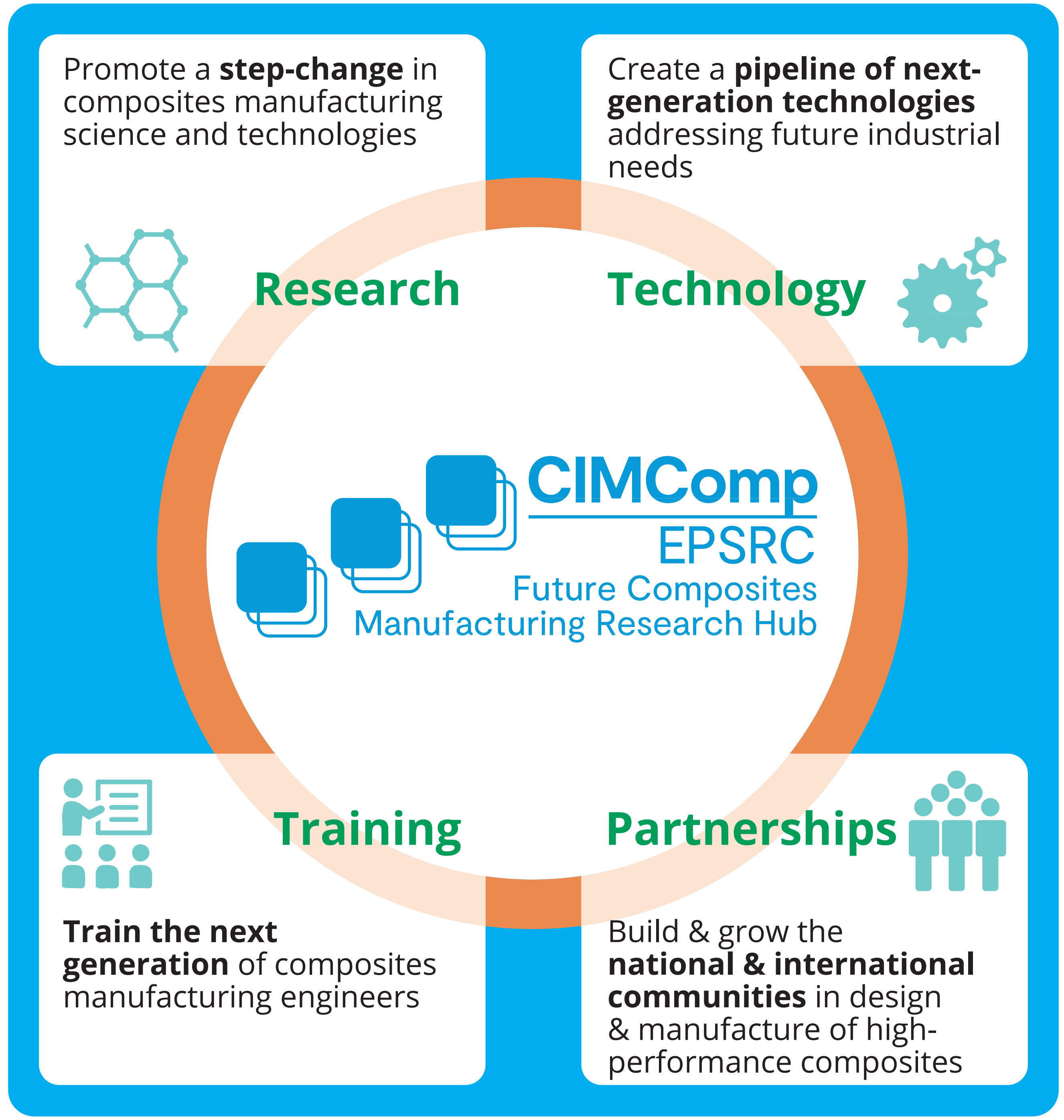
Composites manufacturing research is the key to further exploitation of composites in existing sectors (aerospace, automotive, energy and defence) and more widespread adoption in emerging sectors such as infrastructure, rail and marine.

To achieve this vision, the Hub aims to deliver against core objectives in four key areas: research excellence, technology transfer, training and network building.

Hub Funding Model:



Academic Institutions and Industry have committed to a further £12.6m in support of the £10.3m EPSRC investment.



4 Hub Cumulative Growth

Funding Decision	Date	Hub Growth
Hub launched 3 Core Projects funded 2 Feasibility Studies funded	Jan 2017	Initial academic partners include Nottingham, Bristol, Imperial College, Manchester, Southampton and Cranfield
6 Feasibility Studies funded 3 Core Projects funded	Jun 2017	3 new Spokes join the Hub - Edinburgh, Cambridge, Glasgow
2 Feasibility Studies funded	Oct 2017	1 new Spoke joins the Hub - Brunel
2 Feasibility Studies funded following Innovation Fellowship interviews	Jul 2018	
3 Feasibility Studies funded	Dec 2018	3 new Spokes join the Hub - Ulster, Wrexham, Sheffield
Active RTM Core Project funded	Jun 2019	
2 Innovation Fellowships funded	Jul 2019	1 new Spoke joins the Hub - Warwick
UK Composites Challenge Roadmap launched	Sep 2019	
2 Core Projects funded 4 Feasibility Studies funded	Jan 2020	1 new Spoke joins the Hub - Bath
Hub Mid-Point	June 2020	
5 Synergy Promotion Projects launched	Sep 2020	
Mid-Term Review	Jan 2021	
Feasibility Study Call launched	May 2021	

5 Hub Research

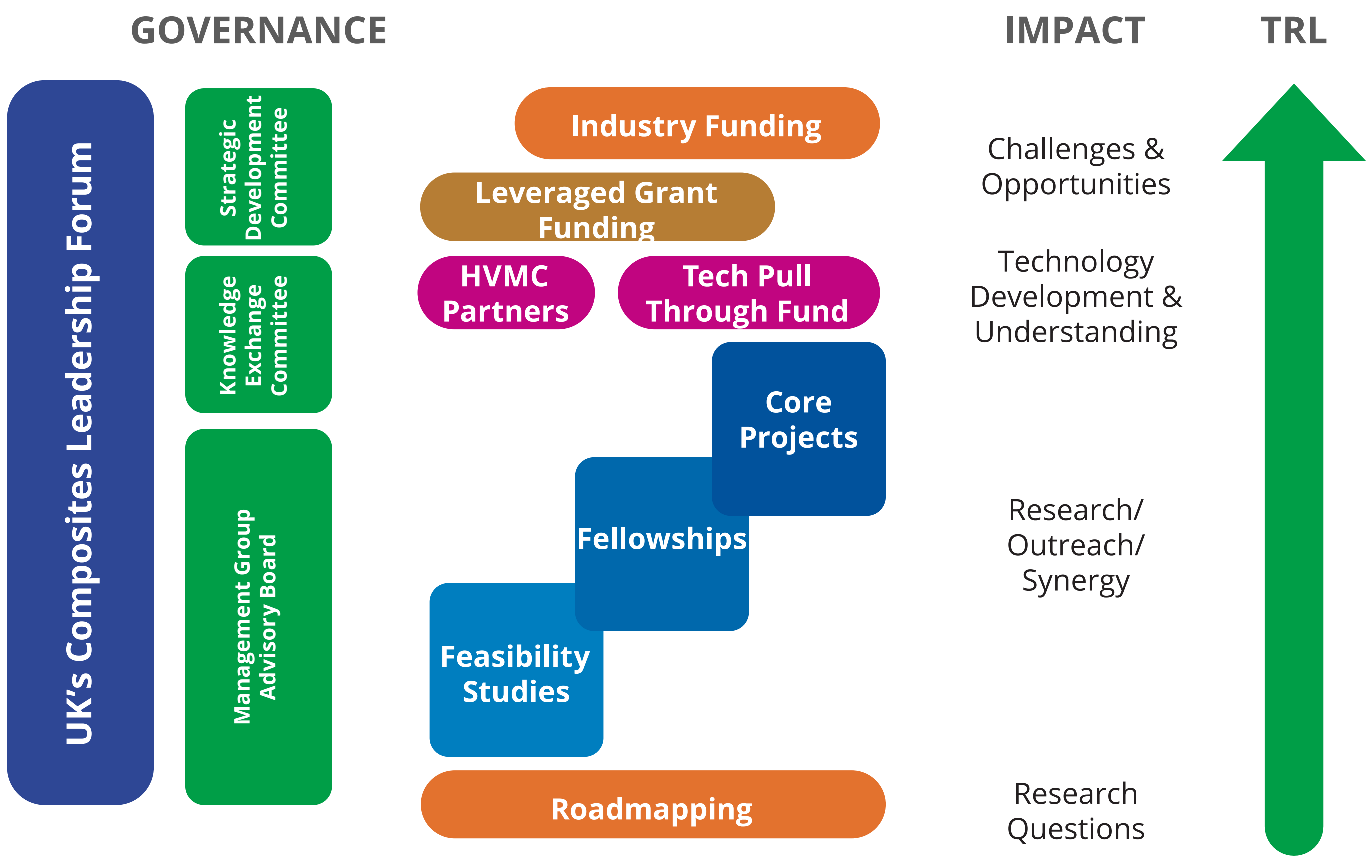
The Hub project portfolio is based on meeting the research challenges facing the UK composites sector and aims to accelerate the uptake of composite materials by reducing the costs of engineered products whilst increasing quality, increasing functionality and striving to meet the 2050 Net Zero targets.

All projects and leveraged studentships are linked to a Work Stream, which is led by the principal investigator of a Core Project or one of the Platform Fellows. The aim is to increase research excellence by ensuring that each Work Stream is driven by national leaders in that technology area, adopting best practices in experimental and modelling manufacturing science across all associated projects.

Our Feasibility Study programme offers up to £50k for novel, ambitious six month projects, which are encouraged, where appropriate, to be developed into proposals for Core Projects (36 month collaborations), of values between £375K and £700K. The rate of continuation from Feasibility Study to Core Project has typically been one in five.

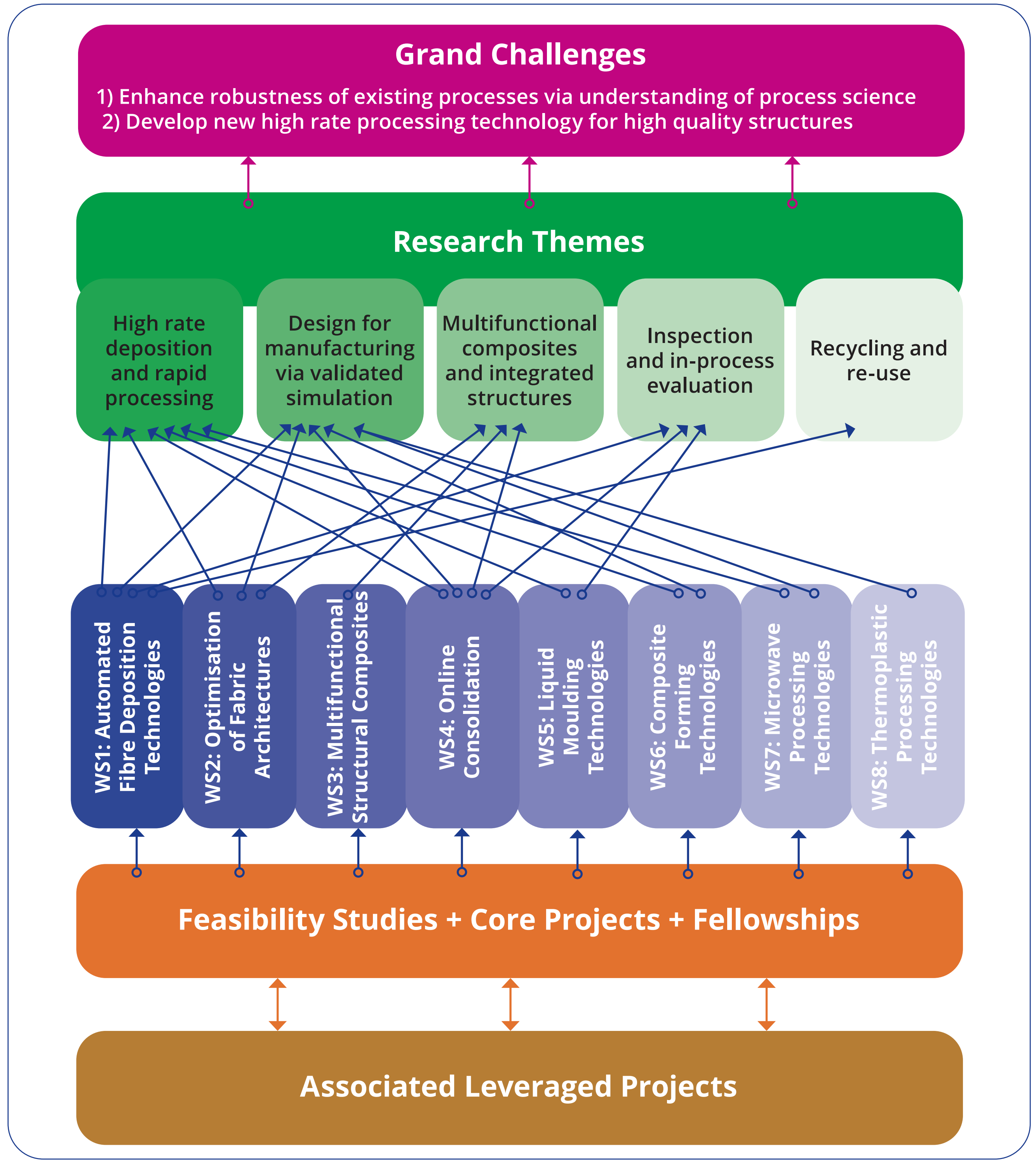
Pathways to Impact

The Hub plays a key role in the composite manufacturing technology pipeline, pushing proven research outcomes through to the HVM Catapult Centres (The National Composites Centre (NCC), Advanced Manufacturing Research Centre (AMRC), Warwick Manufacturing Group (WMG) and Manufacturing Technology Centre (MTC)) so that they mature through the Technology and Manufacturing Readiness Levels (TRL, MRL) into successful products and manufacturing activity, to be exploited by UK industry.



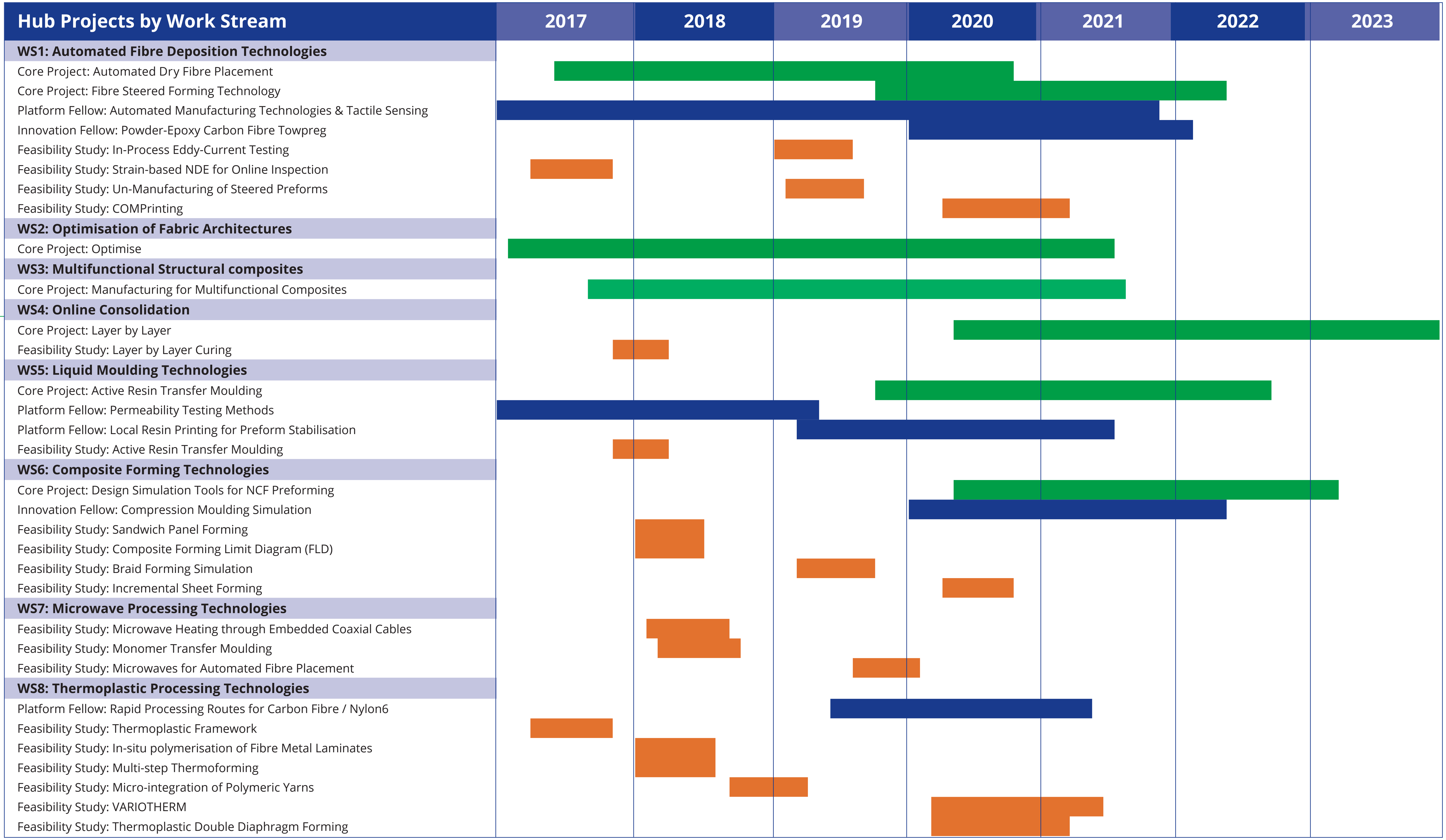
Grand Challenges

The **Grand Challenges** are addressed by five **Research Themes**, with composites sustainability underpinning all of the Themes. This includes considering life cycle assessment, energy use and environmental impact measures across the research portfolio. The challenges in each Research Theme are met by relevant technologies from across the eight Work Streams.



The relationship between individual researchers, their projects and the Work Stream can be viewed using the SharpCloud data visualisation platform.

5.1 Hub Projects by Work Stream



Work Stream 1

Automated Fibre Deposition Technologies

Work Stream Overview

Scan to hear more about the ADFP project

Automated Fibre Deposition is currently used for high specification, often large structures (10m+), requiring precise fibre placement to produce complex geometries. The Universities of Nottingham, Bristol and Edinburgh are researching process parameters to reduce defects, improve manufacturing performance and develop next-generation fibre placement technologies. Flexibility in the use of different materials, such as dry preforms, thermoplastic tapes and recycled fibres, optimising design for manufacture and in-line process monitoring, are key to broadening industrial applications of this technology. WS1 is linked to a £36.7m capital investment programme at the NCC, aimed at transferring the technology to state-of-the-art industrial hardware.

The challenges for automated deposition of composites are closely aligned with the Hub's Grand Challenges of improving quality and rate. There is significant industrial effort at TRL 4-6 to develop existing technologies through incremental changes to the process such as Automated Fibre Placement, and there's a great deal happening in the field of manufacturing which impacts this work. There's also progress in the world of computational science to improve CAE tools, as well as Industry 4.0 trends. This leads to potential work in a number of TRL 1-3 areas:

- Improve the understanding of material behaviour during deposition to improve rate and quality
- Understand the barriers to process implementation
- Make full use of dry fibre formats and exploit the advantages
- Facilitate a Digital Twin for composites manufacturing

Work Stream Aims

- Investigate the rate and quality limiting barriers during the deposition of dry fibres. New AFP processing equipment is being developed alongside a novel Digital Twin programming methodology to enable real-time influencing and inspection of the deposition process, ensuring optimum speed and part accuracy.
- Investigate ways to acquire large quantities of real-time data, which will be integrated within the machine to provide real-time control during fibre deposition. The Digital Twin will subsequently be used to quantify the local permeability effects post deposition to predict preform infusion behaviour through a network based model.
- Rapidly produce components that are not currently manufacturable using conventional AFP, using a combination of novel prepreg material formats and new process developments.
- Modify the University of Bristol-developed Continuous Tow Shearing (CTS) process to feed highly-aligned discontinuous fibre tapes, produced from recycled fibres, to further optimise the drapeability of preforms and enable a step-change in material cost.

Work Stream Team

Principal Investigators: Dr Thomas Turner, Nottingham; Prof Stephen Hallett, Bristol; Prof Janice Barton, Bristol; Dr Byung Chul (Eric) Kim, Bristol; Dr Robert Hughes, Bristol; Dr Dongmin Yang, Edinburgh.

