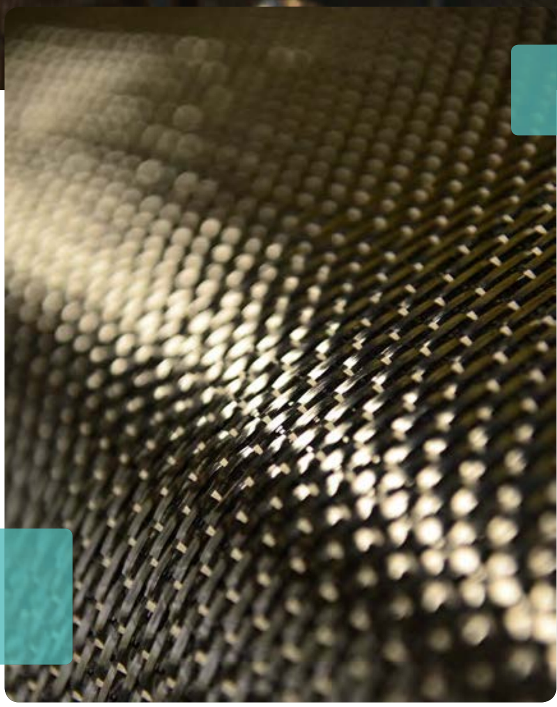
ANNUAL REPORT 2017



EPSRC
Future Composites Manufacturing Research Hub

Underpinning the development of next-generation composite manufacturing processes

EPSRC
Engineering and Physical Sciences Research Council

University of Bristol
Brunel University London
University of Cambridge
Cranfield Manufacturing
The University of Edinburgh School of Engineering
University of Glasgow
Imperial College London
Manchester 1824 The University of Manchester
University of Nottingham UK | China | Malaysia
University of Southampton

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Executive Summary

Professor Andrew Long, Director

"Welcome to the first annual report for the EPSRC Future Composites Manufacturing Research Hub. The Hub was launched in January 2017 and offers the perfect platform to build upon the success of CIMComp, the previously-funded EPSRC Centre for Innovative Manufacturing of Composites. This seven-year initiative will drive forward the development of automated manufacturing technologies, to deliver fibre-reinforced components and structures for demanding applications, whilst underpinning the growth potential of the composites sector by developing the underlying process science. The Hub aims to become the national centre of excellence in fundamental research for composites manufacturing, creating a pipeline of next-generation technologies to address future industrial needs and inform the national composites strategy."

The Hub is led by the University of Nottingham and the University of Bristol, with initial Spokes at Cranfield, Imperial College, Manchester and Southampton. The first year of operation has seen four new Spoke institutions added, including Brunel, Cambridge, Edinburgh and Glasgow, engaging 31 investigators, 11 PhD students and 9 postdoctoral researchers from the UK academic community. The Hub's flexible funding model ensures a timely response to opportunities highlighted by industry, technology roadmapping, and the UK Composites Leadership Forum. Funding has been released to new partners though open calls for short feasibility studies to investigate high-risk and ambitious concepts, with the possibility for follow-on funding through longer-term (up to 3 years) Core Projects. The Hub has funded 10 Feasibility Studies and 3 Core Projects this year, with funding set aside to initiate up to 2 more Core Projects in Year 2.

Members of the Hub have also been successful in securing additional research funding, including EPSRC grants worth in excess of £3.3 million over the course of the year. Notably, this includes a £1.2 million EPSRC Strategic Equipment grant to characterise large composite structures at the University of Southampton, and an EPSRC Platform Grant to simulate new manufacturing processes for composite structures at the University of Bristol.

On an organisational level, the Hub is now firmly rooted within the Advanced Manufacturing Building at the University of Nottingham, with new office space for the Hub's management team and a purpose-built composites manufacturing laboratory focusing on automated processing. The Hub has employed two business development staff, one at Nottingham and one at Bristol, to offer support to industrial and academic partners, and importantly help us leverage significant research income to encourage further development of the Hub. Looking forward, 2018 will see the appointment of two Innovation Fellows via an open competition, which will engage young researchers and support them as a first step to an independent research career. This approach proved successful for CIMComp, where an Innovation Fellow at Bristol went on to secure a permanent academic position.

We continue to support the management and governance of the Industrial Doctorate Centre (IDC), which is an integral activity of the Hub, training the next generation of composite engineers through industry based research projects. Nine new EngD students started in 2017, with the first students from the 2013 cohort graduating to go on to full-time employment within the composites sector. Three new industrial partners also joined the IDC in 2017, committing to support the development of these young research engineers and equip them with the necessary technical and leadership skills to be impactful in industry.

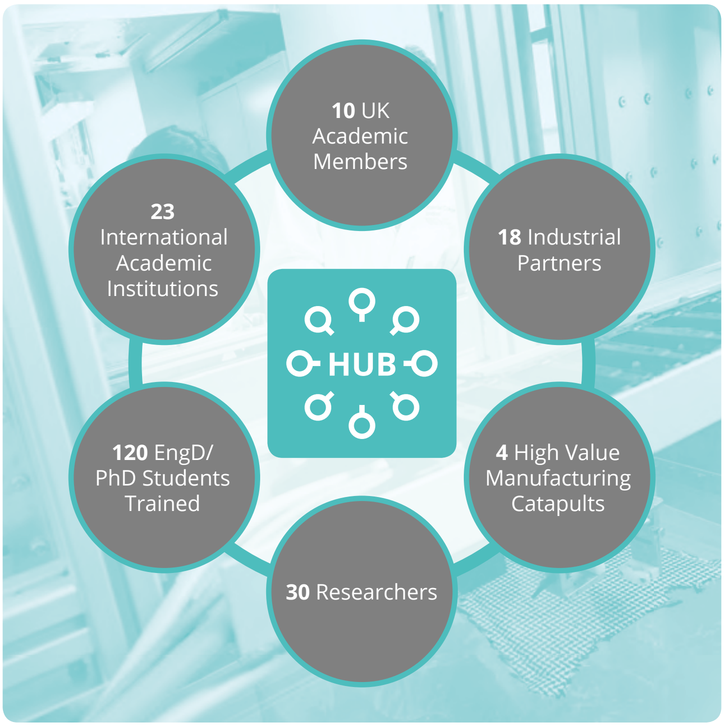
A number of Hub outreach activities have been conducted this year, focusing on wider dissemination of Hub research and international engagement. We hosted our launch event in May in Nottingham, which was attended by 120 people, including a mix of key industry representatives and leading international academics. We exhibited at the Advanced Engineering Show at the NEC, Birmingham, which was attended by over 15,000 people, and presented in the Composites Engineering Open Forum. The Hub was also extremely well represented at the 21st International Conference on Composite Materials (ICCM-21) in Xi'an, China, with 43 conference papers and 2 plenary sessions presented by Hub members. The group took the opportunity to visit 5 leading research institutes in China, to promote the Hub's international researcher network and explore opportunities for collaboration. Upcoming events to look forward to in 2018 include JEC World in Paris — the largest composites trade show in Europe with over 40,000 visitors — and the 11th International Conference on Manufacturing of Advanced Composites (ICMAC), which is being organised in association with the Hub and hosted at the Advanced Manufacturing Building in Nottingham.

We would like to take this opportunity to extend our thanks to all those who are driving forward the Hub with dedication, hard work and vision. Special thanks are due to all our researchers, industrial collaborators and, in particular, the members of the Advisory Board. Moreover, we thank EPSRC for their continued support and sponsorship. We look forward to working with you all in Year 2, and welcoming any new academic or industrial partners to help meet the needs and challenges faced by the UK composites manufacturing industry.

Hub Vision

"A national centre of excellence in fundamental research for composites manufacturing."

The EPSRC Future Composites Manufacturing Research Hub was launched in January 2017 and is a £10.3m investment to expand the national research effort towards delivering a step change in the production of polymer matrix composites, whilst training the next generation of composite engineers.



The Hub forms a key element in the UK's composites manufacturing R&D strategy with a total portfolio of £23M, including £13M in support from 4 High Value Manufacturing Catapults and 18 sector-leading industrial partners.

The Hub is one of eight Future Manufacturing Hubs, a critical investment by the EPSRC to help manufacturing industries respond to future opportunities and drivers, and contribute to a prosperous UK by supporting the commercialisation of early stage research opportunities in emerging areas.

Hub Objectives

Research

Promote a step-change in composites manufacturing science and technologies

Technology

Create a pipeline of next-generation technologies addressing future industrial needs and developing the national composites strategy

Training

Train the next generation of composites manufacturing engineers

Partnerships

Build & grow the national & international communities in design & manufacture of high-performance composites

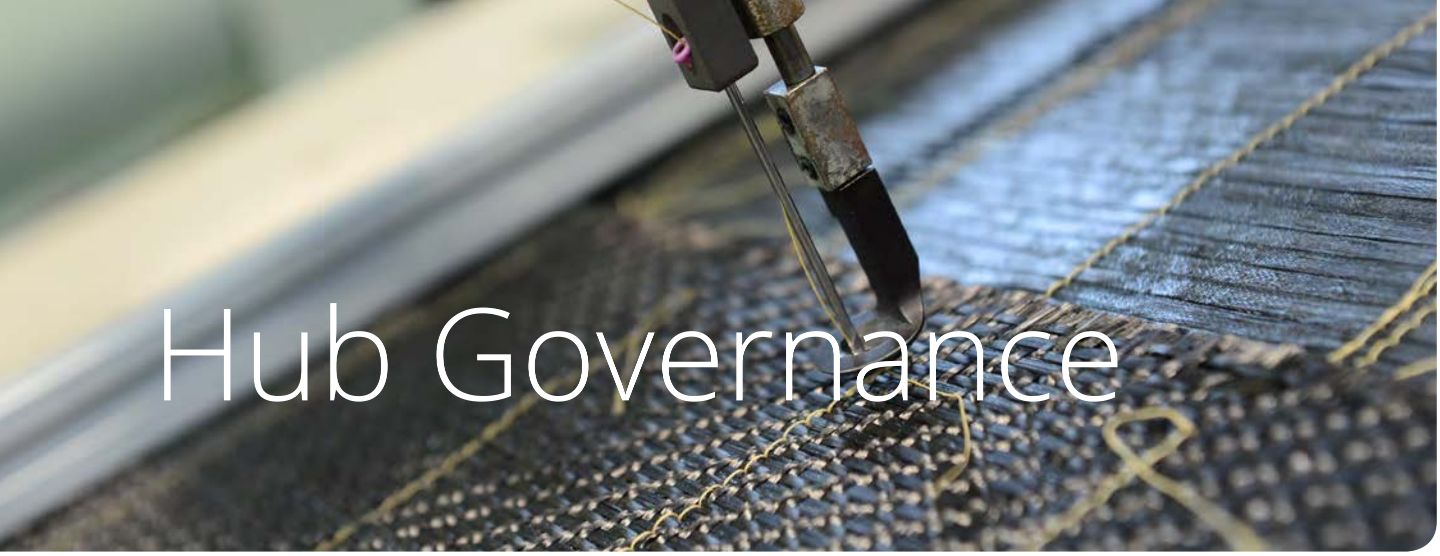
The Hub is focused on addressing two over-arching Grand Challenges:

1. Enhance process robustness via understanding of process science
2. Develop high rate processing technologies for high quality structures

To meet these Grand Challenges, five research priority areas have been identified with the help of industry partners and the broader composites community:

1. High-rate deposition and rapid processing technologies
2. Design for manufacture via validated simulation
3. Manufacturing for multifunctional composites and integrated structures
4. Inspection and in-process evaluation
5. Recycling and re-use

Hub Governance



The **Management Group** is chaired by the Hub Director and coordinates the programme of research to address the Hub's two Grand Challenges.

The **Advisory Board** comprises independent academic and industrial members who take a high-level, strategic view of the needs of Hub stakeholders, and provide guidance to maximise the quality and impact of research.

The **Strategic Development Committee** is focused on identifying potential research partners and coordinating access to external funding sources. The committee comprises industrialists and representatives from funding bodies.

The **Knowledge Exchange Committee** formally manages the links between the Hub, industry, and the High Value Manufacturing Catapult stakeholders and is the principal route for promoting follow-on work and early stage commercialisation.

The **Postgraduate Development Committee** oversees the training and progression of research students at doctoral and postdoctoral levels, and manages an international student exchange scheme through the International Researcher Network.

The **Industrial Doctorate Centre** delivers specialist doctoral training, facilitating the 4-year EngD course in Composites Manufacture for researchers who aspire to key leadership positions in industry.

The **Researcher Network** is led by postdoctoral researchers. It administers early career funds, promotes collaboration and networking, and enhances the cohort experience of postgraduate students.

Hub Partners

Academic Partners

The Hub currently comprises ten leading research groups working on composites manufacturing in the UK. The objective is to build and grow the national community in the design and manufacture of high performance composites. The Hub is led by the University of Nottingham and the University of Bristol and initially included four other Spokes: Cranfield University, Imperial College London, the University of Manchester, and the University of Southampton. The Hub expands its national academic network through periodic feasibility calls. Three new academic partners joined the Hub in October 2017: the University of Cambridge, the University of Edinburgh, and the University of Glasgow. Brunel University London joined the Hub in January 2018.

University of BRISTOL

University of Nottingham
UK | CHINA | MALAYSIA

Brunel University London

UNIVERSITY OF CAMBRIDGE

Cranfield Manufacturing

THE UNIVERSITY of EDINBURGH
School of Engineering

University of Glasgow

Imperial College London

MANCHESTER 1824
The University of Manchester

UNIVERSITY OF Southampton

Industrial Partners

“Hexcel believes that the initial Hub feasibility studies provide critical elements that will support the UK composites manufacturing industry. It is evident that the Hub has made a strong start in its first year and we look forward to supporting future projects.”

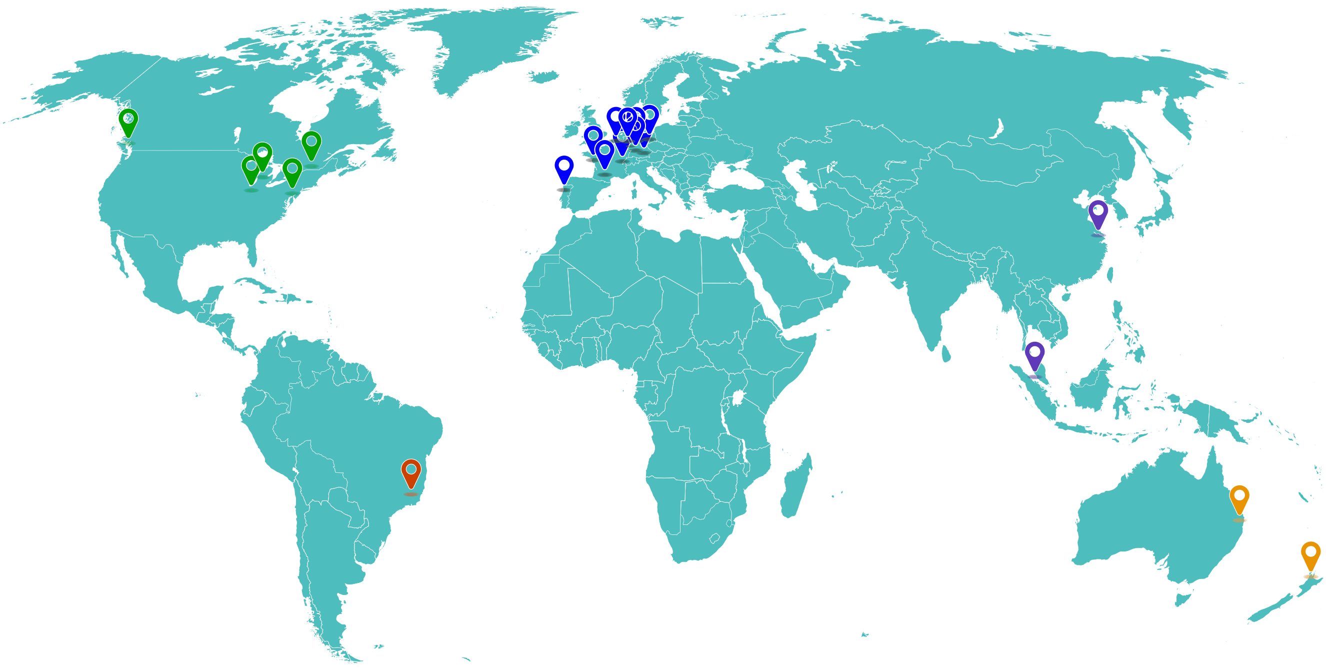
Chris Harrington, Research & Technology Manager, Hexcel Composites Ltd.

The industrial partner network is essential for delivering the pipeline of next generation technologies. The 2016 UK Composites Strategy highlighted the requirements for push/pull technologies in order to ‘deliver, develop and diversify’, which will provide the means to respond to the forecast 160% tp potential 700% growth of the industry over the next five to fifteen years. Key to this strategy is the creation of the Hub in order to push technologies through to the HVM Catapult Centres (NCC, AMRC, WMG and MTC) so that they can be developed through the Technology Readiness Levels (TRLs) and exploited by UK industry. The Hub academic team has a strong track record of collaboration with industrial partners, many of whom were consulted during the development of the Hub. Key industrial partners involved in creating and supporting this network are:

International Partners

As part of the Hub's commitment to train 120 postgraduates and 30 postdoctoral researchers over the seven-years, an international exchange programme has been founded for all researchers funded through the Hub. Twenty three leading international institutions across twelve countries have offered to host three-month visits to share information and developments within the field. This will help to ensure that technologies and highly trained personnel are effectively integrated within academia, research institutes and industry in the future.

