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Manufacturing Research Hub

Engineering and
Physical Sciences
Research Council

Introduction to the EPSRC Future Composites Manufacturing Research Hub

Prof Nick Warrior

Hub Director

University of Nottingham

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

Overview of Hub, Spokes, structure and organisation

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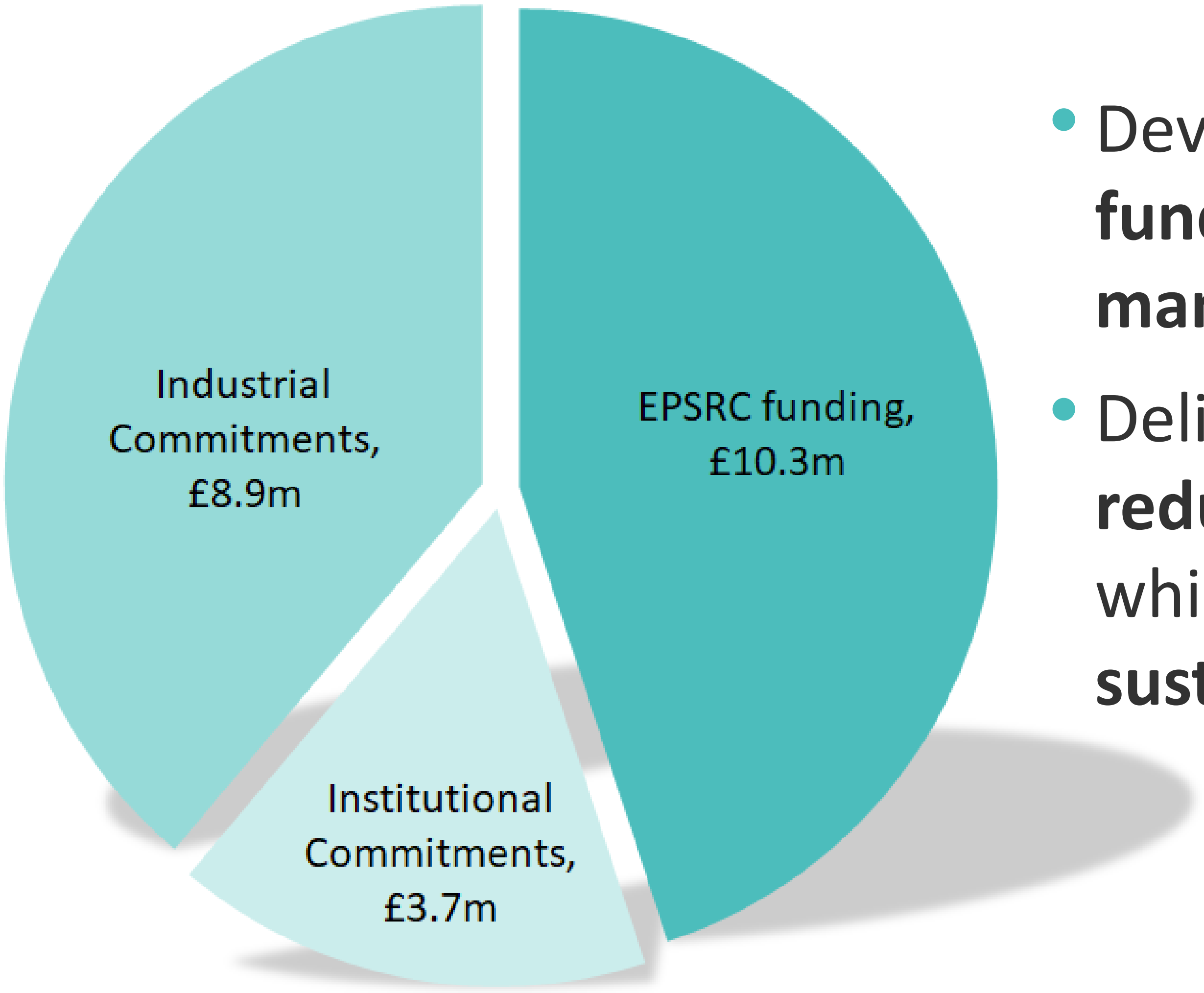
Hub Vision



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- Develop a **national centre of excellence in fundamental research for composites manufacturing**
- Deliver research advances in **cost reduction** and **production rate increase**, whilst improving **quality** and **sustainability**.

Academic Partners – 15 Spokes

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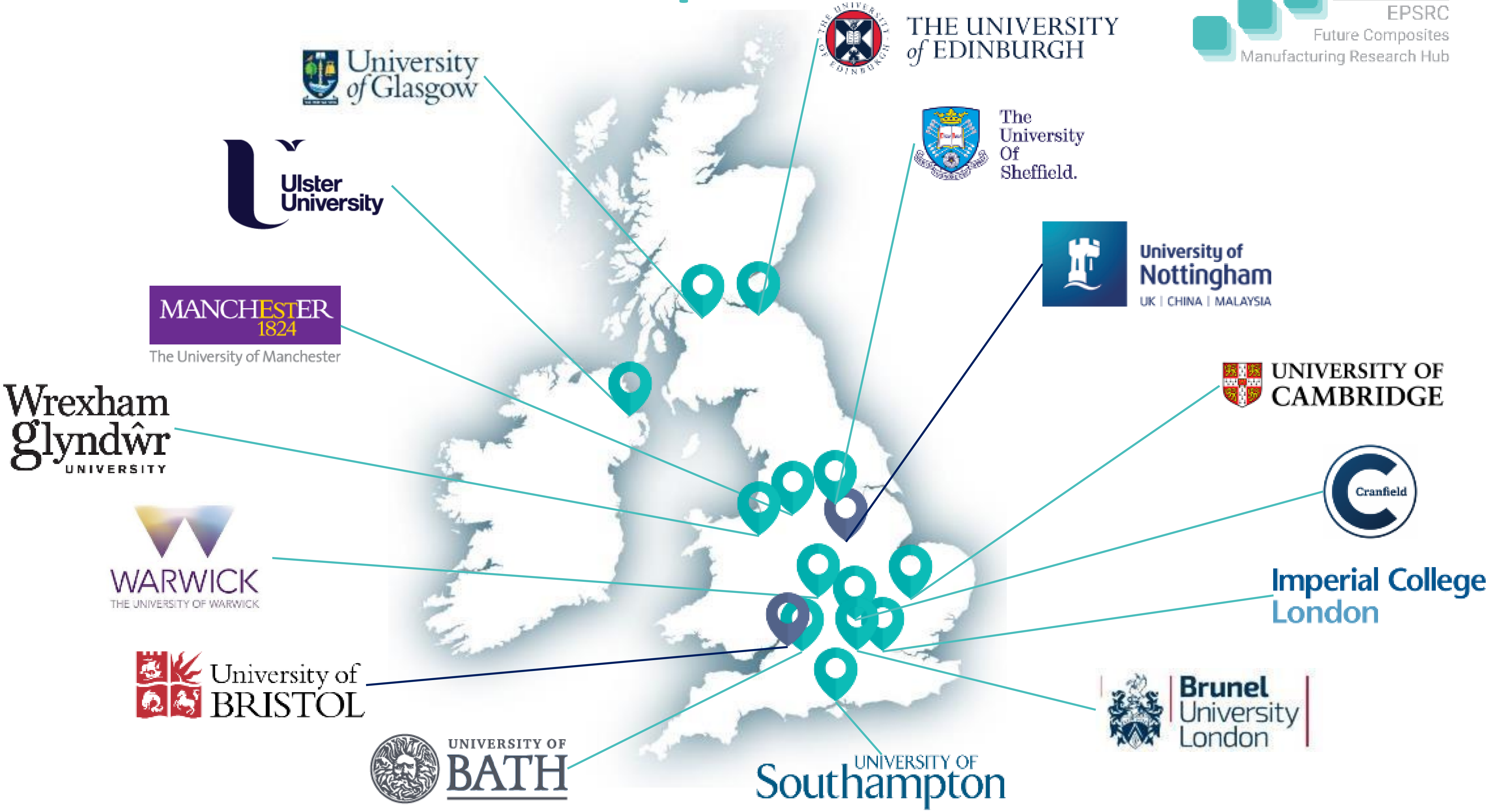