Co-Investigators: Dr Andreas Endruweit, Nottingham; Dr Jonathan Belnoue, Bristol; Dr Marco Longana, Bristol; Prof Stephen Hallett, Bristol; Prof Ian Hamerton, Bristol.

Researchers: Dr Adam Joesbury, Nottingham; Dr Anthony Evans, Nottingham; Dr Ric Sun, Bristol; Dr Logan Wang, Bristol; Dr Marco Longana, Bristol; Dr Lei Wan, Edinburgh; Dr Colin Robert, Edinburgh; Dr Daniel Bull, Southampton; Dr Michael Elkington, Bristol; Dr Bohao Zhang, Bristol; Dr Thomas Noble, Edinburgh.

PhDs: Usman Shafique, Nottingham; Shimin Lu, Nottingham; Murat Celik, Edinburgh.

Industry Partners: ESI, BAE, NCC, Coriolis, GKN Aerospace, AMRC, MTC, WMG, Airbus, Rolls-Royce, Hexcel, Composites Integration, Solvay, Airborne, Heraeus Noblelight, Pentaxia, Sigmatex, Spirit Aerosystems.

Work Stream Projects

- **Core Project:** Automated Dry Fibre Placement Technology & Fibre Steered Forming Technology (Nottingham & Bristol)
- **Feasibility Study:** Virtual Un-manufacturing of Fibre-Steered Preforms for Complex Geometries (Bristol)
- **Feasibility Study:** Evaluating In-process Eddy Current Testing of Composite Structures (Bristol)
- **Feasibility Study:** 3D Printing of Continuous CF Powder Epoxy Towpreg (COMPrinting) (Edinburgh)
- **Feasibility Study:** Strain-based NDE for Online Inspection (Southampton)
- **Platform Fellow:** Automated Manufacturing Technologies and Tactile Sensing (Michael Elkington, Bristol)
- **Innovation Fellow:** Development of a Powder-Epoxy Carbon Fibre Towpreg for High-speed, Low Cost Automated Fibre Placement (Dr Colin Robert, Edinburgh)

Hub Investment
£2.0m

Leveraged Industry Support
£246k

Leveraged Grants
£11.2m

Leveraged Academic Support
£271k

Work Stream Progress

1. A novel and unique experimental rig has been constructed at the University of Nottingham to closely emulate commercial tape-laying processes, which will be used to study process parameters and expand the ADFP operating range.

2. The ADFP Core Project at Nottingham aims to rethink the existing composite design and manufacturing process by producing a new way of describing the structure of a composite part. A Digital Twin has been developed of the ADFP process, encompassing both as-designed data and manufacturing data, which can be used alongside real-time sensor data from the machine to influence the manufacturing of future parts.

3. Continuous Tow Shearing developments at the University of Bristol will enable reclaimed/recycled fibre material from the HiPerDiF process to be used for AFP. This will deliver a high-quality sustainable material, which can be formed into complex curved shapes. The project seeks to provide a novel solution to the challenges of complex 3D AFP parts which cannot be produced by direct 3D deposition:

- The material behaviour of the HiPerDif tape samples and diaphragm materials are being characterised, and the material models for unforming simulation have been developed and are being validated.
- The laboratory tests are underway to guarantee the consistent property of the tape for preform production.
- Initial trials of active feeding mode in the CTS process have been successfully completed.
- The simulation model is currently being tuned, using different full-field measurement techniques to capture material deformation during forming.

4. Edinburgh is developing a tack-free powder epoxy for automated deposition processes. A novel powder-based epoxy from FreiLacke is used in this study. The powder epoxy has significant advantages compared to its liquid equivalents: low minimal viscosity, low exotherm, ability to preshape different parts and co-cure them in a one-shot process and stability at ambient temperature (no refrigeration requirement). These advantages result in lower manufacturing costs and quicker production of mechanically superior composite parts compared to standard liquid epoxy-based composites. This material will be tested on the UoN ADFP rig.

5. A rotational printing technique has been developed by adding a rotation degree to the traditional FFF 3D printer. A special nozzle is used along with the rotation of the printer head which is synchronised with the printing paths, enabling better fibre alignment when printing composites with complex shapes. The printing of this thermosetting based composite has been tested and compared with thermoplastic based composites through various case studies.

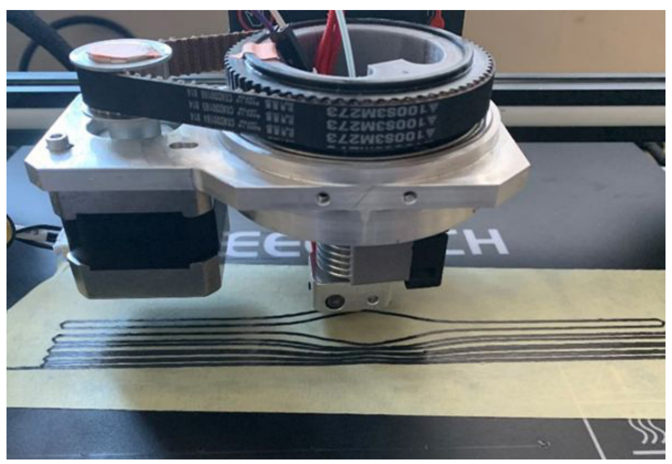


Figure 1: Rotational 3D printing of continuous carbon fibres along identified stress trajectories.

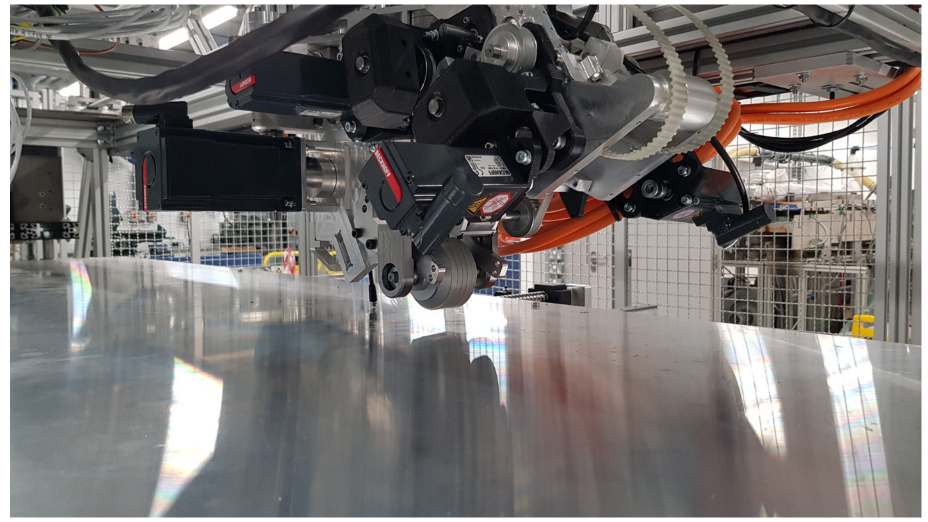


Figure 2: The ADFP head featuring XYZ table surface

Figure 3: The moveable (longitudinal) gantry system and (transverse) table surface

Work Stream Outputs

- Elkington M, Almas E, Ward-Cherrier B, Pestell N, Ward C, Lepora N. *"Real Time Defect Detection During Composite Layup Via Tactile Shape Sensing"*, Journal of Science and Engineering of Composite Materials, 2021; 28 (1) 1-10.
- Yousefi N, Evans AD, Harper LT, Maples HA, James T, Bismarck A. *"Solid Epoxy Resin Systems for Automated Composite Manufacturing"*, Composites Part A: Applied Science and Manufacturing, 2021; Volume 142, 10625.
- Evans AD, Turner TA, Endruweit A. *"Development of Automated Dry Fibre Placement for High Rate Deposition"*, 22nd International Conference on Composite Materials (ICCM22 2019), Melbourne, Australia, 2019.
- Sun X, Belnoue JPH, Kim BC, Wang WT, Hallett S. *"Virtual Un-manufacturing of Fibre-steered Preforms for Complex Geometry Composites"*, 23rd International Conference on Material Forming (ESAFORM2020).
- Robert C, Pecur T, Maguire JM, Lafferty AD, McCarthy ED, Ó Brádaigh CM. *"A Novel Powder-epoxy Towpregging Line for Wind and Tidal Turbine Blades"*, Composites Part B: Engineering, Volume 203, 2020.
- Shafique U. *"Automated Dry Fibre Placement - Infusion Process"*, 4th Composites @Manchester Research Workshop, Manchester, UK, 2019.
- Evans AD. *"Technologies Framework for Automated Dry Fibre Placement"*, EPSRC Future Composites Manufacturing Hub Annual Open Day 2019, Nottingham, UK, 2019.
- Evans AD. *"Technologies Framework for Automated Dry Fibre Placement"*, Advanced Engineering Showcase 2019 – Composites Forum Presentation, Birmingham, UK, 2019.

Work Stream 2

Optimisation of Fabric Architectures

Work Stream Overview

Scan to see our project webpage

3D woven composites offer significant improvements in inter-laminar mechanical properties over more conventional 2D laminated composites. The Universities of Nottingham and Manchester are developing new forms of 3D fibre reinforcement architectures outside of the constraints of conventional textile manufacturing.

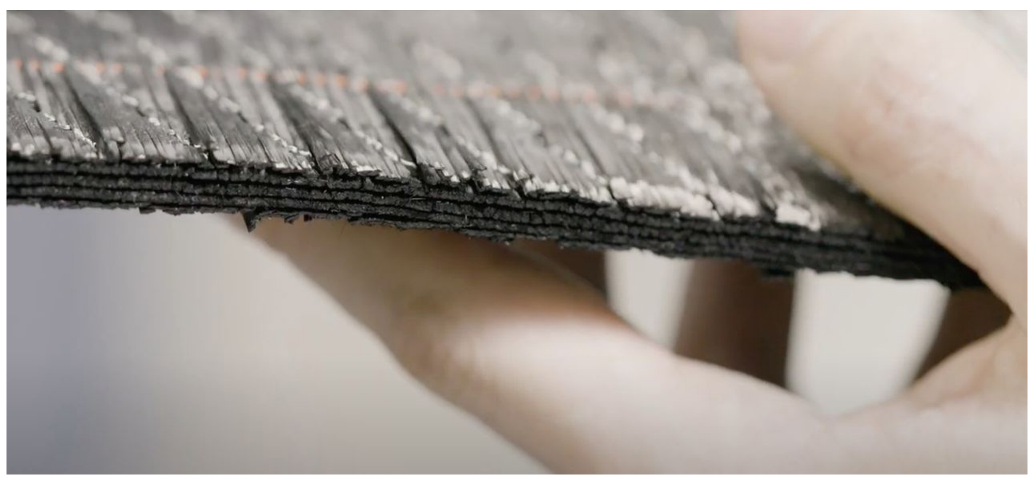
Nottingham is leading on developing multi-scale modelling techniques linked to a multi-objective optimisation framework based on geometries and conformal meshes created in the well-established TexGen software. Manchester is developing complementary fibre placement techniques and machinery to manufacture multi-axial 3D fibre preforms.

The 3D woven fabric approach has been demonstrated to yield over 10% weight-savings compared to optimised non-crimp fabrics (NCFs). 3D fabrics are already used in the aerospace industry (e.g. fan blades) but there is a demand for optimisation tools as well as new forms of preforms.
The research challenges being addressed are:

- How to model complex 3D preforms and optimise their structure.
- How to manufacture these 3D preforms.
- Demonstrate advantages over existing architectures and ensure research is transferrable to industry.

Work Stream Aims

- Establish a computational framework for textile preform optimization not limited to existing manufacturing processes.
- Identify classes of materials with improved properties over existing forms, by conducting a series of case studies.
- Develop new or modified textile preforming technologies to realise these material forms.
- Validate predicted properties and demonstrate performance benefits to materials suppliers and end users.



Work Stream Team

Principal Investigators: Prof Andrew Long, University of Nottingham; Prof Prasad Potluri, University of Manchester.

Co-Investigators: Dr Louise Brown, University of Nottingham.

Researchers: Dr Debabrata Adhikari, Nottingham; Dr Mikhail Matveev, Nottingham; Dr Shankhachur Roy, Manchester; Dr Vivek Koncherry, Manchester.

PhDs: Jinseong Park, Manchester; Kazi Sowrov, Manchester; Sarvesh Dhiman, Manchester/ M Wright & Sons; Christos Kora, Nottingham, Syed Abbas, Manchester.

Industry Partners: Luxfer Gas Cylinders, AMRC, Sigmatex, Airbus, NCC, ESI, BAE Systems, Hexcel, GKN Aerospace, M Wright & Sons, Shape.

Work Stream Project

- **Core Project:** Optimisation of Fabric Architectures (Nottingham & Manchester)

Hub Investment £725k

Leveraged Industry Support £357k

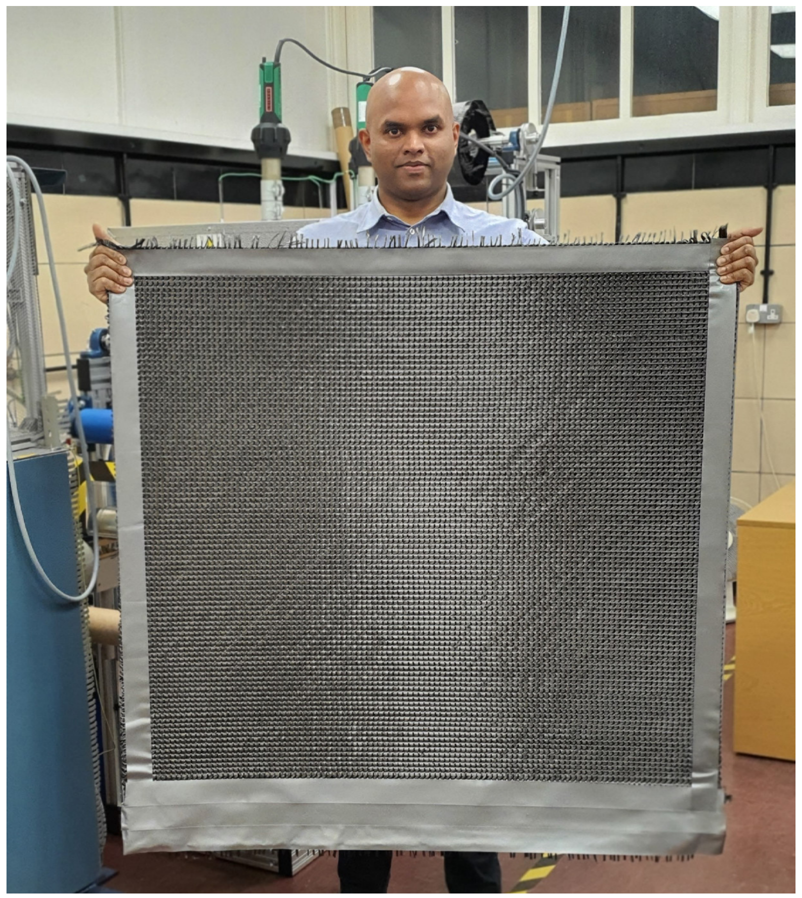
Leveraged Grants £824k

Leveraged Academic Support £181k

Work Stream Progress

Advances in meshing, multi-scale mechanical modelling and permeability modelling:

- Development of a special meshing technique suitable for textiles of arbitrary geometry, while maintaining accuracy and reasonable computational costs.
- A Multiaxial 3D weaving concept has been developed in order to create optimised preforms without imposing the manufacturing constraints of conventional weaving technologies. Manchester has developed a 1m x 1m 3D preform for an automotive floor panel.
- Application of the developed optimisation framework for two demonstrators. Conventional 3D woven textiles have poor properties in the off-axis direction hence either bending or torsion is compromised when these textiles are used as a reinforcement. The optimisation framework has been applied to find an optimum geometry of multi-axial 3D preforms and a technique to manufacture such preforms has been developed.



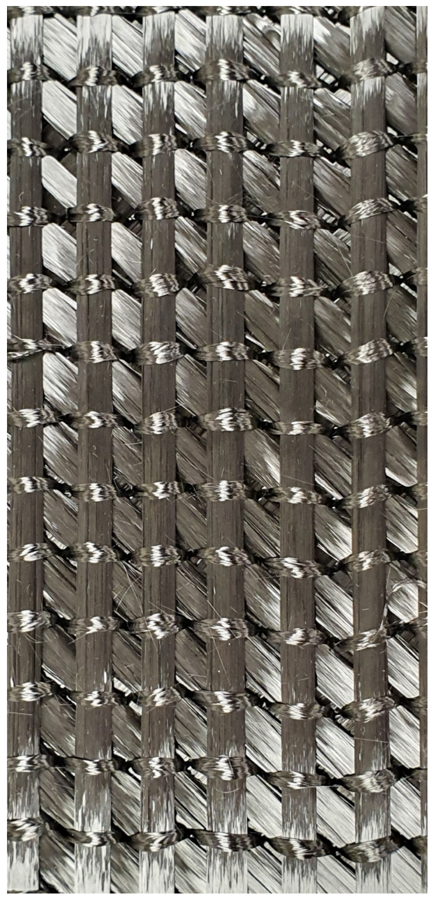


Figure 1: Multiaxial 3D weaving concept has been developed in order to create optimised preforms without imposing the manufacturing constraints of conventional weaving technologies.

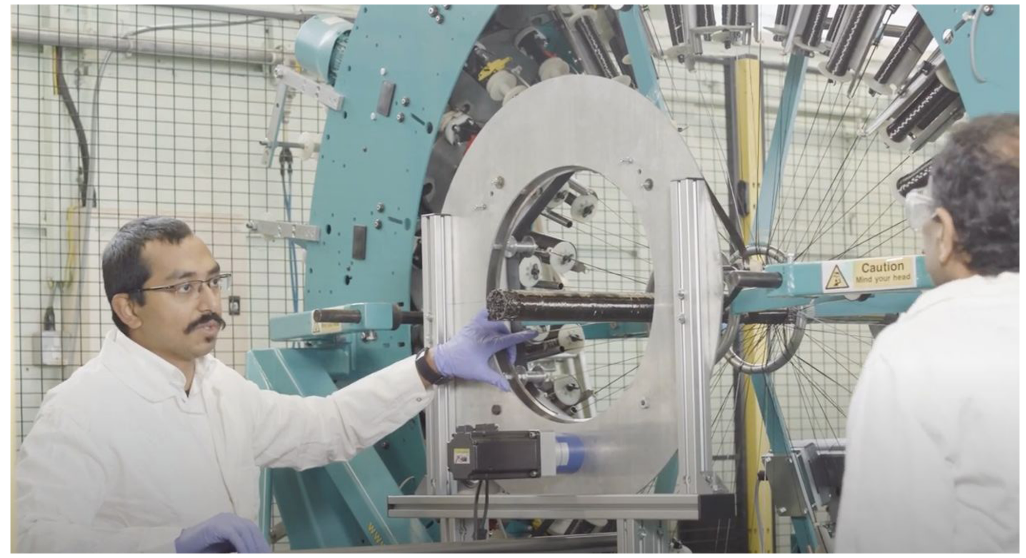


Figure 2: Braid-winding machine developed at the University of Manchester.

Work Stream Outputs

- Yousaf Z, Withers PJ, Potluri P. *"Compaction, Nesting and Image Based Permeability Analysis of Multi-layer Dry Preforms by Computed Tomography (CT)"*, Composite Structures, 263, p. 113676, 2021.
- Gautam M, Sivakumar S, Barnett A, Barbour S, Ogin SL, Potluri P. *"On the Behaviour of Flattened Tubular Bi-axial and Tri-axial Braided Composites in Tension"*, Composite Structures, 261, p. 113325, 2021.
- Karim N, Sarker F, Afroj S, Zhang M, Potluri P, Novoselov KS. *"Sustainable and Multifunctional Composites of Graphene-Based Natural Jute Fibers"*, Advanced Sustainable Systems, 5(3), p. 2000228, 2021.
- Chai Y, Wang Y, Yousaf Z, Storm M, Vo NT, Wanelik K, Burnett TL, Potluri P, Withers PJ. *"Following the Effect of Braid Architecture on Performance and Damage of Carbon Fibre/Epoxy Composite Tubes During Torsional Straining"*, Composites Science and Technology, 200, p. 108451, 2020.
- Matveev et al. *"Efficient Meshing Technique for Textile Composites Unit Cells of Arbitrary Complexity"*, Composite Structures, Volume 254, (112757), 2020.
- Chai et al. *"Following the Effect of Braid Architecture on Performance and Damage of Carbon Fibre/epoxy Composite Tubes During Torsional Straining"*, Composite Science and Technology, 200 (108451), 2020.
- Yan et al. *"Effect of Fibre Architecture on Tensile Pull-off Behaviour of 3D Woven Composite T-joints"*, Composite Structures, 242, 2020.
- Yan et al., *"Meso-scale Modelling of 3D Woven Composite T-joints with Weave Variations"*, Composite Science and Technology, 171, 2019.
- Developed Meshing Technique is Released as a Part of Open-source Code within TexGen www.texgen.sourceforge.net.
- 6 presentations at conferences including a plenary lecture at the 22nd International Conference on Composite Materials in 2019.
- Keynote speech by Prof Prasad Potluri at virtual 9th World Conference on 3D Fabrics and their Applications, 8-9th April 2021.
- Patent: Potluri et al. *"Method and Apparatus for Weaving a Three-dimensional Fabric"*, US Patent 9,598,798.