- 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



- RWTH Aachen University
- Technische Universität Dresden
- École Centrale de Nantes
- Swiss Federal Institute of Technology, Lausanne (EPFL)
- Fraunhofer ICT, Fraunhofer-Gesellschaft
- Université Fédérale Toulouse Midi-Pyrénées
- Institut für Verbundwerkstoffe
- KU Leuven
- LCC Munich
- INEGI, Universidade do Porto
- Universität Stuttgart
- Universiteit Twente
- The University of British Columbia
- Concordia University
- University of Delaware
- Michigan State University
- Purdue University
- McGill University
- The University of Auckland
- University of Southern Queensland
- University of Nottingham Ningbo China
- University of Nottingham Malaysia Campus
- Institute for Technological Research (IPT)

Concordia University

CENTRALE NANTES

Fraunhofer ICT – IMM

U.PORTO

Institut für Verbundwerkstoffe

ipt INSTITUTO DE PESQUISAS TECNOLÓGICAS

KU LEUVEN

TUM

McGill

MICHIGAN STATE UNIVERSITY

PURDUE UNIVERSITY

RWTH AACHEN UNIVERSITY

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

TECHNISCHE UNIVERSITÄT DRESDEN

THE UNIVERSITY OF AUCKLAND NEW ZEALAND

UBC

Universität Stuttgart

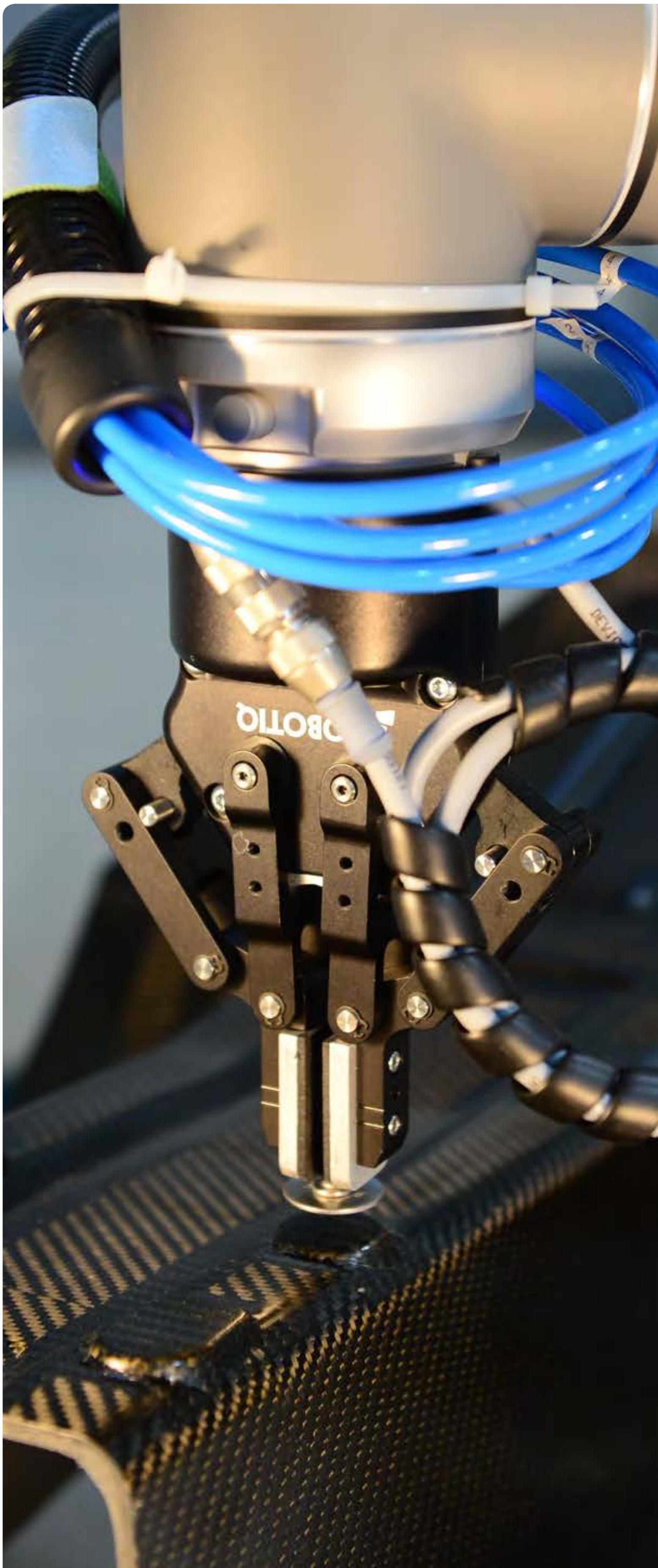
Université Fédérale Toulouse Midi-Pyrénées

UNIVERSITY OF TWENTE.

UNIVERSITY OF DELAWARE

University of Nottingham UK | CHINA | MALAYSIA

UNIVERSITY OF SOUTHERN QUEENSLAND



Key People

Leadership Team

Professor Andy Long

Hub Director

Professor Andy Long is the Director of the Hub. He has worked for over 25 years on manufacturing and design of composite components and structures, and has an international reputation for his work on automated manufacturing technologies, textile composites and process modelling. He has led a number of collaborative EPSRC, TSB and industry funded projects on polymer composites, collaborating with many leading companies and universities, with a career portfolio as Principal Investigator valued at around £28million. Andy represents the academic community on the UK Composites Leadership Forum, responsible for delivery and development of the UK Composites Strategy, reporting to the Department of Business, Innovation and Skills (BIS). Currently he serves as Pro-Vice Chancellor for the Faculty of Engineering at The University of Nottingham.

Professor Kevin Potter

Deputy Director and Chair of the Knowledge Exchange Committee

Professor Kevin Potter is Deputy Director of the Hub and Chair of the Knowledge Exchange Committee. Kevin is NCC Professor of Composites Manufacturing at the University of Bristol and has over 40 years of research experience in advanced composites manufacturing processes and product development, half of which was in industry. He is recognised worldwide for work on composites manufacturing, particularly on reinforcement deformation, dimensional variability and defect generation. Kevin is the NCC-University of Bristol liaison and the Deputy Director of the Industrial Doctorate Centre.

Dr Tom Turner

Deputy Director and Chair of the Strategic Development Committee

Dr Tom Turner is Deputy Director of the Hub and Chair of the Strategic Development Committee. Tom is an Associate Professor at the University of Nottingham where he teaches Aerospace Design. Since joining the Composites Group at Nottingham in 2000 he has been involved with 14 UK research council / UK Government funded projects as well as 5 large industrially funded programmes. He has wide-ranging understanding of all stages of composites design, manufacture & assembly predominantly in the aerospace and automotive fields. His research interests are in process modelling and process automation development for composites manufacturing and assembly, methods for whole life cycle cost assessment covering design, manufacturing and assembly stages and the recovery and re-use of carbon fibres.

Professor Ivana Partridge

Director of the Industrial Doctoral Centre

Professor Ivana Partridge directs the £7M multi-partner EPSRC Centre for Doctoral Training in Composites Manufacture. She is Professor in Composites Processing within the Advanced Composites Centre for Innovation & Science (ACCIS) group at the University of Bristol. Ivana's research expertise includes thermoset resin and composite toughening, through-thickness reinforcement of composites, composite process control and polymer-metal-fibre hybridization.

Dr Mike Johnson

Chair of the Postgraduate Development Committee

Dr Mike Johnson is Chair of the Hub Postgraduate Development Committee and Associate Professor in Engineering Design and Polymer Composites at the University of Nottingham. Mike's principal research is in the field of polymer composites in relation to processing efficiency, resin transfer moulding (RTM) and structural reaction injection moulding (SRIM), including more recent research in the development of lightweight structures and adhesive bonding. Much of Mike's research has been within the automotive, marine and rail transport industries, with unique expertise in rail engineering design.

Dr Lee Harper

Hub Manager

Dr Lee Harper is the Hub Manager and Principal Research Fellow at the University of Nottingham. Lee has worked in the field of composite materials for over 15 years and has established credible expertise in process development and numerical modelling for fibre reinforced polymer composites. His principal research interests focus on developing and modelling automated manufacturing processes for the automotive industry. He currently sits on the UK's Composite Leadership Forum, as part of the Technology Working Group.

Andrew Mills

Spoke Representative

Andrew Mills is the Spoke Representative in the Management Group and a Principal Investigator for the Hub. He leads the development of technology for the cost effective manufacturing of lightweight composite structures in close partnership with industry. Over his thirty years' experience in composites manufacturing research, he has developed a strong track record in knowledge exchange and economic impacting activities. One of the most significant was leading the Airbus UK/Cranfield project AMCAPS, which investigated novel materials and process technology for large composite wing manufacture, some techniques from which have now been qualified for manufacturing the Airbus A380.

Advisory Board

Professor Mike Hinton

High Value Manufacturing Catapult

Chair of the Advisory Board

Dr Warren Hepples

Luxfer Gas Cylinders

Deputy Chair of the Advisory Board

Tim Wybrow

Solvay

Industrial Representative

Dr Enrique Garcia

National Composites Centre

Industrial Representative

Andy Smith

Gordon Murray Design

Industrial Representative

Dr Rob Backhouse

Rolls-Royce

Industrial Representative

Professor Veronique Michaud

École Polytechnique Fédérale de Lausanne

Scientific Expert

Professor Remko Akkerman

University of Twente

Scientific Expert

Dame Professor Jane Jiang

University of Huddersfield

Scientific Expert

Professor Ian Kinloch

University of Manchester

Scientific Expert

Lien Ngo

Innovate UK

Funding Body

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Scientific Expert

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EPSRC

Funding Body

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Professor Emile Greenhalgh

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Professor Derek Irvine

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Dr Dmitry Ivanov

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Dr Mihalis Kazilas

Brunel University London

Dr Eric Kim

University of Bristol

Professor Vasileios Koutsos

University of Edinburgh

Dr James Kratz

University of Bristol

Professor Conchur O'Bradaigh

University of Edinburgh

Dr Andrew Parsons

University of Nottingham

Professor Prasad Potluri

University of Manchester

Professor Paul Robinson

Imperial College London

Dr Dipa Roy

University of Edinburgh

Professor Milo Shaffer

Imperial College London

Professor Ian Sinclair

University of Southampton

Dr Alex Skordos

Cranfield University

Professor Michael Sutcliffe

University of Cambridge

Professor Ole Thomsen

University of Southampton

Professor Michael Tretyakov

University of Nottingham

Dr Carwyn Ward

University of Bristol

Professor Nick Warrior

University of Nottingham

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Dr Aurèle Bras
Cranfield University

Dr Daniel Bull
University of Southampton

Dr Shuai Chen
University of Nottingham

Dr Lawrence Cook
Cranfield 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 Vivek Koncherry
University of Manchester

Dr Dimitrios Mamalis
University of Edinburgh

Dr Mikhail Matveev
University of Nottingham

Dr Euan McGookin
University of Glasgow

Dr Oliver McGregor
University of Nottingham

Dr Daniel Mulvihill
University of Glasgow

Dr Daniel Richards
University of Glasgow

Dr Shankhachur Roy
University of Manchester

Dr Ric (Xiaochuan) Sun
University of Bristol

Dr Jin Zhou
University of Cambridge

EngD Students

Name	Institution	Sponsor
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
Harry Clegg	University of Bristol	National Composites Centre
Alex Cochrane	University of Bristol	Rolls-Royce
Sarvesh Dhiman	University of Manchester	M Wright & Sons
Mattia Di Francesco	University of Bristol	National Composites Centre
Matt Etchells	University of Nottingham	National Composites Centre
Nikita Gandhi	University of Bristol	National Composites Centre
Vincent Gill	University of Bristol	Rolls-Royce
Daniel Griffin	University of Bristol	National Physical Laboratory
Robbie Herring	University of Bristol	National Composites Centre
Dimitris Karanatsis	University of Nottingham	Hexcel
Jakub Kucera	University of Bristol	National Composites Centre
Edward Lewis	University of Nottingham	Pentaxia
Jack Lindley-Start	University of Bristol	Rolls-Royce
Josh Loughton	University of Bristol	National Composites Centre
Ffion Martin	University of Nottingham	Jaguar Land Rover
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	Aviation Enterprises Ltd
Laura Pickard	University of Bristol	National Composites Centre
Laxman Sivanathan	University of Bristol	Jo Bird
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
Petar Zivkovic	University of Bristol	Rolls-Royce

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Name	Affiliation
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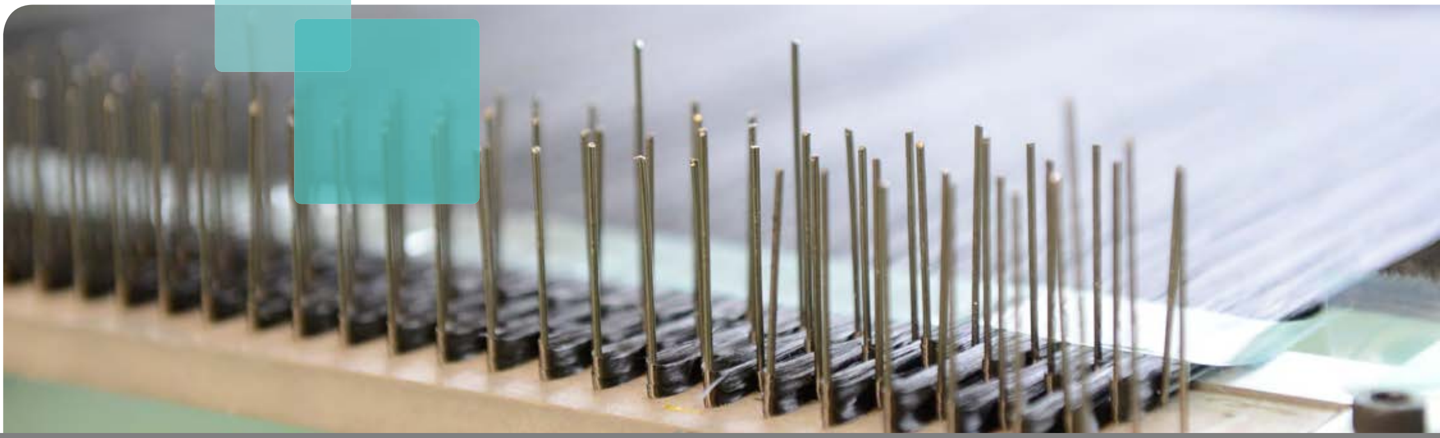
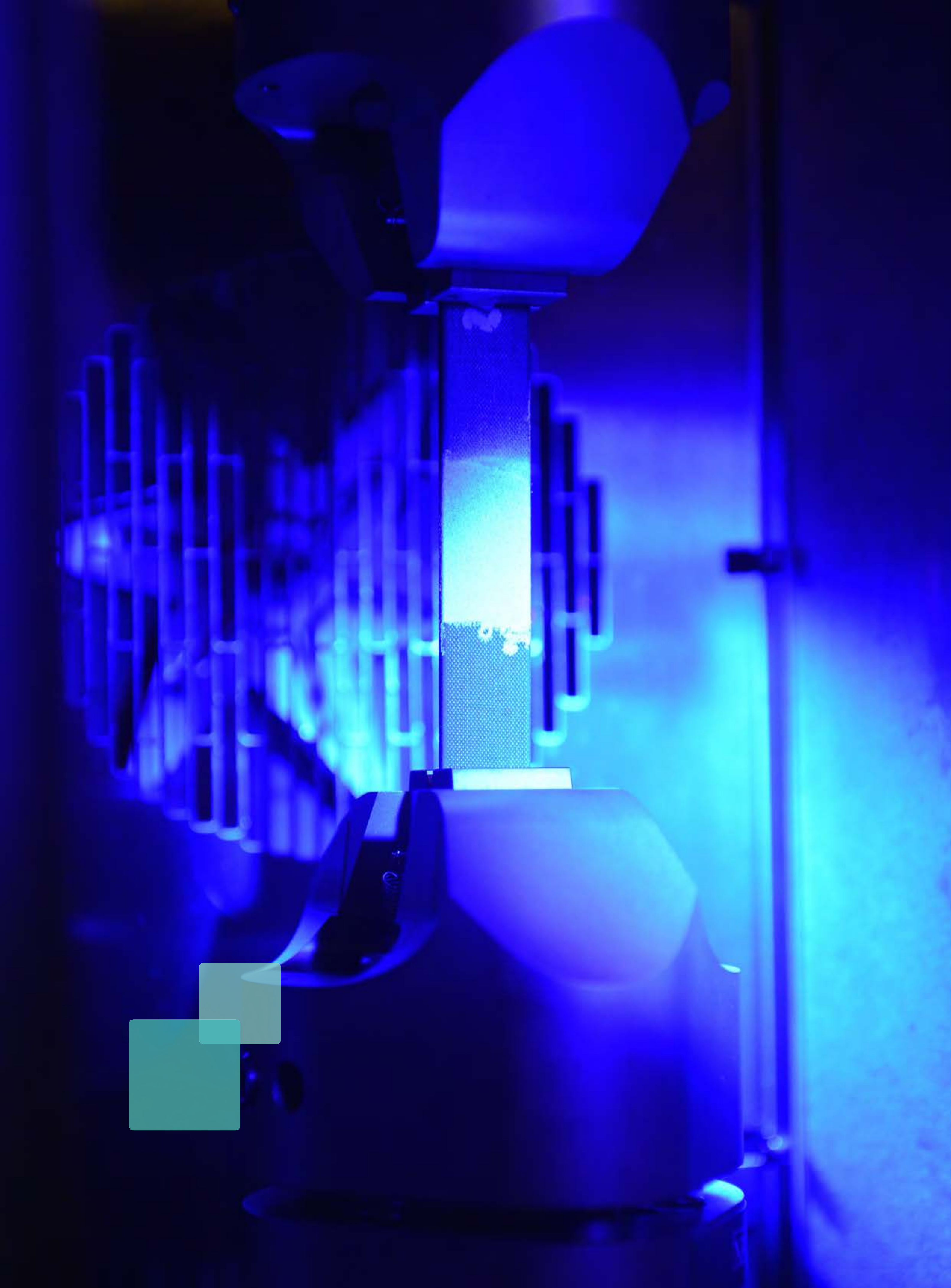
Iain Campbell	University of Glasgow
Matthew Collinson	Advanced Manufacturing Research Centre
Rob Iredale	University of Bristol
Irene Jiménez-Fortunato	University of Southampton
Caroline O'Keefe	University of Bristol
Bethany Russell	University of Bristol
Usman Shafique	University of Nottingham
Alice Snape	Advanced Manufacturing Research Centre
Konstantinos Tifkitsis	Cranfield University
Maria Valkova	Imperial College London
Verner Viisainen	University of Cambridge
Jibran Yousafzai	University of Bristol

Support Staff

Name	Position	Institution
Dr Holly Ranger	Hub Administrator	University of Nottingham
Dr Richard Gravelle	Hub Business Development Manager	University of Nottingham
Julie Grady	Hub Business Development Manager	NCC / University of Bristol
Jo Brooks	IDC Centre Manager	University of Bristol
Maria Aviles	IDC Administrator	University of Bristol





Project Summaries

Core Projects

Core Projects deliver fundamental research based on the Hub's five priority themes. Core Projects are a collaboration between two academic partners, and typically employ two postdoctoral researchers and four PhD students. The Hub provides funding for up to three years, and industrial partners are invited to support the project by sponsoring postgraduate students affiliated to the project or offering in-kind contributions. Three Core Projects were launched at the start of the Hub in 2017 and are based on previous successful research funded through the CIMComp Centre. The Hub expects to support eight Core Projects over the life of the Hub.

