ACM5

AUTOMATED COMPOSITES MANUFACTURING

Fifth International Symposium **on Automated Composites Manufacturing**

Conference Programme

NATIONAL COMPOSITES CENTRE

University of BRISTOL

Bristol Composites Institute

Conference Chairs

Prof. Kevin Potter, Chairman, University of Bristol
Prof. Ole Thomsen, Co-Chairman, University of Bristol
Dr Enrique Garcia, Co-Chairman, National Composites Centre

Local Organising Committee

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Prof. Ivana Partridge, University of Bristol
Prof. Paul Hogg, British Composites Society
Prof. Nick Warrior, University of Nottingham
Jools Granville, National Composites Centre
Matt Scott, National Composites Centre
Nicci McCambridge, National Composites Centre

International Scientific Committee

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Farjad Shadmehri, Concordia University
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Ali Yousefpour, NRC
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Dear ACM5 attendees,

I'd like to welcome you all, to the event and to this collection of extended abstracts - alongside my Co-Chairs Ole Thomsen of Bristol Composites Institute and Enrique Garcia of the National Composites Centre. ACM has been a very positive contribution to the composites conference landscape since its inception in 2013, ably developed by Suong van Hoa and his team at Concordia University. We were originally intending to hold the conference in 2021, but like the rest of the world's scientific community we have had to rely on virtual meetings for the last two years due to the global COVID pandemic. Whilst we did all manage to keep things moving, I'm sure that, like me, most of you have been missing the chance to meet in the real world for the discussions and relationship building that is really the lifeblood of scientific research. We have conference participants with 19 different nationalities attending this conference, demonstrating the breadth of interest in the technology across the world.

The two main UK organisations supporting Composites Manufacturing research from academia through to industrial application are the EPSRC Future Composites Manufacturing Research Hub (previously the EPSRC Centre for Innovative Manufacture in Composites – or CIMComp) and the National Composites Centre (NCC), both of which are now past their 10th birthday and focussed heavily on the automation of composites manufacture and you'll hear from both organisations during the conference. I'd like to think that the presentations and discussions taking place over the next two days will help to identify future research directions for both organisations and for the wider composites manufacturing community. It will be our pleasure to welcome you to the NCC and to the city of Bristol, to demonstrate what has been achieved here and introduce you to the range of its capabilities.

Lastly, whilst great strides have been made in automating composites manufacture there are still some areas where we need to up the game to open up new applications and new markets in support of achieving a sustainable low carbon future. I would encourage all of you to put these issues at the centre of your discussions and the new relationships that will be forged during this conference. Please enjoy the next couple of days and leave us ready to move on to the next phase of the composites manufacturing story.

Kevin Potter
Professor of Composites Manufacturing and Design
Chair for ACM5

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With thanks to our sponsors and exhibitors at this year's conference.

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Baker Hughes is an Energy Technology Company who develop and deploy technology to help meet the world's demand for energy and to advance industry and take energy forward, making it safer, cleaner, and more efficient for the people and the planet.

We are working to drive new technology into an industry that is reluctant to change, and composites are the new disruptive technology for the industry. We have formed a strong partnership with NCC to develop suitable technologies within the sector, and automation of the manufacturing processes will be key to the successful utilisation of composites in this field.

CIMComp
EPSRC
Future Composites
Manufacturing Research Hub

The Future Composites Manufacturing Research Hub is a £10.3m investment by the EPSRC to engage academics from across the UK to deliver a step-change in the production of polymer matrix composites. The Hub is driving the development of automated manufacturing technologies to deliver components and structures for demanding applications, within the aerospace, transportation, and renewable energy sectors. The vision is to develop a national centre of excellence in fundamental research for composites manufacturing – delivering research advances in cost reduction and production rate increase, whilst improving quality and sustainability. Our aim is to underpin the growth potential of the UK composite sector by developing the underlying manufacturing process science.

CORIOLIS

Coriolis Composites develops, makes and markets robotic and gantry cells for automated fiber placement. We are mainly using a standard robot enabling the laying of continuous or discontinuous fibers, in all directions and on complex geometrical surfaces.

Our objective is to develop and supply automated solutions for the manufacture of composite parts. The aim is to enhance mechanical performance thanks to low costs and an energy efficient, reliable technology that enables layup using a variety of composite materials.