Work Stream 3

Multifunctional Structures

Work Stream Overview

Scan to see our YouTube Video

Imperial College has demonstrated that a structural composite sandwich panel can be used to store energy as a supercapacitor, by embedding carbon fibres in a carbon aerogel (CAG). This technology could be transformative for transport and mobile electronics sectors, removing the need for conventional battery storage and delivering a substantial weight and volume reduction. WS3 aims to research the challenges in manufacturing 3D components from these panels. Imperial College is working with Bristol to develop a novel printing process to produce a textile with discrete regions of CAG structure, which can be shaped into a 3D preform structure for liquid moulding. Bristol is using its explicit Finite Element (FE) forming expertise to develop a specific modelling approach for these structures. Functional sub-elements from microbraids with metallic filaments have also been developed by Bristol to provide added functionality through improved electrical and thermal conductivity.

Work Stream Aims

Multifunctional structural composites, in which structural composites are imbued with additional functions, offer solutions to achieve a step change in weight/volume savings, as well as facilitate new design freedoms. The overarching aim of the Core Project is to create a set of tools to facilitate the design and manufacture of complex, multifunctional structures. These will be used to overcome the challenges associated with using multifunctional materials and provide a methodology to compare and contrast multifunctional systems.

The specific application under investigation is structural power (structural composites which store/deliver electrical energy). The carbon aerogel used in the devices is very rigid, but brittle, so the processing is challenging, but is a critical step to promote adoption of this emerging composite technology by industry.

Integration of functional elements can be achieved in different ways. The project focuses on integration of (a) metal-carbon braided hybrid threads by means of tufting and (b) micro-additives by means of local injections. The enhanced properties are then examined in sensing, inductive heating, and structural properties.

There are two key objectives:

1. To explore the manufacturing issues associated with the creation of structural power materials formed into complex geometries, and develop tools to predict performance and enable multifunctional design.
2. To explore the design and manufacture of multi-matrix / multi-fibre composites to optimise heat and electrical conduction.

Work Stream Team

Principal Investigators: Prof Emile Greenhalgh, Imperial College London; Dr Dmitry Ivanov, University of Bristol.

Researchers: Dr Ian Gent, Bristol; Dr Laura Pickard, Bristol; Dr Sang Nguyen, Imperial; Dr David Anthony, Imperial.

PhDs: Caroline O'Keeffe, Bristol; Arjun Radhakrishnan, Bristol; Mark Turk, Bristol; Maria Valkova, Imperial.

Industry Partners: BAE Systems, Airbus, NCC, Hexcel, Qinetiq, Chomarat, Oxeon, GKN Aerospace.

Work Stream Project

- **Core Project:** Manufacturing for Multifunctional Composites (Imperial College & Bristol)

Hub Investment £708k

Leveraged Industry Support £25k

Leveraged Grants £4.6m

Leveraged Academic Support £389k

Work Stream Progress

Manufacture and demonstration of curved structural power components:

- Exceeded structural supercapacitor target performance: Energy and Power densities of 1.4Wh/kg & 1.1 W/kg respectively achieved.
- A collaboration between ICL/UoB led to the successful demonstration of masking and barriers to facilitate the infusion of curved multifunctional structures.
- Developed scale up for current collection, encapsulation, multicell assembly and demonstration.

Modelling and Multifunctional Design for Structural Power:

- Fabric compaction model developed & published, providing the foundation for the electrochemical & mechanical model development.
- Numerical model developed to predict compaction effects, which includes the influence of CAG defects.
- Multifunctional design methodology developed and demonstrated against several platforms, including aircraft cabin, air-taxi and fully electric aircraft.

Conductive sub-reinforcements:

- The feasibility of improving the through-thickness properties of composites by tufting of hybrid micro-braided threads has been proven to be feasible, creating novel hybrid composites.
- Tufted hybrid composites show elevated electrical conductivity, capability for delamination sensing and superior structural properties.
- New modelling tools have been created and validated for assessing electrical conductivity of hybrid braids.
- Induction heating/curing trials have been conducted for reference and tufted panels (quick repair applications). The architecture of the through-thickness tuft is shown to act as a potentially strong heat sink – this feature can be exploited as a tool to aid thermal management during cure.

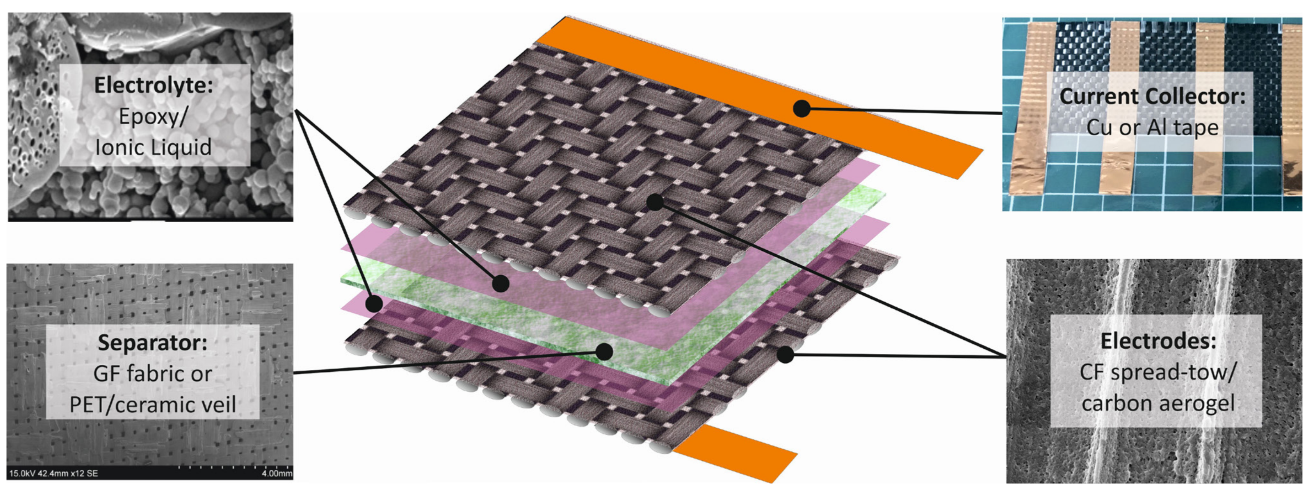


Figure 1: Architecture of structural supercapacitor composite, based on carbon aerogel-modified carbon fibre fabric electrodes, glass fibre fabric separator, bicontinuous structural electrolyte and metallic tape current collectors.

Multi-matrix composites:

- Modelling tools have been developed for allocating multifunctional patches and examining forming deformation of remaining monofunctional, structural, material.
- A concept to mitigate against forming defects by stabilising preform with liquid resin patches has been demonstrated.
- New experimental procedure developed for deriving local properties of patches hosted in dry preform – virtually confirmed for viscous and non-linear elastic behaviour of materials.
- Design tool has been developed for liquid resin printing for void free creation of patches and barriers for flow separation – thermal history / loading rates / applied pressure.
- Relatively high conductivity is demonstrated for locally integrated micro-additives.
- Demonstrator for complex sizeable tool has been designed to showcase some of the key features of forming with functional elements.

Figure 2: Structural Power Demonstrator developed at ICL– Manufacture of scale model fuselage (40 cm x 30 cm) and door mechanism..

Work Stream Outputs

- Prof. Emile Greenhalgh has been awarded a Chair in Emerging Technologies on Structural Power and ten years of funding (£2.7M) to support his research in this area.
- Nguyen SN, Millereux A, Pouyat A, Greenhalgh ES, Shaffer MSP, Kucernak ARJ, Linde P. *“Conceptual Multifunctional Design, Feasibility and Requirements for Structural Power in Aircraft Cabins”*, Aerospace Research Central https://doi.org/10.2514/1.C036205, 2021.
- O’Keeffe C, Pickard LR, Cao JAJ, Partridge IK, Ivanov DS. *“Multi-material Braids for Multifunctional Laminates: Conductive Through-thickness Reinforcement”*, Functional Composite Mater 2, 5, 2021.
- Turk MA, Vermes B, Thompson AJ, Belnoue JP-H, Hallett SR, Ivanov DS, *“Mitigating Forming Defects by Local Modification of Dry Preforms”*, Composites Part A: Applied Science and Manufacturing, Vol 128, 105643, 2020.
- Valkova M, Anthony DB, Kucernak ARJ, Shaffer MSP, Greenhalgh ES. *“Predicting the Compaction of Hybrid Multilayer Woven Composite Reinforcement Stacks”*, Composites Part A: Applied Science and Manufacturing, Vol 133, 105851, 2020.
- Nguyen S, Anthony DB, Qian H, Yue C, Singh A, Bismarck A, Shaffer MSP, Greenhalgh ES. *“Mechanical and Physical Performance of Carbon Aerogel Reinforced Carbon Fibre Hierarchical Composites”*, Composites Science and Technology, Vol 182, 107720, 2019.
- Greenhalgh ES. *“En Route to ‘Massless’ Energy Storage With Structural Power Composites”*, JEC Magazine, Nov 2019.

Workstream 4

Online Consolidation

Work Stream Overview

Scan to hear about our project

Placement, consolidation and curing have historically remained separate and sequential steps carried out to manufacture composites structures. There is an urgent need to move to automated lay-up to reduce production time for high performance composite structures manufactured from pre-impregnated material. Layer by Layer curing combines deposition, consolidation and curing of thermosetting composites into a single manufacturing step that controls material microstructure at the point of application to eliminate defects and decrease costs by avoiding the autoclave. Cranfield and Bristol are developing a fully coupled (thermal-consolidation-thermomechanical) 3D simulation of the Layer by Layer (LbL) curing process, aiming to maximise interfacial toughness, minimise process duration and control residual stresses. A laboratory scale pilot plant will be constructed to demonstrate the applicability of LbL to other composites manufacturing technologies.

Work Stream Aims

Starting in June 2020, the aim of the LbL Core Project is to develop the scientific and technological tools necessary for industry to successfully implement the LbL concept, and to establish the new process at the scale and level of complexity required for application to advanced composite structures. This will be achieved by addressing the following objectives:

1. Development of fully coupled 3D simulation of the LbL process, combining appropriate modelling tools in an open source interface.
2. Development of constitutive models and associated characterisation using conventional and snap-curing systems with LbL curing.
3. Process optimisation to maximise interfacial toughness, minimise process duration and control residual stresses.
4. Development of tailored process setups for complex geometries/components, including end effectors and zonally heated reusable bagging.
5. Optimisation of LbL process implementation to minimise defect generation due to ultralow viscosity, ply drop offs, gaps and curvature.
6. Demonstration of applicability based on pilot scale LbL implementations of automated fibre/tape placement, pultrusion and filament winding.
7. Demonstration of LbL process capabilities through the development of hybrid thermoset/ thermoplastic components, stabilised preforms and laminates with tailored residual stress state.

Work Stream Team

Principal Investigators: Dr Alex Skordos, Cranfield University; Dr James Kratz, University of Bristol.

Researchers: Dr Gabriele Voto, Cranfield University; Dr Mehdi Asareh, Cranfield University; Dr Arjun Radhakrishnan, Bristol; Dr Robin Hartley, Bristol; Dr Mario Valverde, Bristol.

PhDs: Michael O'Leary, Bristol/Airbus; Adam Fisher, Bristol/Nantes; Axel Wowogno, Bristol/Rolls Royce.

EngD: Anastasios Danezis, Cranfield University/Heraeus.

Industry Partners: National Composites Centre, Rolls Royce, Exel Composites, Heraeus Noblelight, Airbus.

Work Stream Projects

- **Core Project:** Layer by Layer (Cranfield & Bristol)
- **Feasibility Study:** Layer by Layer Curing (Cranfield & Bristol)

Work Stream Progress

Key research questions being addressed by the Core Project Case Study on thick laminate:

- Interfaces: will the layers stick together?
- Consolidation: will the laminate have the desired fibre volume fraction and low porosity?
- Dimensional stability: will residual stresses create warpage?
- Hybridisation: will high temperature processing thermoplastic layers degrade the properties of underlying thermoset prepregs?

The LbL Curing Feasibility Study previously demonstrated:

- ~50% saving in cure times for thick components.
- Linear scaling of process time with component thickness, making manufacturing of ultra-thick components feasible.
- Using LbL process to merge consolidation with curing for planar geometries provides equivalent quality to a conventional autoclave process.
- Interfacial properties preserved in partially cured interfaces.

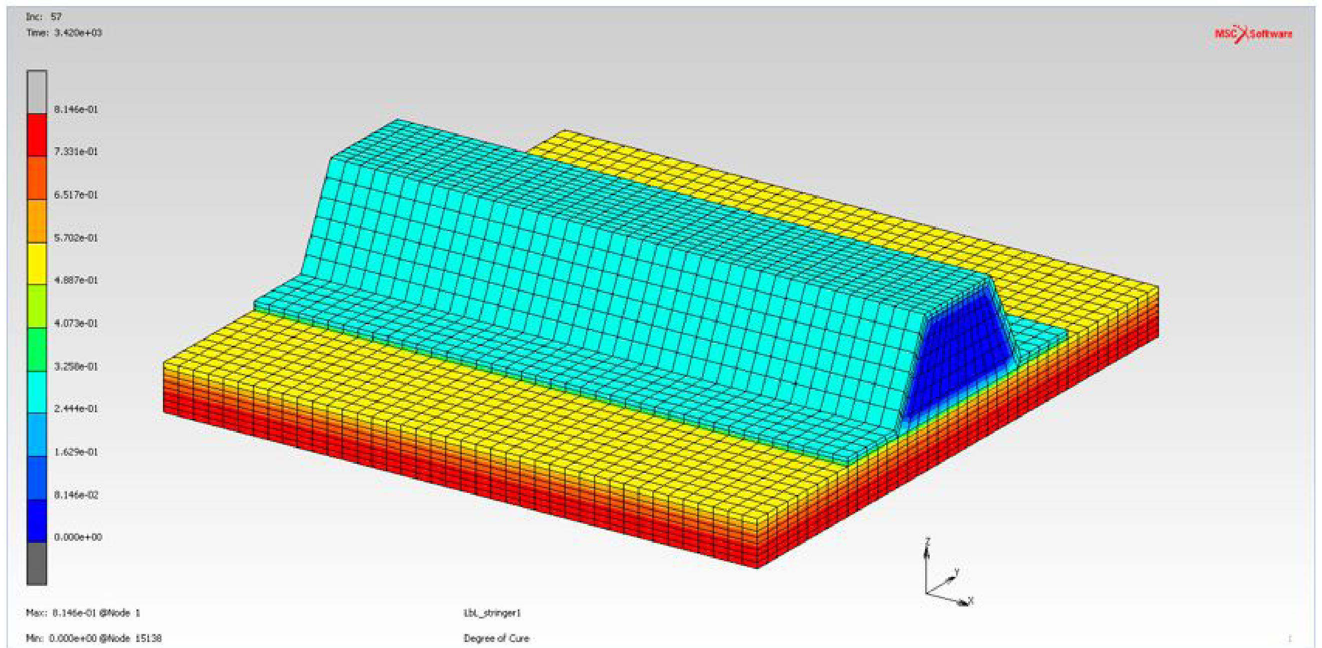


Figure 1: Degree of cure distribution in the Layer-by-Layer processing of a skin panel reinforced with an omega stringer at the time the first quarter of the stringer thickness has been deposited.

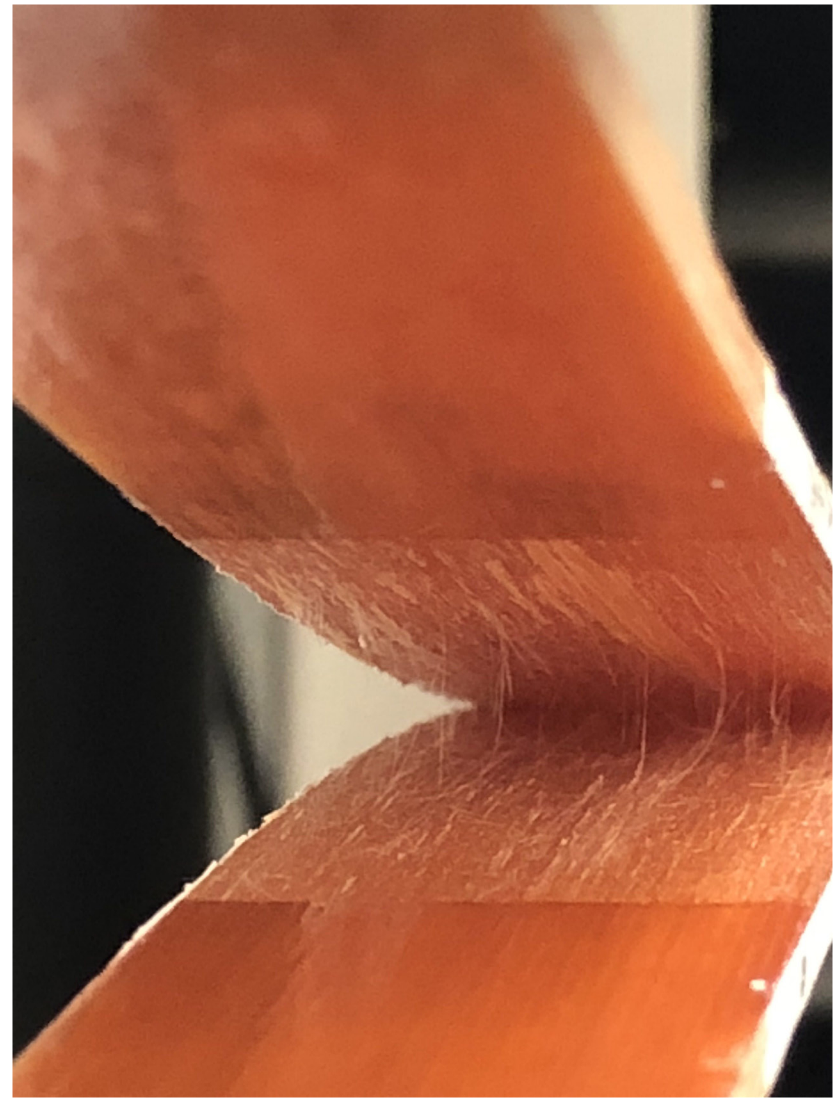


Figure 2: Delamination at an interface of plate processed using Layer-by-Layer curing with a degree of precure close to resin gelation (~60%).

Work Stream Outputs

- Belnoue J, Sun R, Cook L, Tifkitsis K, Kratz J, Skordos AA. *"A Layer-by-Layer (LbL) Manufacturing Process for Composite Structures"*, ICMAC 2018, Nottingham, July 2018.
- Mesogitis T, Kratz J, Skordos A A. *"Heat Transfer Simulation of the Cure of Thermoplastic Particle Interleaf Carbon Fibre Epoxy Prepregs"*, Journal of Composite Materials, 53(15), pp. 2053–2064, 2019.
- An EPSRC Impact Accelerator Account was awarded for a project with Airbus (Oct 2019 to Mar 2020), *"Infusion of Integrated Structures With Partially Cured Elements"* with a leveraged grant value of £97,864. Concepts developed in the LbL Feasibility Project were used to partially cure a part that was integrated into a demonstrator. The scientific challenges identified in the higher TRL demonstrator are being addressed in the LbL Core Project, as part of an Airbus sponsored CDT studentship.

Workstream 5

Liquid Moulding Technologies

Work Stream Overview

Scan to hear about the project

Liquid Moulding Technologies, where resin is injected into a dry fibre preform, offer significant rate improvements over traditional autoclave-based manufacturing processes. However, variabilities in the preforming and moulding aspects and limitations in existing simulation methods compound to add uncertainty and increase the risk of defects.

A collaboration between Mathematics and Engineering at Nottingham is developing novel Bayesian Inversion algorithms for detecting defects during the moulding stage using in-process data and applying a correction to process parameters via estimation algorithms to eliminate defects. The algorithms have been validated for defects of arbitrary shape using Digital Twin models and laboratory experiments.

Industrial needs:

- Standardisation of procedure for reliable permeability characterisation.
- Development of tools for better process design.
- Utilisation of in-process sensors to achieve better process control.

Work Stream Aims

Starting in November 2019 the Active Resin Transfer Moulding (RTM) Core Project was developed from a successful Feasibility Study. The aim of this project is to create an in-process NDE system for the RTM process. There are two objectives to achieve this aim:

1. The creation of a Digital Twin for the RTM process to capture in-process data to estimate local deviations from the design for any manufactured part. The project will develop, improve and test innovative Bayesian inversion algorithms (BIA) to restore the local permeability of composite components, based on data collected from sensors during resin injection into the reinforcement.