NEW MANUFACTURING TECHNIQUES FOR OPTIMISED FIBRE ARCHITECTURES

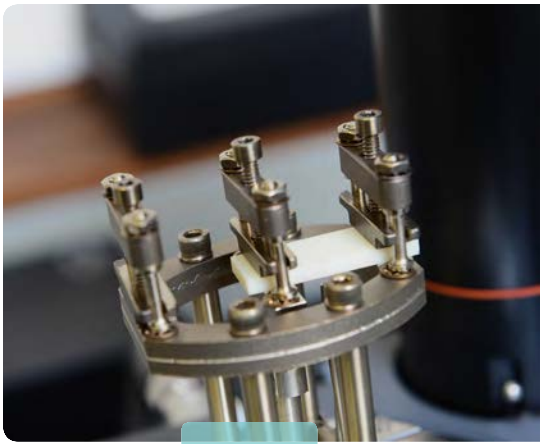
Establishing a computational framework for textile preform optimisation **(Manchester, Nottingham)**

MANUFACTURING FOR STRUCTURAL APPLICATIONS OF MULTIFUNCTIONAL COMPOSITES

Exploration, development and evaluation of manufacturing processes for multifunctional composite structures **(Imperial, Bristol)**

TECHNOLOGIES FRAMEWORK FOR AUTOMATED DRY FIBRE PLACEMENT (ADFP)

Establishing novel material delivery systems for advanced control of dry fibre distribution **(Bristol, Nottingham)**



Theme: Design for Manufacture via Validated Simulation

"New Manufacturing Techniques for Optimised Fibre Architectures"

Andy Long, Prasad Potluri, Mikhail Matveev, Vivek Koncherry, Shankhachur Roy

Aims and objectives

Textile composites produced by liquid moulding based on 3D woven preforms offer several advantages over other composites such as those based on unidirectional prepreg, including automated manufacture for complex geometries, ability to integrate geometric features (e.g. T and I sections), and delamination resistance via inclusion of through-thickness fibres. Generally in-plane fibres are orthogonal, although experimental machines have been developed which allow ±45° yarns. Other textile processes offer alternative fibre architectures, for example triaxial braiding which produces yarns at 0/±θ.

Like 3D weaving this is based on established textiles machinery rather than technology developed specifically for composites. This project aims to discover new 3D textile preform architectures. Computational modelling or "virtual testing" will evaluate the utility of different textile designs within an optimisation framework to determine the best solution for a particular application. This framework will not be constrained to architectures that can be produced using existing manufacturing technologies such as weaving or braiding. Optimum textile preforms will be realised either by modifying existing textile processes or, where potential benefits justify, by developing entirely new, bespoke manufacturing technologies. This will result in a step change in performance, leading to significant weight reductions and lower cycle times through routine use of automated manufacturing technologies. Earlier it was shown that, for a specific application, a weight saving of at least 50% can be achieved by relaxing constraints on binder path and in-plane fibre orientations. Here we will further relax constraints on the fibre architecture, aiming to identify and manufacture a number of classes of improved material forms.

The project aims to establish a computational framework for textile preform optimisation not limited to existing manufacturing technologies. The framework will be built and extended based on a

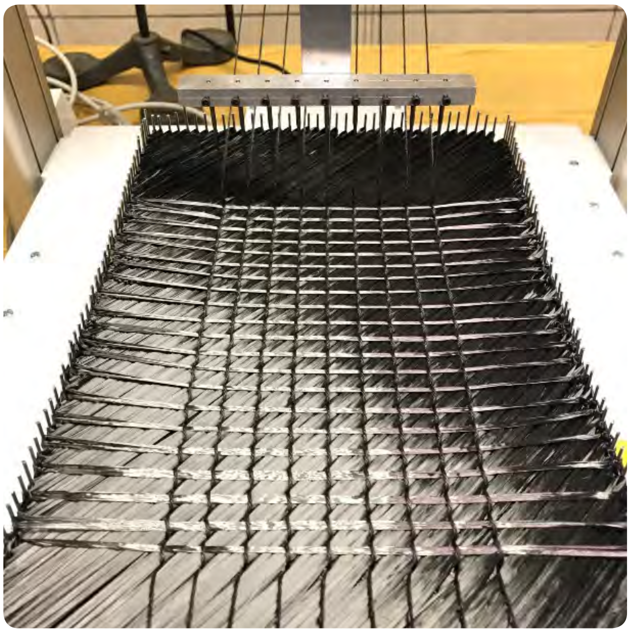


Figure 1: 3D woven textile

series of case studies to identify classes of materials with improved properties. New manufacturing technologies will be developed for these materials and used to validate the predicted properties.

Progress to date

Implementing an effective computational optimisation framework requires the ability to create realistic models of complex textile reinforcements. Geometric models for such reinforcements can be created using TexGen software but the meshing of these geometries for subsequent prediction of mechanical and processing properties presents a problem. A novel meshing approach has been implemented within TexGen software in order to construct nearly-conformal meshes which are suitable for analysis of stiffness and strength of textile composites. The implemented meshing technique enables modelling of more complex reinforcements in an automatic way. Alongside this an analytical approach based on orientation averaging has been developed to provide fast predictions for composite elastic properties. As demonstrated through initial optimisation trials based on a genetic algorithm, this approach offers significant reductions in computation times for problems based only on elastic performance.

In order to deliver step-change manufacturing technologies, initial research has concentrated on overcoming the key limitation of commercial 3D weaving technology – inability to place tows at an angle (off-axis) to the two principal tow directions, warp and weft. The first prototype of a multi axial 3D woven fabric has been developed using a combination of robotic fibre placement and weaving principles. This approach enables us to insert off-axis tows without the need for complex rotating creel systems found in the literature. The next stage of development will create a multi-axial 3D woven architecture comparable to conventional Jacquard woven 3D weaves in terms of tow densities and appearance. Additionally, we are working on creating a multiaxial 3D woven architectures in seamless tubular form as an improvement over multi-layer 2D braiding or roll-wrapping techniques.

Key findings

A novel technique was implemented within TexGen software to support automatic generation of finite element meshes of complex textile geometries.

An iso-strain approach based on orientation averaging was implemented in TexGen to predict elastic properties for the candidate materials.

A combined fibre placement/weaving technique was developed to produce 3D textiles including off-axis fibres.

Project partnerships to date

Rolls Royce, M Wright & Sons, Sigmatex, Luxfer Gas Cylinders, National Composites Centre (NCC), Advanced Manufacturing Research Centre (AMRC).

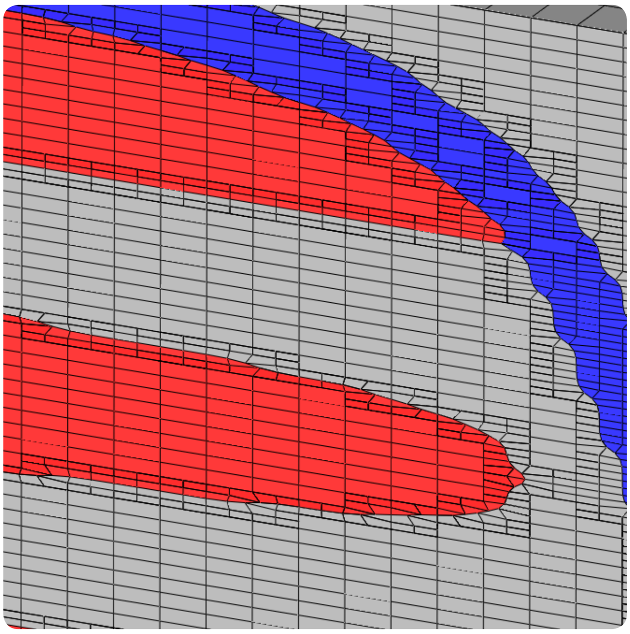


Figure 2: The Octree Mesh Method is used to plot and generate at high speed complex 3D solid objects

Theme: Manufacturing for Multifunctional Composites and Integrated Structures

"Manufacturing for Structural Applications of Multifunctional Composites"

Ivana Partridge, Emile Greenhalgh, Carwyn Ward, Dmitry Ivanov, Milo Shaffer, Ian Gent, Caroline O'Keefe, Arjun Radhakrishnan, Maria Valkova, Kaan Bilge

Aims and objectives

The over-arching aim of the project is to investigate and address the design and manufacturing issues associated with multifunctional composites, addressing specifically the transport phenomena of heat and electrical conduction.

Aim 1: To explore novel manufacturing methods for creating multi-matrix and multi-fibre graded composites and local integration of functionalised patches. The locality within matrix is achieved through liquid resin printing enabling integration of additive-rich resins in predefined patterns through the thickness and in-plane of composite laminates. The specific focus of the matrix study is on the relation between processing parameters (injection, consolidation, curing), chemorheology of injected resins, and the morphology of printed patches. The specific focus of the fibre modification is the insertion of novel multi-material threads and fibres into dry fibre preforms, both in-plane and out-of plane of the structure.

Aim 2: To explore the manufacturing issues associated with the creation of structural power materials (structural supercapacitors), which simultaneously store, and deliver, electrical energy whilst carrying mechanical loads. Such multifunctional materials offer a completely different approach to using composites in transport and mobile electronics, and have the potential to provide a step change in weight and volume driven designs.

The research to date has focussed on demonstration of the concept and addressing the scientific challenges associated with this novel class of materials, but within this Composite Manufacturing Hub project, the general design and manufacturing issues associated with structural power materials are being addressed. Such research is vital to facilitate adoption of these materials by industry, and is of general relevance to a wide range of potential multifunctional composite systems which must harmonise conflicting requirements.

Progress to date

At Bristol, the new Hertzog microbraider has been commissioned (see image) and preliminary work carried out using standard reinforcing thread types. Early trials using metallic wires and threads to co-braid with fine carbon fibre rovings are producing flexible but stable braids of under 1 mm in diameter. The limits of achievable braiding patterns are being explored for different material combinations.

Promising stable multi-material braids have resulted from early braiding trials at Bristol, potentially addressing a current industrial problem by protecting fragile commercial carbon fibre threads from frequent breakage in the tufting operation. A collaboration between Bristol and the NCC ensures that such early braided products can be tested for suitability of use in the industrial tufting head, thus providing pointers for future modification of the braiding patterns.

Regarding Carbon Aerogel (CAG) development in the context of structural supercapacitors, trials on precursor infusion and pyrolysis have been undertaken at Imperial College on a number of different dry fabrics, such as spread tow weaves and NCF materials. Good infusion of the CAG into the interior of the tows and bonding of the CAG to the fibres has been achieved, however, interaction with the binder for the spread-tow has caused some difficulties. Further development work is currently underway to introduce active elements onto the CAG to further enhance the electrical performance. In

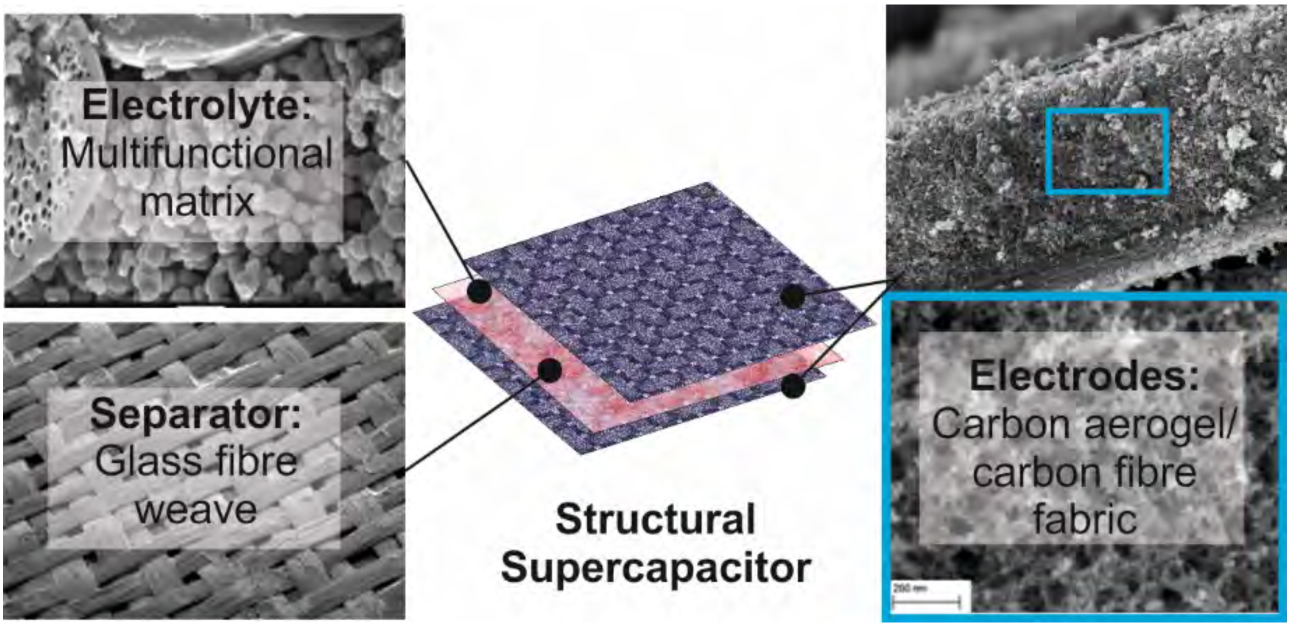


Figure 1: Carbon Aerogel (CAG) is infused into the interior of the tows in multimaterial structural supercapacitors

parallel, studies are underway to rank and identify the best separator materials.

Work has started to address structural supercapacitor device design and modelling of mechanical performance. Finite element models (Abaqus) are being developed to predict the compaction of the devices during consolidation (see image), to understand how processing will influence the microstructure and hence the performance of the devices.

Project partnerships to date

National Composites Centre (NCC), BAE Systems, Airbus, Qinetiq, Hexcel.

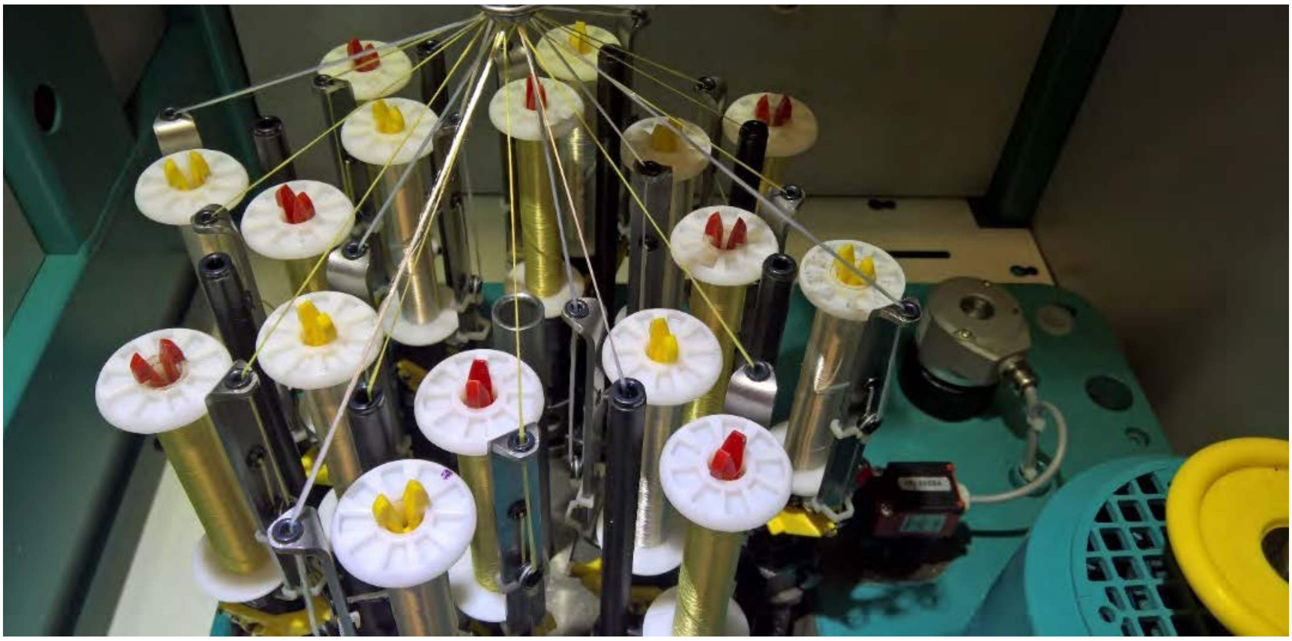


Figure 2: University of Bristol's microbraider

Theme: High-rate Deposition and Rapid Processing Technologies

“Technologies Framework for Automated Dry Fibre Placement (ADFP)”

Thomas Turner, Kevin Potter, Eric Kim, Carwyn Ward, Anthony Evans, Michael Elkington, Usman Shafique, Laura Veldenz

Aims and objectives:

Automated Fibre Placement (AFP) technology has been adopted within the aerospace industry for the manufacture of carbon fibre reinforced components, such as wing spars, wing box covers and fuselage barrel segments. AFP has the ability to control fibre orientation as a result of its fibre steering capabilities by directing fibres onto a complex geometry or curved surface. The robustness, low wastage and repeatability through automation result in a desirable process for high quality high volume manufacture. AFP eliminates the labour intensive hand lay-up methodology that significantly increases production times. Traditionally, AFP uses thermoset or thermoplastic prepreg slit tapes, using the tack of the matrix material to adhere the fibres into position. However, these materials are expensive, require accurate temperature control during storage and deposition, to ensure sufficient adhesive properties are not effected by aging, and require further consolidation processing, such as by autoclave. The latter further increases initial equipment cost and operation cost as well as cycle times in comparison to liquid composite moulding (LCM) processes. Therefore, automated dry fibre placement (ADFP) has become of particular interest with the aim of reducing cost and cycle times whilst maintaining the high quality and low wastage of fibre placement technologies.