Coriolis provides: Machines, software and Composites engineering services as well as maintenance support for machines in operation.

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POSTER PRESENTATIONS

ACM5 Overview & Preliminary Programme

Venue: National Composites Centre, Bristol & Bath Science Park, Emersons Green, Bristol BS16 7FS

Day 0 – Tuesday 5 April 2022.

Time	
16.00-17.00	**Tour of National Composites Centre (NCC)** Bristol & Bath Science Park, Emersons Green, Bristol BS16 7FS
17.00 -18.30	**Registration & Welcome reception** NCC, Bristol Poster session
	BUS TRANSPORT from Bristol city centre (hotels) to the NCC and Bus return to Bristol city centre after welcome reception **Collection point in city centre:** Collection at College Green, BS1 5UY 15:20 (leaving College Green by 15:30). Arrival at National Composites Centre (NCC) by 16:00. Return to College Green, BS1 5UY Leaving NCC at 18:45-19:00. Arrival at College Green around 19:15 – 19:30

ACM5 Preliminary Oral Presentations Schedule

Day 1 – Wednesday 6 April 2022.

Time	Speaker	Title
9.00	Kevin Potter, BCI/University of Bristol & Enrique Garcia, NCC, UK	**Opening remarks and welcome**
Session 1. Automated Fibre Placement 1. Session chair: Sayata Ghose, Boeing		
9.15	**Suong Van Hoa, Concordia University, CA**	**Keynote 1. Recent Advances and Challenges in Automated Composites Manufacturing**
9.45	Yi Wang, University of Bristol, UK	A simulation platform for the influence of process conditions on steering-induced defects in automated fibre placement (AFP)
10.05	Xiaochuan Sun, University of Bristol, UK	On-the-fly Process Control in Automated Fibre Placement
10.25	Lars Brandt, TU DLR, D	Introduction of 3-dimensional process simulation for thermoplastic AFP for enhanced process parameter identification
10.45	Iryna Tretiak, University of Bristol, UK	Cyclic Compressive loading of Carbon/Epoxy Prepregs: Novel Challenges and Model Requirements
11.05	**Tea and Coffee break**	
Session 2. Automated Fibre Placement 2. Session chair: Anoush Poursartip, University of British Columbia, CA		
11.20	Ralf Schledjewski, Montanuniversität Leoben, A	Improved layup quality during automated thermoplastic tape layup – Inline detection of consolidation force and tape geometry

11.40	Yi Wang, University of Bristol, UK	A modelling framework for the evolution of prepreg tack under processing conditions
12.00	Daniël MJ Peeters, TU Delft, NL	Predicting the formation of gaps and overlaps due to width variations of dry-fiber tapes during automated fiber placement
12.20	Anthony Evans, University of Nottingham, UK	Developing a Testbed for Automated Fibre Placement Technologies
12.40	Evangelos Zympeloudis, iCOMAT, UK	Fibre Steering for the manufacture of next generation advanced composites
13.00	**Lunch and Poster Session**	
Session 3. Forming Technologies 1. Session Chair: Sean Cooper, NCC, UK		
14.30	**Malin Åkermo, Royal Institute of Technology, S**	**Keynote 2 Composites Manufacturing in Future Light Weight Design**
15.00	Byung Chul Kim, University of Bristol, UK	Fibre-Steered Forming Technology for High-Volume Production of Complex Composite Components
15.20	Chrysoula Aza, University of Bath, UK	Fibre length effect on the design of formable laminates for complex geometries
15.40	Long Bin Tan, A-star, SG	Development of Machine Learning Model for Composites Thermoforming Process
16:00	**Tea and coffee break**	
Session 4. Forming Technologies 2. Session Chair: Eric Kim, BCI/University of Bristol, UK		
16.15	Anoush Poursartip, University of British Columbia, CA	Forming Process Simulation and Experimental Validation
16.35	Carl Scarth, University of Bath, UK	Stacking sequence selection for defect reduction in forming of long composite spars
16.55	Steven Roy, NRC, CA	AFP Inspection: From OCT A-Scans to the Digital Twin
17.15	**End of session remarks**	