HVM Catapult Partners – 4

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NATIONAL COMPOSITES CENTRE

The University Of Sheffield. / AMRC
Advanced Manufacturing Research Centre

mtc
Manufacturing Technology Centre

WMG
THE UNIVERSITY OF WARWICK

Industrial Partners – 25
Industrial Supporters - 14

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Industrial Supporters

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

Hub Objectives

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Research — Promote a ***step change*** in composites manufacturing science and technologies

Technology — Create a ***pipeline of next generation technologies*** addressing future industrial needs

Training — ***Train the next generation*** of composites manufacturing engineers

Partnerships — Build & grow the ***national & international communities*** in design & manufacture of high performance composites

Typical Manufacturing Challenges

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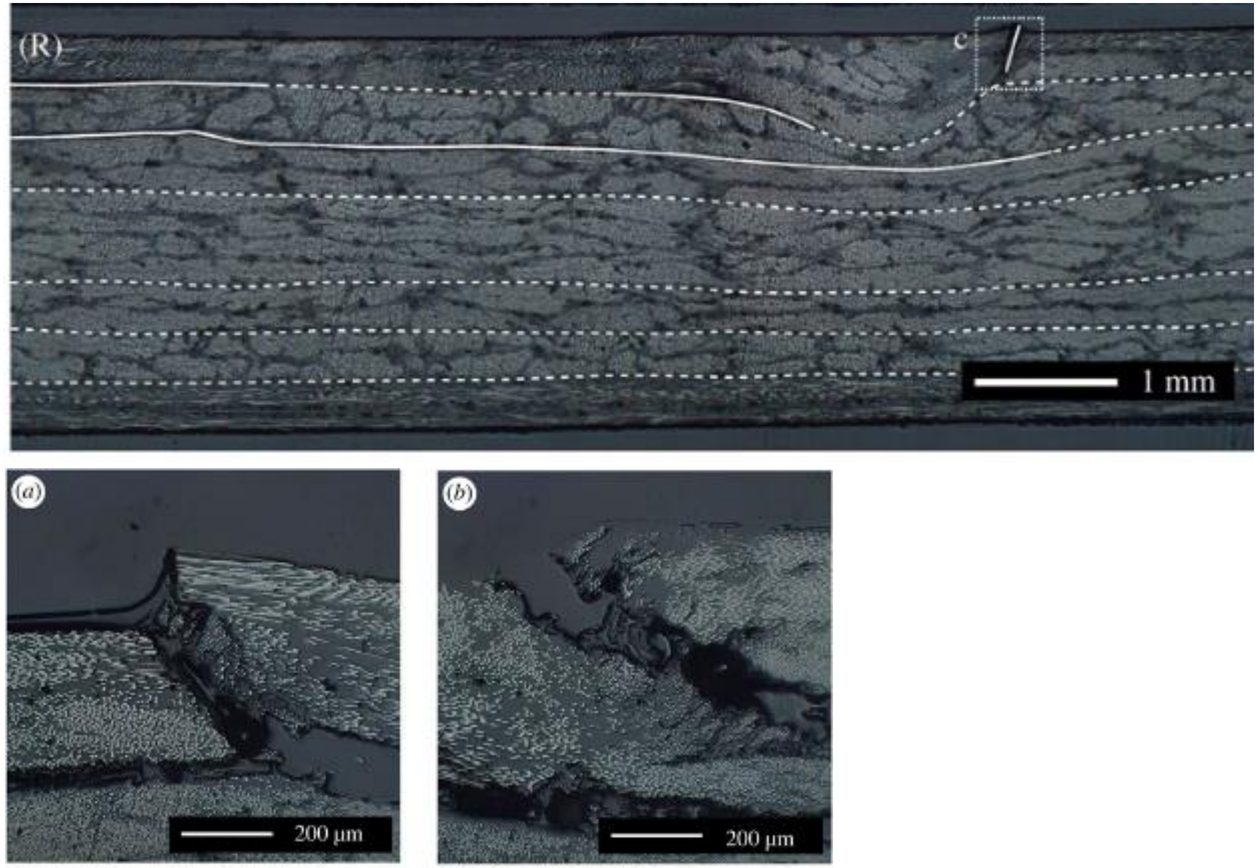
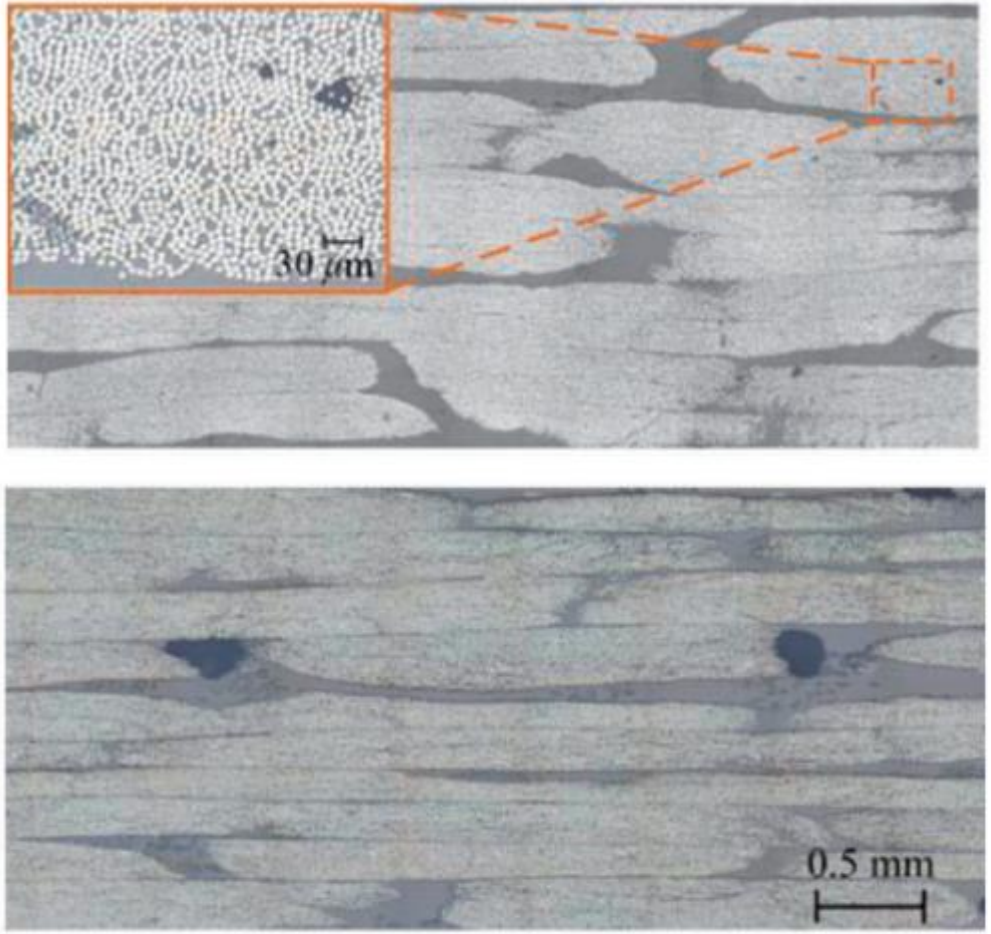
Precise fibre placement free from winkles