The overall aims are to understand the rate and quality limiting effects in the ADFP process and develop models to increase understanding of the critical factors. The project consists of several work packages: 1) The process design package will determine hardware effects and control of the deposition apparatus whilst developing lab scale equipment to demonstrate these. 2) The material design package will investigate the fundamental tow/tape/NCF structure, optimising the binder content (type and volume) for tack and the prevention of fibre fuzzing during deposition. 3) The deposition process work package will quantify the tack properties with respects to rate and temperature of dry fibre systems as well as the studying the compaction and topology to predict behaviour of single tows or ply stacks and their interactions with the deposition roller. 4) The infusion process package will quantify the permeability effects of the fibre architecture post deposition. 5) Finally, the part design package will part geometric effects in terms of processing rate and quality of the preforms.

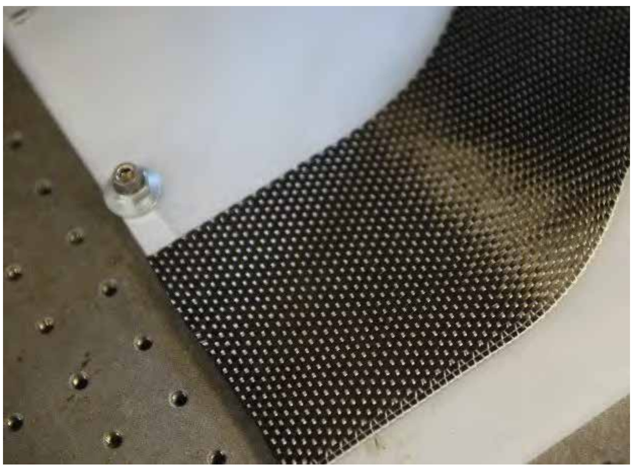


Figure 1: Automated deposition of carbon fibre tape using advanced fibre steering technology

Progress to date

A range of dry fibre AFP materials are commercially available (or available in developmental quantities) that are processable using the Coriolis AFP machine at the National Composites Centre using laser heating to activate the binders. The material variants include both slit tape and towpreg, with the majority of products being towpregs.

Figure 2: A researcher adjusts the wide tape continuous tow steering (CTS) machine head

These materials have been assessed against a set of requirements based on the factors such as:

- strength of bonding to tool substrates and previously laid down plies
- minimum steering radius
- bulk factor
- volume fraction as laid and under pressure
- in and out of plane permeability with and without deliberately induced course to course gaps
- the generation of fluff in process (leading to machine downtime)

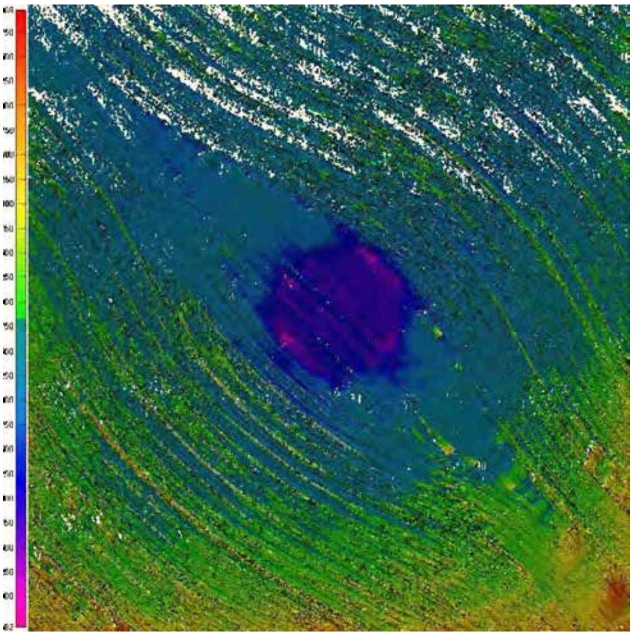


Figure 3: Output from a laser line scanner depicting the surface geometry profile of the panel from the steering trial (Laura Veldenz, NCC)

No significant improvement in steering radius is seen from the use of current commercially available dry fibre tapes compared to the use of impregnated tapes

None of the materials tested to date have an ideal set of properties and significant opportunity exists to generate improved dry fibre AFP forms, which will be a feature of the work to be carried out in this project. Alternative approaches to conventional AFP can be used to generate very significantly tighter steering radii for both dry fibre and prepregged reinforcements from relatively low cost reinforcement forms.

Project partnerships to date

National Composites Centre (NCC), ESI

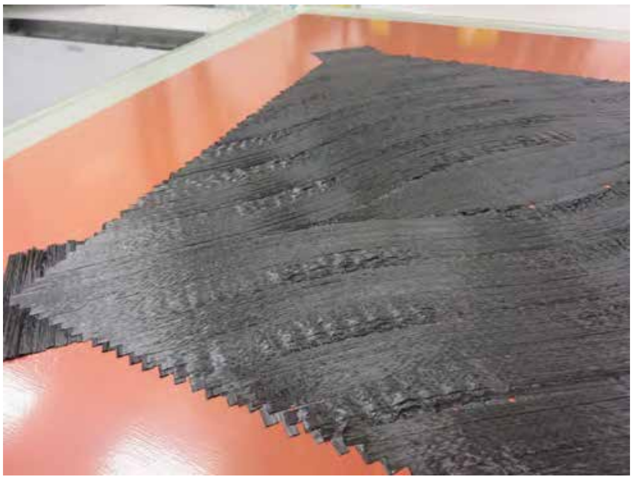
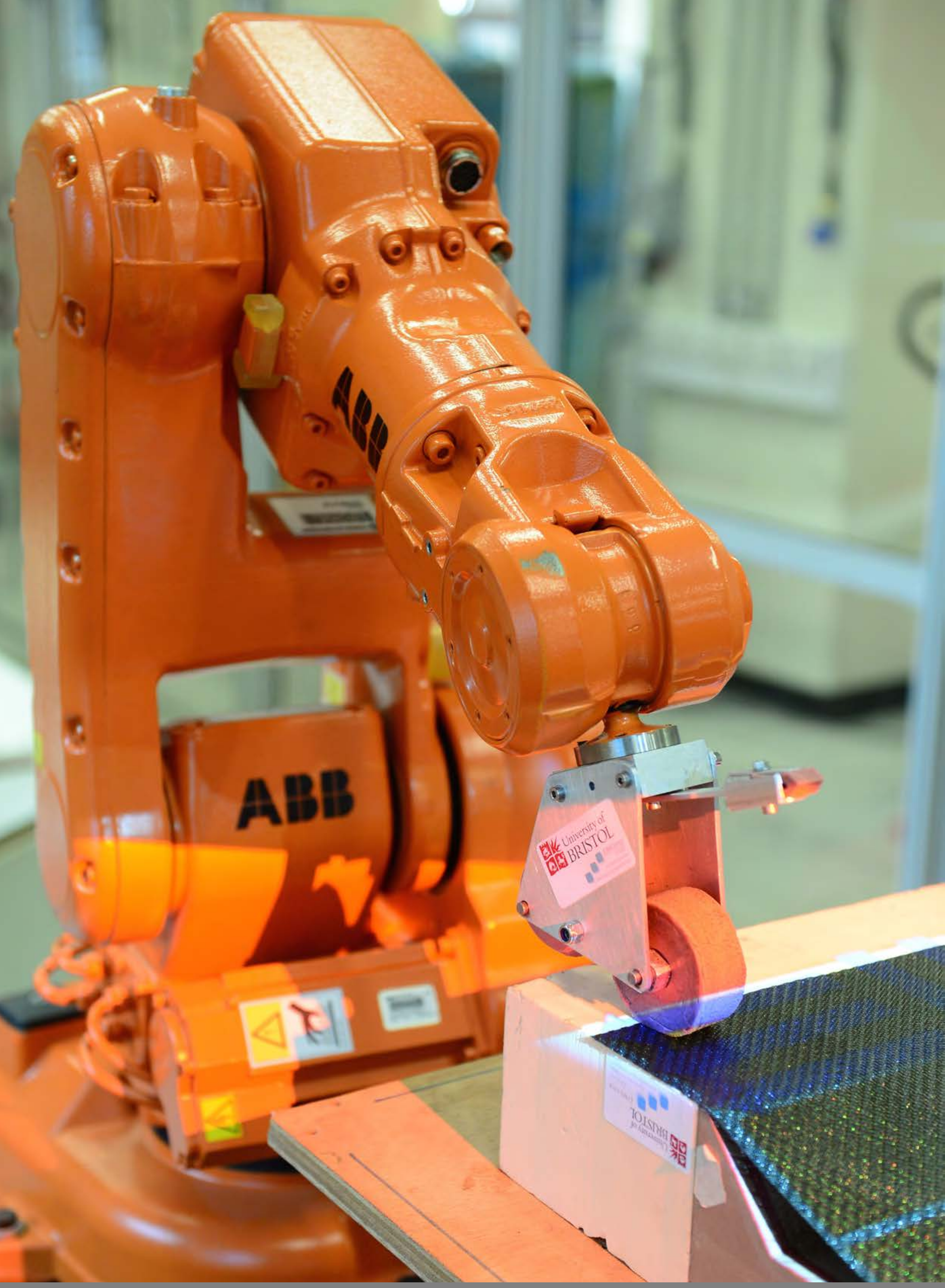


Figure 4: A DFAFP steering trial shows defects generated by steering at too tight a radius (Laura Veldenz, NCC)

Figure 5: The automated forming of a dry fibre broadgood cloth using an ABB IRB140 6DOF robotic arm and novel end effectors to a complex geometry, also demonstrating the exploitation of low cost visualisation tools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Feasibility Studies

Feasibility Studies are the primary mechanism through which new academic partners can gain Spoke status within the Hub. Successful Feasibility Studies are awarded £50,000 for short-term projects (up to 6 months) to address a fundamental step-change in composites manufacturing technology aligned to one or more of the Hub's five research priorities. Proposals can address the development of new manufacturing technologies, analytical studies to develop a fundamental understanding of state-of-the-art processes, or the development of process modelling and optimisation techniques. Access to further Hub funding can be released if feasibility is demonstrated, with the potential to expand the Feasibility Study into a three-year Core Project.

Following two calls for proposals in May and October 2017, the Hub received 90 applications from 29 UK academic institutions. Each proposal was reviewed by at least 3 independent reviewers from the Advisory Board, who followed the EPSRC's rules of probity and declared any conflicts of interest. Ten Feasibility Studies were funded by the Hub in 2017, with further research funding available through a planned third call for proposals in Year 4.

Affordable Thermoplastic Matrix CFC / Metallic Framework Structures Manufacture

(Cranfield University)

LAYER BY LAYER CURING

(Cranfield University)

NOVEL STRAIN-BASED NDE FOR ONLINE INSPECTION AND PROGNOSTICS OF COMPOSITE SUB-STRUCTURES WITH MANUFACTURING INDUCED DEFECTS

(University of Southampton)

SIMULATION OF FORMING 3D CURVED SANDWICH PANELS

(University of Nottingham)

CAN A COMPOSITE FORMING LIMIT DIAGRAM BE CONSTRUCTED?

(University of Cambridge)

MANUFACTURING THERMOPLASTIC FIBRE METAL LAMINATES BY THE IN-SITU POLYMERISATION ROUTE

(University of Edinburgh)

MULTI-STEP THERMOFORMING OF MULTI-CAVITY MULTI-AXIAL ADVANCED THERMOPLASTIC COMPOSITE PARTS

(University of Glasgow)

ACTIVE CONTROL OF THE RTM PROCESS UNDER UNCERTAINTY USING FAST ALGORITHMS

(University of Nottingham)

MICROWAVE HEATING THROUGH EMBEDDED SLOTTED COAXIAL CABLES FOR COMPOSITES MANUFACTURING

(Brunel University London)

ACCELERATION OF MONOMER TRANSFER MOULDING USING MICROWAVES

(University of Nottingham)

Theme: High-rate Deposition and Rapid Processing Technologies

"Affordable Thermoplastic Matrix CFC/Metallic Framework Structures Manufacture"

Andrew Mills, Lawrence Cook, Aurèle Bras

Aims and objectives

The project investigated novel design and manufacturing techniques, which show the potential for manufacturing lightweight structural frameworks at high manufacturing rate using carbon fibre reinforced polyamide matrix laminate or tubing and metallic joints. Novel joining techniques have been developed to provide connection by interlocking so as to eliminate mechanical fasteners and adhesive bonding. The project aimed to establish the feasibility and potential affordability of the conceptual process in terms of frame section and joining piece manufacture and frame and joint attachment technique, and to propose framework designs based on the proposed approach for structural applications.

Progress to date

Many concepts for thermoplastic matrix and metallic hybrid structures have been identified. Taking a sports car fully body structure geometry and carrying out a loading study, novel structures suitable for high rate manufacturing have been proposed. These utilise combinations of pultruded tubular sections and folded thermoplastic 'organosheets'. The tubular parts are proposed to be joined using low cost metallic connectors. The concepts do not therefore require dedicated mould tooling for shaping the parts.

The following concepts are considered to offer the most potential for structural application and further investigation:

a. Metallic joint wrapping

b. Composite tube swaging

c. Metal joint interlocking with composite sections

Figure 1: Composite tube

Figure 2: Thermoplastic Matrix CFC Tube with Swaged Joining to Aluminium End Fittings

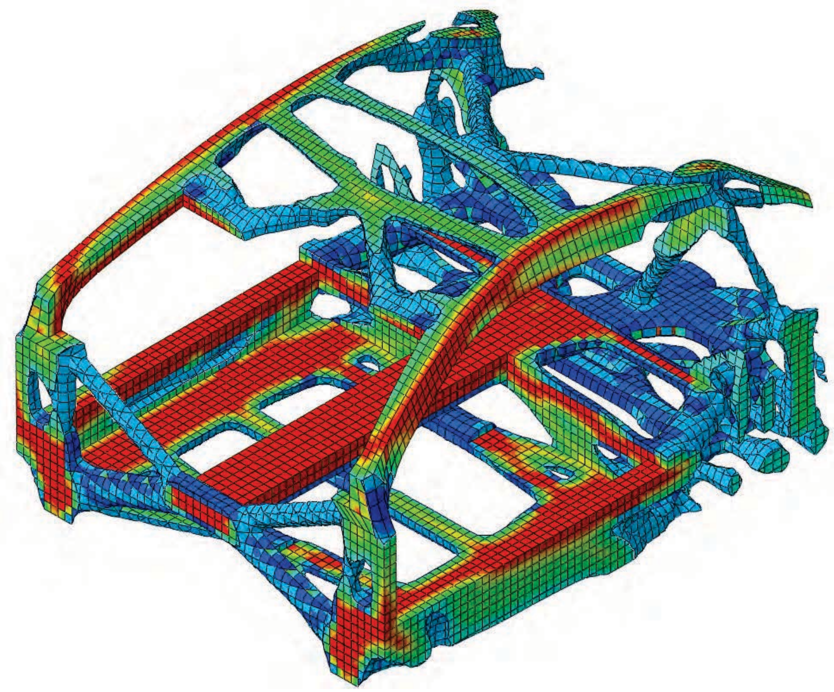


Figure 3: Topological Structural Optimisation of a Mid-engine Sports car Showing Strain Distribution after Application of Crash Loading

Project partnerships to date

Expert Tooling and Automation, Advanced Manufacturing Research Centre (AMRC), TU Dresden

Impact

The project's findings comprising design and manufacturing understanding have been used in a variety of ways. For example:

Design and manufacture of attachment fittings for a medium volume, lightweight car body floor structure. These have been built into the project demonstrator for a £7M AMSCI collaborative project Lightweighting Excellence, a full carbon fibre composite platform for a medium volume car in conjunction with Nissan UK and Bentley Motors.

A KTP was launched in July 2016 with the project partner bigHead fasteners to translate the project-developed technology into new types of composite attachment fittings for volume manufacture using the CIMComp project findings.

The project results are also being utilised with the CIMComp project team involvement in a BAE SYSTEMS led Innovate UK project, HITEA for fighter aircraft primary structure joints.

Use in both Master's courses and an industry focused short course in composites manufacturing.

In February 2018, the Cranfield Research Fellow Lawrence Cook left the University to join one of the project's industrial partners bigHead. BigHead will be developing new fastener types and application techniques initially investigated during the project. Envisaged market sectors for these are; worldwide automotive bodies, lorry structures and wind turbine generators.

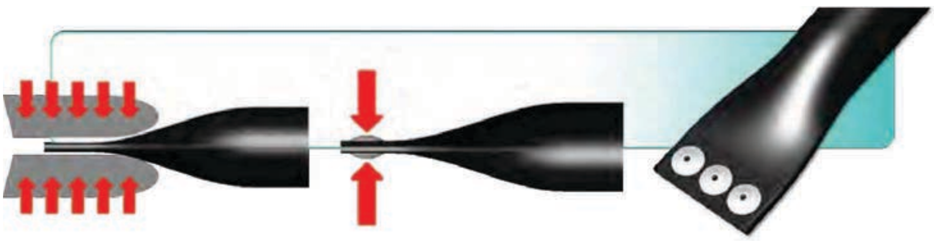


Figure 4: The Tube Crimping Concept

Theme: Inspection and In-process Evaluation

“Novel Strain-based NDE for Online Inspection and Prognostics of Composite Sub-structures with Manufacturing Induced Defects”

Janice Dulieu-Barton, Ole Thomsen, Ian Sinclair, Daniel Bull, Irene Jiménez-Fortunato

Aims and objectives

To save time and reduce wastage it is essential that an inspection technology is developed that can be used to intervene at the manufacturing stage and provide high fidelity data for model based prognostic capability (beyond simply sizing defects) to further inform the decision process of ‘accept,’ ‘rework,’ ‘repair’ or ‘scrap’. To this end a novel inspection procedure for cured composite components needed to be developed, and the overarching aim of the project is a system deployed alongside current inspection approaches in the production environment. This procedure has the ability to simultaneously measure the strain and a stress measure in the vicinity of a manufacturing defect or intrinsic subsurface artefact (including the variability of fibre volume fraction and fibre orientation, not just the geometry and size), and provide high fidelity data to inform model-based prognostics, and define how a given defect will evolve under service load.

The objectives of the of the feasibility study were:

- To establish the underlying physical principles, and to demonstrate the viability of the experimental methodology based on combining thermoelastic stress analysis (TSA) and digital image correlation (DIC) and collecting data simultaneously.
- Demonstrate that the data necessary for the model based prognosis system could be obtained by demonstrating the viability of the approach at a sub-structural level.

Key findings

The feasibility study is completed. It has been fully demonstrated that DIC and TSA can be used simultaneously to collect data from composite components. The approach has been demonstrated on a high value carbon fibre aircraft component and shown that the results can be linked to the findings of high fidelity prognostic models, with defect geometry defined by X-ray CT.