Time	**Conference Banquet, Bristol**
19.30-	Avon Gorge by Hotel du Vin, Sion Hill, Clifton, Bristol BS8 4LD (by Clifton Suspension Bridge) Pre-dinner drinks from 19:30. Dinner 20:00. **BUS TRANSPORT:** Collection at National Composites Centre at the end of conference at 17:15pm. Collection point outside South Gate Reception. Brief drop off at College Green, BS1 5UY to allow you to return to hotels to change if required Collection from College Green, BS1 5UY to travel to The Avon Gorge Hotel, Clifton. 19:00 (Leaving by 19:10) to arrive at hotel at 19:20 Return to National Composites Centre, BS16 7FS including a drop off at College Green, BS1 5UY for people staying centrally at approx. 11:15pm.

Day 2 – Thursday 7 April 2022.

Time	Speaker	Title
Session 5. Developing Technologies Session Chair: John Summerscales, University of Plymouth, UK		
9.00	**Ed Findon, LM Wind Power, DK**	**Keynote 3. Challenges in the manufacture of large wind turbine blades**
9.30	**Nicholas Warrior, University of Nottingham, UK**	**Keynote 4. Automation projects within the EPSRC Future Composites Manufacturing Research Hub**
10.00	**Tea and Coffee**	
10:15	Andrea Codolini, University of Cambridge, UK	Influence of tool orientation on the drapeability of unidirectional non-crimp fabrics.
10.35	Marco Bogenschütz, University of Hannover, DE	Determination and impact of fiber angle deviations in automated processing of carbon fiber non-crimp fabrics
10.55	Narongkorn Krajangsawasdi, University of Bristol, UK	Highly Aligned Discontinuous Fibre Composite Filaments for Fused Deposition Modelling: Printability investigation
11.15	Lourens Blok, Lineat, UK	Exploring commercial use cases for aligned short fibre composites
11.35	Laura Rhian Pickard, University of Bristol, UK	Manufacturing of novel hierarchical hybridised composites
11.55	Tim Searle, Composite Integration, UK	From Resin Confusion to Resin Infusion – Understanding, Process Control & Automation
12.15	**Sponsor & Exhibitor Presentations**	
12.35	**Lunch and Poster Session**	
Session 6. Robotics and Moulding Technologies 1 Session Chair: Stephen Hallett, BCI/University of Bristol, UK		
14.15	**Philippa Glover, CNC Robotics, UK**	**Keynote 5. Applications of robots across composites manufacture**
14.45	Goran Fernlund, Convergent, CA	Data mining and science-based analytics for automation of composites processing
15.05	James Streatfield, Loop Technology, UK	High rate composite deposition for large scale aerostructures
15.25	Rachael Weare, WMG, UK & Andy Bools, Expert Technologies Group, UK	Automated Stamp Forming of CF-Prepreg Materials
15:45	**Tea and Coffee**	
Session 7. Robotics and Moulding Technologies 2		

Session Chair: James Kratz, BCI/University of Bristol, UK		
16.05	Andrew J Parsons, University of Nottingham, UK	Enhanced Characterisation and Simulation Methods for Thermoplastic Overmoulding – ENACT
16.25	Julien van Campen, TU Delft, NL	The Effect of Multi-Patch Laminate Design on the Manufacturing Efficiency of Composite Plates
16.45	Joe Summers, Airborne, UK	Design For Automation: Lessons from a High Rate Development Project
17.05	Per Saunders, NCC, UK	Low-cost photogrammetric control for automated trimming of composite preforms
17.25	**Closing remarks & end of conference**	

SESSION 5
DEVELOPING TECHNOLOGIES

MANUFACTURING OF NOVEL HIERARCHICAL HYBRIDISED COMPOSITES

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Keywords: Fibre-reinforced composites, pultruded rods, compression, overbraiding, hybridisation

ABSTRACT

Inspired by natural composites such as bamboo (Figure 1) or bone, the NextCOMP programme seeks to improve compressive performance through a novel, hierarchical approach to advanced composites. Features designed to improve compressive performance are introduced at multiple length scales. Novel fibres and resins are under development, along with new approaches at the ply level.