2. The project will develop and test an active control system based on information from sensors and on physical models together with on-line parameter estimation algorithms to improve resin injection. This control system will minimise the occurrence of defects and ensure process robustness.

These objectives are being delivered via an interdisciplinary approach between engineers and applied mathematicians, which will lead to a set of algorithms and tools that can be applied across a wide variety of technologies and industry sectors.

Work Stream Team

Principal Investigators: Prof Michael Tretyakov, University of Nottingham.

Co-Investigators: Dr Andreas Endruweit, Nottingham; Prof Andrew Long, Nottingham; Dr Marco Iglesias, Nottingham.

Researchers: Dr Mikhail Matveev, Nottingham; Dr Andrew Parsons, Nottingham; Dr Adam Joesbury, Nottingham.

PhDs: Gwladys Popo, Nottingham.

Industry Partners: ESI, LMAT, NCC, GNK Aerospace, AMRC.

Work Stream Project

- **Core Project:** Active Resin Transfer Moulding (RTM) (Nottingham)
- **Platform Fellow:** Permeability testing Methods (Dr Andreas Endruweit - Nottingham)
- **Platform Fellow:** Local Resin Printing for Preform Stabilisation (Dr Adam Joesbury - Nottingham)
- **Feasibility Study:** Active Resin Transfer Moulding (Nottingham)

Hub Investment £948k

Leveraged Industry Support £235k

Leveraged Grants £8k

Leveraged Academic Support £70k

Work Stream Progress

1. A novel Regularising Ensemble Kalman filter Algorithm based on the Bayesian paradigm was applied to RTM processes to estimate local porosity and permeability of fibrous reinforcements using measured values of local resin pressure and flow front positions during resin injection. The algorithm enables the detection of locations of defects in the preform. It was tested in virtual experiments with two geometries, a two-dimensional rectangular preform and a more complex 3D shape, as well as in laboratory experiments. In both the virtual and laboratory experiments, it was demonstrated that the proposed methodology is able to successfully discover defects and estimate local porosity and permeability with good accuracy.
2. The algorithm also provides confidence intervals for the predictions and estimations of defect probabilities, which are valuable for analysis of the process. The algorithm can cope with more localised but still important defects (e.g. race-tracking).
3. Development of a virtual lab demonstrator is underway.

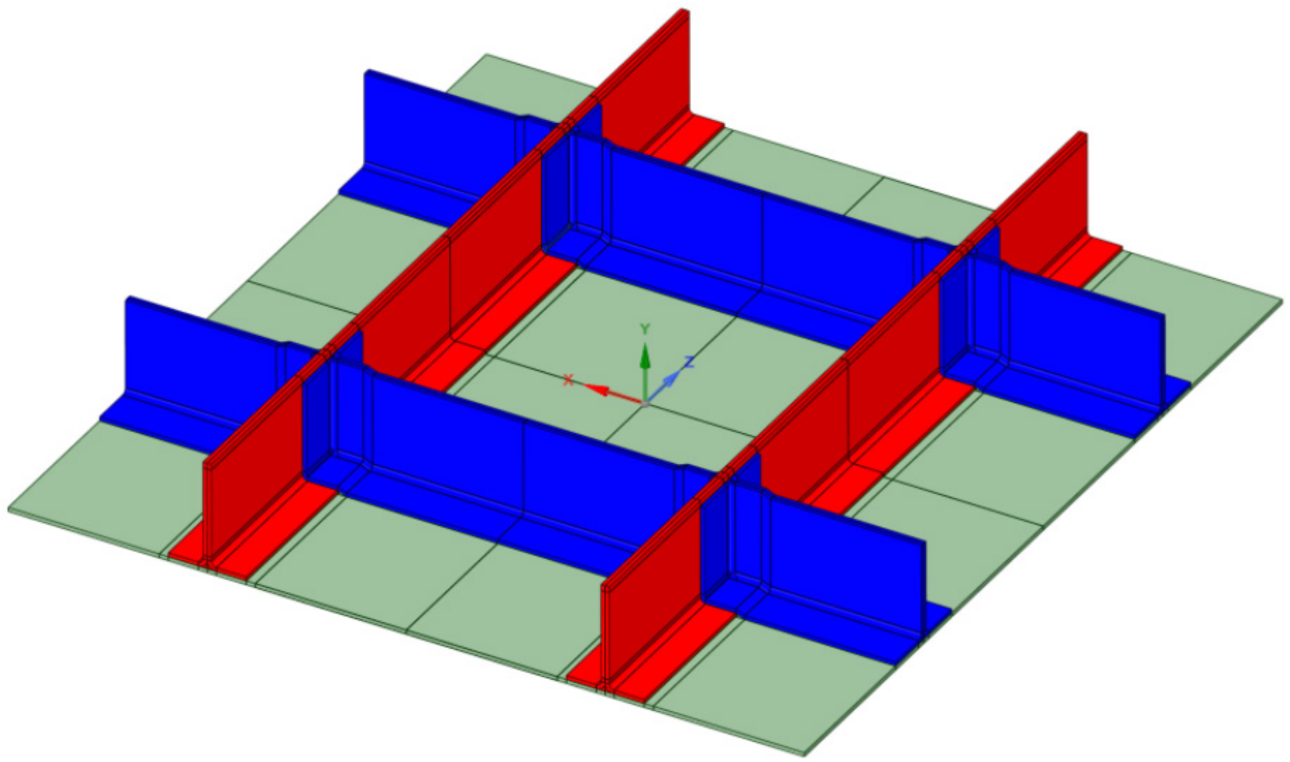


Figure 1: Virtual demonstrator for a defect detection and flow control in a stiffened panel.

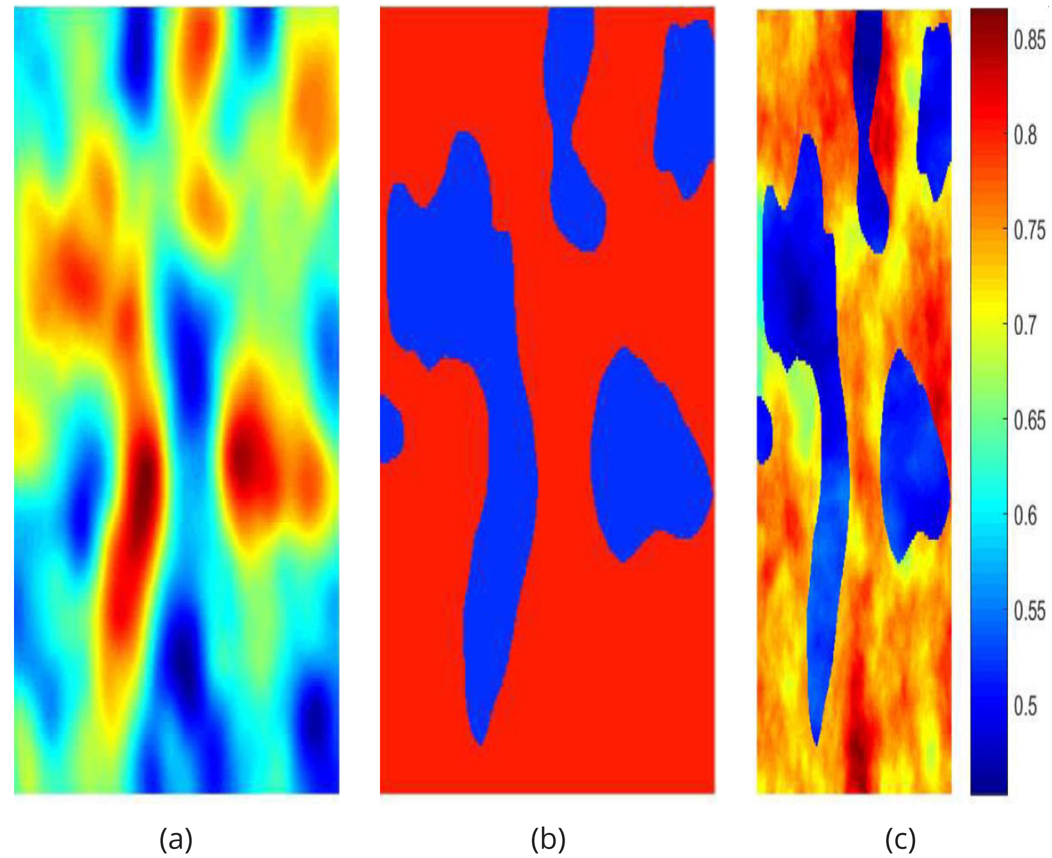


Figure 2: Two-level parametrisation of a porosity field. (a) level-set function; (b) truncated level-set function defining regions of porosity (Region 1 in blue, Region 2 in red); (c) random porosity field.

Work Stream Outputs

- Impact Exploration Grant (Nottingham Impact Accelerator) helped to better understand industrial needs.
- Matveev M, Endruweit A, Iglesias M, Long AC, Tretyakov MV. *"Bayesian Inversion Algorithm for Estimating Local Variations in Permeability and Porosity of Reinforcements Using Experimental Data"*, Composites Part A: Applied Science and Manufacturing, 143, 106323, 2021.
- Iglesias M, Yang Y. *"Adaptive Regularisation for Ensemble Kalman Inversion"*, Inverse Problems, 37(2): 025008, 2021.
- May D et al. *"In-Plane Permeability Characterization of Engineering Textiles Based on Radial Flow Experiments: a Benchmark Exercise"*, Composites Part A, 121, pp. 100-114, 2019.
- Endruweit A, Zeng X, Matveev M, Long A. *"Effect of Yarn Cross-sectional Shape on Resin Flow Through Inter-Yarn Gaps in Textile Reinforcements"*, Composites Part A, 104, pp. 139-150.

Workstream 6

Composite Forming Technologies

Work Stream Overview

Scan to hear about our project

Automated composite forming is recognised as an important enabling technology, offering significant improvements on manufacturing rate, volume and quality compared to hand layup. Starting in September 2020, the Core Project leading WS6 was developed from the combination of two successful Feasibility Studies which developed a process-specific forming limit diagram for dry non-crimp fabrics (NCFs) and a finite element forming simulation of composite sandwich panels incorporating NCFs.

The mechanics of fabric deformation in forming has been developed to an advanced level, but defect formation and forming limits are not clearly characterised. Bath, Cambridge and Nottingham will deliver enhanced experimental material characterisation methods and high-fidelity explicit FE simulation techniques to enable 3D formed composite components to be manufactured from woven and Non Crimp Fabric (NCF) textiles with a high degree of precision.
Research challenges:

- The mitigation of defects during forming.
- Lack of robust and validated simulation tools including defect avoidance

Work Stream Aims

The aim of the Design Simulation Tools for NCF Preforming Core Project is to provide process improvements and simulation design tools that will enable composite components to be designed and manufactured from textile preforms more efficiently and with greater confidence in their performance. The project will focus specifically on dry non-crimp fabrics (NCFs) and Double Diaphragm Forming (DDF), to create high-performance preforms suitable for liquid moulding.

Selected materials and manufacturing routes have been strongly influenced by the experience of the industry collaborative partners.

Work Stream Team

Principal Investigators: Prof Michael Sutcliffe, Cambridge.

Co-Investigators: Dr Lee Harper, Nottingham; Dr Andrew Rhead, Bath; Prof Richard Butler, Bath; Dr Evros Loukaides, Bath.

Researchers: Dr Shuai Chen, Nottingham; Dr Andrea Codolini, Cambridge; Dr Connie Qian, Warwick.

PhDs: Angela Lendinez Torres, Nottingham; Guy Lawrence, Nottingham; Rajan Jagpal, Bath; Verner Viisainen, Cambridge; Salem Erouel, Nottingham; Fei Yu, Nottingham.

Industry Partners: Hexcel, Gordon Murray Design, GKN Aerospace, Dassault Systemes.

Work Stream Projects

- **Core Project:** Design Simulation Tools for NCF Preforming (Bath/Cambridge/Nottingham)
- **Innovation Fellow:** Compression moulding simulation (Connie Qian – Warwick)
- **Feasibility Study:** Sandwich Panel Forming (Nottingham)
- **Feasibility Study:** Composite Forming Limit Diagram (Cambridge)
- **Feasibility Study:** Braid Forming Simulation (Nottingham)
- **Feasibility Study:** Incremental Sheet Forming (Bristol/Nottingham)

Hub Investment £1.1m

Leveraged Industry Support £72k

Leveraged Grants £620k

Leveraged Academic Support £545k

Work Stream Progress

1. A global to local finite element forming simulation tool has been developed to increase the fidelity of fabric drape modelling. The model has been developed to predict the occurrence of small amplitude wrinkles (~ 1-2 mm) for large length scale components (+ 10 m).

2. An intra-ply stitch removal algorithm has been developed to remove local stitches in NCF plies to improve formability, in an effort to reduce ply wrinkling. The model uses a multi-objective Genetic Algorithm to selectively remove stitches from each ply in the layup with the objective of reducing the maximum shear angle, whilst minimising the area of stitches removed to maintain stability during handling.

3. A novel resin printing method has been explored, using additive manufacturing techniques to locally control the shear stiffness of non-crimp fabrics.

4. A wrinkle prediction tool has been developed using a Deep Learning approach to understand why defects occur according to certain features within the tool geometry, ensuring designers can produce parts that are fit for manufacture via the DDF process.

5. A new friction characterisation method has been developed to capture the inter-ply frictional behaviour during DDF. The rig has been designed to determine the dynamic coefficient of friction under an applied normal pressure of 0.1 MPa, whilst enabling the effects of in-plane fabric shear and fabric saturation to be studied.

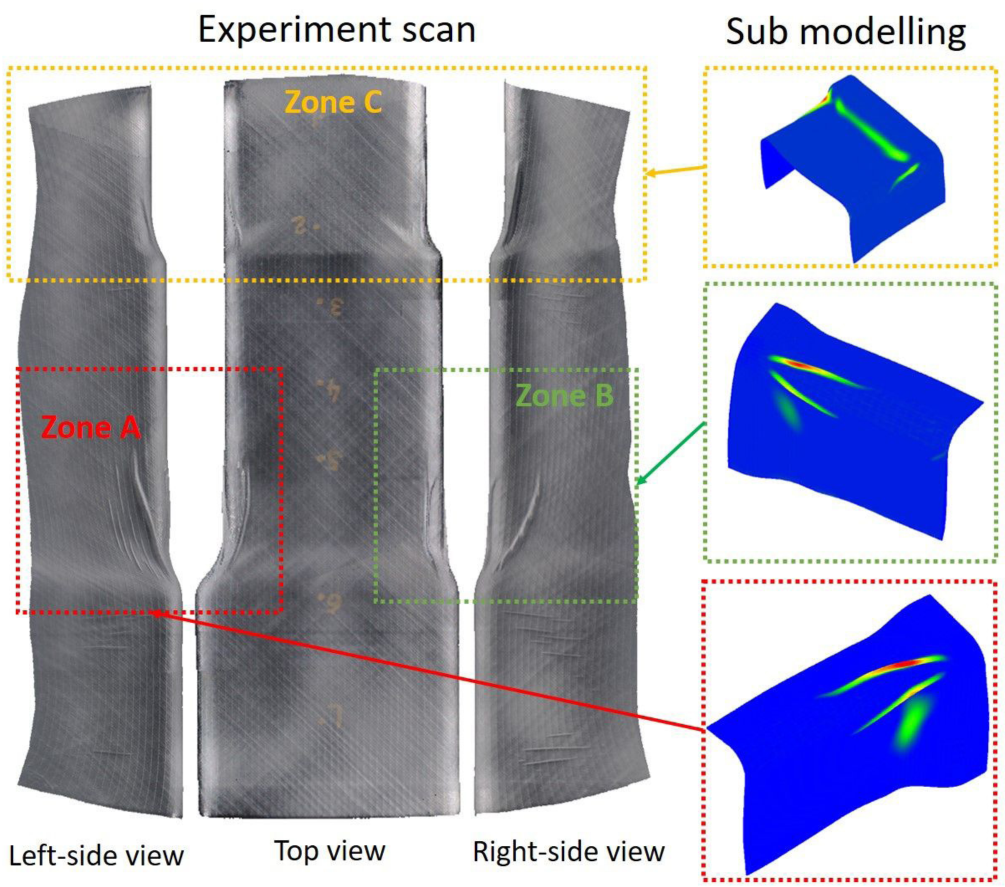


Figure 1: Wrinkle patterns form experiment and simulation results based on a global-to-local sub modelling approach.

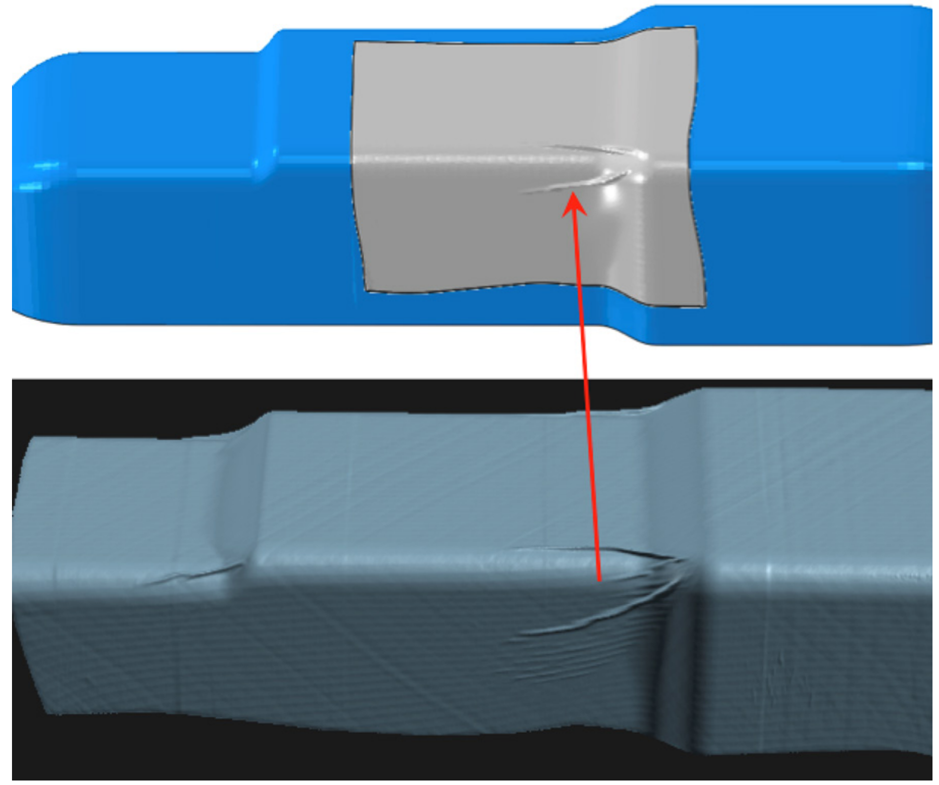


Figure 2: Comparison of global to local fabric forming model output (Top) with experimental preform (bottom)

Work Stream Outputs

- Chen S, McGregor OPL, Endruweit A, Harper LT, Warrior NA. *"Simulation of the Forming Process for Curved Composite Sandwich Panels"*, International Journal of Material Forming. Open Access: https:// doi.org/10.1007/s12289- 019-01520-4, 2019.
- Yu F, Chen S, Viisainen JV, Sutcliffe MPF, Harper LT, Warrior NA. *"A Macroscale Finite Element Approach for Simulating the Bending Behaviour of Biaxial Fabrics"*, Composites Science and Technology, Vol 191, 108078, 2020.
- Yu F, Chen S, Harper LT, Warrior NA. *"Simulating the Effect of Fabric Bending Stiffness on the Wrinkling Behaviour of Biaxial Fabrics During Preforming"*, Composites Part A: Applied Science and Manufacturing, Volume 143, 106308, 2021.
- Viisainen JV, Hosseini A, Sutcliffe MPF. *"Experimental Investigation, Using 3D Digital Image Correlation, into the Effect of Component Geometry on the Wrinkling Behaviour and the Wrinkling Mechanisms of a Biaxial NCF During Preforming"*, Composites Part A: Applied Science and Manufacturing, Volume 142, 106248, 2021.
- Viisainen JV, Zhou J, Sutcliffe MPF. *"Development of a Composite Forming Limit Diaphragm: a Feasibility Study"*, 22nd International Conference on Composite Materials (ICCM22), Melbourne, Australia, August 2019.
- Chen S, McGregor OPL, Endruweit A, Harper LT, Warrior NA. *"Finite Element Forming Simulations of Complex Composite Sandwich Panels"*, 22nd International Conference on Composite Materials (ICCM22), Melbourne, Australia, August 2019.