The approach has also been demonstrated on materials typical of those used in high volume manufacturing made from carbon fibre/epoxy discontinuous compression moulded preforms. The work has linked observations from X-ray CT to the mechanical response and that the combination of DIC and TSA for assessment of the material shows great promise. In particular it is possible to predict the localised stiffness variations, linked to local variability of fibre volume fraction and fibre orientation, throughout the preform. This indicates that the manufacturing control process could be directly informed/updated using the technique. It has also been demonstrated that the technique can be protable (i.e. no need for a test machine to load the components) by exciting the component briefly at its resonant frequency.

The PhD study is focusing on developing a low cost infra-red camera for TSA. The work has revealed in the first 9 months what the scientific challenges are in developing the technology further, and provided the first steps in developing signal processing routines that will address the challenges.

Fully integrated DIC and TSA: the key challenge was in collecting the data simultaneously. This was done by using lock-in processing for the DIC. Although the technique was developed at University of Southampton previously, the key challenge was deploying this on a realistic component.

The strain measurements from the DIC and the thermoelastic response, which is dependent on the local fibre orientations and fibre volume fractions have provided strong indication of identification of stiffness distribution and resin-rich volumes.

Initial demonstration of vibration based technique on panels.

Impact

The technology developed in the feasibility study is new and the next steps will provide practical demonstrators based on a realistic high volume manufactured and high value manufactured components loaded either naturally or by excitation at their resonant frequency. Now feasibility has been demonstrated, a strong consortium with a focus on manufacturing of composite components both high value and high volume will be established to seek further funding from the Future Composites Manufacturing Research Hub, to develop the study into a Core Project.

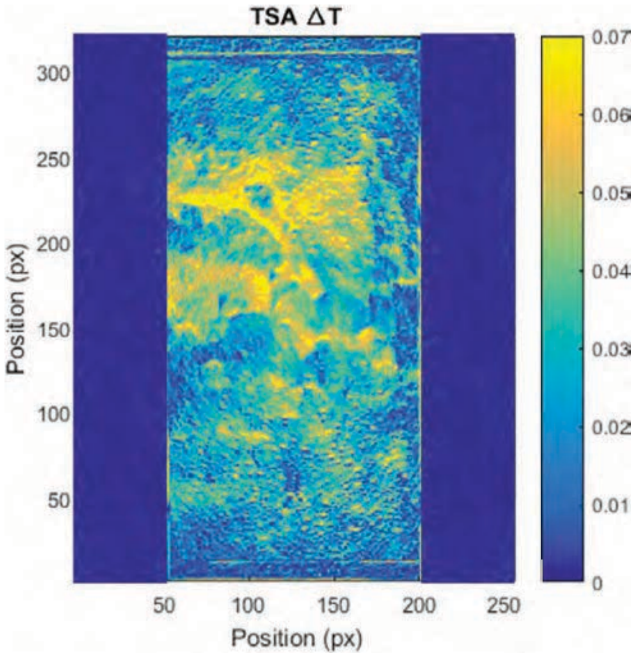
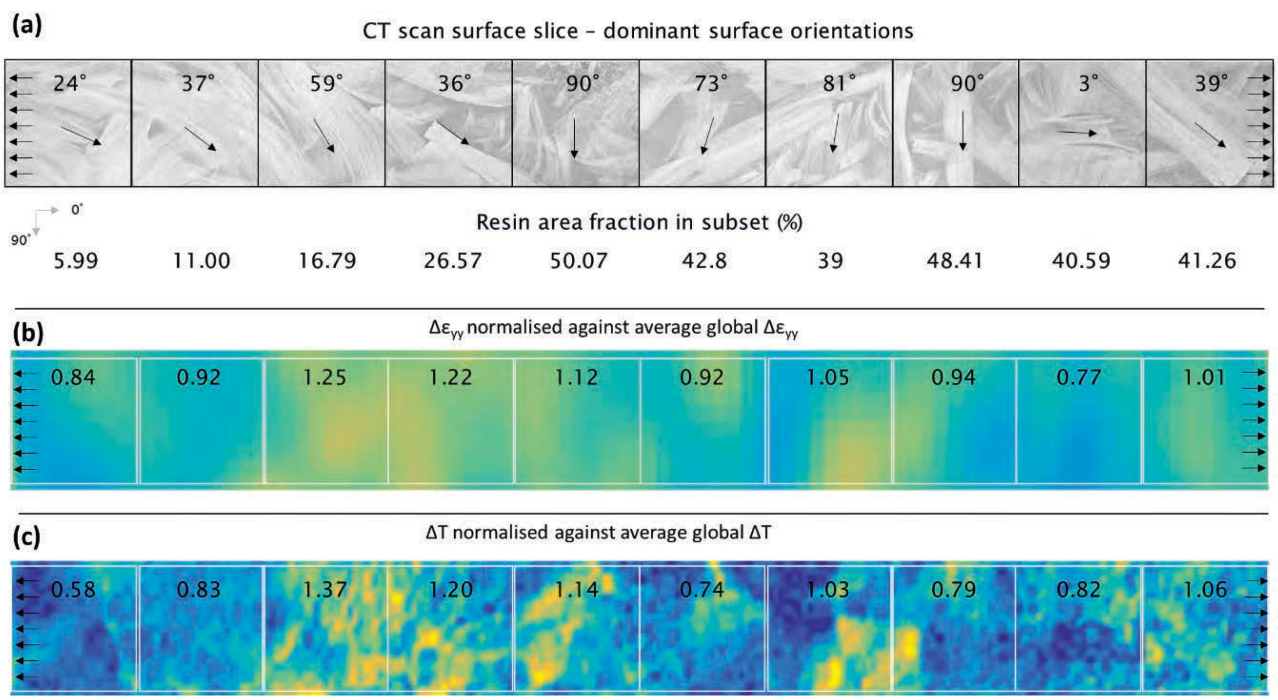


Figure 2: In-situ manufacturing inspection of parts based on vibration based loading

Figure 1: X-ray CT quantifies volumetric variability in local resin volume content and distribution of local fibre orientations



Theme: Design for Manufacture via Validated Simulation

“Can a Composite Forming Limit Diagram be Constructed?”

Michael Sutcliffe, Jin Zhou, Verner Viisainen

Aims and objectives

This feasibility study on composite forming, explores wrinkling issues during draping of non-crimp fabric (NCF) and the possibility of constructing a composite forming limit diagram. The timeliness of the project arises from the urgent need from a wide range of industries to improve their simulation capability for pre-forming of dry fabric and pre-preg. Wrinkling during draping of non-crimp fabric will be measured using the Digital Image Correlation (DIC) method and modelling work will be undertaken using finite element analysis in conjunction with the University of Nottingham. The current research will provide clear guidelines for assessing wrinkle formation. The proposed work complements existing activity within the CIMComp program on forming of composites, providing a framework to fit experiments and modelling of deformation and wrinkling.

The aim of the project is to demonstrate the feasibility of developing a forming limit diagram for textile composites, capturing the limits imposed by defects such as macro-wrinkling, tow level buckling and yarn sliding.

The key objectives of the project are to

1. Use existing measurements of wrinkle formation in woven and NCF fabrics to develop a preliminary FLD;
2. Extend the range of test configurations to explore the generality of the derived FLDs;
3. Examine the feasibility of using a range of canonical finite element calculations to interpolate and extrapolate the FLD from a limited set of tests;
4. Use the results to inform a full-scale proposal which will develop the concept of FLDs to include a wider range of materials and forming situations.

Progress to date

1. A preliminary literature review has been informed by a review of wrinkling in textile forming.
2. Preliminary tests have used DIC to measure strains during draping of non-crimp fabric.
3. Finite element modelling has been used to simulate the existing experimental work and to implement a user-defined fabric subroutine in Abaqus/Explicit.

Project partnerships to date

Hexcel and Dassault Systèmes. Benefits to industrial partners will include better understanding of the mechanical properties and performance, more opportunity for application of these materials across industry sectors, a wider range of materials and forming situations.

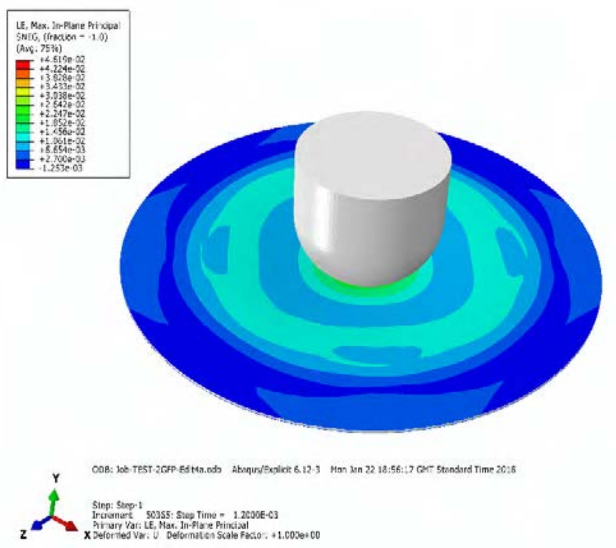


Figure 1: Wrinkle detection from finite element forming simulation

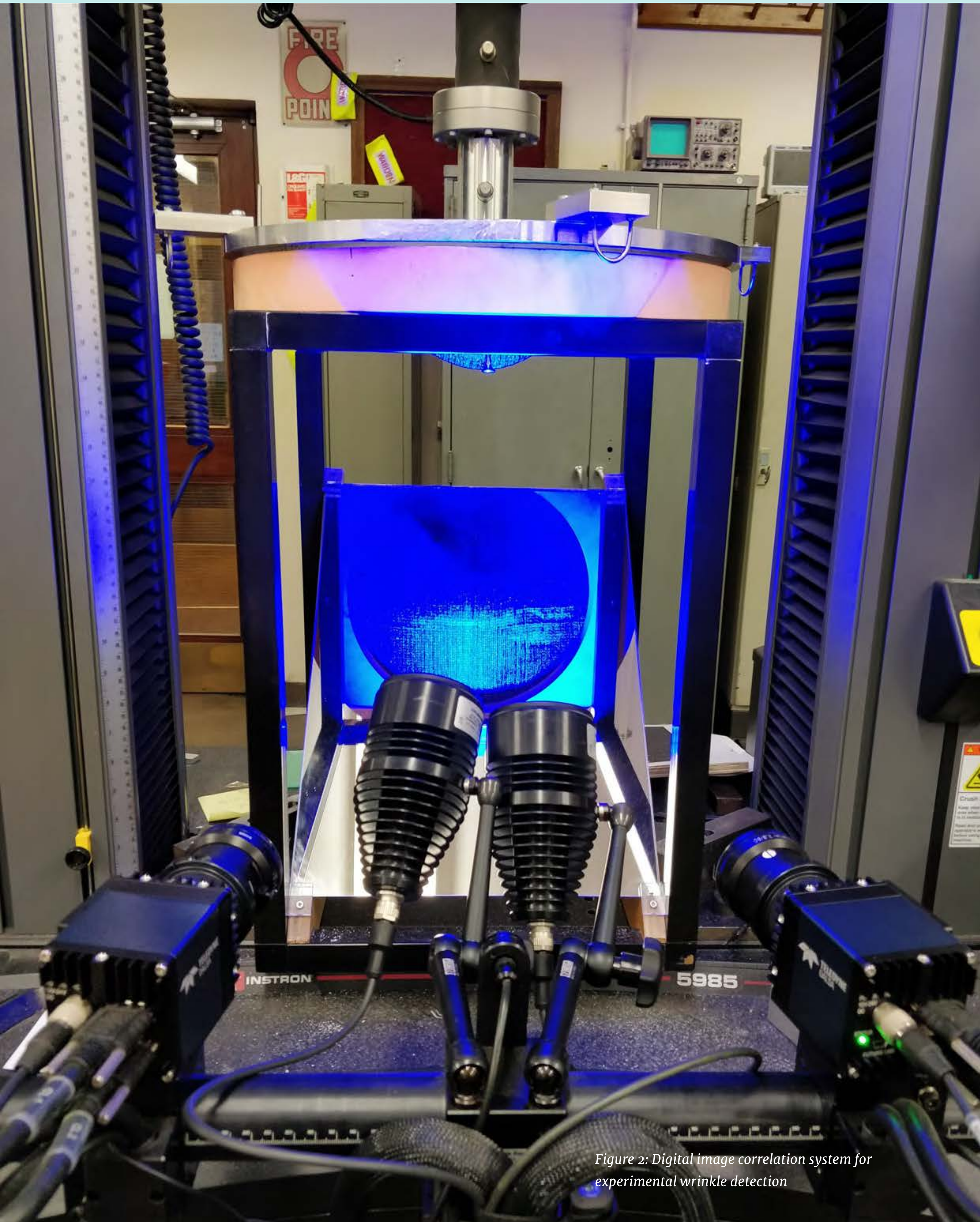


Figure 2: Digital image correlation system for experimental wrinkle detection

Themes: High-rate deposition and rapid processing technologies & Design for manufacture via validated simulation

"Multi-step Thermoforming of Multi-Cavity Multi-axial Advanced Thermoplastic Composite Parts"

Philip Harrison, Euan McGookin, Daniel Mulvihill, Daniel Richards, Iain Campbell

Aims and objectives

This feasibility study aims to improve the thermoforming of multi-layered pre-consolidated thermoplastic parts using a novel hybrid laminate configuration consisting of composite and metal layers. It will implement a controllable multi-actuator press and use it to investigate the forming mechanics of the hybrid sheet at high temperatures. The aim is to use the metal to heat the layup from the inside via Joule heating, melt the metal and then use the molten metal as a low viscosity lubricating medium to eliminate forming defects. The multi-actuator press will squeeze out the molten metal during forming (like toothpaste from a tube), aided by the metals high surface tension. The aim will be to reduce wrinkling in the final formed part and to reduce energy costs associated with heating.

Progress to date

Conducted initial experiments on moulding of metallic sheets.

Project partnerships to date

Institute of Science and Innovation in Mechanical and Industrial Engineering (INEGI), Porto

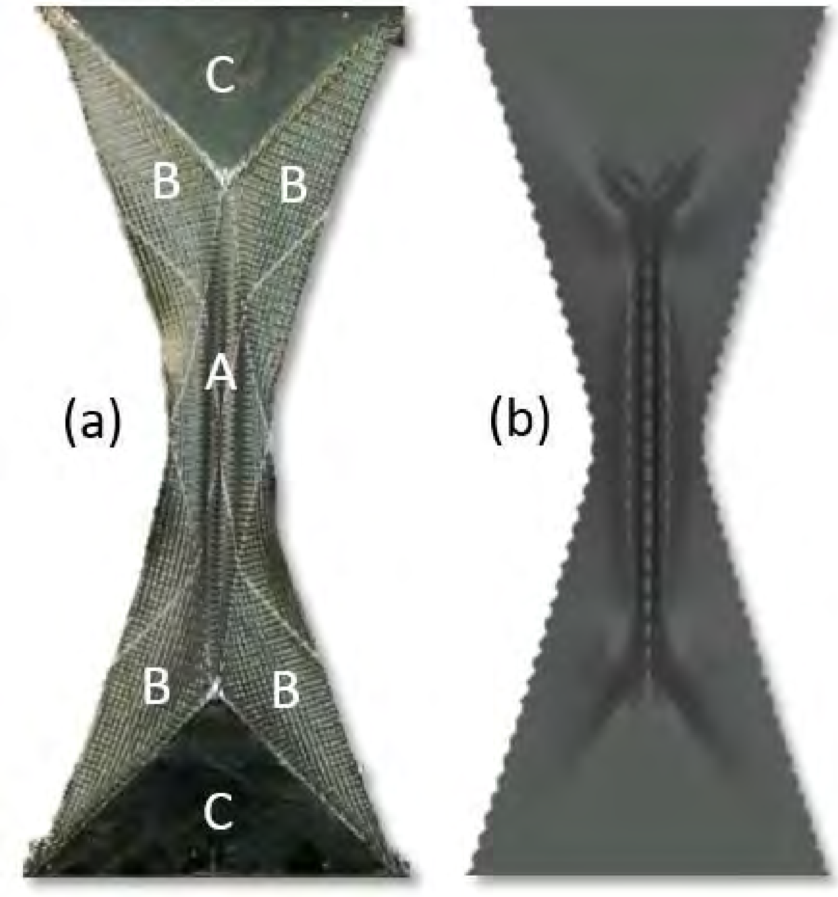


Figure 1

(a) A modified UBE test with aluminium (painted black) bonded to Region C of a twill-weave, with a pronounced wrinkle

(b) wrinkle prediction in finite element simulation.

Theme: High-rate deposition and rapid processing technologies

"Microwave Heating Through Embedded Slotted Coaxial Cables for Composites Manufacturing"

Mihalis Kazilas

Aims and objectives

The M-Cable project will use slotted coaxial cables to facilitate microwave (MW) heating in tooling for composites manufacturing. The concept enables delivery of MW heating to many processing environments such as autoclave, infusion, RTM and pultrusion. The energy used for processing can be adjusted according to the shape/geometry and size of the part, enabling considerable energy savings over conventional heating methods while benefiting by the high heating rates (cure cycle reduction) that can be achieved using instantaneous volumetric MW heating.

The overall aim of the project is to test the feasibility of uniform MW heating of composites during manufacturing by using a number of slotted coaxial cables embedded in tools. The following objectives will be addressed:

1. Simulate the energy output of the slotted coaxial cables and the absorbance of this energy by carbon fibres, either in the tool or in the composite part,
2. Produce tools with embedded slotted coaxial cables,
3. Manufacture composite laminates using the new concept tools,
4. Quality assessment of the produced laminates and
5. Efficiency assessment of the new tool compared to conventional heating methods.