Royal Society Open Science, 2018
https://doi.org/10.1098/rsos.180082

High integrity matrix free from voids



Journal of Composite Materials 2019, Vol. 53(12) 1579–1669

Hub Grand Challenges

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Two **industry-inspired challenges** to underpin the growth potential of the UK Composites sector

- **Enhance process robustness via understanding of process science**
- **Develop high rate processing technologies for high quality structures**

Operational Core

- Integrated with EP/L015102/1 EPSRC Centre for Doctoral Training in Composites Manufacture
- Advisory Board provides industrial guidance
- Linked to Composites Leadership Forum

Overview of Hub Research

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Hub Research Themes

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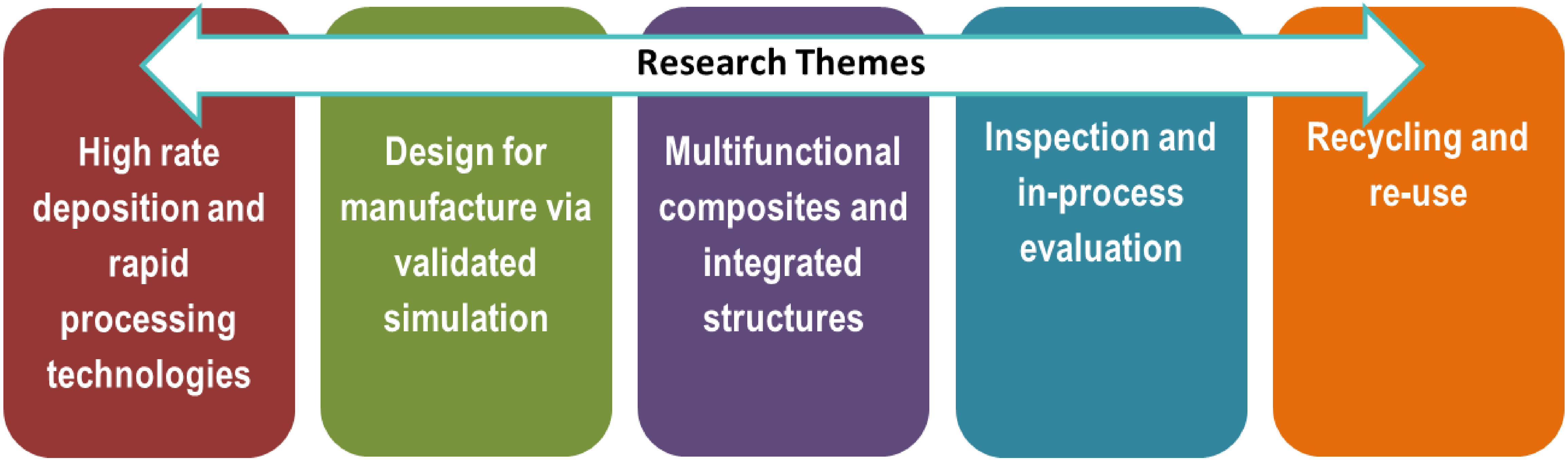

- Research Themes define broad topics for the Hub programme
- Developed with input from CIMComp Advisory Board and wider community via CIMComp Open Day (Jun 2015 >150 people)
- Reconfirmed in 2019

Hub Research Portfolio 2017-2024

- 29 investigator-led projects funded to date
  - 6 Core Projects
  - 19 Feasibility Studies
  - 4 Fellowships
- 35 investigators
- 28 PhD Research Students
- 39 EngD Research Students
- 22 Post Doctoral Research Assistants
  - Aim to fund 37 projects by 2024

Integration Through Work Streams

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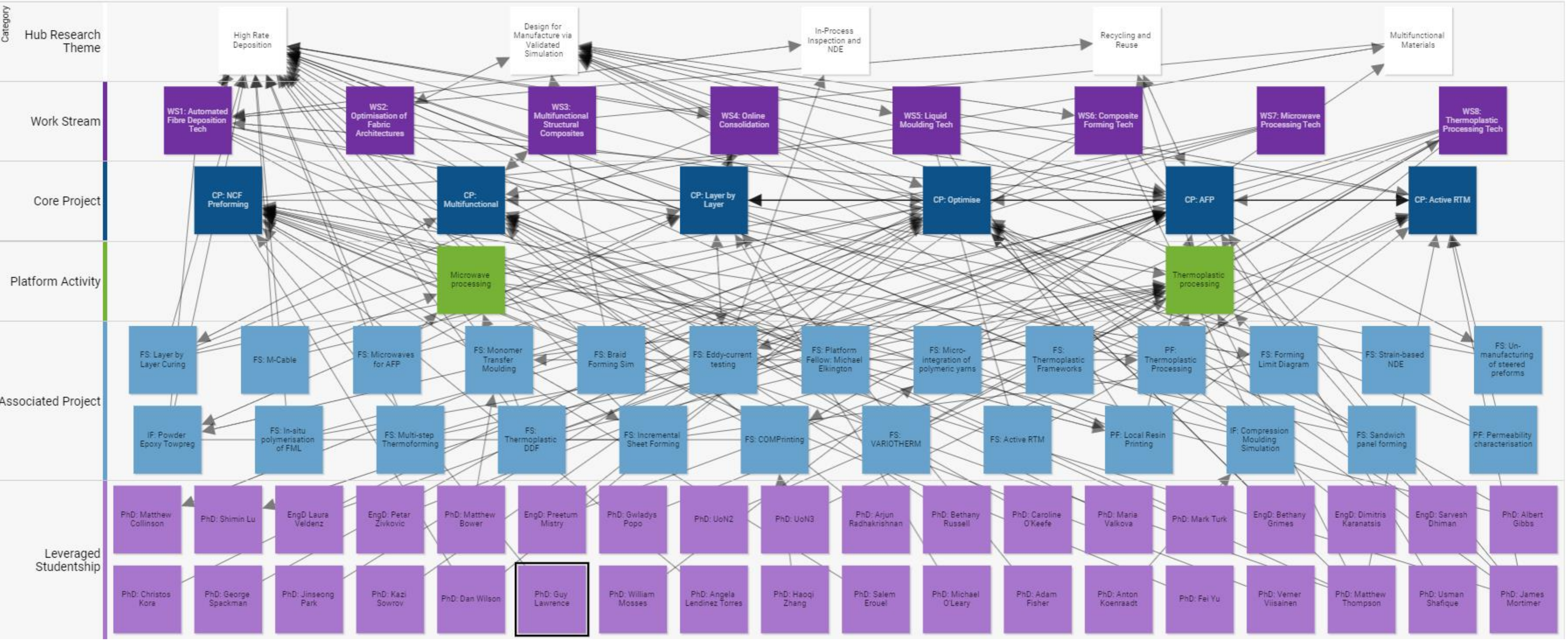