Workstream 7

Microwave Processing Technologies

Work Stream Overview

Scan to hear about our project

Microwave heating has long promised great potential for increased control and reduction in curing time via rapid and localised heating, as well as a reduction in processing power requirements. However, significant technical and safety challenges remain unsolved. WS7 aims to research microwave technologies for fibre tow-based manufacturing processes and in-mould heating for curing of thermosets and polymerisation of thermoplastics. This will include development of microwave cavities and waveguides suitable for material deposition rates in the range of 100 kg/hour to meet industry productivity demands. Research challenges related to conductive fibres and containment of radiation will be addressed with modelling and laboratory experiments.

WS7 is led by Wrexham Glyndŵr as a combination of smaller projects, and was established in February 2019 following the Hub Synergy Workshop, which identified Microwave Processing Technologies as a key enabler for high rate material deposition and processing. There is currently no Core Project to lead this Work Stream, but this presents an opportunity for the three Feasibility Studies and development of future projects within this research area.

Work Stream Aims

Three Feasibility Studies have been conducted to optimise the use of microwave heating for three different sets of materials and production methods. The latest Feasibility Study "Microwaves for Automated Fibre Placement" finished in January 2021. The Project aimed to:

1. Develop microwave cavities suitable for in line heating of tows at 2.45 GHz and to couple to an existing 2 kW microwave system.
2. Assess the potential heating rates achievable on narrow static tows in the laboratory using a sealed system.
3. Investigate designs of microwave choke or screening to ensure that the microwave radiation is contained during processing with conductive fibres.
4. Conduct simple trials at UoB to assess the potential of the microwave system in enhancing the lay down rate of wide (100 mm) tape. This objective was modified due to restrictions caused by COVID-19, and a rig for narrow tape was built at WGU and tested instead.
5. Consider methods for increasing the power delivered in follow on projects.

Work Stream Team

Principal Investigators: Prof Richard Day, Glyndŵr; Prof Derek Irvine, Nottingham; Dr Mihalis Kazilas, Brunel.

Co-Investigators: Dr Betime Nuhiji, University of Sheffield; Dr Chris Dodds, Nottingham; Dr Andrew Parsons, Nottingham.

Researchers: Dr Nataliia Luhyna, Glyndŵr; Dr Asimina Manta, Sheffield.

PhDs: Dimitris Fakis, Brunel.

Industry Partners: MX Group, BAE Systems.

Work Stream Projects

- **Feasibility Study:** Microwaves for Automated Fibre Placement (AFP) (Sheffield/Wrexham)
- **Feasibility Study:** Microwave Heating through Embedded Coaxial Cables (Brunel)
- **Feasibility Study:** Monomer Transfer Moulding (Edinburgh/Nottingham/Sheffield)

Work Stream Progress

Results from the recently completed Microwaves for AFP Feasibility Study:

1. A truncated WR9a waveguide section was identified as the most promising cavity design based on modelled and laboratory trials, where power was limited to 200W. Heating rates in the trials showed that the target layup rate of 100kg/hr for carbon/epoxy could potentially be achieved with a power of 6 kW, similar to that used in diode laser heating systems.

2. Models of the selected microwave cavity were assessed using the electromagnetic simulation software to determine optimal containment. The modelling demonstrated the effectiveness of a Faraday cage solution and the limitations of a choke design for an AFP system.

Work Stream Outputs

- Discussions are underway to create a demonstration facility for microwave-based tape laying at the AMRC in Sheffield.
- A follow-on project, subject to funding, has the potential to provide a step change in layup rates, either on its own or combined with laser heating, and is being undertaken in collaboration with BAe Systems to understand susceptibility of BMI-based materials to high frequency microwaves.
- Continuation of work at 200 W/ 5.8 GHz (BMIs) and 2kW/ 2.45 GHz for higher power/laydown rate to test modelling further (and further outputs).
- There is potential for collaboration with Nottingham and Bristol since both are working on AFP projects and Nottingham have a project on direct heating.
- There is overlap with other work at Bristol and Southampton, now part of a Synergy project connecting the work on microwave processing of composites with expertise in sensor development looking at residual stress and temperature development during microwave cure.

Workstream 8

Thermoplastic Processing

Work Stream Overview

Scan to hear about our project

Thermoplastic composites offer potential for rapid consolidation, the possibility of multi-stage forming, jointing by welding and relative ease of recycling. They also offer reduced Takt times compared to thermosetting materials, making them attractive for high-volume applications. The UK is currently some way behind the research leaders in the Netherlands, who are Hub international partners, therefore the aim is to accelerate this activity.

In 2020, a Hub Thermoplastics Working Group was established with objectives to generate a new collaborative project and applications for external funding. An international mission with a focus on engaging with thermoplastic composites groups in the Netherlands and Germany will be conducted in 2021. With UK companies such as Victrex, the creators of PEEK polymer, and investments from the likes of GKN in the recently completed Filton Aerospace Technology Centre, the UK is well placed to be competitive in this area.

Research opportunities and challenges:

- High rate forming and thermal cycling.
- Assembly and bonding.
- Liquid moulding.
- Additive manufacturing.
- Sustainability of manufacturing and end of life waste.

Work Stream Aims

The overarching aim of this Work Stream is to support and expand the UK's thermoplastic research activities and capabilities, promoting the benefits of thermoplastic composites and establishing new collaborations. Research into Thermoplastic Processing has been active since the Hub began, but the recent Hub Synergy Promotion event has enabled links to be created between a range of Hub investments. A number of Feasibility Studies have investigated the forming behaviour of fibre reinforced thermoplastic sheet materials, under the Composite Forming Technologies Work Stream 6. These include "Incremental sheet forming of thermoplastics", "Monomer transfer moulding using microwaves", and the "Layer by Layer" Feasibility Study.

Work Stream Team

Principal Investigators: Dr Andreas Endruweit, Nottingham; Dr Lee Harper, Nottingham; Dr Dipa Roy, Edinburgh; Prof Derek Irvine, Nottingham; Andrew Mills, Cranfield; Dr Mike Johnson, Nottingham; Prof Ton Peijs, Warwick; Dr Philip Harrison, Glasgow; Dr Edward Archer, Ulster; Prof Richard Day, Glyndwr.

Researchers: Dr Andrew Parsons, Nottingham; Dr Mikhail Matveev, Nottingham; Dr Adam Joesbury, Nottingham; Dr N Reynolds, Warwick; Dr A Bras , Cranfield; Dr L Cook, Cranfield; Dr J Hurley, Cranfield.

PhDs: George Street.

Industry Partners: Surface Generation, Bruggemann, Engel, Evonik, Veeloheat, AMRC, Gordon Murray Design, FAR-UK, Arkema, Eirecomposites, Toray, Expert Tooling & Automation, TU Dresden, European Thermodynamics, INEGI, Induction Coil Solutions, Forrest Precision Engineering.

Work Stream Projects

- **Platform Fellowship:** Development of Rapid Processing Routes for Carbon Fibre/ Nylon6 (Nottingham)
- **Feasibility Study:** Thermoplastic Framework (Cranfield)
- **Feasibility Study:** In-situ Polymerisation of Fibre Metal Laminates (Edinburgh)
- **Feasibility Study:** Multi-step Thermoforming (Glasgow)
- **Feasibility Study:** Micro-integration of Polymeric Yarns (Ulster)
- **Feasibility Study:** VARIOTHERM (Warwick)
- **Feasibility Study:** Thermoplastic Double Diaphragm Forming (Edinburgh/Nottingham)

Hub Investment £526k

Leveraged Industry Support £5k

Leveraged Grants £181k

Leveraged Academic Support £145k

Work Stream Progress

1. Ulster demonstrated the successful incorporation of through-thickness thermoplastic micro-yarns into fabrics to improve delamination resistance.

2. Cranfield provided an extensive assessment of proof of concept for automotive assembly without fasteners. Cranfield was one of the first partners to engage with the thermoplastics working group and is leading the Layer by Layer Core Project.

3. The recently completed Incremental Forming Feasibility Study at Nottingham has successfully demonstrated the use of bulk vacuum forming with precision robot forming to produce difficult geometries. The feasibility study demonstrated the concept of die-less forming using local heat and pressure.

4. The Double Diaphragm Forming project at Nottingham has progressed through its first milestones, successfully producing a nylon test panel between flexible tooling and the production of a small scale forming frame, which is currently being evaluated.

5. Glasgow demonstrated a new concept for multistage forming with novel induction heating and that work is continuing, with a recent paper published and a presentation at the British Plastics Federation Webinar.

6. The Variotherm project successfully demonstrated the use of thermoelectric heating and cooling to achieve a very rapid heat and cool cycle, cooling and then heating by a rate of 40 degrees centigrade per minute. A larger, double sided multicell system is in development which will demonstrate the ability to vary heating control across a tool face.

Work Stream Outputs

- Harrison P, Campbell I, Guliyev E, McLelland B, Gomes R, Curado-Correia N, McGookin E, Mulvihill DM. *"Induction Melt Thermoforming of Advanced Multi-axial Thermoplastic Composite Laminates"*, Journal of Manufacturing Processes, Volume 60: Pages 673-683, 2020.
- ENACT Enhanced Characterisation and Simulation Methods for Thermoplastic Overmoulding funded by Innovate UK, March 2020. New international engagement with Michigan State University and a new UK industrial partner, Surface Generation.
- Mamalis D, Obande W, Koutsos V, Blackford JR, Ó Brádaigh CM, Ray D. *"Novel Thermoplastic Fibre-metal Laminates Manufactured by Vacuum Resin Infusion: the Effect of Surface Treatments on Interfacial Bonding"*, Materials & Design, Volume 162, Pages 331-344, 2019.
- Mills A, Cook L, Bras A. *"Affordable Thermoplastic Matrix C FC / Metallic Framework Structures Manufacture"*, 8th International Symposium on Composites Manufacturing for High Performance Applications (ISCM 2018), Marknesse, Netherlands, November 2018.
- A Researcher from the University of Edinburgh has visited University of Auckland, New Zealand to support their work in developing a next generation mixing system for in-situ polymerisation of Nylon.

Demonstration of Rapid Heating and Cooling using VARIOTHERM Tooling

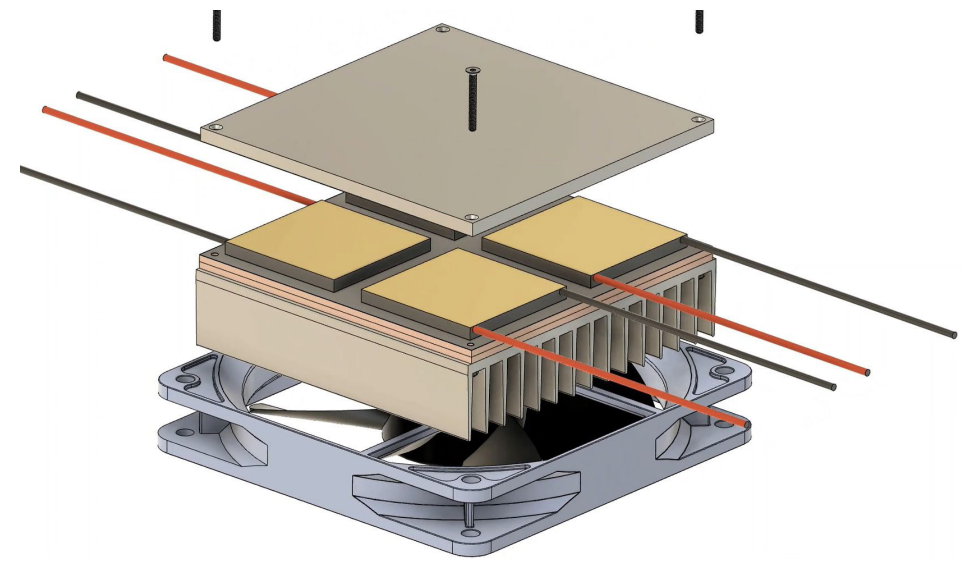


Figure 1: Exploded view 2 x 2 TE system

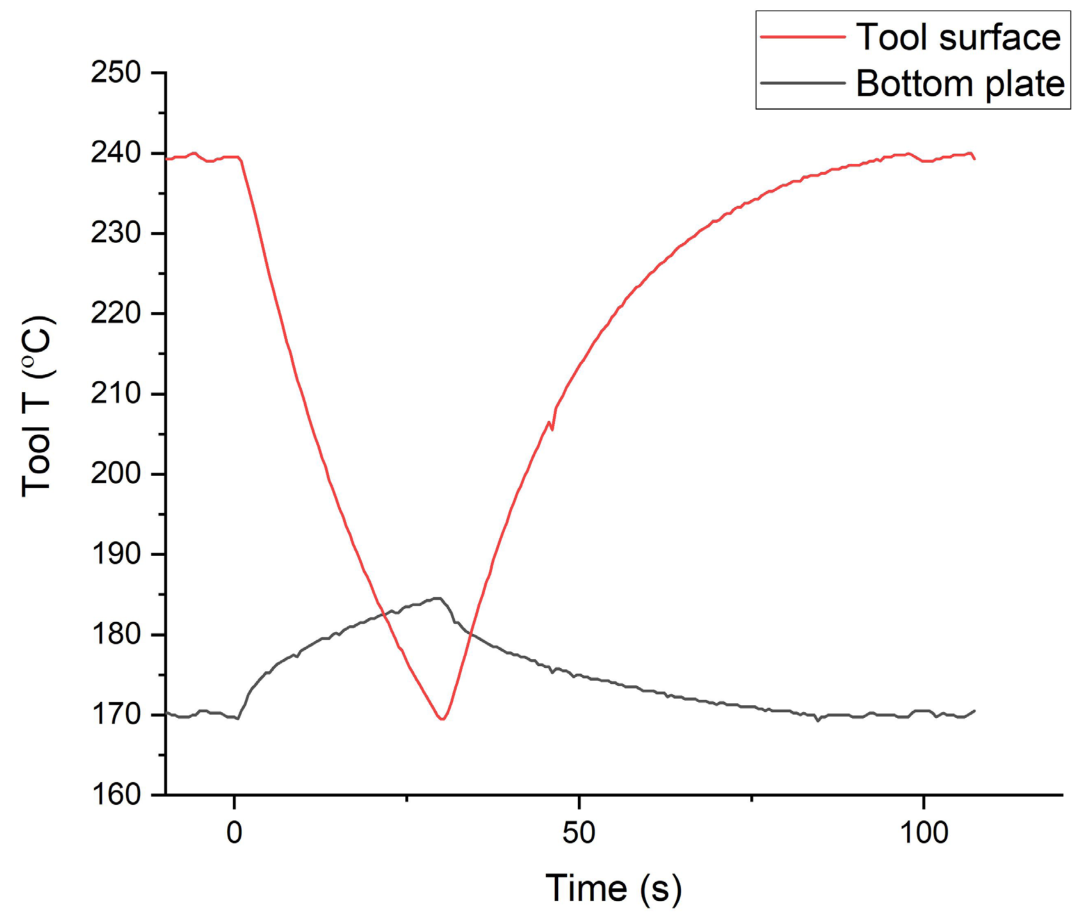


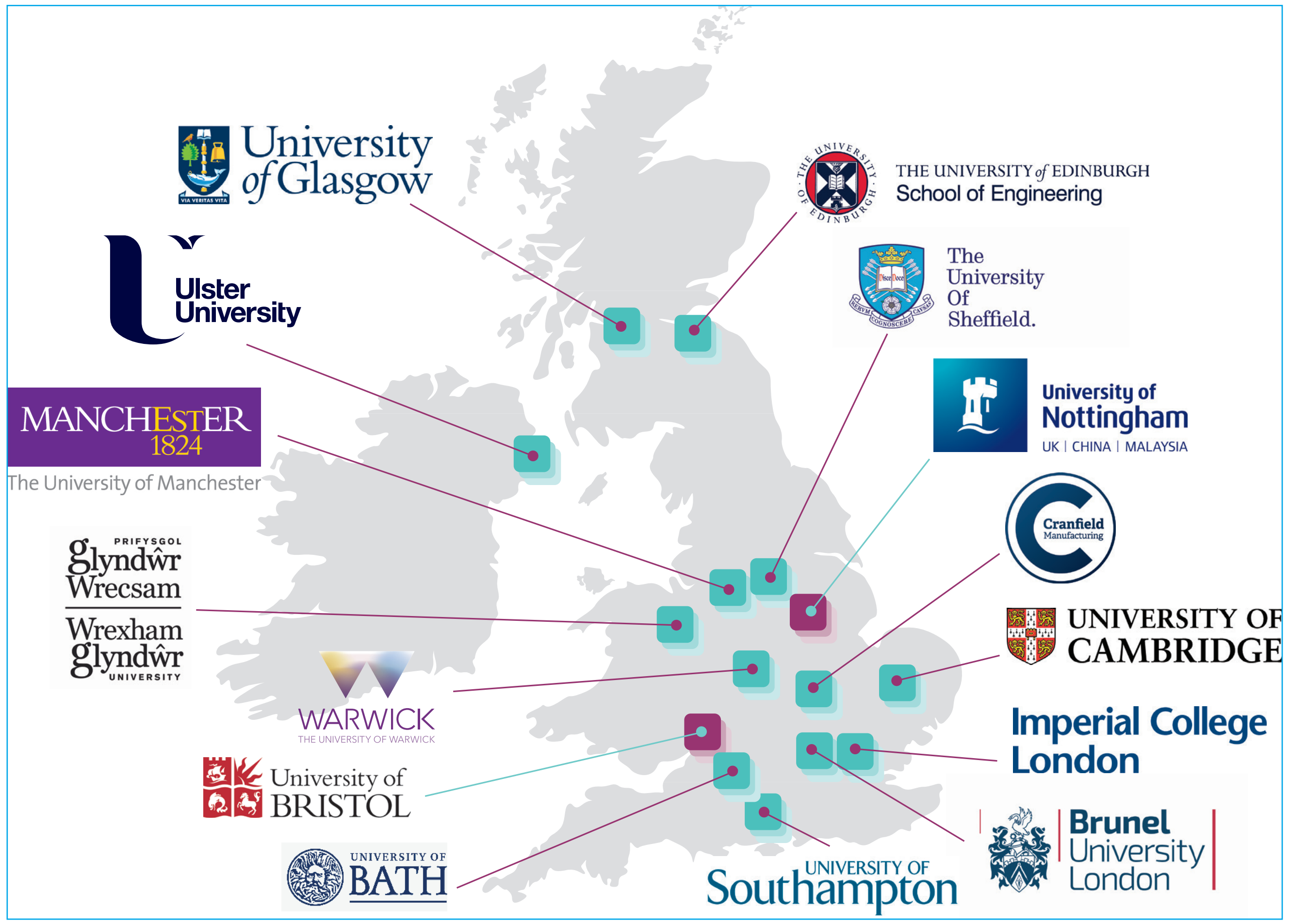
Figure 2: Temperature vs. time for tool surface/bottom plate

6 Hub Network

The key to sustaining the Hub is in developing the national and international communities to establish important ongoing partnerships for future research programmes. One of the KPIs defined for the Hub was to leverage a further £20m of funding for new research projects, some of which were intended to extend beyond the life of the current programme. The current total leveraged grant income stands at £18.9m.

6.1 Academic Partners

The Hub continues to engage with the national academic network in composites manufacturing research through active collaboration with UK research groups. Engagement beyond the original Hub membership of Nottingham and Bristol and four Spokes (Manchester, Imperial, Southampton and Cranfield), has primarily been through Feasibility Study calls. Successful applicants are invited to become Spokes and we currently have 15 academic members participating in the Hub.