Figure 1 Location of slotted cables that provide microwave heating in composite blades

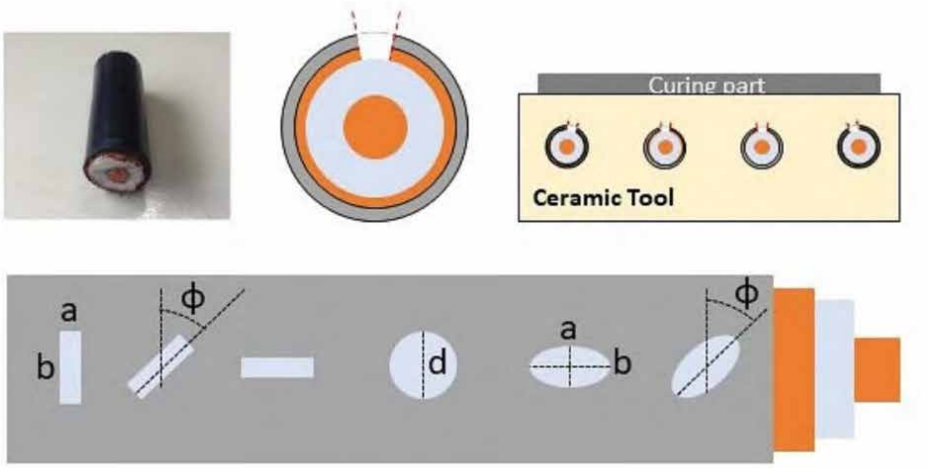


Figure 2 The M-Cable concept: embedded slotted coaxial cables provide microwave (MW) heating in tooling

Theme: High-rate deposition and rapid processing technologies

"Layer by Layer Curing"

Alex Skordos, James Kratz, Lawrence Cook, Jonathan Belnoue, Ric Sun, Konstantinos Tifkitsis

Aims and objectives

The project aim is to establish the capability of producing composites by processing in a single layer by layer (LbL) step. The main objectives are:

- **Simulation of the layer by layer process – including consolidation, thermal and curing effects.**
- **Evaluation of interlaminar properties at interfaces produced using partially cured sub-laminates.**
- **Process optimisation to identify conditions combining high speed and sufficient layer adhesion.**
- **Implementation and demonstration of the whole layer variant of the process.**
- **Assessment of product quality to validate the development.**

Progress to date

The main activities to date are as follows:

- Adaptation of 1D consolidation and 1D heat transfer models.
- Development of model coupling strategy.
- Consolidation characterisation.
- Thermo-analytical characterisation.
- Selection of cure cycles for partially cure delamination specimens.
- Manufacturing of specimens with partially cured interfaces.
- Work has focused on simulation developments/ adaptations allowing coupling of heat transfer cure modelling with consolidation in 1D. The selected material (913 glass prepreg) has been characterised and manufacturing process conditions for partially cured interfaces have bene established and applied.

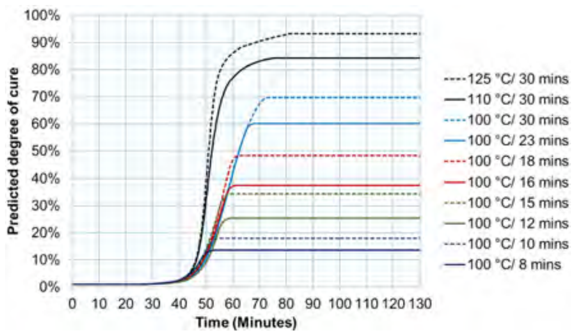
Key findings/ Notable achievements

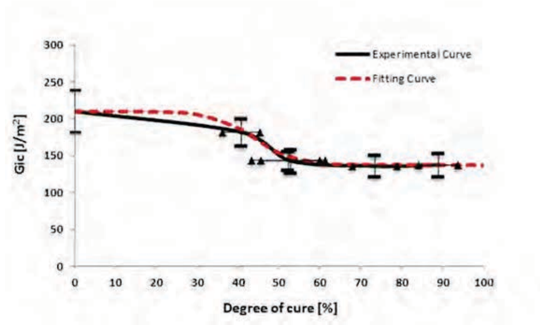
Mathematical models of the layer by layer process have been developed. These take into account the complex physics of consolidating the pre-impregnated material and curing it, and translate it into the particular arrangement of the layer by layer process.

The necessary characterisation to inform the models has also been carried out; this comprises measurements of the pre-impregnated material deformation under consolidation conditions, of the kinetics of the curing reaction and of the thermal properties of the material.

Project partnerships to date

Heraeus Noblelight, Coriolis Composites, National Composites Centre (NCC).





Figures 1 & 2: Simulations of the thermal and interlaminar consolidation curing effects in the layer by layer process

Themes: High-rate deposition and rapid processing technologies & Design for manufacture via validated simulation

"Simulation of Forming 3D Curved Sandwich Panels"

Nick Warrior, Shuai Chen, Oliver McGregor

Aims and objectives

The composite sandwich forming process offers a step-change in manufacturing rates for high performance structures. The process aims to form a 3D curved panel with varying thickness from a 2D sandwich format based on a matched tool forming set, offering an affordable high volume technology for carbon fibre chassis and other demanding structural applications. In order to exploit the full potential of this process a simulation tool is crucial to predict the forming behaviour and to design and optimise this process. This optimisation route will not be feasible via experimentation as too many parameters exist to solve by trial-and-error. At present, there is no suitable FE model available to simulate the forming process for curved sandwich panels. The novelty here is in the extension of existing fabric forming modelling techniques and the incorporation of the forming of a complex core geometry. The primary difficulties lie in the modelling of the behaviour of the core material and structure as well as the interface conditions between the core and the composite skins during forming.

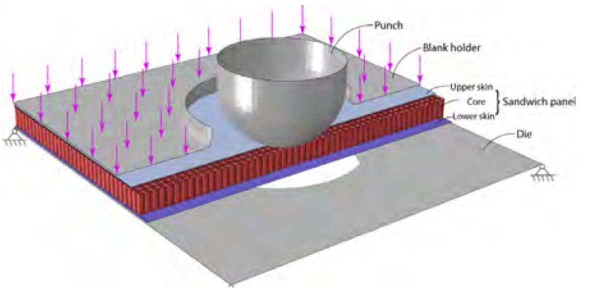


Figure 1: Schematic of the FE model

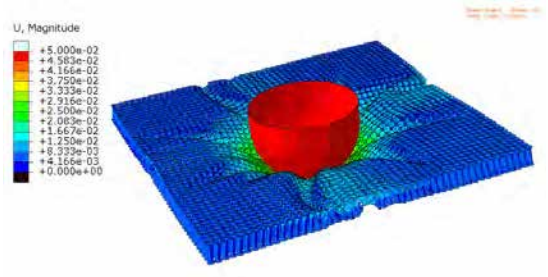


Figure 2: Meso-scale Finite Element results of the forming process using literature material data

Experimental tests are scheduled to collect the mechanical behaviour of the core material (that will be prepared as the inputs for FE simulations) and the global structural behaviour of the core, including bending and local crushing (that will be used to validate the core model). Experimental forming studies are planned to validate the complete FE composite sandwich model. The developed model and methodology will be applied in a forming demonstrator part with the industrial partner, Gordon Murray Design. This technical demonstrator study is to summarise general guidelines for industrial applications.

The aim of this feasibility study is to develop a numerical tool as an essential catalyst to accelerate this step change in composite manufacturing. The simulation tool will facilitate the improvement of the forming process and extend the opportunity to apply this low-cost technique in manufacturing complex parts in high volumes. FE simulation provides an effective and efficient way to determine a set of compatible process parameters to ensure a successful manufacturing solution. It is able to comprehensively visualise the forming behaviour of all areas, including the surface panels and the internal structure of the core.

The main objectives of this work are (1) to develop an explicit Finite Element (FE) model of the forming process of sandwich panels to understand the primary factors of producing a defect-free product and (2) to develop a feasible solution to manufacture high-quality curved sandwich parts. The developed FE model will be used to inform design choices and to drive future manufacturing process design and optimisation.

Themes: Manufacturing for multifunctional composites and integrated structures & Recycling and re-use

"Manufacturing Thermoplastic Fibre Metal Laminates by the In Situ Polymerisation Route"

Dipa Roy, Vasileios Koutsos, Conchúr Ó Brádaigh, Dimitrios Mamalis

Aims and objectives

Recently, there has been a growing interest to combine composite layers and traditional metal alloys developing the hybrid materials which are also called fibre-metal laminates (FMLs). The FMLs combine the superior properties of both the constituents. They offer improved fatigue resistance and enhanced damage tolerance under impact in comparison to the individual monolithic metallic alloys or fibre reinforced polymer composites. Thus, FMLs are promising lightweight materials for future application in various industries including transport, construction, renewable energy etc. However, the ultimate performance of the FMLs is not only determined by the two constituent materials, but is also influenced to a large extent by the interface formed between them.

The interfacial bonding between the metal sheets and fiberglass plies is significantly affected by their surface roughness and surface energy characteristics. Therefore, surface treatment of the metal, prior to bonding with the composite layer, is a critical step in the bonding process which controls the mechanical performance of the FMLs.

The aim of the project is to develop a new generation of thermoplastic composite (fibre)-metal hybrid laminates using inexpensive resin infusion route. These laminates are likely to be thermoformable and recyclable/reusable.

This will allow manufacturing of hybrid laminates at a lower cost in industrial scale with enhanced properties. Once the properties are validated, these laminates have a potential to find application in transport, construction, renewable energy industries. Representatives from the relevant industries have been contacted and meetings will be held soon to get their inputs on the project findings.

This project involves three major steps:

1. To prepare the surface of the metal alloy sheets with suitable chemical or physical (atmospheric plasma) treatments to achieve an acceptable level of interfacial bonding with the composite layer.
2. To manufacture FMLs using vacuum assisted resin infusion route.
3. To investigate the properties of the FMLs in comparison to an equivalent reference laminate with no metal interlayer.

In the first step of the project, different chemical and physical (atmospheric plasma) surface treatment methods were evaluated. Trial FMLs were manufactured with the treated metal layers. The fibre-metal bondings were qualitatively tested to downselect the optimum treatment processes for the next step of FML manufacturing.

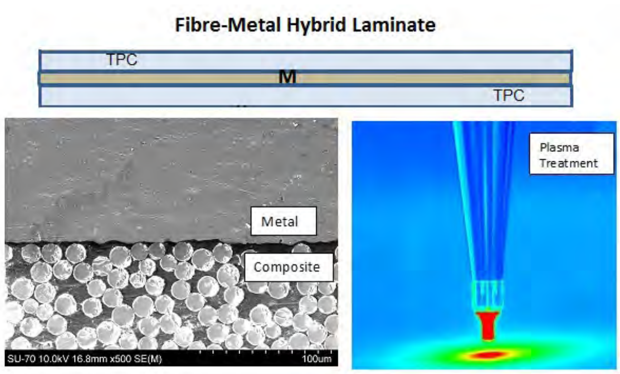


Figure 1: Fabrication of thermoplastic fibre-metal composites laminates: surface treatment of the metal alloy sheets with atmospheric plasma

In the second step, novel thermoplastic composite (fibre)-metal laminates (FML) were successfully manufactured with infusible thermoplastic liquid resin Elium® as matrix, using Vacuum Assisted Resin Infusion technique. Few micron thickness of an organic coating (epoxy acrylate) was applied at the interface of the surface treated metal and the composite layer to promote bonding through in-situ polymerisation with the matrix resin.

The overall objective of the project is to develop thermoplastic composite (fibre)-metal hybrid laminates by low-cost VARTM route. The laminates will be thermoformable and recyclable with enhanced mechanical properties.

Progress to date

- Al alloy sheets (6082-T6) were prepared for manufacturing fibre-metal laminates (FMLs) i.e. hole mapping for resin infusion process.
- Surface treatments were done with chemicals i.e. alkaline and acid etching of the Al alloy sheets. The effects of different parameters such as treatment time, concentration and mixing of the chemical solutions on the Al alloy surface were studied.
- Surface modifications of the Al alloy sheets were also done using atmospheric plasma with varying conditions such as distance of the plasma nozzle, scan speed and number of scans.
- Chemically and plasma treated Al alloy sheets were examined via optical microscopy, surface profilometry and contact angle goniometry.
- FMLs were manufactured by vacuum assisted resin infusion process (VARTM) with thermoplastic Elium® resin/glass fibres and Al alloy sheets.
- Mechanical characterisation of the fabricated FMLs such as short beam shear test (interlaminar shear strength) and flexural tests (3-point bend test) were performed.
- The interfacial bond strengths between the Al alloy sheets and the thermoplastic composite layers with the use of two types of epoxy acrylate coatings were tested qualitatively.

Key findings/ notable achievements

- Down-selection of the optimum chemical treatments and atmospheric plasma treatment conditions for Al alloy sheets
- Successful VARTM manufacturing of fully-wetted FMLs with liquid thermoplastic resin
- Successful coupon extraction from the laminates for testing without any debonding at the thermoplastic composite-metal interface
- Mechanical characterisations
  - Flexure strength- Reference (no metal) 500 MPa and FML-463 MPa
  - Flexural Modulus-Reference (no metal) 24 GPa and FML-28 GPa.
- Bonding achieved between Al alloy sheets and thermoplastic composite layers through in-situ polymerisation, which is first of its kind and has never been reported before
- New generation of thermoplastic fibre metal laminates were produced with low cost VARTM route using Elium® thermoplastic liquid resin and Al alloy sheets which can offer enhanced fatigue resistance and improved damage tolerance in comparison to the monolithic metallic alloys or composites. Such FMLs can fulfil a large demand in industry to have strong, lightweight, recyclable and durable structures.
- Interfacial bonding achieved between the fibre and the metal layers via surface treatment and an organic coating through in-situ polymerisation with the matrix is novel and can have a significant impact on the FRP industry.

Project partnerships to date

Arkema Innovative Chemistry, Composite Solutions UK Ltd, BeemCar, Ultrawise Innovation Ltd, Far-UK, ÉireComposites, National Physical Laboratory

Theme: Design for manufacture via validated simulation

"Active Control of the RTM Process Under Uncertainty using Fast Algorithms"

Michael Tretyakov, Andy Long, Marco Iglesias, Mikhail Matveev

Aims and objectives

Consistent and repeatable manufacturing is seen by the composite industry to be the key to achieving repeatable mechanical properties of composite components. For the resin transfer moulding (RTM) process, repeatability is achieved not only by the absence of incomplete mouldings, but also by repeatable cycle time or mould filling time.

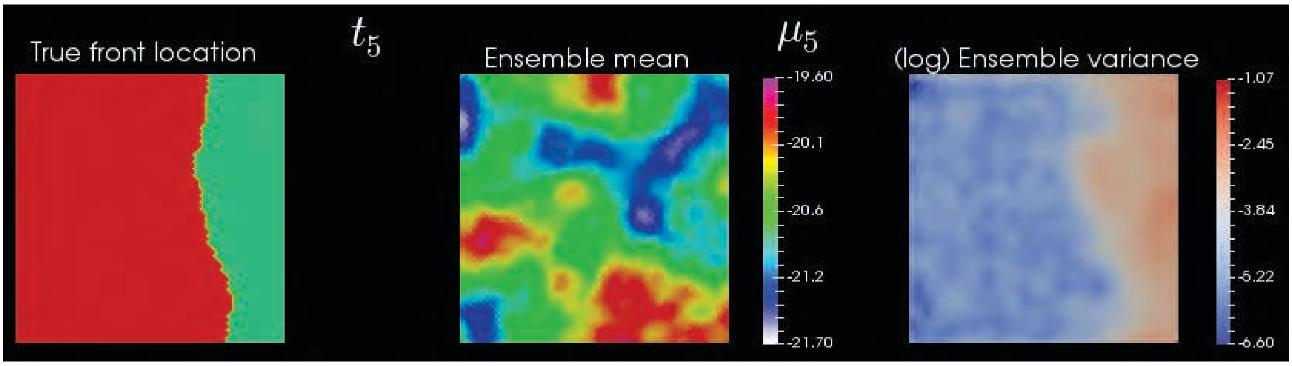
The possibility of a dry spot can prevent the RTM process from being used for high-value components. Difficulties during the RTM process are often results of defects and variabilities in a dry preform. While the uncertainty in the RTM process has already been modelled to some extent, it is still impossible to employ existing predictive techniques for online monitoring and control. This project aims to improve the repeatability of the RTM process by developing novel algorithms which are fast enough to work as part of an active control system (ACS) to ensure that the mould filling process has minimum deviations from the design. The novelty of the project will include fast online estimation of the local permeability using a Bayesian inversion technique and hence more accurate process control. Via estimation of permeability, a non-destructive, cheap and quick assessment for the quality of components will be developed.

The project will develop an active control system and supporting algorithms, which will aid more robust RTM processing. This will be achieved through several steps starting with developing an algorithm for an online estimation of the permeability distribution using a Bayesian inversion. The estimated permeability will be used to predict the local resin arrival times and the total mould filling time. Finally, the ACS will be integrated with these algorithms to provide a control of the mould filling.

Progress to date

The project has already implemented an algorithm for Bayesian inversion for estimating permeability and this is currently being integrated with commercial resin infusion software.

Figure 1: Estimation of the local permeability will be performed using Bayesian inversion:



Data from sensors *Estimated permeability* *Variance of the estimated permeability*

Theme: High-rate deposition and rapid processing technologies

“Acceleration of Monomer Transfer Moulding using Microwaves”

Derek Irvine, Chris Dodds, Andrew Parsons, Alex Ilchev

Aims and objectives

The project will develop a manufacturing process that will facilitate and accelerate the production of thermoplastic composites through the use of microwave (volumetric) heating.

Thermoplastic composites are a significantly growing market because they offer a combination of high processing speeds, good toughness and attractive thermal/chemical resistance. However, because they typically exhibit high melt viscosity, successful infusion of thermoplastic resin into fibre forms can be challenging. Monomer transfer moulding (MTM) is an effective, low pressure method of producing fibre-reinforced thermoplastic composites from dry fibre that exhibit good fibre/matrix interface quality, while avoiding issues with viscosity, fibre crushing and matrix degradation.