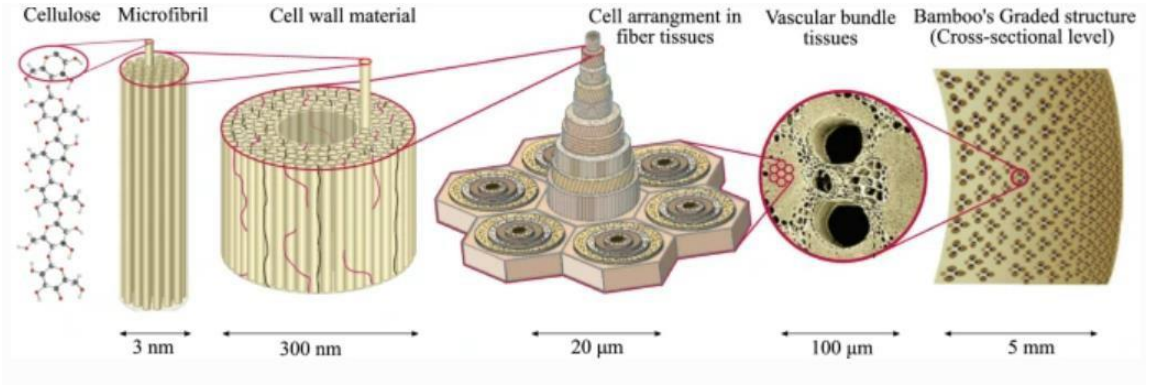

Figure 1: Illustration of hierarchical structure of bamboo. Reproduced from [1].

This new approach to composites brings its own manufacturing challenges, combining multiple methods both automated and manual.

Cylindrical struts, consisting of carbon-fibre epoxy pultruded rods of circular cross section plus an infused resin, have previously been manufactured [2] and subjected to compression after impact testing [3]. Struts overwound with Kevlar to confine the kink bands exhibited greater compressive strength than comparable struts without overwinding. X-ray CT images (Figure 2) show multiple smaller kink bands in the former case compared to a single large kink band in the latter.

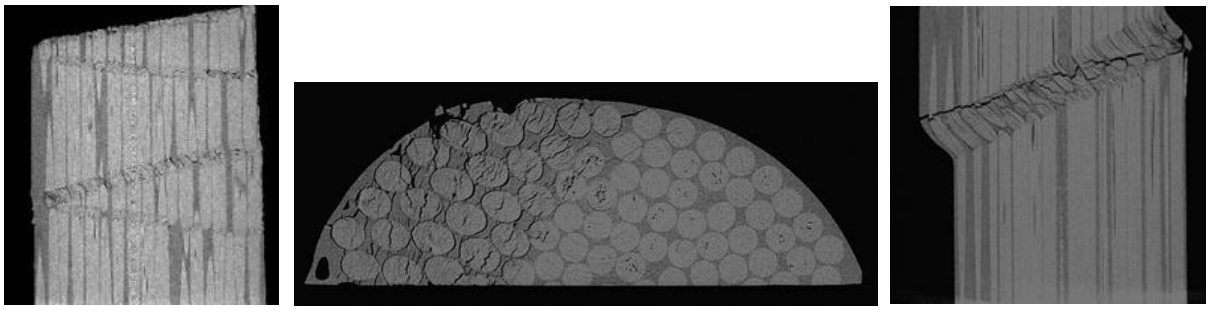

Figure 2: Slices from XCT reconstructions of samples from experiments reported in [2]. Strut with overwind shown left with multiple smaller kink bands, strut without overwind shown right and centre with single kink band.

In the hierarchical approach overbraiding of individual rods is employed, introducing hybridisation where rod and overbraid fibres differ. Various materials and geometries are under test (Figure 3), including a range of rod cross section shapes and areas. These overbraided rods are then integrated into larger structures, including but not limited to cylindrical struts.

Figure 3: Circular cross section carbon fibre-epoxy rods overbraided with Toray T300 carbon (left), Teijin high modulus Zylon (centre) and Teijin Twaron 2200 aramid (right).

This presentation focuses on our latest investigations into the design, manufacture and compression testing of single and hierarchical composite overbraided architectures. Optimisation of overbraiding for different test cases will be explored. The work is placed in context regarding what this new approach to composites may mean for manufacturing, with a look towards future challenges and opportunities.