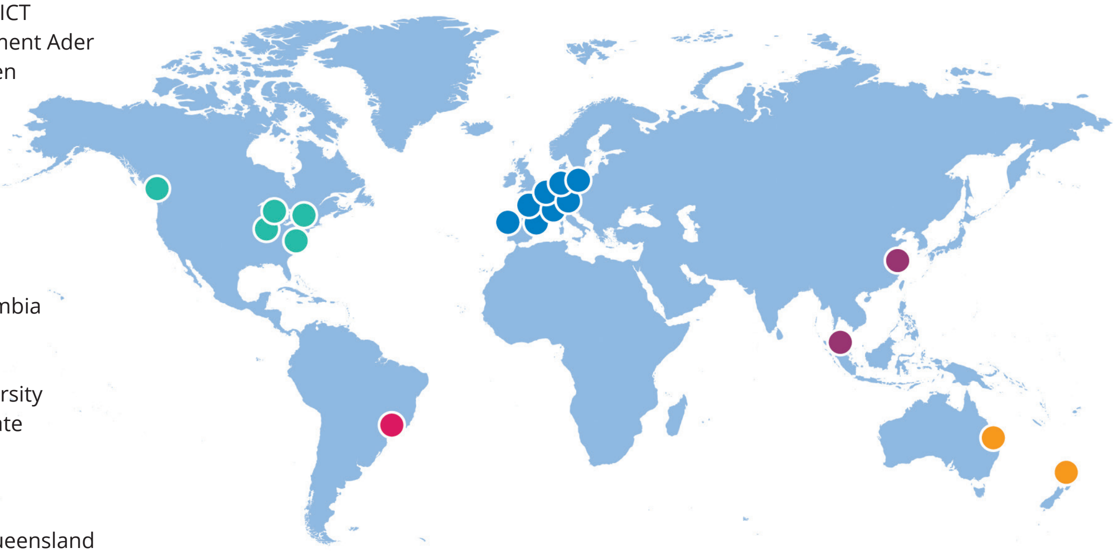


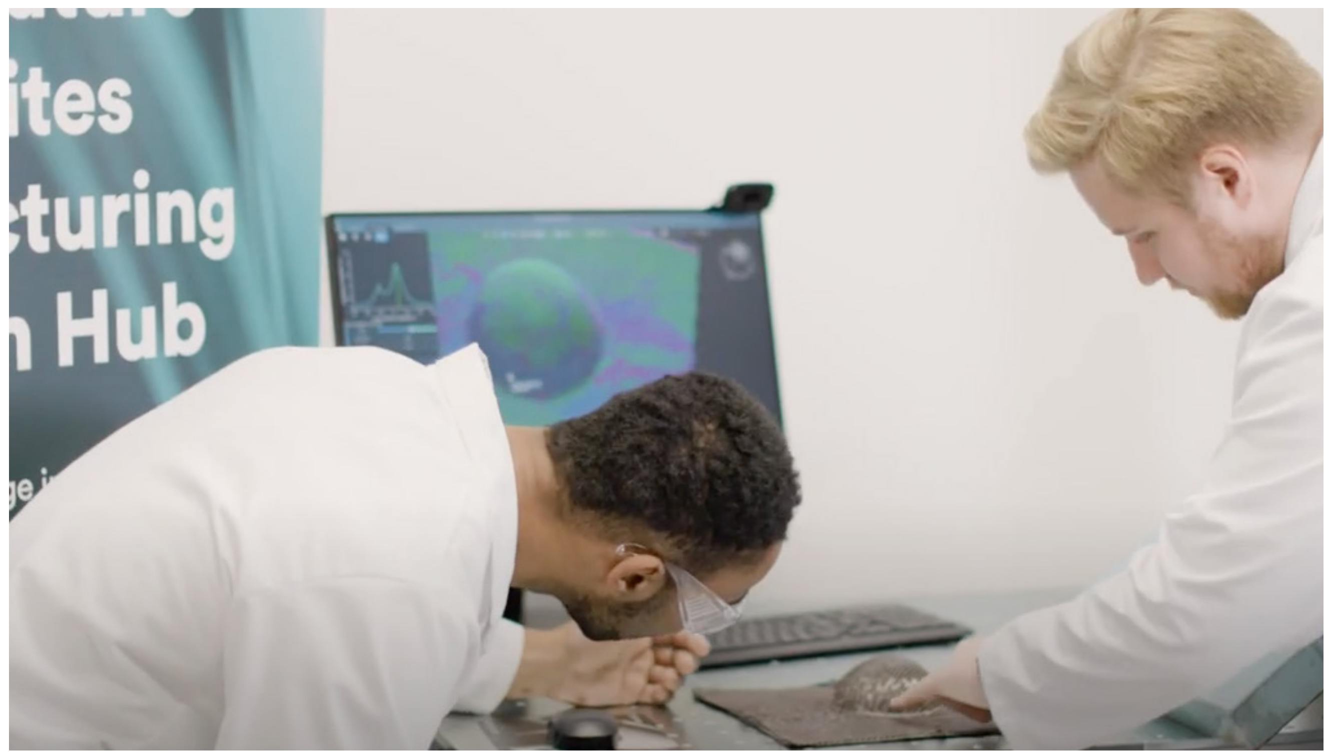
6.2 International Network

The Hub has developed a network of 23 leading institutions across 11 countries. This is important not only for sharing information and developments in composites manufacturing, but also in our training aspirations, as Hub postgraduate students will have the opportunity to spend a three months secondment at one of the linked institutions, accessing new expertise and facilities and developing their personal networks. We have successfully funded three Study Placements within our international partner network, helping students to foster independence.

- Aachen
- Dresden
- École Centrale
- EPFL
- Federal
- Fraunhofer ICT
- Institut Clement Ader
- Kaiserslauten
- Leuven
- Munich
- Porto
- Stuttgart
- Twente
- UNNC
- UNMC
- British Columbia
- Concordia
- Delaware
- McGill University
- Michigan State
- Purdue
- LEL-IPT
- Auckland
- Southern Queensland

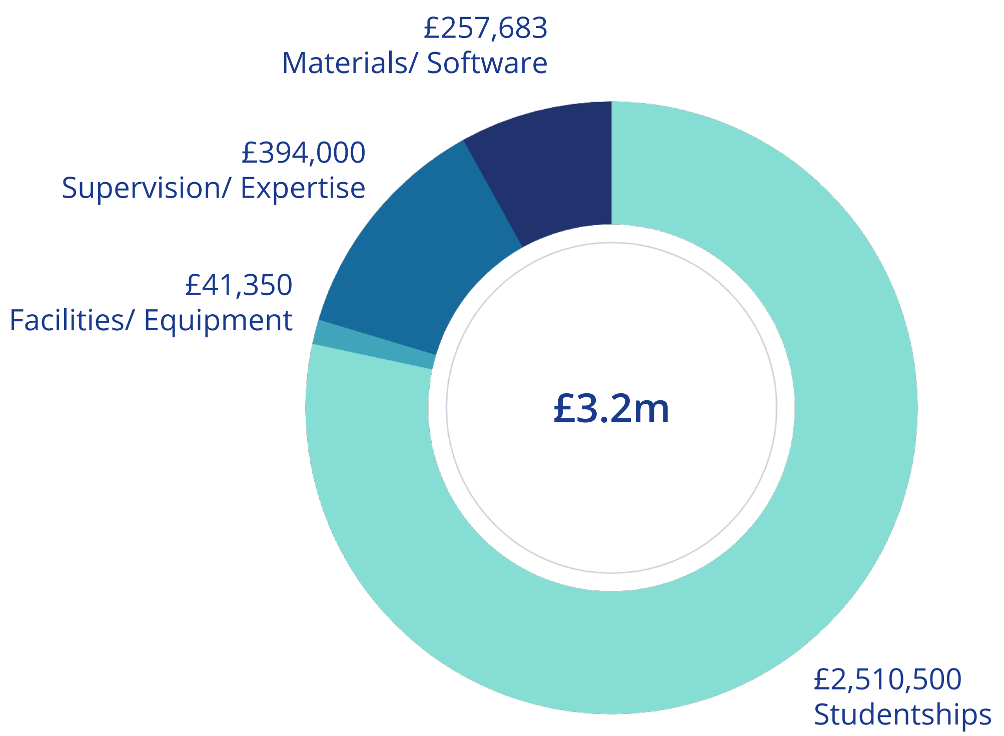
- 23 leading institutions across 11 countries
- Share information and developments in the field
- Facilitate visits and exchange of people
- Establish informal or formal partnerships in research programmes
- All have agreed to host visits from staff and students for 3 months





6.3 Industry and Catapult Partners

Industrial support has grown strongly over the life of the Hub. Research projects are supported by a network of 37 industrial partners and four centres within the HVM Catapult, providing £3.2m of leveraged support in the form of studentships, supervision, materials and access to equipment.



Industry contributions totalling £3.2m to date; Largest contribution is for studentships, the National Composites Centre is the largest supporter to date - £1.4m.

The Hub is pleased to welcome PAC Group, Northern Ireland, as the latest company to join the consortium as an Industrial Partner.

Industry Partners

The University Of Sheffield. Advanced Manufacturing Research Centre BOEING
AIRBUS
ASTON MARTIN
BAE SYSTEMS
BENTLEY
Bitrez
COMPOSITE INTEGRATION ltd
CORIOLIS composites
DASSAULT SYSTEMES
esi get it right®
European Thermodynamics Limited Intelligent Thermal Management
GE Aviation
FreiLacke
GKN AEROSPACE
GORDON MURRAY DESIGN
HEXCEL
LUXFER GAS CYLINDERS
mtc Manufacturing Technology Centre
M.Wright & Sons Ltd. Engineered Textile Structures (Established 1860)
NATIONAL COMPOSITES CENTRE
NetworkRail
PAC GROUP
PENTAXIA
Rolls-Royce
SCOTT BADER
sigmatex material innovation
TORAY Innovation by Chemistry
WMG THE UNIVERSITY OF WARWICK

Additional Industry Partners

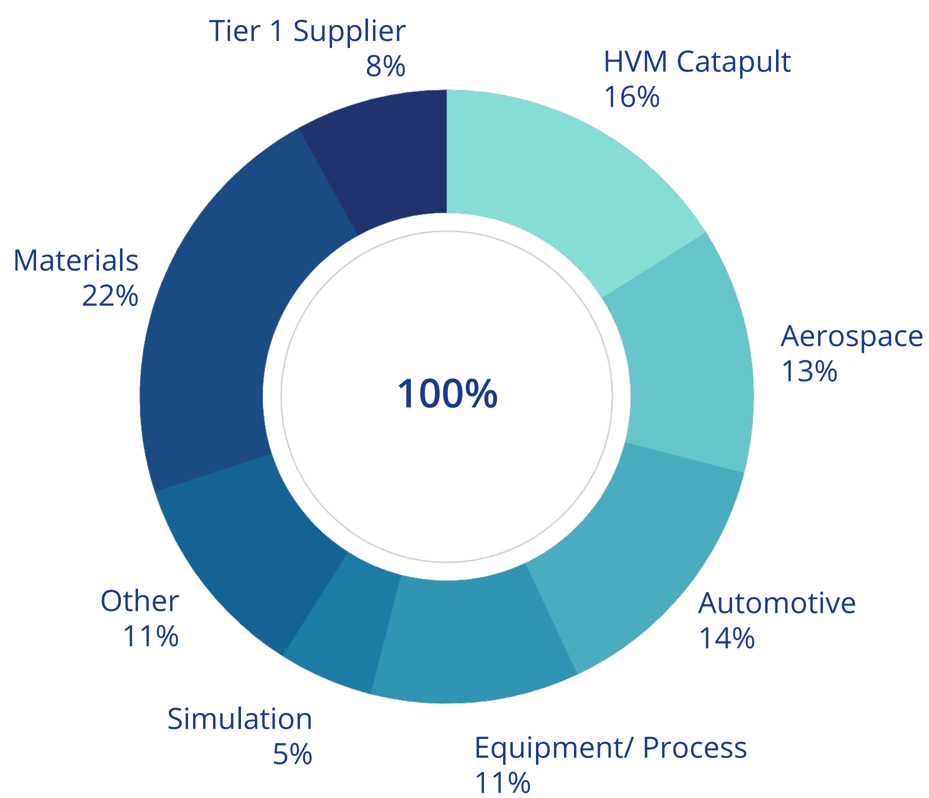
Alexander Dennis	Heraeus Precision	Solvay
Arkema	Heraeus Noblelight	QinetiQ
Expert Tooling & Automation	Induction Coil Solutions	Shape Machining
FAR UK	KW Special Projects	Surface Generation
Forrest Prescision	Porcher	Toray Advanced Composites

Industrial Engagement

Support from our Industry Partners helps to ensure our research is industrially relevant and that outputs progress towards commercialisation. This occurs through two mechanisms; support from the Hub's Advisory Board and hosting regular technical project review meetings with our Industry Partners. All project leads are appointed a mentor from the Advisory Board to help identify opportunities for exploitation. This insight helps to coordinate project-level technical meetings for each Work Stream, where specific partners are invited biannually to engage in comprehensive reviews of the projects and offer guidance.

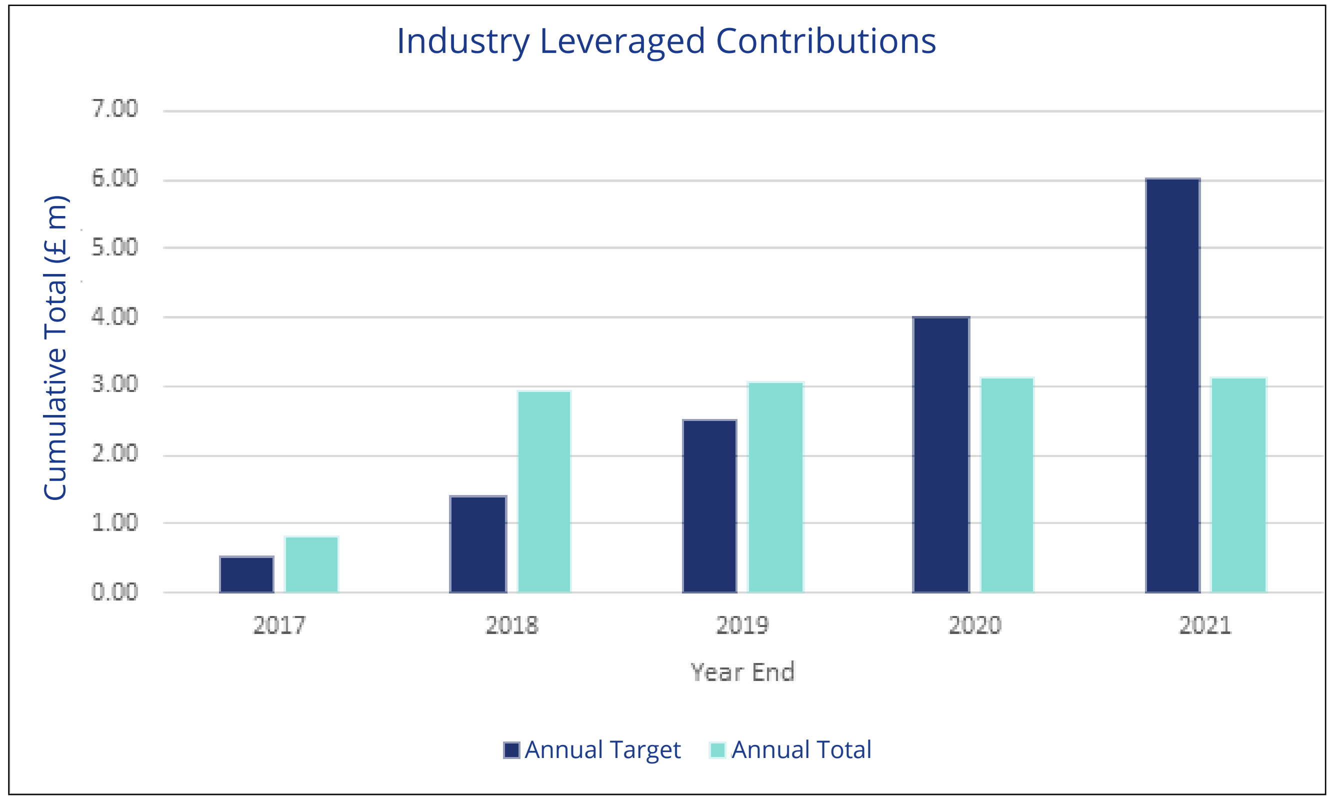
We have endeavoured to create a balanced portfolio of partners, including material suppliers, Tier One Suppliers and OEMs, supporting aerospace, automotive and energy (including high pressure gas storage) sectors equally, and emerging industry sectors such as rail and construction, marine and renewables. We actively encourage our industrial partners to put forward ideas for academia to adopt, ensuring the research is industrially relevant and also ambitious and high-risk. Mechanisms for interaction with new and existing partners are outlined in the Hub's Industrial Engagement Strategy . This provides a framework for engagement and supports our aim to create a collaborative environment where fundamental research can be developed with the support and involvement of industry.

Hub Partners by Sector



The cumulative value of support from our Industrial Partners to date is presented below, in addition to other leveraged contributions including student support, supply of materials, use of facilities and software. The graph summarises the contributions made by the 18 industry partners, plus the contributions from the 4 HVM Catapult Centres who originally wrote letters of support for the Hub. By April 2021, we had leveraged 54% of our £6m 2021 target. We have successfully engaged with 17 of the original 22 proposal supporters, with the largest contribution (£1.4m) coming from the HVM Catapult National Composite Centre (NCC).

There are still a number of significant opportunities across the sector and two Business Development Managers have been actively working with other composite partners to realise these and leverage additional support. In addition to our Industry Partners, a further 45 companies (who did not provide letters of support in the Hub proposal) have actively supported or contributed to Core Projects and Feasibility Studies. By April 2021 we have achieved 58% of our £5m 2021 target for additional industry support.



Associated Leveraged Projects

Links with associated leveraged projects have enabled us to build a wider network and develop key skills. Over £18m has been leveraged for new grants, including an EPSRC Strategic Equipment Grant (EP/T006420/1) and a Programme Grant (EP/S017038/1), underpinned by a further £2.9m of industrial support. In addition, an exciting international collaboration is underway with universities in the USA, linked to the Institute for Advanced Composites Manufacturing Innovation (IACMI) and their partner companies.

7 Hub Training

We are currently training 36 PhD students, 46 EngDs and 26 postdoctoral researchers.

The Hub is committed to training 150 researchers over the lifetime of the Programme to help support the anticipated growth in the UK composites sector over the next ten years. The flexibility of our funding model offers an effective way for early-career researchers to develop and express their own ideas. Under our training remit, all Hub Spokes are eligible to study the taught EngD modules within the EPSRC Industrial Doctoral Centre in Composites Manufacturing (IDC), encouraging the Spoke members to continue to engage with the Hub beyond their initial project, widening their expertise and skills.

Our Staff Development Policy outlines a culture where postgraduate students, researchers and academics are supported throughout their affiliation with the Hub. The policy aims to provide Hub members with opportunities to support their career progression above and beyond those typically on offer by their home institution. The policy is built around a network of senior academics and members of the Advisory Board, who focus on giving support to junior members of the team. We actively encourage researchers to engage with the Management Group and Advisory Board, requiring them to present technical project summaries at the quarterly meetings to help build their independence.

Researchers Network

The Hub's Researcher Network has been an effective delivery mechanism for developing skills and providing training. This network administers our Early-Career Feasibility Studies (£5k), which give younger Hub members the opportunity to express their independent ideas and experience the peer-review process. The researchers organise their own workshops to develop composite manufacturing skills. These offer practical experience to all students, who might otherwise only be involved in simulation-based projects. In January this year, a virtual event was organised for PhDs and researchers who shared their work and gave virtual lab tours. The event was well attended with 30 attendees.

Fellowships

Fellowships are an effective first step for researchers looking to establish an independent career. To date, we have funded 3 Platform Fellows and 2 Innovation Fellows across 4 Hub institutions. A Call for a third Innovation Fellowship will be launched this year with a view to the position starting in early 2022. A Transitional Fellow will also be recruited this year enabling an additional senior postdoctoral researcher to progress over a 3-year period to a permanent academic position in the Faculty of Engineering at Nottingham.

Industrial Doctoral Centre in Composites Manufacturing (IDC)

All activities of the IDC have been impacted to different extents by the circumstances of this year but despite the challenges to our industry support base, the IDC have been able to welcome five new Research Engineers since the summer of 2020, bringing the total number of EngD students being trained through the IDC to 46 students.

Industrial Doctoral Centre in Composites Manufacturing new recruits:

- Joe Soltan, NCC, Project Title: Manufacturing complex, large-scale composite components through "Modular Infusion"
- Patrick Sullivan, NCC, Project Title: Effective Use of Recycled Composites
- Will Darby. NCC, Project Title: Advanced Thermoplastic Composites Manufacturing - Understanding Defects and Failure
- Benjamin Chappell, iCOMAT, Project Title: CRaToS 3D (Carbon Rapid Tape Shear 3D)
- Humza Mahmood, Airborne, Project Title: Digitalisation of composite manufacturing

Recent Industrial Doctoral Centre EngD awards and destinations:

- Oliver Parks "The Future of Composites for Marine Applications" EngD project was supported by and conducted at Airborne UK. Post EngD work involved the development of a one-shot vertical infusion process for a 6m high hull structure https://youtu.be/_a9B8zpqbY0.
- Sarvesh Dhiman is employed at his EngD supporter company M Wright & Sons Ltd, as a Composite Development Engineer and awaiting his viva.
- Laxman Sivanathan "Developing process control in contact moulding and infusion processing for low cost, high volume manufacture of critical safety products" is sponsored by JoBird Ltd, Laxman is now head of R&D in this progressive SME.
- Petar Zivkovic "The Investigation of Pseudo-Woven Automated Fibre Placement Laminates" was sponsored by Rolls-Royce and is now employed at the National Composites Centre.
- Simon Wilkinson, Daniel Griffin and Matt Etchells are due to submit their EngD theses shortly and all have started working for the National Composites Centre.
- Jack Linley-Start has submitted his Rolls-Royce supported thesis on repair processes in composites.