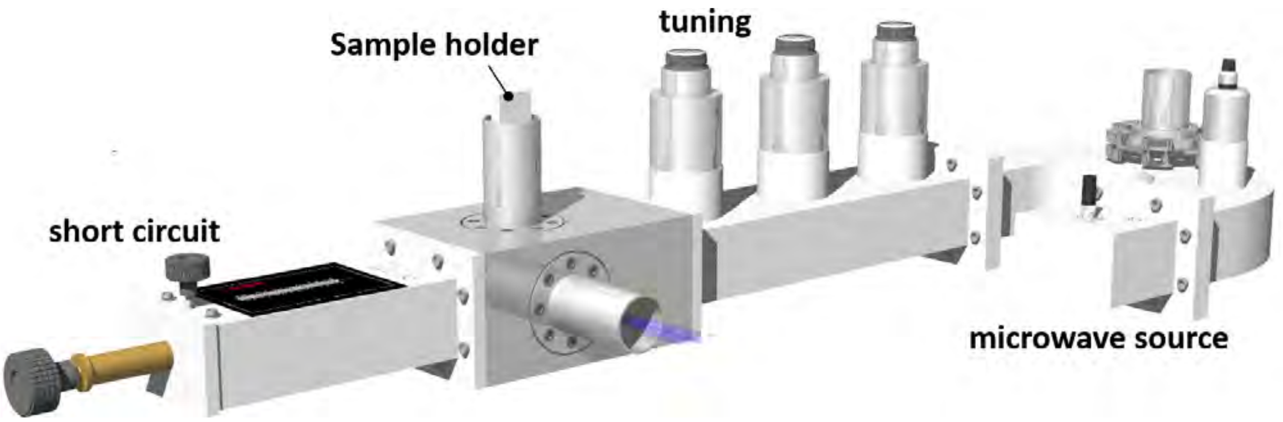
The main limitation of MTM is the time required for polymerisation, but studies on polymer reactions indicate that microwave heating can significantly decrease the time required. The objective of this project is to demonstrate that a microwave heating process can successfully produce a composite panel on an acceptable time scale, to establish production parameters and determine that the process is scalable. Initially a single thermoplastic (polycaprolactone) will be utilised for the tests as its microwave characteristics are well understood. The project will also assess the applicability of the method to other thermoplastics that are of interest to the automotive and aerospace industries, with a view to undertaking a broader manufacturing project.

Project partnerships to date

Dr Betime Nuhiji, Microwave Technology Lead at the Advanced Manufacturing Research Centre (AMRC).

Figure 1: The Vötsch microwave curing oven at AMRC measures 1.8m x 2.8m and provides heating at 450°C.

Figure 2: A mini-flow microwave reactor is used to examine the early stage microwave chemistry and curing




INSTRON

Outreach

"As part of our commitment to add value to the UK composites manufacturing community, the Hub leads engagement and collaboration enterprises with and beyond its core members. In 2017-2018, the Hub has promoted its activities through initiatives including a successful launch event, two international exhibitions, and an ongoing media partnership. Through keynote lectures, seminars, and workshops, the Hub has reached an audience of over 4000 people."

Media

Working with the Hub's media partner, NetComposites, the Hub reaches nearly 800 unique users per quarter via press releases disseminated to the wider commercial community. Press releases this year have announced the successful Feasibility Studies, advertised the Hub's involvement at the Advanced Engineering Show and strategic partnership with ICMAC 2018, and publicised our first annual free-to-attend Hub-IDC Open Day.

We've also developed a new website - cimcomp.ac.uk – reaching over 5,500 unique users over the last year. Visitors to the site can find out more about the Hub's vision, team, and research, and get involved by learning about recruitment opportunities, studying with the IDC, or by signing up to our quarterly newsletter – a new initiative to reach industrial partners and keep them up to date with Hub news and activities. The newsletter currently has over 250 subscribers, with over a quarter of readers outside the UK and nearly 20% of those outside Europe.

In August 2017, our twitter account, @EPSRC_CIMComp, was launched. On the twitter story feed we can disseminate news of Hub activity, including promotion of event attendance, success stories, and Hub-related vacancies. These tweets are regularly seen by over 7,000 Twitter users, broadening our reach across both expert and general audiences

Launch Event

In May, the Hub held its launch event in Nottingham to introduce current funded research and explain how the wider composites community can engage with the Hub. Half of the 135 registered delegates at the event were from industry, representing the aerospace, automotive, defence, energy and rail sectors, from all aspects of the composites supply chain.

Andy Long opened the proceedings on 4th May with an introduction to the Hub, outlining the objectives over the next seven years and how they fit within the broader UK composites strategy. Enrique Garcia, Chief Technology Officer at the National Composites Centre (NCC) and member of the industrial Advisory Board, explained the importance of the Hub from an industrial perspective and talked about the role

the NCC will play in pulling through promising technologies, in order to advance them through the Technology Readiness Levels in preparation for industrial adoption. Ivana Partridge discussed recent success stories from the Industrial Doctoral Training Centre in Composites Manufacturing and explained how the IDC will deliver the next generation of skilled composite engineers to support these fundamental developments in composites manufacturing. Andy Long reflected, "This event has provided us with the perfect platform to introduce the Hub to new potential stakeholders, in our effort to become the national centre of excellence in fundamental research for composites manufacturing."

Advanced Engineering Show 2017

The Leadership Team attended the Advanced Engineering Show 2017, held on 1st-2nd November at the NEC, Birmingham (UK). Advanced Engineering is the UK's largest meeting place for advanced engineers, and the flagship exhibition for the Hub. The event attracted over 16,000 visitors across two days, and the Hub exhibited alongside some of the industry's biggest names. New for 2017, the 3D backlit stand provided a talking point to attract visitors, who could view exhibits and samples, pick up a Hub brochure, watch video presentations, and network with the Hub team. The Hub also hosted a drinks reception on the afternoon of the first day for partners across the supply chain, from a range of composite engineering specialisms including automation, design and test engineering, process control, and machining. The Hub also hosted an Open Forum event where Hub investigators presented their current research, outputs, and future direction to attendees. Dr Rob Backhouse, Engineering Specialist and Global Process Owner (Polymer Composites), at Rolls Royce Plc gave an industry viewpoint on the Future Composites Manufacturing Research Hub.

Industrial Doctorate Centre in Composites Manufacture

"Training advanced industry-sponsored Research Engineers who aspire to key leadership positions in the UK composites industry."

- EPSRC funding: £7.5M to 2023, with over £1.3M industrial cash contribution to date
- Industry-led and industry-based research projects (each lasting four years), underpinned by specialist technical units and business skills training
- Continuing collaboration between the Universities of Bristol (lead), Cranfield, Manchester and Nottingham

This year sees the graduation of the earliest IDC recruits, already securing industry jobs well before thesis completion. We have an increasingly dynamic group of 30 current EngD students working within their individual sponsoring companies, including Jo Bird, MWright, Pentaxia, Hexcel, Bombardier, AEL Airborne, Albany Engineered Composites, NOV, Fibrelean, NPL, as well as the National Composites Centre and Rolls-Royce. With the increased numbers and company locations spread between Aberdeen and the Cornish coast, the Research Engineers ensure effective horizontal as well as vertical cohort integration by the use of modern IT and social media. The Student Committee provides the student input into IDC management, overarching management of STEM activities and organisation of social events. A highly successful cohort event in Bristol in October 2017 included information on routes to Chartered Engineer status from practitioners as well as from an IoM3 representative.

We hope to welcome Heraeus, Vestas, QinetiQ and Airbus into our supporting companies group in the near future. The applied research projects are designed to directly address the sponsor's commercial research priorities. All IP generated is owned by the sponsoring company, in some cases already bringing in new income.

As this novel EngD programme reaches maturity, the Study Tour element of the compulsory training is coming into a clear focus. Under the inspired leadership of Dr Hamish McAlpine, the Study Tour is an individually designed piece of work intended to meet two requirements for each Research Engineer: (a) to provide an opportunity to contrast his/her everyday in-company experience with a significantly different work environment and (b) to put into practice some elements of the business skills training provided in the compulsory taught programme. In the last two years this element of the training has seen our Research Engineers range as far as Antigua, Dubai, the University of British Columbia, University of Delaware and the Government Office of Science in London, in pursuit of the new experience and knowledge. The examined outcomes have been classed as 'outstanding' by our external examiner and we plan to share some of the reports in a more public forum.

The efforts of our Research Engineers have been appreciated by their Study Tour hosts: "..he has not only introduced new methods, materials and tools to manufacture composite parts in shorter time, but has also eliminated additional processes that consume a lot of time and cost..."

S.Sumanasekera, General Manager TCTI, UAE.

As well as satisfying the requirements of the compulsory taught element of the programme, the IDC Research Engineers continue to attend conferences in the UK (e.g. SAMPE UK&Ireland meetings, annual Rolls-Royce EngD conferences) and overseas (SAMPE USA in 2016, 'Automated Composites' in Montreal in 2017, ECCM Munich in 2016, ICCM in Xi'An in 2017) to present their work to academic and industrial audiences. Financial support by the sponsoring companies, the IoM3 Carnegie Fund and The Royal Society of Chemistry for some of these trips is gratefully acknowledged.

Recent external awards and prizes include:-

- conference paper at SAMPE US (Long Beach 2016) selected for direct publication (only 8 from 220) - M. di Francesco et al;
- RCUK Government Office of Science internship awarded to Ms L.Veldenz for 2017;
- RAeS "Young lecturer competition" 2016 winner for Composites section - Ms L. Veldenz (http://www.raesbristol.org.uk/);
- runners-up in Industry Innovations awards 2016 - Ms F. Martin in JLR/NCC team
- the Leslie Holliday 2016 award from the IoM3 to the IDC Director, Prof I. K. Partridge
- WEAF "Aerospace Ambassador Young Entrant Award" 2017 to M. di Francesco
- £1k travel award by the RSC to D. Griffin.

The EPSRC IDC in Composites Manufacture continues to play an integral and vibrant role within the wider activities of CIMComp, providing the vital link from basic research to industry application.

Enhancing our Capability

Shaping the Future of UK Manufacturing

In December 2017 the Composites Research Group at the University of Nottingham moved their laboratory and offices over to the new purpose build Advanced Manufacturing Building (AMB) on the Jubilee Campus.

This state-of-the-art facility, costing £25M, co-locates the Composites Research Group with the Centre for Additive Manufacturing, the Manufacturing Metrology Team, the Precision Manufacturing Centre, and the Institute for Advanced Manufacturing from the Faculty of Engineering in a world-class environment for research and teaching. This new facility will be the home for the Future Composites Manufacturing Research Hub for the next six years, enhancing the ability for the Hub to deliver high class research outputs from current projects and to further develop new ventures with industrial and academic partners.

A High-fidelity, Data-rich Paradigm for Structural Testing

The University of Southampton have been awarded a £1.2M equipment grant from EPSRC to support the development of their National Infrastructure Laboratory on the Boldrewood Campus, due to be completed in October 2018.

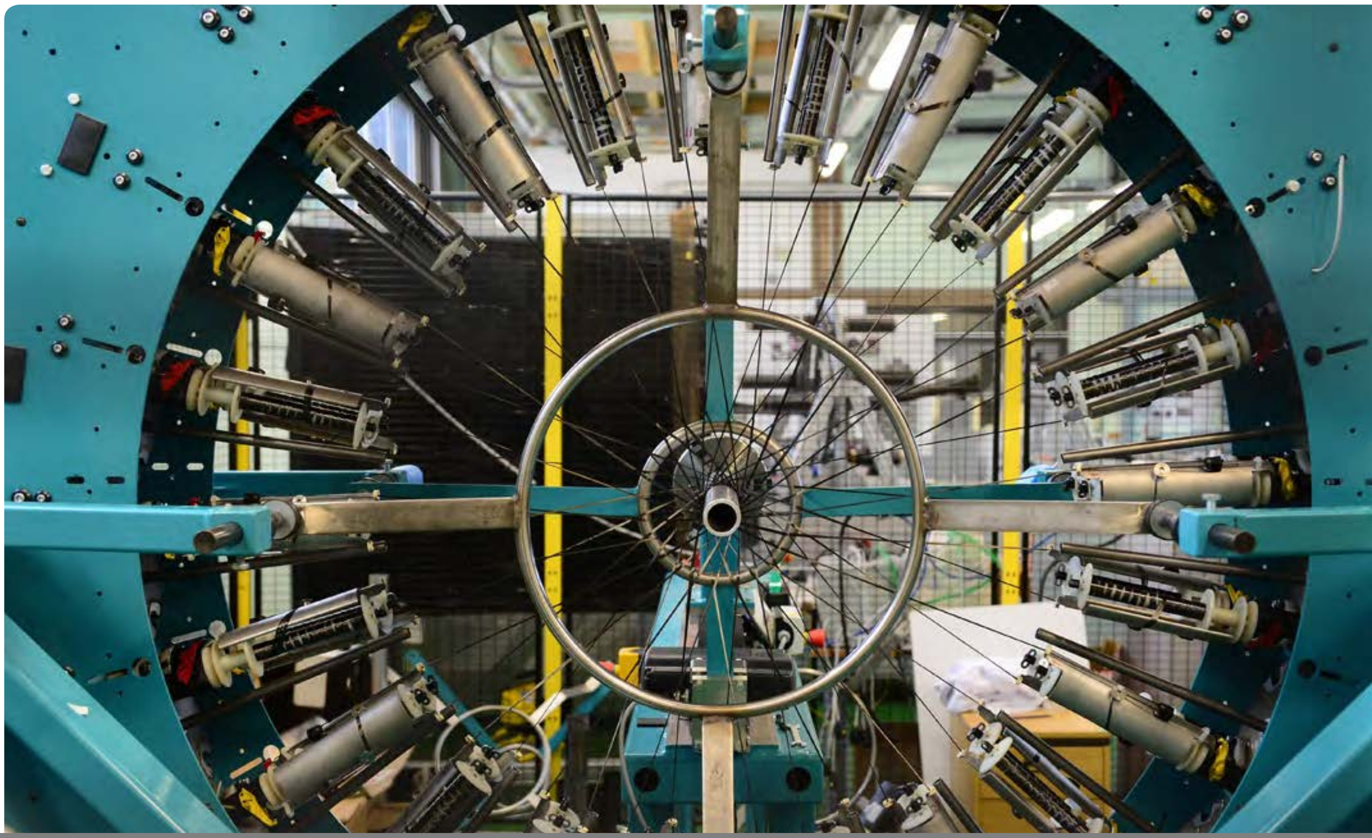
The centre will be a world-leading facility for conducting multi-scale materials and structures testing. "Structures 2025" (EP/R008787/1) will provide a novel integrated imaging and loading system that is flexible, and can be used for the testing and assessment of a wide range of structures across industry sectors.

This will be developed in close collaboration with 16 industry partners, representing the rail infrastructure, civil engineering, energy, marine and offshore, and aerospace sectors, as well as several university partners. Structures 2025 will provide what can be termed high-fidelity data-rich testing of structural components, to integrate with multi-scale computational modelling to provide better predictive models of structural failure and create safer and more efficient structures.

This will further develop the work initiated during the Hub-funded Feasibility Study, 'Strain-based NDE for online inspection and prognostics of structures with manufacturing defects'.

Additional Leveraged Funding

- EU Clean Sky 2 Project ID: 754581: £591,000. 2017. Multiscale Analysis of Airframe Structures and Quantification of Uncertainties System (MARQUESS). Investigators: I A Jones, D Chronopoulos, C Hyde, S Li, A C Long, S McWilliam, S Triantafyllou, T Turner.
- EP/P027350/1. May 17 – April 22, £1,115,704. SIMulation of New Manufacturing PROcesses for Composite Structures (SIMPROCS). PI Stephen Hallett, Cis, Ivana Partridge, Dmitry Ivanov Kevin Potter, Carwyn Ward, Luiz Kawashita, Eric Kim, James Kratz. Project partners: Airbus, BAES, Bombardier, ESI, GKN, JLR, LMAT, NCC, RR
- EP/P027288/1. July 17 – June 19, £101,114. Novel Tow Termination Technology for High-quality AFP Production of Composite Structures with Blended Ply Drop-offs. PI Eric Kim. Project partners. Airbus, BAES, NCC, RR.
- EP/P027393/1. Dec 17 – Dec 20, £1,036,426. High Performance Discontinuous Fibre Composites - A Sustainable Route to the Next Generation of Composites. PI Ian Hammerton, CIs Kevin Potter, T Rendall. Project partners: Airbus Group Limited, BAE Systems, Coriolis Composites UK, Hexcel Composites Ltd, National Composites Centre, Hitachi, Toyota, Oxford Advanced Suraces, Solvay, ELG Carbon Fibre Ltd.
- EP/R021597/1. Feb 18 – July 19, £101,082. Achieving a Predictive Design for Manufacture Capability in Composites by Integrating Manufacturing Knowledge and Design Intent. PI Carwyn Ward. Project partner: NCC.
- EP/R023247/1. Feb 18 – Jan 21, £518,156. Advanced Continuous Tow Shearing in 3D (ACTS3D): Advanced Fibre Placement Technology for Manufacturing Defect-free Complex 3D Composite Structures. PI Eric Kim. Cis, Kevin Potter, Stephen Hallett, Paul Weaver. Project partners: ABB, Airbus, BAES, NCC.



Strategic Development

Mapping the UK Composites Landscape

In conjunction with the ATI and Composites UK, the Hub is involved in the preparation of a roadmap which will deliver greater understanding of aerospace OEM composite product development targets and aspirations. The roadmap will identify capabilities and gaps in the UK and international composites supply chain, and survey the relevant research landscape.

This will act as a catalyst for greater adoption of composites in the aerospace industry by enabling new consortia to be formed and promoting synergistic working between industry and academia. Identification of gaps in the current research landscape will allow academics to focus their research to meet the needs of the aerospace industry and enable funding bodies and policy makers to identify key areas for strategic funding. Collectively these will contribute to the Hub's undertaking to facilitate a doubling of production capacity every two years for high value polymer composites by 2030.

Developing an International Community

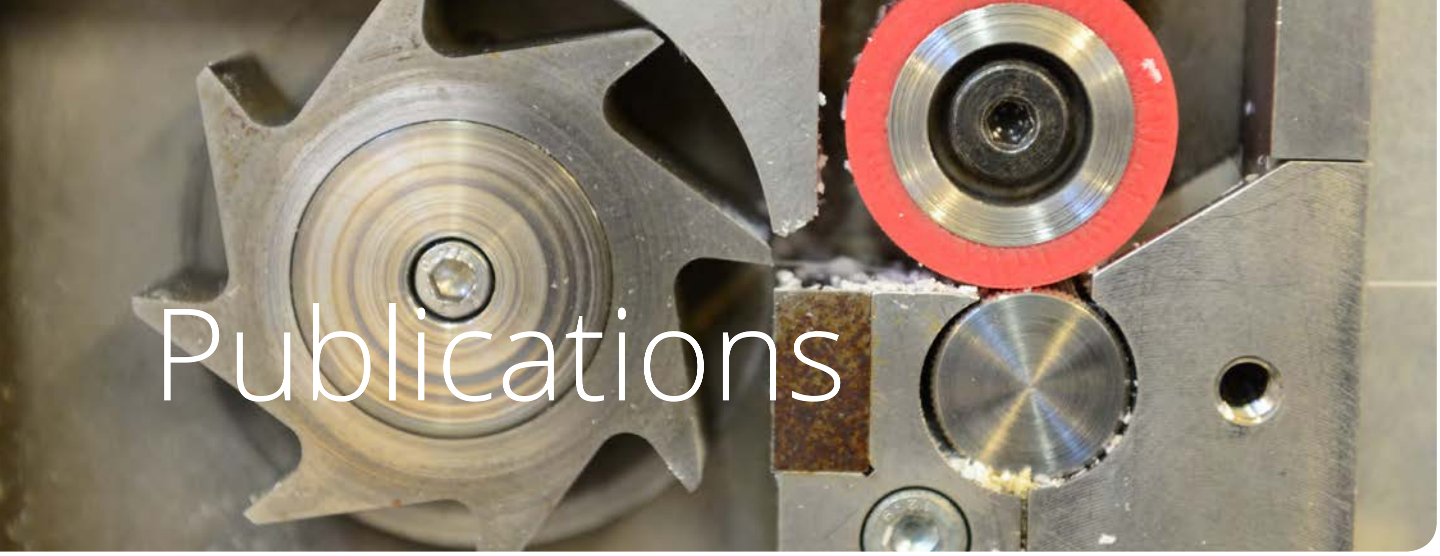
As part of the Hub's goal to expand our international research network and develop new collaborative research programmes, our first international mission is planned for Spring 2018 to the Republic of Ireland. Further missions will be planned annually, with potential visits including France, Russia, India, Australia, Canada, and Spain.