The Hub Work Streams

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WS1: Automated Fibre Deposition Technologies

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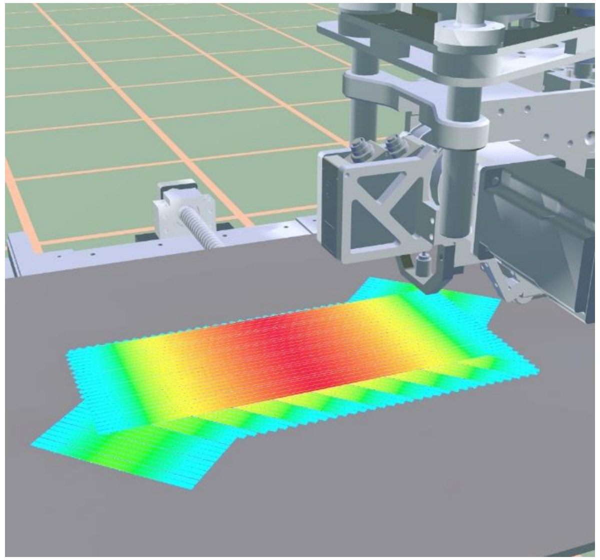
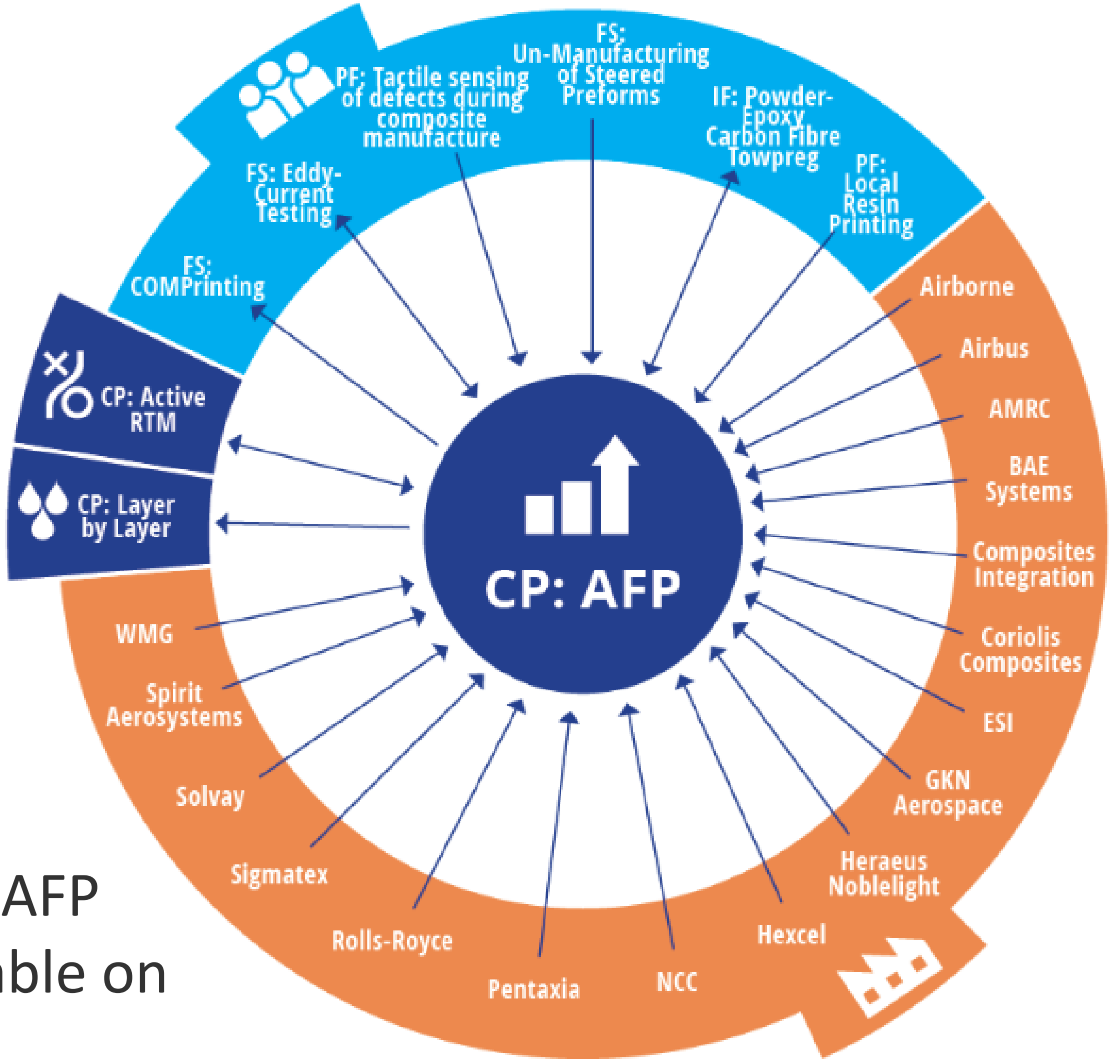
Aims to rapidly produce components not currently manufacturable using conventional AFP, using a combination of novel prepreg material formats and new process developments.





Work Stream Impact

Real-time model-based machine control strategies for AFP have been implemented that are currently not achievable on commercial systems.