8 Outreach Activities

Hub Webinars

The Hub hosted its first virtual webinar on 4th November 2020. The session focused on the latest hub research and development projects in Rapid Composite Processing Technologies:

- Executive Summary: A Mid-Term Review, Prof Nick Warrior, Hub Director and Professor at the University of Nottingham
- Optimised Manufacturing of Structural Composites via Thermoelectric Vario-thermal Tooling (VarioTherm), Dr Neil Reynolds, Hub Researcher and Senior Research Fellow at Warwick Manufacturing Group
- Design simulation tools and process improvements for NCF preforming, Dr Lee Harper, Hub Manager and Associate Professor at the University of Nottingham
- Layer by Layer Curing, Dr James Kratz, Hub Investigator and Lecturer at the University of Bristol

The second virtual event took place on 17th February 2021. The session focused on Work Stream 1, Automated Fibre Deposition Technologies:

- Hub Introduction, Prof Nick Warrior, Hub Director and Professor at the University of Nottingham
- Technologies Framework for Automated Dry Fibre Placement, Dr Thomas Turner, Hub Deputy Director, Chair of the Strategic Development Committee and Associate Professor at the University of Nottingham
- Fibre Steered Forming Technology, Dr Eric Kim, Associate Professor in Composites Design and Manufacture at the University of Bristol
- Automated Production of Powder Epoxy Carbon Fibre Tape for Automated Fibre Placement, Dr Colin Robert, Hub Innovation Fellow and Chancellor's Fellow at the University of Edinburgh
- COMPrinting: Novel 3D Printing of curved continuous carbon fibre reinforced powder-based epoxy composites, Dr Dongmin Yang, Senior Lecturer at the University of Edinburgh

Each webinar was well attended with over 100 attendees and there were opportunities for further discussions in a Q&A session at the end of each webinar. Recordings of the webinars are available on our website.

Project Webinar

The Hub recently supported a webinar for the Core Project Active RTM. The webinar took place in March 2021 and welcomed guest speaker Francisco Chinesta, Professor of Computational physics at ENSAM Institute of Technology (Paris). Francisco presented his work on data-driven modelling in the seminar "Empowering Hybrid Twins from Physics-Informed Artificial Intelligence". The webinar reached an international audience of over 50 people and positive feedback was received. The recording of the session has been made available on CIMComp's YouTube channel and website.

Researchers Network

In February 2021 the Researcher Network participated in the Festival of Science and Curiosity (FOSAC). The Festival is an annual event in Nottingham which encourages students and researchers to engage with the local community. The Researcher Network contributed to the festival by producing a video targeted at school students with an Engineering perspective. It featured Hub PhD student Matthew Thompson showing how a simple composite material can be made at home with household ingredients such as water, a refrigerator and spaghetti. The video was a great success reaching an audience of over 300 people, the Researcher Network also submitted a magazine entry for the online audience.

STEM activities allow the hub the opportunity to influence the younger generation with the academic discipline of engineering as well as initiating involvement with the wider community.

Hub PhD student; Matthew Thompson performing an experiment for the FOSAC to show how a simple composite material can be made at home. Click here to view the video.

SAMPE Seminar and Media competition – March 2021

In March 2021 the Hub supported the Annual SAMPE UK seminar "Composites – Progressing from the Pandemic" which was held online. The event welcomed a diverse range of topics, processes and speakers from academia and Industry, one of the keynotes included Hub Spoke representative; Dr Dipa Roy, Senior Lecturer at the University of Edinburgh. The event was held over two days and featured a 'Young Engineer and Students' Media competition based on the 'Resilience of the composite materials community during the COVID-19 pandemic'.

Students were invited to produce their composites research or services through a creative and informative video for the wider community, based on the following criteria:

- How the research has been affected by COVID
- Development of new products to diversify business
- New opportunities or services they have offered during the pandemic to support the local community

The competition had six team entries from across academia and industry. The videos were reviewed by a panel of experts. All video submissions were of high quality making it difficult for the judges to select one winning team, consequently, two teams were chosen, each were awarded cash prizes and free SAMPE UK and Ireland annual membership.

The winning teams were 'FAC Technology' from industry, their winning video can be viewed here.

The second winning team were the 'Pandemic Preforms' from the University of Nottingham, their winning video can be viewed here.

University of Nottingham, Future Composites Manufacturing Research Hub students from left to right; James Mortimer, Christos Kora, Preetum Mistry and Matthew Thompson show their resilience to the global pandemic.

9 Publications

Publications support the delivery of the Hub programme and vision, in both high impact factor journals and at international conferences and workshops. Hub investigators have continued to publish research from previous projects initiated by the EPSRC Centre (EP/I033513/1), bringing the total journal paper output for CIMComp to 57 since January 2017.

2021

57. Sang N. Nguyen, Alexis Millereux, Aymeric Pouyat, Emile S. Greenhalgh, Milo S.P. Shaffer, Anthony R.J. Kucernak, Pete Linde (2021) "Conceptual Multifunctional Design, Feasibility and Requirements for Structural Power in Aircraft Cabins", Aerospace Research Central https://doi.org/10.2514/1.C036205

56. Yousaf, Z., Withers, P. J. & Potluri, P. (2021)"Compaction, nesting and image based permeability analysis of multi-layer dry preforms by computed tomography (CT)", Composite Structures, 263, p. 113676.

55. Gautam, M., Sivakumar, S., Barnett, A., Barbour, S., Ogin, S.L., Potluri, P. (2021) On the behaviour of flattened tubular Bi-axial and Tri-axial braided composites in tension. Composite Structures, 261, 113325. Grant Number: EP/P006701/1. doi.org/10.1016/j.compstruct.2020.113325

54. Iglesias, M., Yang, Y. (2021) Adaptive regularisation for ensemble Kalman inversion. Inverse Problems, 37 (2) 025008. Grant Number: EP/P006701/1. doi.org/10.1088/1361-6420/abd29b

53. Karim, N., Sarker, F., Afroj, S., Zhang, M., Potluri, P., Novoselov, K.S. (2021) Sustainable and Multifunctional Composites of Graphene-Based Natural Jute Fibers. Advanced Sustainable Systems, 5 (3) 2000228. Grant Number: EP/P006701/1. doi.org/10.1002/adsu.202000228

52. Matveev, M. J., Endruweit, A., Long, A.C., Iglesias, M.A., Tretyakov, M.V. (2021). Bayesian inversion algorithm for estimating local variations in permeability and porosity of reinforcements using experimental data. Composites Part A: Applied Science and Manufacturing, 143, 106323. Grant Number: EP/P006701/1. doi.org/10.1016/j.compositesa.2021.106323

51. Mistry, P.J., McRobie, C.A., Johnson, M.S., Jones, I.V. (2021) Design of A Lightweight Multifunctional Composite Railway Axle Utilising Coaxial Skins. Journal of Composites Science, 5, 77. Grant Number: EP/P006701/1. doi.org/10.3390/jcs5030077

50. O'Keeffe C., Pickard L.R., Cao J., Allegri J., Partridge I.K., Ivanov D.S, (2021). Multi-material braids for multifunctional laminates: conductive through-thickness reinforcement. Functional Composite Materials, 2, article 5. Grant Number: EP/P006701/1. doi.org/10.1186/s42252-021-00018-0

49. Viisainen, J.V., Hosseini, A., Sutcliffe, M.P.F. (2021). Experimental investigation, using 3D digital image correlation, into the effect of component geometry on the wrinkling behaviour and the wrinkling mechanisms of a biaxial NCF during preforming. Composites Part A: Applied Science and Manufacturing, 142, 106248. Grant Number: EP/P006701/1. doi.org/10.1016/j.compositesa.2020.106248

48. Yousefi, N; Evans; A, D., Harper, L.T., Maples, H.A., James, T., Bismarck, A. (2021) Solid Epoxy Resin Systems for Automated Composite Manufacturing. Composites Part A: Applied Science and Manufacturing, 142, 106205, Grant Number: EP/P006701/1. doi.org/10.1016/j.compositesa.2020.106205

47. Yu, F. Chen S, Harper L. H., Warrior N.A. (2021). Simulating the effect of fabric bending stiffness on the wrinkling behaviour of biaxial fabrics during preforming. Composites Part A: Applied Science and Manufacturing, 143, 106308. Grant Number: EP/P006701/1. doi.org/10.1016/j.compositesa.2021.106308

2020

46. Budwal, N., Kasper, K., Goering, J., Ward, C. (2020) Flexible, low-cost tooling solutions for a one-shot resin infusion of a 3D woven and multi-textile preform. Procedia Manufacturing, 51, 856863. Grant Number: EP/P006701/1. doi.org/10.1016/j.promfg.2020.10.120

45. Chai, Y., Wang, Y., Yousaf,, Z., Storm, M., T. Vo, N., Wanelik, K., Burnett,T.L., Potluri, P., Withers, P, J. (2020). Following the effect of braid architecture on performance and damage of carbon fibre/epoxy composite tubes during torsional straining. Composites Science and Technology, 200, 108451. Grant Number: EP/P006701/1. doi.org/10.1016/j.compscitech.2020.108451

44. Elkington, M., Almas, E., Ward-Cherrier, B., Pestell, N., Lloyd, J., Ward, C., Lepora, N. (2020). Real Time Defect Detection During Composite Layup via Tactile Shape Sensing. Journal of Science and Engineering of Composite Materials, Grant Number: EP/P006701/1. doi.org/10.1515/secm-2021-0001

43. Gandhi, N., Rose, R., Croxford, A., Ward, C. (2020) Developing a high-fidelity knowledge base for improvements in the non-destructive testing of advanced composite material products. Procedia Manufacturing, 51, 345352. Grant Number: EP/P006701/1. doi.org/10.1016/j.promfg.2020.10.049

42. Harrison, P., Campbell, I., Guliyev, E., McLelland, B., Gomes, R., Curado-Correia, N., McGookin, E., Mulvihill, D.M. (2020). Induction melt thermoforming of advanced multi-axial thermoplastic composite laminates. Journal of Manufacturing Processes, 60, 673-683. Grant Number: EP/P006701/1. doi.org/10.1016/j.jmapro.2020.10.026

41. Johannisson, W., Nguyen, S., Lindbergh, G., Zenkert, D., Greenhalgh, E., Shaffer, M.S.P., Kucernak, A. (2020). A Residual Performance Methodology to Evaluate Multifunctional Systems. Multifunctional Materials. Grant Number: EP/P006701/1. doi.org/10.1088/2399-7532/ab8e95

40. Mistry P.J., Johnson M.S., Galappaththi, U.I.K. (2020). Selection and Ranking of Rail Vehicle Components for Optimal Lightweighting using Composite Materials. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, 235 (3) 390-402, Grant Number: EP/P006701/1. doi.

39. Matveev,M.Y., Brown, L.P., Long, A. C. (2020) Efficient meshing technique for textile composites unit cells of arbitrary complexity. Composite Structures, 254, 112757, Grant Number: EP/P006701/1. doi.org/10.1016/j.compstruct.2020.112757

38. Turk, M., Vermes, B., Thompson, A., Belnoue, J. P.H., Hallett, S. R., Ivanov, D. S. (2020). Mitigation Against Forming Defects by Local Modification of Dry Preforms. Composites Part A, Special Issue of Euromech 602 congress : Composite manufacturing processes. Analyses, modelling and simulations. Grant Number: EP/P006701/1. doi.org/10.1016/j.compositesa.2019.105643

37. Valkova, M., Anthony, D.B., Kucernak, A., Shaffer, M.S.P., Greenhalgh, E.S. (2020). Predicting the Compaction of Hybrid Multilayer Woven Composite Reinforcement Stacks. Composites Part A: Applied Science and Manufacturing, 133. Grant Number: EP/P006701/1. doi.org/10.1016/j.compositesa.2020.105851

36. Willicombe, K., Elkington, M., Hamerton, I., Ward, C. (2020) Development of Novel Transportation Shells for the Rapid, Automated Manufacture of Automotive Composite Parts. Procedia Manufacturing, 51, 2020, 818-825. Grant Number: EP/P006701/1. doi.org/10.1016/j.omfg.2020.10.115.954409720925685

35. Yu, F., Chen, S., Viisainen, J.V., Sutcliffe, M.P.F., Harper, L.T., Warrior, N.A. (2020). A Macroscale Finite Element Approach for Simulating the Bending Behaviour of Biaxial Fabrics. Composites Science and Technology. 191. Grant Number: EP/P006701/1. doi.org/10.1016/j.compscitech.2020.108078

34. Chen, S., McGregor, O. P. L., Endruweit, A., Harper, L. T., Warrior, N, A. (2019). Simulation of the Forming Process for Curved Composite Sandwich Panel. International Journal of Material Forming. Grant Number: EP/P006701/1. doi.org/10.1007/s12289-019-01520-4

33. Herring, R, Dyer, K, Macleod, A, Martin, F, Ward, C. (2019). The Increasing Importance of Leading Edge Erosion and a Review of Existing Protection Solutions. Renewable and Sustainable Energy Reviews. Grant Number: EP/P006701/1. doi.org/10.1016/j.rser.2019.109382

32. Herring, R, Dyer, K, Macleod, A, Ward, C. (2019). Computational Fluid Dynamics Methodology for Characterisation of Leading Edge Erosion in Whirling Arm Test Rigs. Journal of Physics: Conference Series. Grant Number: EP/P006701/1. doi.org/10.1088/1742-6596/1222/1/012011

31. Matveev, M.Y., Belnoue, J.P-H., Nixon-Pearson, O.J., Ivanov, D.S., Long, A.C., Hallett, S.R., Jones, I.A. (2019). A Numerical Study of Variability in the Manufacturing Process of Thick Composite Parts. Composite Structures. 208, 23-32. Grant Number: EP/IO33513/1. doi.org/10.1016/j.compstruct.2018.09.092

30. Matveev, M., Endruweit, E., De Focatiis D. S. A., Long A.C., Warrior, N.A. (2019) A Novel Criterion for the Prediction of Meso-scale Defects in Textile Preforming. Composite Structures. 226, 111263. Grant Number: EP/P006701/1. doi.org/10.1016/j.compstruct.2019.111263

29. May, D., Aktas, A., Advani, S.G., Endruweit, A., Fauster, E., Lomov, S.V., Long, A., Mitschang, P., Abaimov, S., Abliz, D., Akhatov, I., Allen, T.D., Berg, D.C., Bickerton, S., Bodaghi, M., Caglar, B., Caglar, H., Correia, N., Danzi, M., Dittmann, J., Ermanni, P., George, A., Grishaev, V., Kabachi, M.A., Kind, K., Lagardère, M.D., Laspalas, M., Liotier, P.J., Park, C.H., Pipes, R.B., Pucci, M., Raynal, J., Rodriguez, E.S., Schledjewski, R., Schubnel, R., Sharp, N., Sims, G., Sozer, E.M., Umer, R., Willenbacher, B., Yong, A., Zaremba, S., Ziegmann, G. (2019). In-plane Permeability Characterization of Engineering Textiles Based on Radial Flow Experiments: A Benchmark Exercise. Composites Part A: Applied Science and Manufacturing. 121, 110 -114. Grant Number: EP/P006701/1. doi.org/10.1016/j.compositesa.2019.03.006

28. Mistry, P, J., Johnson, M. S. (2019). Lightweighting of Railway Axles for the Reduction of Unsprung Mass and Track Access Charges. Part F: Journal of Rail and Rapid Transit. Grant Number: EP/ P006701/1.doi.org/10.1177/0954409719877774

27. Veldenz, L., Di Francesco, M., Giddings, P., Kim, B.C., Potter, K. (2019). Material Selection for Automated Dry Fiber Placement using the Analytical Hierarchy Process. Advanced Manufacturing: Polymer and Composites Science, 83-96. Grant Number: EP/P006701/1. doi.org/10.1080/20550340.2018.1545377

26. Yan, S., Zeng, X., Long, A.C. (2019). Meso-scale Modelling of 3D Woven Composite T-joints with Weave Variations. Composites Science and Technology. 171,171-179. Grant Number: EP/IO33513/1. doi.org/10.1016/j.compscitech.2018.12.024rg/10.1177/0954409719877774

2018

25. Endruweit, A., Zeng, X., Matveev, M., Long. A.C. (2018). Effect of Yarn Cross-sectional Shape on Resin Flow Through Inter-yarn Gaps in Textile Reinforcements. Composites Part A: Applied Science and Manufacturing. 104 (1) 139-150. Grant Number: EP/I033513/1. doi: 10.1016/j.compositesa.2017.10.020

24. Mamalis, D., Obande, W., Koutsos, V., Blackford, J., Ó Brádaigh, C.M., Ray, D. (2018). Novel Thermo-plastic Fibre-metal Laminates Manufactured by Vacuum Resin Infusion: The Effect of Surface Treatments on Interfacial Bonding. Materials & Design. 162, 331-344. Grant Number: EP/P006701/1. doi.org/10.1016/j.matdes.2018.11.048

23. Mesogitis, T.,Kratz, J., & Skordos, A.A. (2018). Heat Transfer Simulation of the Cure of Thermoplastic Particle Interleaf Carbon Fibre Epoxy Prepregs. Journal of Composite Materials. 53 (15), 2053-2064. Grant Number: EP/IO33513/1. doi./10.1177/0021998318818245

22. Yan, S., Zeng, X., Brown, L.P., Long, A.C. (2018). Geometric Modeling of 3D Woven Preforms in Composite T-joints. Textile Research Journal. 88 (16), 1862-1875. Grant Number: EP/IO33513/1. doi.org/10.1177/0040517517712098

21. Yan, S., Zeng, X., Long, A.C., (2018). Experimental Assessment of the Mechanical Behaviour of 3D woven Composite T-joints. Composites Part B. 154, 108- 113. Grant Number: EP/IO33513/1. doi.org/10.1016/j.compositesb.2018.08.007

2017

20. Akonda, M., Stefanova, M., Potluri, P., & Shah, D. (2017). Mechanical Properties of recycled carbon fibre/polyester thermoplastic tape composites. Journal of Composite Materials. 51 (18), 2655-2663. Grant Number: Not acknowledged. doi.org/10.1177/0021998316672091

19. Atas, A., Gautam, M., Soutis, C., Potluri, P. (2017) Bolted Joints in Three Axially Braided Carbon Fibre /Epoxy Composites with Moulded-in and Drilled Fastener Holes. Applied Composites Materials. 24 (2), 449-460. Grant Number: Not acknowledged. doi:10.1007/s10443-016-9542-z

18. Belnoue, J., Tassos, M., Nixon-Pearson, O.J., Kratz, J., Ivanov, D.S., Partridge. I.K., Potter. K.D., Hallett, S.R. (2017). Understanding and predicting defect formation in automated fibre placement pre-preg laminates. Composites Part A: Applied Science and Manufacturing. 102, 195-206. Grant Number: EP/I033513/1. doi: 10.1016/j.compositesa.2017.08.008

17. Corbridge, D.M., Harper, L.T., de Focatiis, D.S.A., Warrior, N. (2017). Compression moulding of composites with hybrid fibre architectures. Composites Part A: Applied Science and Manufacturing. 95 (1): 87-99. Grant Number: EP/I033513/1. doi: 10.1016/j.compositesa.2016.12.018

16. Di Francesco, M., Veldenz, L., Dell'Anno,G., Potter, K. (2017). Heater power control for multi-material, variable speed Automated Fibre Placement. Composites Part A: Applied Science and Manufacturing. 101, 408-421. Grant Number: EP/P006701/1. doi.org/10.1016/j.compositesa.2017.06.015

15. Gautam, M., Katnam, K., Potluri, P., Jha, V., Latto, J., Dodds, N. (2017). Hybrid Composite Tensile Armour Wires in Flexible Risers: A Multi-scale Model. Composites Structures. 162, 13-27. Grant Number: Not acknowledged. doi.org/10.1016/j.compstruct.2016.11.090

14. Goktas, D., Kennon, W., Potluri, P. (2017). Improvement of Model Interlaminar Fracture Toughness of Stitched Glass/Epoxy Composites. Applied Composites Materials 24 (2), 351-375. Grant Number: Not acknowledged. doi.org/10.1007/s10443-016-9560-x

13. Gommer, F., Endruweit, A., Long, A.C. (2017). Influence of the micro-structure on saturated transverse flow in fibre arrays. Journal of Composite Materials. 52 (18), 2463-2475. Grant Number: EP/IO33513/1. doi. org/10.1177/0021998317747954

12. Hartley, J.W., Kratz, J., Ward, C., Partridge, I.K., (2017). Effect of tufting density and loop length on the crushing behaviour of tufted sandwich specimens. Composites Part B: Engineering. 112 (1): 49-56. Grant Number: EP/I033513/1. doi: 10.1016/j.compositesb.2016.12.037