International missions advance our knowledge of the global composites industry by enabling us to conduct capability mapping and strategic technology assessment activities, benefitting UK businesses and institutions through access to new knowledge and technology around the world.

Maximising our Capabilities

As part of our ongoing commitment to address industry needs and develop the national composites strategy, we are constantly updating a register of the facilities and equipment held by our partners and other active research institutions. This builds on work conducted during CIMComp and will facilitate access to equipment by Hub members. It will also provide a mechanism for composites researchers to recognise institutional competencies both within and outside the Hub structure, potentially leading to ideas for collaboration.

You can view our equipment register here: **cimcompkit.nottingham.ac.uk**



Publications

“Publications support the delivery of the Hub programme and vision. This list illustrates both the continued success of the CIMComp Centre and the level of activity of the Hub in its first year. In this reporting period (2017-2018), publications include peer-reviewed journal articles, conference papers and poster presentations, and a patent application.”

Journals

EP/P006701/1: EPSRC Future Composites Manufacturing Research Hub

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.

EP/I033513/1: EPSRC Centre for Innovative Manufacturing in Composites

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.

Ataş, A., Gautam, M., Soutis, C., Potluri, P., (2017) Bolted Joints in Three Axially Braided Carbon Fibre/Epoxy Textile Composites with Moulded-in and Drilled Fastener Holes, Applied Composite Materials 24 (2), 449-460.

Belnoue, J., Ivanov, D., Hallett, S. (2016) Novel Simulations for Predicting Fibre Path Defect Formation in Composites Manufacturing, Benchmark - The International Magazine for Engineering Designers and Analysts.

Belnoue, J., Nixon-Pearson, O., Ivanov, D., Hallett, S. (2016) A Novel Hyper-viscoelastic Model for Consolidation of Toughened Prepregs Under Processing Conditions, Mechanics of Materials 97 (1), 118-134.

Belnoue, J., Tassos, M., Nixon-Pearson, O., Kratz, J., Ivanov, D., Partridge, I., Potter, K., Hallett, S. (2017) Understanding and Predicting Defect Formation in Automated Fibre Placement Prepreg Laminates, Composites Part A: Applied Science and Manufacturing 102 (1), 196-206.

Corbridge, D., Harper, L., de Focatiis, D., Warrior, N. (2017) Compression Moulding of Composites with Hybrid Fibre Architectures, Composites Part A: Applied Science and Manufacturing 95 (1), 87-99.

Endruweit, A., Zeng, X., Matveev, M., Long, A. (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, 139-150.

Evans, A., Qian, C., Turner, T., Harper, L., Warrior, N. (2016) Flow Characteristics of Carbon Fibre Moulding Compounds, Composites Part A: Applied Science and Manufacturing 90 (1), 1-12.

Gommer, F., Endruweit, A., Long, A. (2016) Quantification of Micro-scale Variability in Fibre Bundles, Composites Part A: Applied Science and Manufacturing 87 (1), 131-137.

Gommer, F., Brown, L., Wedgwood, K. (2016) Analytical Method using Gamma Functions for Determining Areas of Power Elliptical Shapes for use in Geometrical Textile Models, Composites Part A: Applied Science and Manufacturing 81 (1), 222-224.

Gommer, F., Brown, L., Brooks, R. (2016) Quantification of Mesoscale Variability and Geometrical Reconstruction of a Textile, Journal of Composite Materials 50 (23), 3255-3266.

Harrison, P. (2016) Modelling the Forming Mechanics of Engineering Fabrics using a Mutually Constrained Pantographic Beam and Membrane Mesh, Composites Part A: Applied Science and Manufacturing 81 (1), 145-157.

Hunt, C., Kratz, J., Partridge, I. (2016) Cure Path Dependency of Mode I Fracture Toughness in Thermoplastic Particle Interleaf Toughened Prepreg Laminates, Composites Part A: Applied Science and Manufacturing 87, 109-114.

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.

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, Composite Structures 162, 13-27.

Göktaş, D., Kennon, W., Potluri. P. (2017) Improvement of Mode I Interlaminar Fracture Toughness of Stitched Glass/Epoxy Composites, Applied Composite Materials 24 (2), 351-375.

Hartley, J., Kratz, J., Ward, C., Partridge, I. (2017) Effect of Tufting Density and Loop Length on the Crushing Behaviour of Tufted Sandwich Specimens, Composites Part B: Engineering 112 (1), 49-56.

Koncherry, V., Potluri, P., Fernando A. (2017) Multifunctional Carbon Fibre Tapes for Automotive Composites, Applied Composite Materials 24 (2), 477-493.

Matveev, M., Long, A., Brown, L., Jones, I. (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.

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.

Mesogitis, T., Skordos, A., Long, A. (2016) Stochastic heat transfer simulation of the cure of advanced composites, Journal of Composite Materials 50 (21), 2971-2986.

Nixon-Pearson, O., Belnoue, J., Ivanov, D., 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.

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.

Prabhu, V., Elkington, M., Crowley, D., Tiwari, A., Ward, C. (2017) Digitisation of Manual Composite Lay-up Task Knowledge using Gaming Technology, Composites Part B: Engineering 112 (1), 314-326.

Roy, S., Potluri, P., Soutis, C. (2017) Tensile Response of Hoop Reinforced Multiaxially Braided Thin Wall Composite Tubes, Applied Composite Materials 24 (2), 397-416.

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.

Selver, E., Potluri, P., Hogg, P., Soutis, C. (2016) Impact Damage Tolerance of Thermoset Composites Reinforced with Hybrid Commingled Yarns, Composites Part B: Engineering 91 (1), 522-538.

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.

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.

Conference Papers

EP/P006701/1: EPSRC Future Composites Manufacturing Research Hub

Bull, D., Dulieu-Barton, J., Thomsen, O., Butler, R., Rhead, A., Fletcher, T., Potter, K. Reshaping the Testing Pyramid: Utilisation of Data-rich NDT Techniques as a Means to Develop a 'High fidelity' Component and Sub-structure Testing Methodology for Composites, 21st International Conference on Composite Materials, Xi'an, 20-25 August 2017.

Di Francesco, M., Veldenz, L., Atwood, S., Giddings, P., Dell'Anno, G. Feature-Based Design for Manufacturing Guidelines for Dry Fibre AFP, International Symposium on Automated Composites Manufacturing, Montreal, 20-21 April 2017.

Koncherry, V., Patel, D., Yusuf, Z., Potluri, P. Influence of 3D Weaving Parameters on Preform Compression and Laminate Mechanical Properties, 21st International Conference on Composite Materials, Xi'an, 20-25 August 2017.

Mamalis, D., Obande, W., Koutsos, V., Ó Brádaigh, C.M., Roy, D. Effects of Surface Treatments on the Bonding and Interlaminar Fracture Toughness of Aluminium/Fiberglass Thermoplastic Laminates Produced by In-situ Polymerisation Route, European Conference on Composite Materials, Athens, 24-28 June 2018.

Matveev, M., Long, A., Iglesias, M., Tretyakov, M. Fast Algorithms for Active Control of Mould Filling in RTM Process with Uncertainties, 14th International Conference on Flow Processing in Composite Materials (FPCM-14), Luleå, Sweden, 30 May–1 June 2018.

Obande, W., Mamalis, D., Koutsos, V., Ó Brádaigh, C., Roy, D. Fabrication and Mechanical Characterisation of Thermoplastic Fibre-Metal Laminates Produced by In-situ Polymerisation Route, European Conference on Composite Materials, Athens, 24-28 June 2018.

Radhakrishnan, A., Hamerton, I., Shaffer, M., Ivanov, D. Localised Control of Composite Properties using Liquid Resin Printing (poster presentation), Bristol Composites Institute Conference, Bristol, 15 November 2017.

Roy, S., Yang, D., Potluri, P. Influence of Bending on Wrinkle Formation and Potential Method of Mitigation, 21st International Conference on Composite Materials, Xi'an, 20-25 August 2017.

Roy, D. Intelligent Composite Design and Manufacture, SAMPE UK & Ireland Chapter Annual Seminar & SME Table Top Exhibition, Nottingham, 7 February 2018.

Roy, D. Out of Autoclave Processing of Composites, Challenges and Opportunities: Innovate UK, Belfast, 15 March 2018.

Veldenz, L., Di Francesco, M., Atwood, S., Giddings, P., Kim, B., Potter, K. Assessment of Steering Capability of Automated Dry Fibre Placement through a Quantitative Methodology, International Symposium on Automated Composites Manufacturing, Montreal, 20-21 April 2017.

Waddington, B., Caballero, A., Roy, S., Kennon, W., Potluri, P. Damage Tolerance of Carbon/Epoxy Quasi-interwoven Composites Subjected to Low Velocity Impacts, 21st International Conference on Composite Materials, Xi'an, 20-25 August 2017.

Yan, S., Long, A., Zeng, X. Design Optimisation of 3D Woven T-joint Reinforcements, 21st International Conference on Composite Materials, Xi'an, 20-25 August 2017.

Zympeloudis, E., Potter, K., Weaver, P., Kim, B.C., Advanced Automated Tape Laying with Fibre Steering Capability using Continuous Tow Shearing Mechanism, 21st International Conference on Composite Materials, Xi'an, 20-25 August 2017.

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Belnoue, J., Kratz, J., Nixon-Pearson, O., Mesogitis, T., Ivanov, D., Hallett, S. Predicting Wrinkle Formation in Components Manufactured from Toughened UD Prepreg, 17th European Conference on Composite Materials, Munich, June 2016.

Hallett, S., Belnoue, J., Nixon-Pearson, O., Mesogitis, T., Kratz, J., Ivanov, D., Partridge, I., Potter, K. Understanding and Prediction of Fibre Waviness Defect Generation, American Society for Composites 31st Technical Conference, Williamsburg, September 2016.

Ivanov, D., Volatier, J., Rosli, A., Nixon-Pearson, O., Belnoue, J., Potter, K., Hallett, S. Novel Methods of Assessing Inter-ply Properties of Toughened Prepregs in Application to the Analysis of Fibre Path Defects, 20th International Conference on Composite Materials, Copenhagen, July 2015.

Kratz, J., Mesogitis, T., Skordos, A., Hamerton, I., Partridge, I. Developing Cure Kinetics Models for Interleaf Particle Toughened Epoxies, SAMPE Conference and Exhibition, Long Beach, May 2016.

Nixon-Pearson, O., Belnoue, J., Ivanov, D., Hallett, S. The Compaction Behaviour of Un-cured Prepregs, 20th International Conference on Composite Materials, Copenhagen, July 2015.

Thompson, A., Belnoue, J., Hallett, S. A Meso-scale Modelling Approach for Virtual Characterisation of Dry Textile Preforms, Euromech Colloquium 569 – Multiscale Modelling of Fibrous and Textile Materials, Châtenay-Malabry, April 2016.

Thompson, A., Belnoue, J., Hallett, S. A Numerical Modelling Approach for the Prediction of Defect Generation During the Preforming Process of Multiple Layers of 2D Woven Fabrics, 17th European Conference on Composite Materials, Munich, June 2016.

Patents

Potluri, P., Jetavat, D., Sharma S. (2017) Method and Apparatus for Weaving a Three-dimensional Fabric, US Patent 9,598,798.

Prizes/Esteem Indicators

April 2016 – IoM3 Leslie Holliday Award to Professor Ivana Partridge.

June 2017 – Janice Dulieu-Barton and Ole Thomsen – Seminar at University of Illinois at Urbana-Champaign, USA.

August 2017 – Andy Long - Keynote Lecture on "Multi-scale modelling for processing and performance of textile composites", 21st International Conference on Composite Materials, Xi'an, China.

August 2017 – Milo Shaffer - Keynote Lecture on "Hierarchical Composite Materials: structural and multifunctional opportunities", 21st International Conference on Composite Materials, Xi'an, China.

August 2017 - Janice Dulieu-Barton and Ole Thomsen – Seminars at Bejing Jiaotong University, Beijing Institute of Technology, and Northwestern Polytechnic University, Xi'an.

September 2017 – Andy Long - Keynote Lecture on "Analysis of flow through porous media during composites manufacturing", 3rd UK InterPore Conference on Porous Media, University of Warwick.

September 2017 – Janice Dulieu-Barton and Ole Thomsen - Invited Presentation 'Towards a new paradigm for high-fidelity testing and integrated multi-scale modelling of composite substructures and components' at International Seminar 'Novel Composite Materials & Processes for Offshore Renewable Energy', Cork, Ireland.

September 2017 – Emile Greenhalgh – Invited Presentation on the latest developments in structural power, at the Airbus Structures event organised to showcase new technologies to the staff across the company, Bremen, Germany.

October 2017 – Andy Long - Invited Lecture on "Design, manufacture and performance of textile composites", FiBreMoD Marie Sklodowska-Curie European Training Network, École des Mines de Paris.

November 2017 – Michael Sutcliffe became a University Professor at the University of Cambridge.

November 2017 - Janice Dulieu-Barton and Ole Thomsen - Keynote Presentation 'Towards a new paradigm for high-fidelity testing and integrated multi-scale modelling of composite substructures and components", at 2nd International Symposium on Multiscale Experimental Mechanics (ISMEM 2017), DTU, Denmark.

June 2018 – Dr Arthur Levy will spend 3 months at University of Bristol in the summer of 2018, sharing Université de Nantes (France) expertise on in-plane and out-of-plane electrical conductivity measurements in composites.

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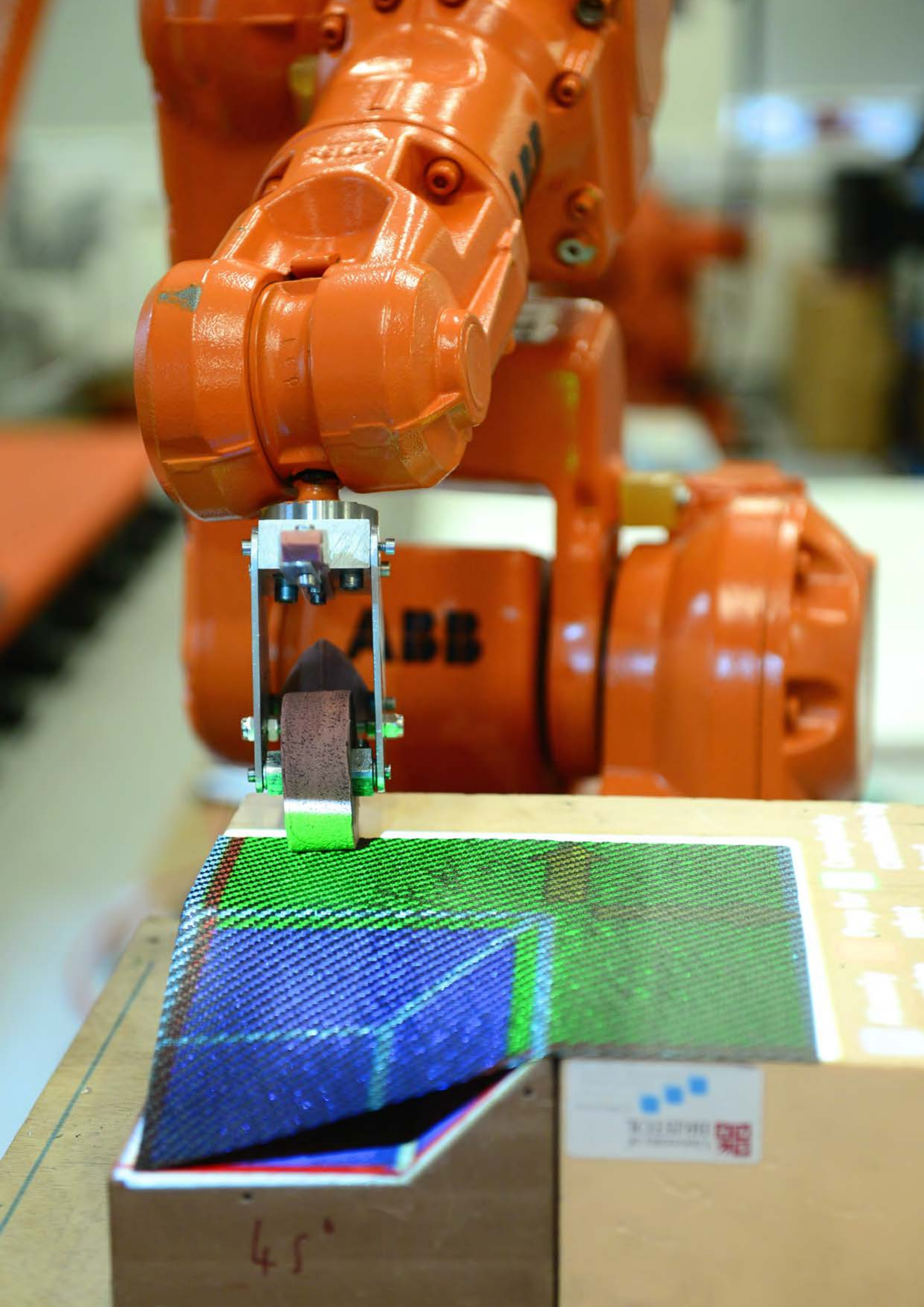
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