WS1: ADFP Digital Twin

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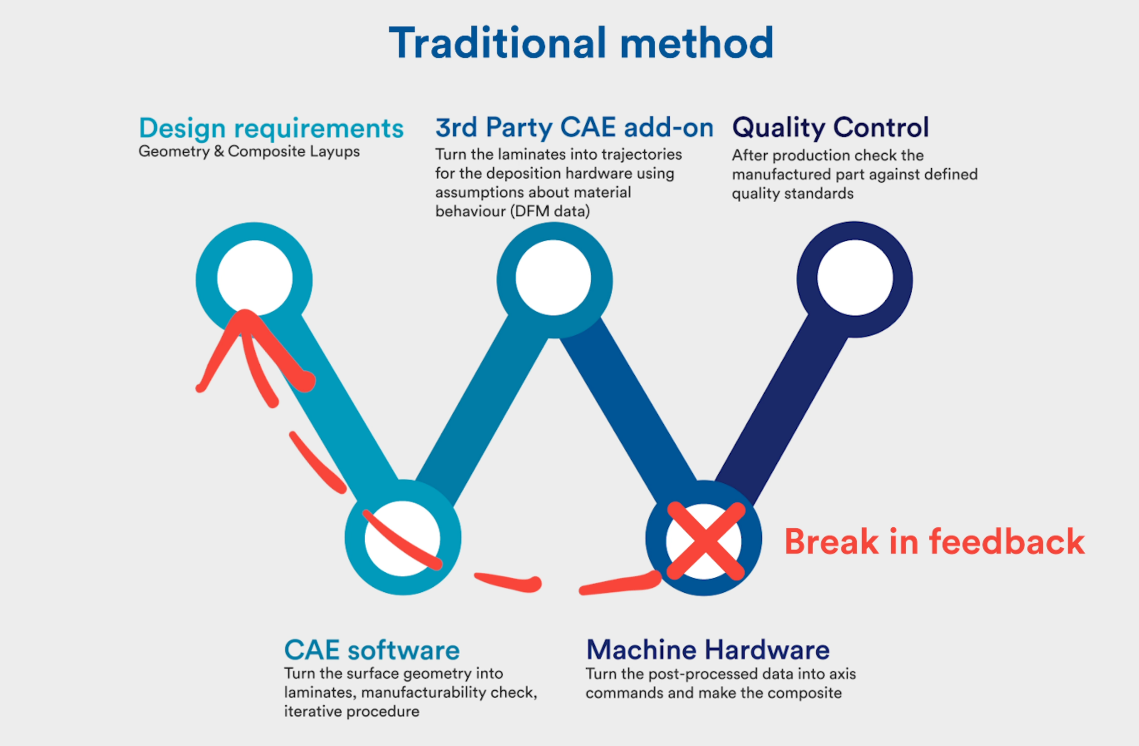

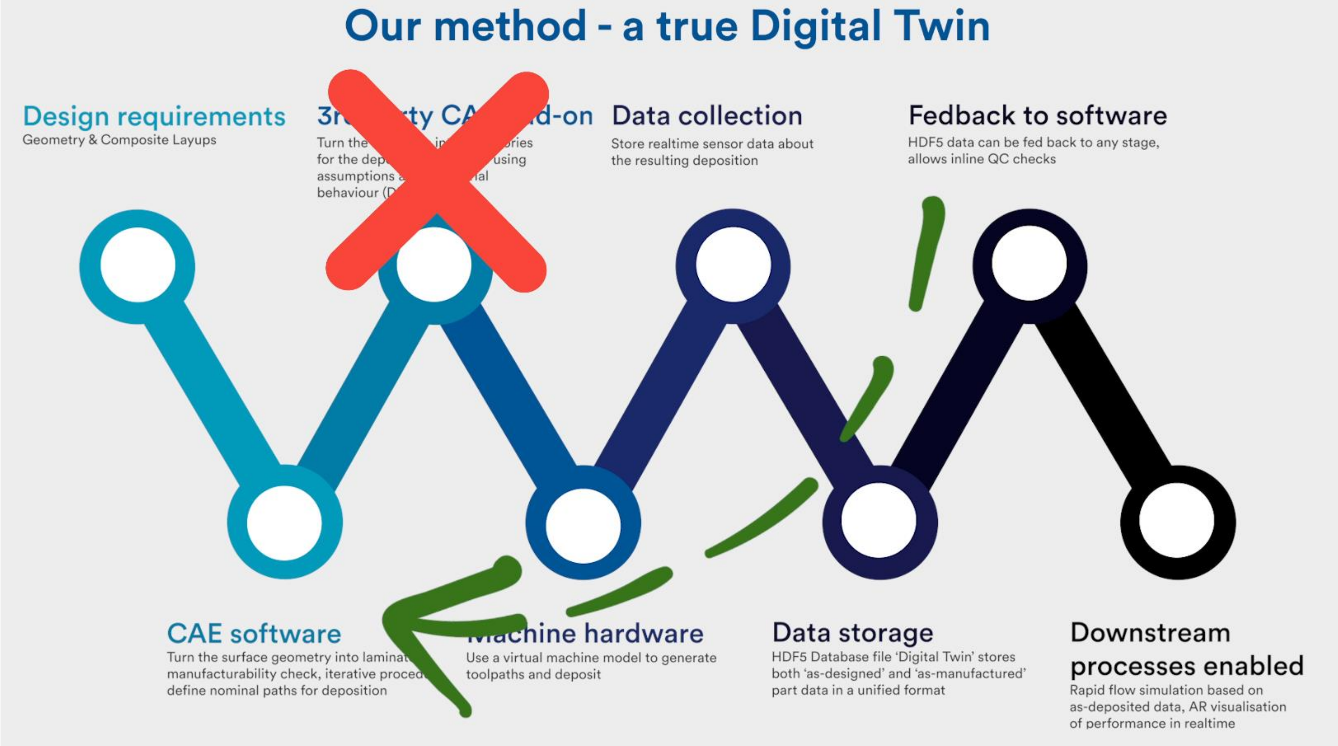

WS1 ADFP Lab-Scale Rig

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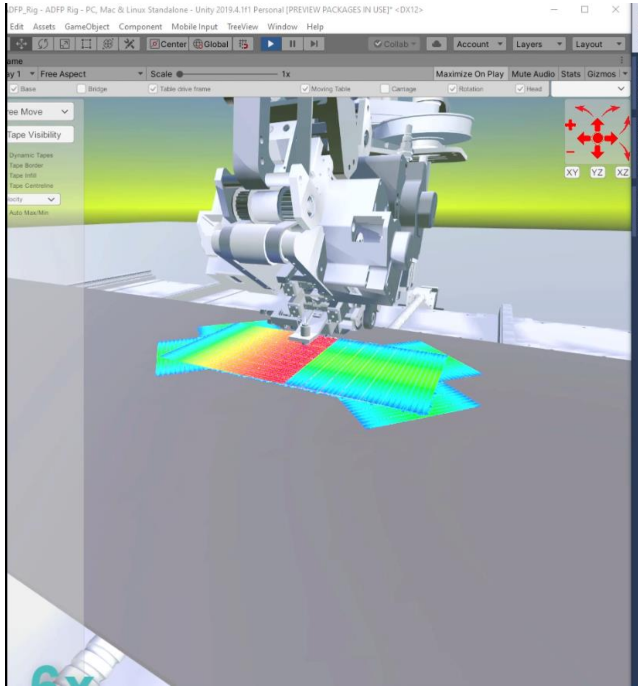