The authors kindly acknowledge the funding for this research provided by UK Engineering and Physical Sciences Research Council (EPSRC) programme Grant EP/T011653/1, Next Generation Fibre-Reinforced Composites: a Full Scale Redesign for Compression in collaboration with Imperial College London.

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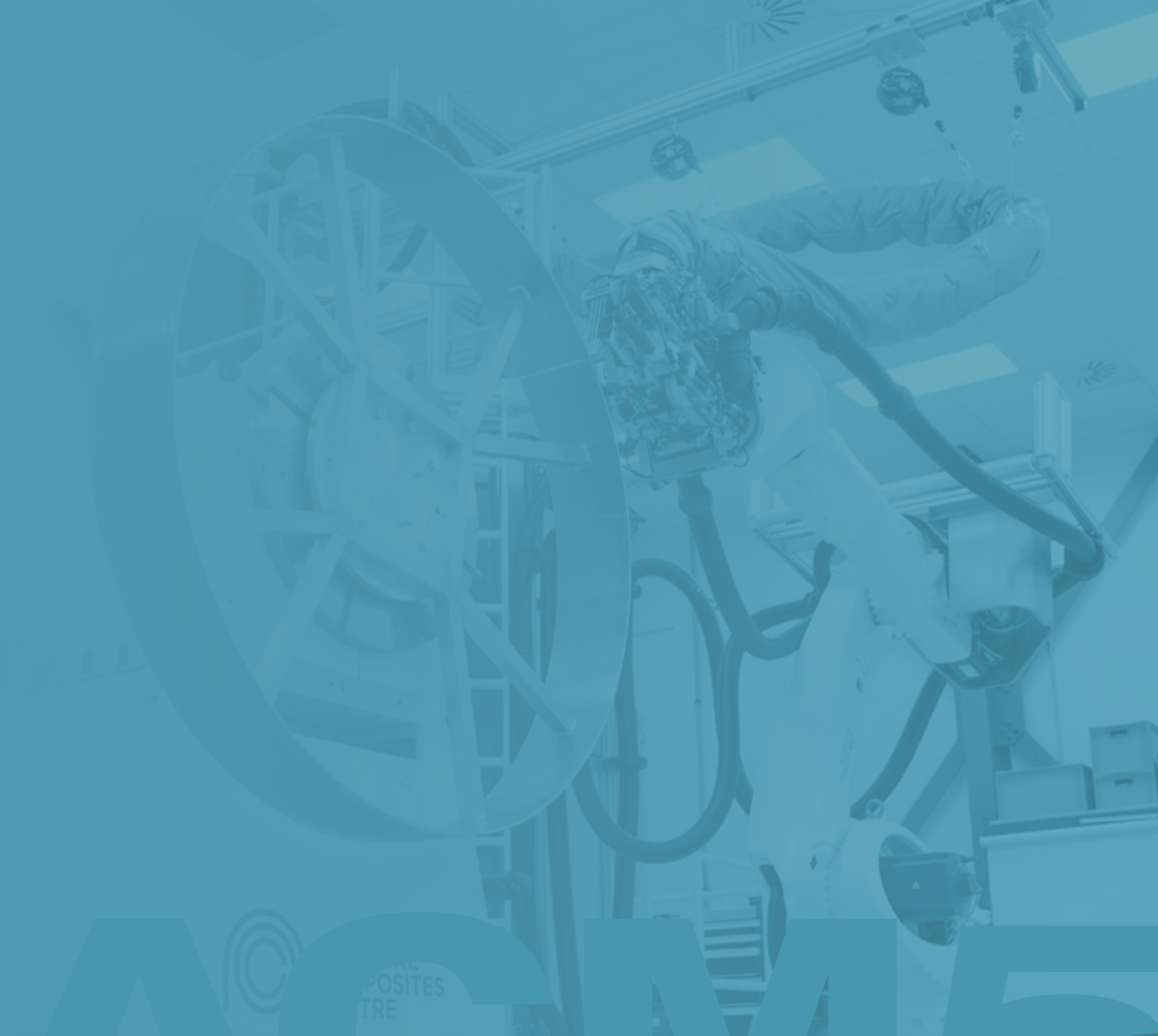

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