11. Jones, H., Roudaut, A., Chatzimichali, A., Potter, K., Ward, C. (2017). The Dibber: Designing a standardised handheld tool for lay-up tasks. Applied Ergonomics. 65 (1), 240-254. Grant Number: EP/I033513/1. doi: 10.1016/j.apergo.2017.05.014

10. Koncherry, V., Potluri, P., Fernando, A. (2017). Multifunctional Carbon Fibre Tapes for Automotive Composites. Applied Composite Materials. 24 (2), 477-493. Grant Number: Not acknowledged. doi.org/10.1007/s10443-016-9550-z

9. Matveev, M.Y., Long, A.C., Brown, L.P., Jones, I.A. (2017). Effects of layer shift and yarn path variability on mechanical properties of a twill weave composite. Journal of Composite Materials. 51 (7), 913-925. Grant Number: EP/I033513/1. doi: 10.1177/0021998316655870

8. Mesogitis, T., Skordos, A., Long, A. (2017). Stochastic Simulation of the Influence of Fibre Path Variability on the Formation of Residual Stress and Shape Distortion. Polymer Composites. 38 (12), 2642-2652. Grant Number: Not acknowledged. doi.org/10.1002/pc.23856

7. Nixon-Pearson, O.J., Belnoue, J.P-H., Ivanov, D.S., Potter, K., Hallett, S. (2017). An experimental investigation of the consolidation behaviour of uncured prepregs under processing conditions. Journal of Composite Materials. 51 (13), 1911-1924. Grant Number: EP/I033513/1. doi: 10.1177/0021998316665681

6. Pavlopoulou, S., Roy, S., Gautam, M., Bradshaw, L., Potluri P. (2017). Numerical and Experimental Investigation of

the Hydrostatic Performance of Fibre Reinforced Tubes. Applied Composite Materials. 24 (2), 417-448. Grant Number: Not acknowledged. doi.org/10.1007/s10443-016-9563-7

5. Prabhu, V.A., Elkington, M., Crowley, D., Tiwari, A., Ward, C., (2017). Digitisation of manual composite layup task knowledge using gaming technology, Composites Part B: Engineering. 112 (1), 314-326. Grant Number: EP/I033513/1. doi: 10.1016/j.compositesb.2016.12.050

4. Roy, S., Potluri, P, Soutis, C. (2017). Tensile Response of Hoop Reinforced Multiaxial Braided Thin Wall Composite Tubes. Applied Composite Materials. 24 (2), 397-416. Grant Number: Not acknowledged. doi:10.1007/s10443-016-9570-8

3. Saleh, M., Wang, Y., Yudhanto, A., Joesbury, A., Potluri, P., Lubineau, G., Soutis, C. (2017). Investigating the Potential of Using Off-axis 3D Woven Composites in Composite Joints Applications. Applied Composite Materials. 24 (2), 377-396. Grant Number: Not acknowledged. doi. org/10.1007 /s10443-016-9529-9

2. Thompson, A., El Said, B., Ivanov, D., Belnoue, J., Hallett, S. (2017). High Fidelity Modelling of the Compression Behaviour of 2D Woven Fabrics. International Journal of Solids and Structures. 154, 104-113. Grant Number: EP/L504919/1. doi.org/10.1016 /j.ijsolstr.2017.06.027

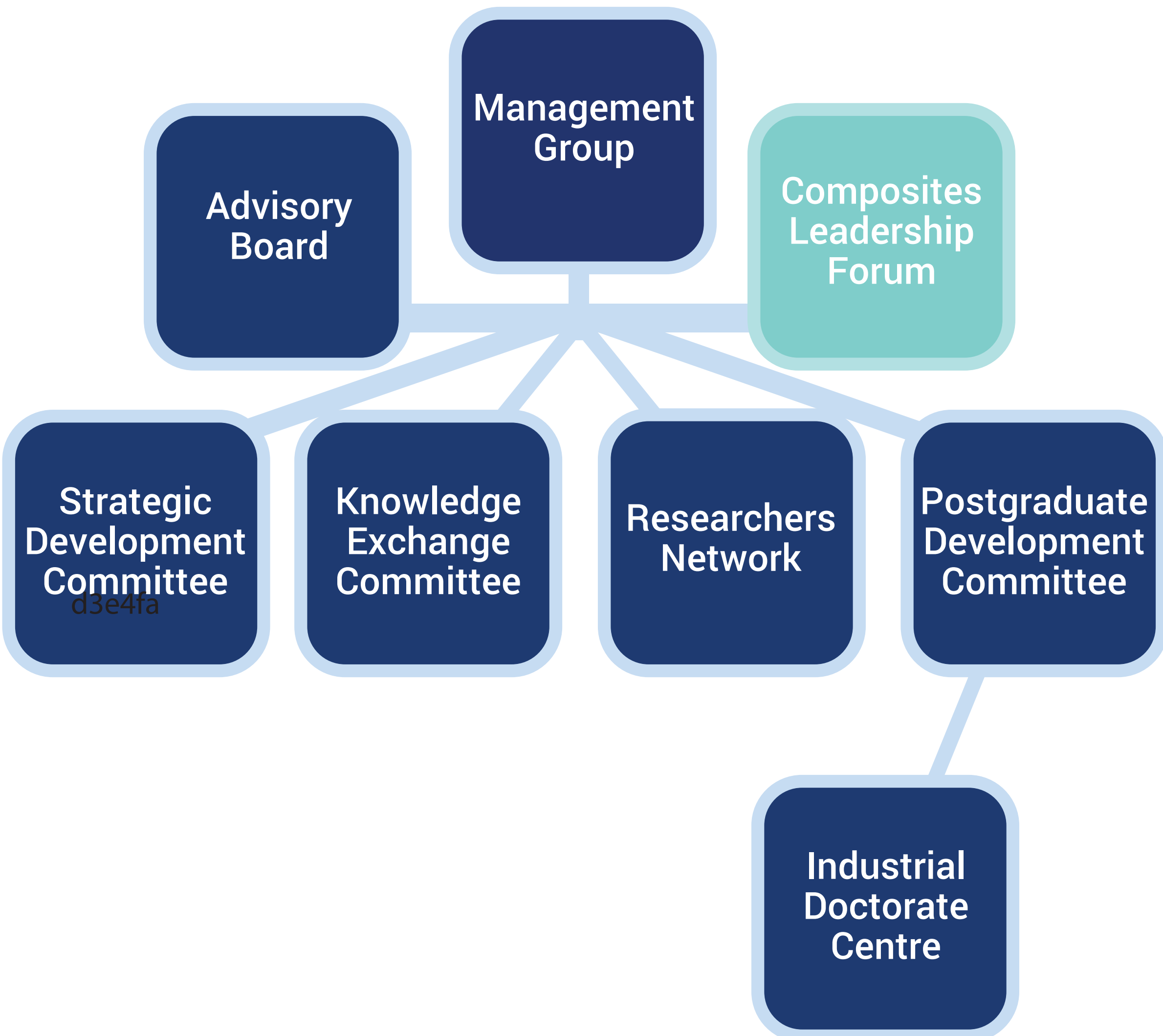
1. Yousaf, Z., Potluri, P., Withers, P. (2017). Influence of Tow Architecture on Compaction and Nesting in Textile Preforms. Applied Composite Materials. 24 (2), 337-350. Grant Number: Not acknowledged. doi. org/10.1007/s104 43-016-9554-8

10 Hub Governance

The Management Group is supported by the Advisory Board and three committees: Knowledge Exchange Committee, Strategic Development Committee and the Postgraduate Development Committee).

The **Management Group** (MG) is chaired by Prof Nick Warrior, the Hub Director, with overall responsibility for developing and delivering the Hub's strategy. He is supported by two Deputy Directors, Prof Ole Thomsen and Dr Tom Turner, and the Chairs of the KEC, SDC and PDC committees.

The **Advisory Board** (AB) is chaired by Prof Mike Hinton and takes a high level, strategic view of the needs of all the Hub stakeholders, offering guidance on the delivery and impact of research, ensuring the needs of the UK composites community are addressed. The AB plays a key role in advising the MG on technical progress and relevance to industry needs. The AB membership is a mix of independent academic and industrial members from the UK and abroad. Members represent a broad section of the UK supply chain, including end users from automotive and aerospace, material suppliers and HVM Catapult Centres. This year the AB aims to increase its membership to 12 and include membership from the infrastructure, marine and renewables sectors.



From top left to right: Prof Janice Barton, Deputy Director of the IDC; Prof Mike Hinton, Chair of the AB; Dr Mike Johnson, Chair of the PDC; Dr Mikhail Matveev, Chair of the RN; Prof Ole Thomsen, Chair of the KEC;. Dr Tom Turner, Chair of the SDC; Prof Nick Warrior, Hub Director and Chair of the MG

The **Strategic Development Committee** (SDC), chaired by Dr Tom Turner, engages with funders, industry and government bodies to develop knowledge and strategies to evolve the Hub's priority areas, using the two Hub Business Development Managers to secure additional R&D funding, map capability and influence research priorities.

The **Knowledge Exchange Committee** (KEC), chaired by Prof Ole Thomsen, is the formal link between the Hub and the HVM Catapult stakeholders and contains representatives from four Centres. The KEC is responsible for identifying and strengthening collaboration opportunities between Hub Spokes, administering funding for synergy promotion and technology pull-through (NCC TPT fund), and managing IP emerging from Hub projects.

The **Postgraduate Development Committee** (PDC), chaired by Dr Mike Johnson, oversees the training and progression of research students, at doctoral level via the IDC and at postdoctoral level via the **Researcher Network** (RN, chaired by Dr Mikhail Matveev). The RN is led by postdoctoral researchers to promote collaboration and enhance the cohort experience, engaging in outreach activities as STEM ambassadors. The PDC also manages an international student exchange scheme through the **International Researcher Network**, establishing partnerships in research programmes across 23 leading institutions in 12 countries.

The Hub is represented within the national **Composites Leadership Forum** (CLF). The Hub Director sits on the main board and members' of the MG and AB are active members of the CLF sub-committees supporting Working Groups in Technology, Sustainability, Automotive, Aerospace, Workforce Development and Regulations. This strong interaction enables a continued alignment of the Hub activities with the UK Composites Strategy, ensuring that the Hub research priorities address evolving long-term sector needs. The CLF has facilitated dissemination of the CiRCL road mapping activity to an industrial audience and resulted in the Hub's involvement in an Innovate UK International Mission to the USA to develop collaborative research programmes. Prof Pickering's involvement in the CLF Sustainability Working Group also led the Hub's contribution to the UK Vision and Roadmap for Sustainable Composites.

11 The Hub Team

Management Group

Professor Nick Warrior
Hub Director
University of Nottingham

Professor Ole Thybo Thomsen
Deputy Hub Director
University of Bristol

Dr Thomas Turner
Deputy Hub Director
University of Nottingham

Dr Lee Harper
Hub Manager
University of Nottingham

Dr Mike Johnson
Chair of the Postgraduate Development Committee
University of Nottingham

Andrew Mills
Deputy Chair of the Postgraduate Development Committee
Cranfield University

Dr Mikhail Matveev
Chair of the Researcher Network
University of Nottingham

Professor Ivana Partridge
Director of Industrial Doctorate training Centre
University of Bristol

Professor Janice Dulieu-Barton
Deputy Director of Industrial Doctorate Training Centre
University of Bristol

Dr Dipa Roy
Hub Spoke Representative
University of Edinburgh

Alex Hammond
Hub Deputy Manager
University of Nottingham

Advisory Group

Professor Remko Akkerman
Scientific Expert
University of Twente

Dr Rob Backhouse
Industrial Representative
Rolls-Royce

Craig Carr
Industrial Representative
GKN Aerospace

Dr Enrique Garcia
Industrial Representative
National Composites Centre

Brett Hemingway
Industrial Representative
BAE Systems

Dr Warren Hepples
Industrial Representative
Luxfer

Professor Mike Hinton
Advisory Board Chair
CTO, HMV Catapult

Tom James
Industrial Representative
Hexcel Reinforcements

Dame Professor Jane Jiang
Scientific Expert
University of Huddersfield

Professor Ian Kinloch
Scientific Expert
University of Manchester

Professor Veronique Michaud
Scientific Expert
EPFL

Dr Elizabeth Saunders
EPSRC Representative
EPSRC

Andy Smith
Industrial Representative
Gordon Murray Design

Tim Wybrow
Industrial Representative
NEOS Composites

Investigators

Dr Edward Archer
Ulster University

Professor Janice Barton
University of Bristol

Professor Richard Butler
University of Bath

Professor Richard Day
Wrexham Glyndwr University

Professor Chris Dodds
University of Nottingham

Dr Andreas Endruweit
University of Nottingham

Professor Emile Greenhalgh
University of Nottingham

Professor Stephen Hallett
University of Bristol

Dr Lee Harper
University of Nottingham

Dr Philip Harrison
University of Glasgow

Dr Robert Hughes
University of Bristol

Dr Darren Hughes
University of Warwick

Dr Marco Iglesias
University of Nottingham

Professor Derek Irvine
University of Nottingham

Dr Dmitry Ivanov
University of Bristol

Dr Mike Johnson
University of Nottingham

Dr Mihalis Kazilas
Brunel University

Dr Eric Kim
University of Bristol

Professor Vasileios Koutsos
University of Edinburgh

Dr James Kratz
University of Bristol

Professor Andrew Long
University of Nottingham

Edward M^cCarthy
University of Edinburgh

Dr Euan M^cGookin
University of Glasgow

Professor Alistair M^cIlhagger
Ulster University

Andrew Mills
Cranfield University

Dr Daniel Mulvihill
University of Glasgow

Professor Conchur O'Bradaigh
University of Edinburgh

Professor Ton Peijs
University of Warwick

Professor Steve Pickering
University of Nottingham

Professor Prasad Potluri
University of Manchester

Dr Andrew Rhead
University of Bath

Dr Daniel Richards University of Glasgow

Professor Paul Robinson
Imperial College, London

Dr Dipa Roy
University of Edinburgh

Professional Milo Shaffer
Imperial College, London

Professor Ian Sinclair
University of Southampton

Dr Alex Skordos
Cranfield University

Dr Michael Sutcliffe
University of Cambridge

Professor Ole Thomsen
University of Bristol

Professor Michael Tretyakov
University of Nottingham

Dr Thomas Turner
University of Nottingham

Dr Carwyn Ward
University of Bristol

Professor Nick Warrior
University of Nottingham

Dr Dongmin Yang
University of Edinburgh

12 Students

Researchers

Dr Debabrata Adhikari
University of Nottingham

Dr Ankur Bajpai
University of Edinburgh

Dr Jonathan Belnoue
University of Bristol

Dr Kaan Bilge
Imperial College, London

Dr Aurele Bras
Cranfield University

Dr Dan Bull
University of Southampton

Dr Shuai Chen
University of Nottingham

Dr Andrea Codolini
University of Cambridge

Dr Lawrence Cook
Cranfield University

Dr Dorian Dixon
Ulster University

Dr Thomas Dooher
Ulster University

Dr Wenbo Duan
Brunel University

Dr Michael Elkington
University of Bristol

Dr Anthony Evans
University of Nottingham

Dr Ian Gent
University of Bristol

Dr Alex Ilchev
University of Nottingham

Dr Adam Joesbury
University of Nottingham

Dr Vivek Koncherry
University of Manchester

Dr Nataliia Luhyna
Wrexham Glyndwr University

Dr Dimitrios Mamalis
University of Edinburgh

Dr Asimina Manta
Wrexham Glyndwr University

Dr Mikhail Matheev
University of Nottingham

Dr Sang Nguyen
Imperial College, London

Dr Thomas Noble
University of Edinburgh

Dr Laura Pickard
University of Bristol

Dr Connie Qian
University of Warwick

Dr Arjun Radhakrishnan
University of Bristol

Dr Calvin Ralph
Ulster University

Dr Neil Reynolds
University of Warwick

Dr Colin Robert
University of Edinburgh

Dr Shankhachur Roy
University of Manchester

Matt Smith
AMRC Sheffield

Dr Ric (Xiaochuan) Sun
University of Bristol

Dr Verner Viisainen
University of Cambridge

Dr Gabriele Voto
Cranfield University

Dr Lei Wan
University of Edinburgh

Dr Logan Wang
University of Bristol

Dr Bohao Zhang
University of Bristol

Dr Jin Zhou
University of Cambridge

PhD Students

Syed Abbas
University of Manchester

Matthew Bower
AMRC, University of Sheffield

Iain Campbell
University of Glasgow

Murat Celik
University of Edinburgh

Matthew Collinson
AMRC, University of Sheffield

Ubong Equere
Cranfield University

Salem Erouel
University of Nottingham

Dimitris Fakis
Brunel Composites Centre

Adam Fisher
University of Bristol

Albert Gibbs
University of Nottingham

Rob Iredale
University of Bristol

Rajan Jagpa
University of Bath

Irene Jimenez-Fortunato
University of Southampton

Christos Kora
University of Nottingham

Guy Lawrence
University of Nottingham

Chanhui Lee
Imperial College, London

Angela Lendinez Torres
University of Nottingham

Shimin Lu
University of Nottingham

James Mortimer
University of Nottingham

William Mosses
Ulster University

Caroline O'Keefe
University of Bristol

Michael O'Leary
University of Bristol

Jinseong Park
University of Manchester

Gwladys Popo
University of Nottingham

Bethany Russell
University of Bristol

Usman Shafique
University of Nottingham

Alice Snape
AMRC, University of Sheffield

Kazi Sowrov
University of Manchester

George Spackman
University of Nottingham

George Street
University of Nottingham

Matthew Thompson
University of Nottingham

Kostas Tifkitsis
Cranfield University

Mark Turk
University of Bristol

Maria Valkova
Imperial College, London

Daniel Wilson
University of Nottingham

Jibran Yousafzai
University of Bristol

Fei Yu
University of Nottingham

Haoqi Zhang
University of Edinburgh

EngD Students

Harry Barnard
University of Bristol
Elmar

Ashley Barnes
University of Bristol
Rolls-Royce

Nikita Budwal
University of Bristol
Albany

Pete Calvert
University of Bristol
Rolls-Royce

Ben Chappell
University of Bristol
iCOMAT

Harry Clegg
University of Bristol
National Composites Centre

Alex Cochrane
University of Bristol
Rolls-Royce

Anastasios Danezis
Cranfield University
Heraeus

Will Darby
University of Bristol
National Composites Centre

Sarvesh Dhiman
University of Manchester
M Wright & Sons

Mattia Di Francesco
University of Bristol
National Composites Centre

Phil Druiff
University of Bristol
National Composites Centre

Huw Edwards
University of Bristol
National Composites Centre

Matt Etchells
University of Nottingham
National Composites Centre

Zoe Fielden-Stewart
University of Bristol
Rolls-Royce

Nikita Gandhi
University of Bristol
National Composites Centre

Vincent Gill
University of Bristol
Rolls-Royce

Daniel Griffin
University of Bristol
National Physical Laboratory

Bethany Grimes
University of Nottingham
National Composites Centre

Robbie Herring
University of Bristol
National Composites Centre

Claudia Jimenez-Martin
University of Bristol
Airbus

Dimitris Karanatsis
University of Nottingham
Hexcel

Jakub Kucera
University of Bristol
National Composites Centre

David Langston
University of Bristol
ORE Catapult

Jack Lindley-Start
University of Bristol
Rolls-Royce

Josh Loughton
University of Bristol
National Composites Centre

Humza Mahmood
University of Bristol
Airborne Composites Ltd

Ffion Martin
University of Nottingham
Jaguar Land Rover

Lewis Munshi
University of Bristol
National Composites Centre

Caterina Palange
University of Bristol
Fiberlean

Nikita Budwal
University of Bristol
Albany

Maria Onoufriou
University of Bristol
Rolls-Royce

Preetum Mistry
University of Nottingham
Bombardier

Lewis Munshi
University of Bristol
National Composites Centre

Maria Onoufriou
University of Bristol
Rolls-Royce

Caterina Palange
University of Bristol
Fiberlean

Oli Parks
University of Bristol
AEL

Laura Pickard
University of Bristol
National Composites Centre

Anagnostis Samanis
University of Bristol
Airborne Composites Ltd

Laxman Sivanathan
University of Bristol
Jo Bird

Joe Soltan
University of Bristol
National Composites Centre

Patrick Sullivan
University of Bristol
National Composites Centre

Owen Taylor
University of Bristol
National Composites Centre

Laura Veldenz
University of Bristol
National Composites Centre

Gabriele Voto
Cranfield University
Hexcel

Simon Wilkinson
University of Bristol
National Composites Centre

Lachlan Williams
University of Bristol
Airbus

Maria Zilidou
University of Bristol
Qinetiq

Petar Zivkovic
University of Bristol
Rolls-Royce

cimcomp.ac.uk

+44 (0) 115 951 3823

info@cimcomp.ac.uk

EPSRC_CIMComp

Compiled and designed by fluency marketing