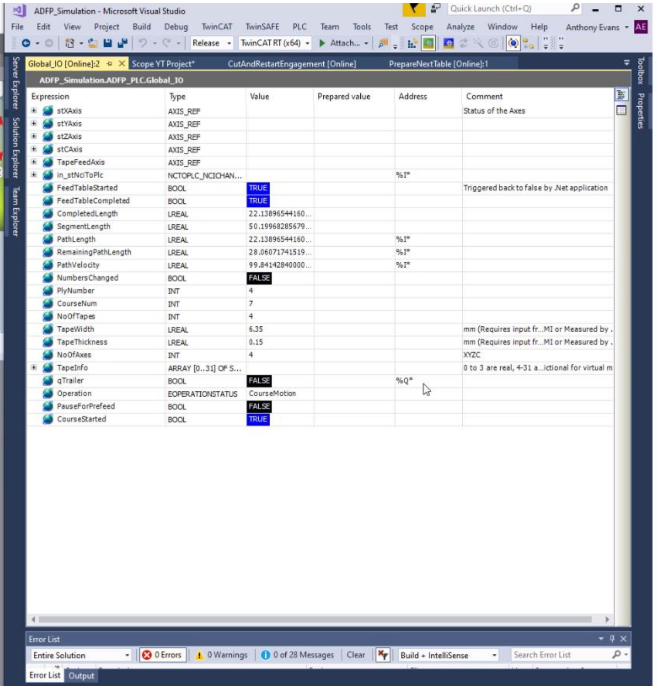

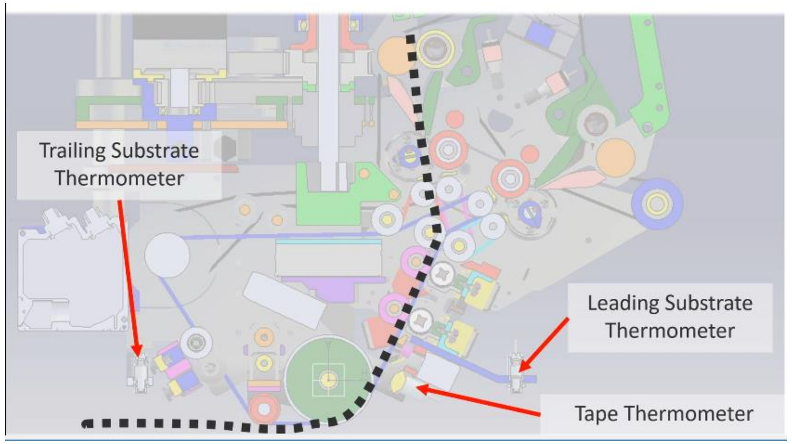

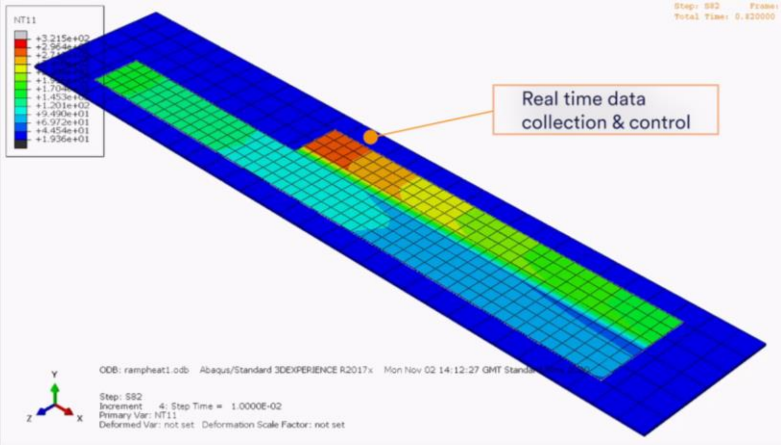

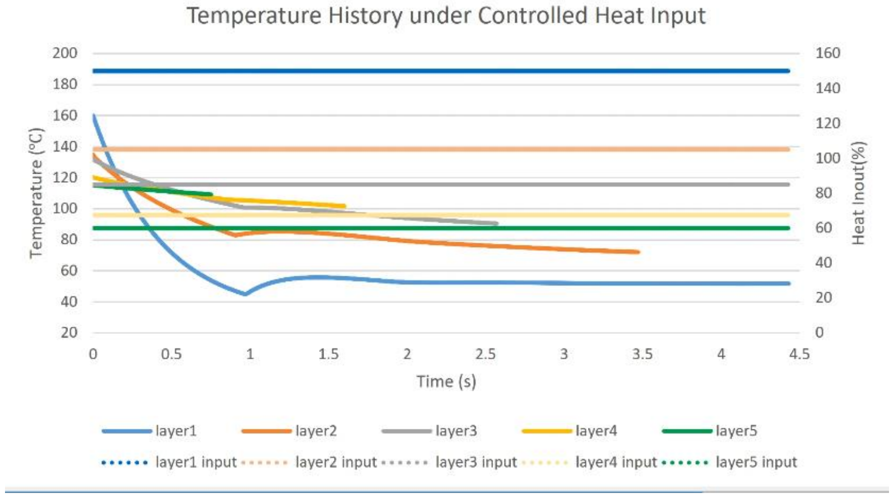

WS1: 2D Fibre Steered + 3D Forming

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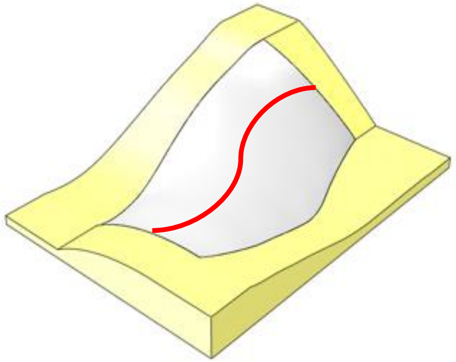
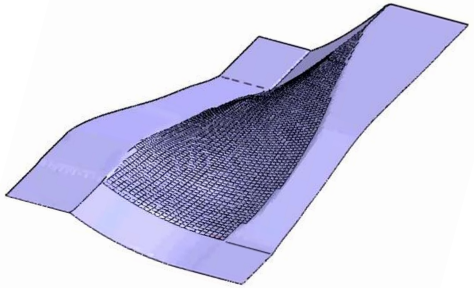
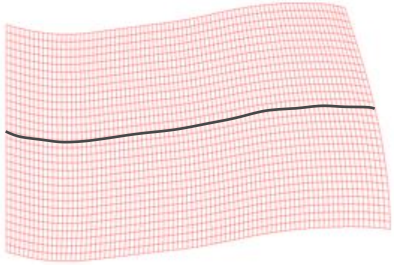


3D mould geometry & Target fibre path

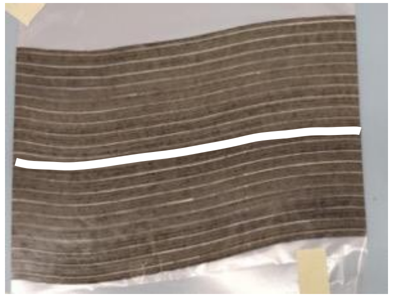


Unforming simulation (Diaphragm forming)



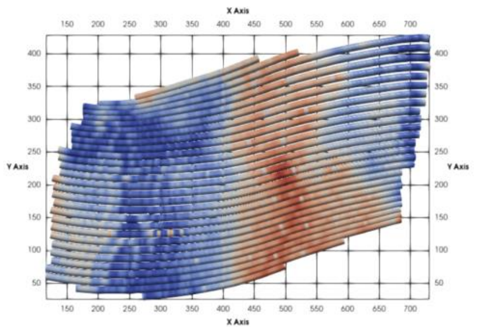
2D fibre-steered preform design

Continuous tow shearing - CTS process

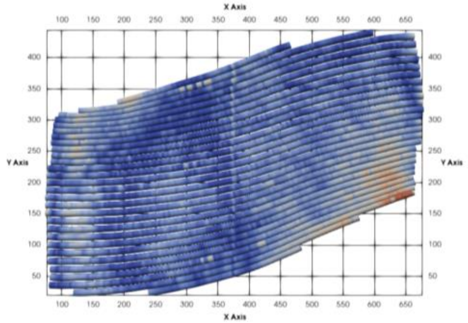


CTS production using HiPerDiF preforms

Diaphragm forming



Straight Prepreg



Steered Prepreg

WS1: Novel tape formats

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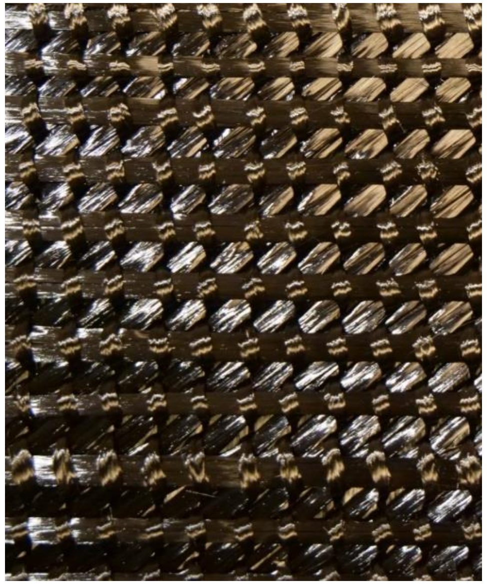
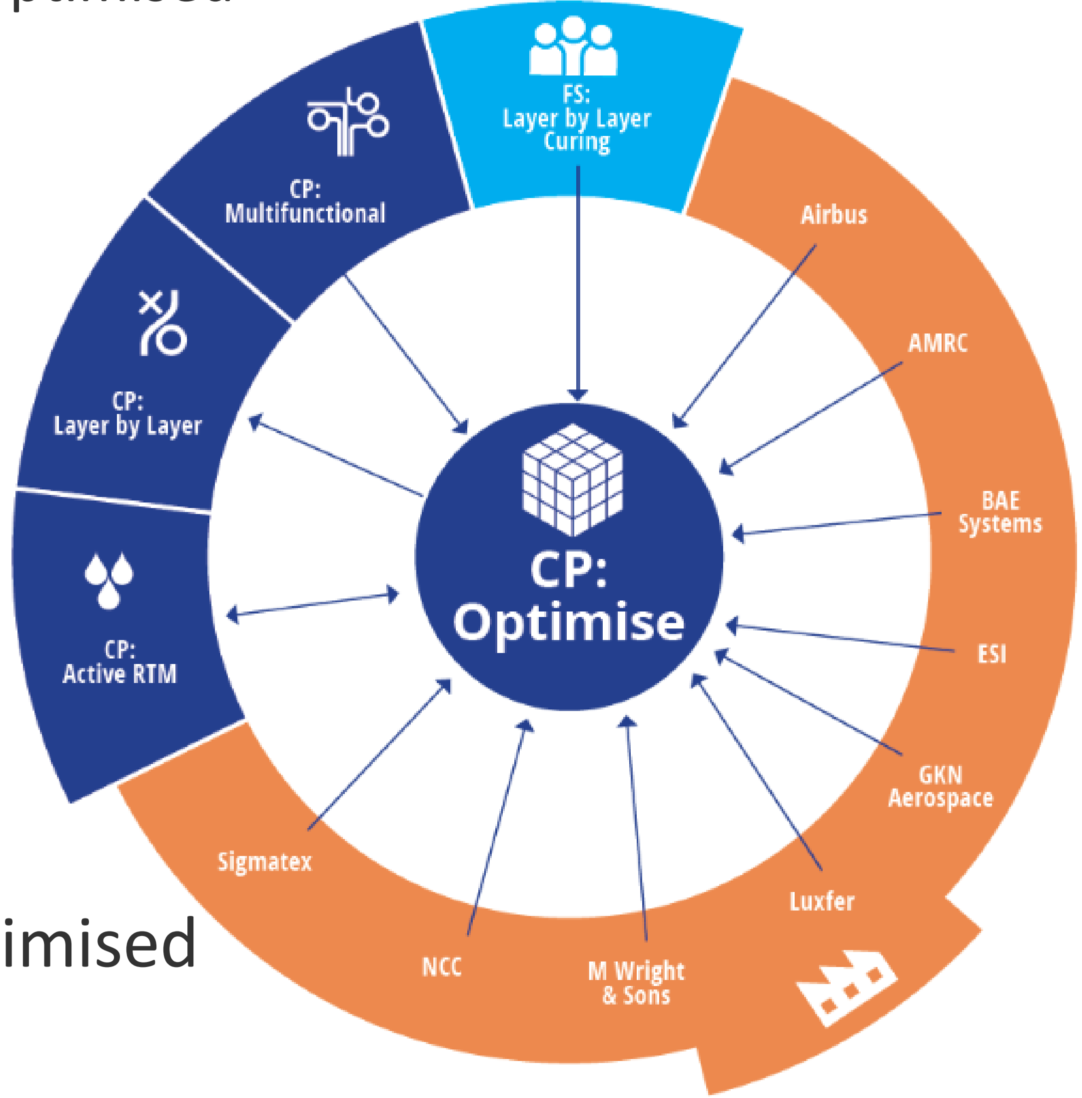
Unwind	Powder deposition	Joule heating	Re-wind
Magnetic tension brake + tension sensor	Controlled flow for electrostatic powder gun + excess powder vacuum extraction	Infrared temperature measurement + Joule heating via copper rollers	Tape distribution + speed sensor

WS2: Optimisation of Fabric Architectures

Improving through-thickness performance and reduce manufacturing cost and rate through application of 3D woven and optimised architectures





Work Stream Impact

Additional 10% weight-saving compared to optimised non-crimp fabrics (NCFs)

WS2: Multi-scale modelling of 3D fibre preforms

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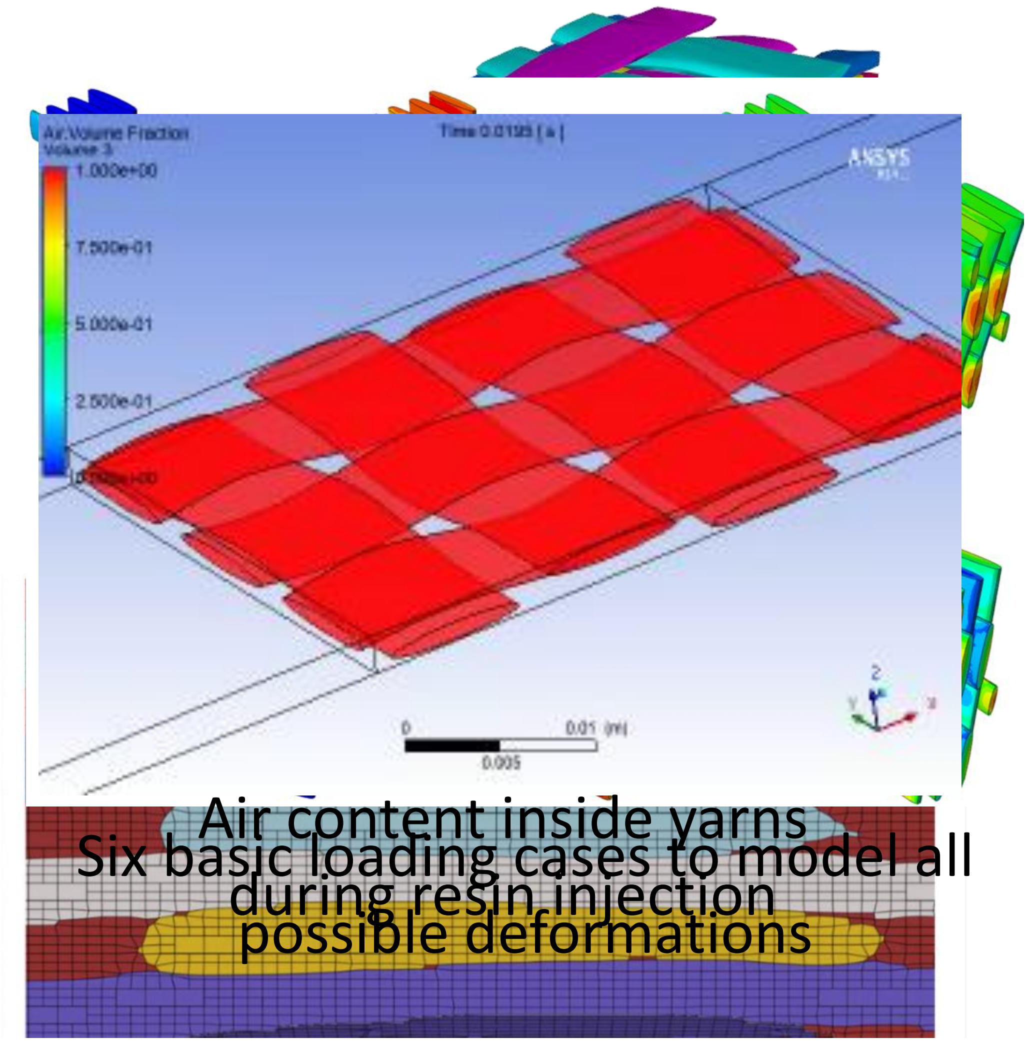
- Novel meshing technique - TexGen
- Multi-scale modelling to obtain the macro-scale mechanical properties using meso-scale geometries
- Flow modelling for predicting permeability of preforms and minimising void content in composites
- **The developed modelling framework and genetic algorithm (GA) are employed for the optimisation of 3D architectures**



Air content inside yarns during resin injection

Six basic loading cases to model all possible deformations

WS2: 3D multi-axial reinforcements

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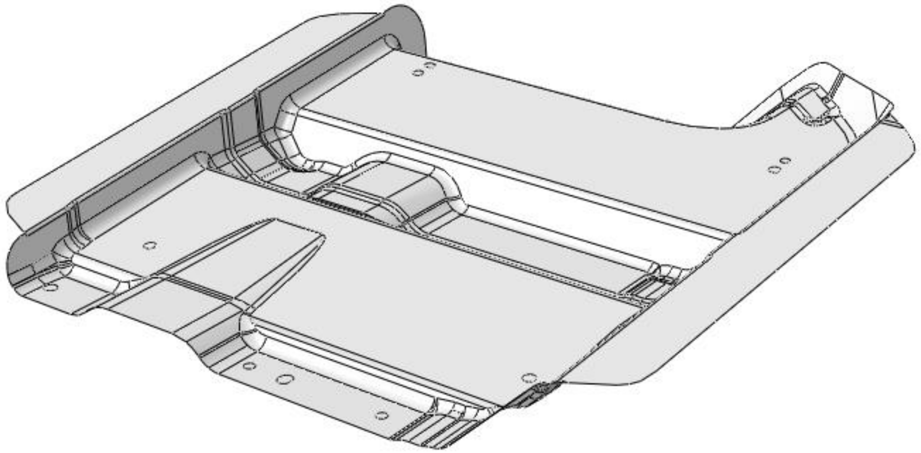
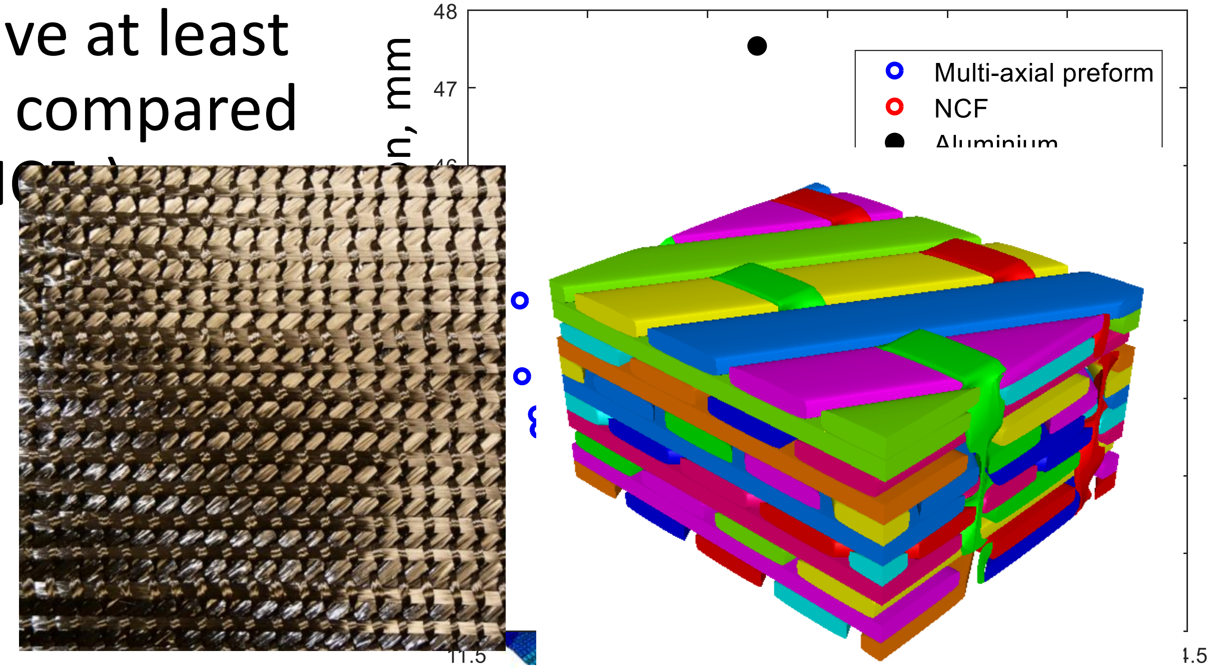
Demonstrator: car floor pan (from AMRC)   **Load cases**: Bending, Torsion

- Conventional orthogonal weaves have poor off-axis properties
- A framework for optimization (UoN) and manufacturing (UoM) of multi-axial preforms
- Optimised 3D multiaxial preforms to give at least an additional 10% weight-saving when compared to optimised ±45° non-crimp fabrics (NC...



Floor pan geometry



Displacement in bending, mm

New multi-axial 3D preforms

WS2: Braid-winding of tubular preforms

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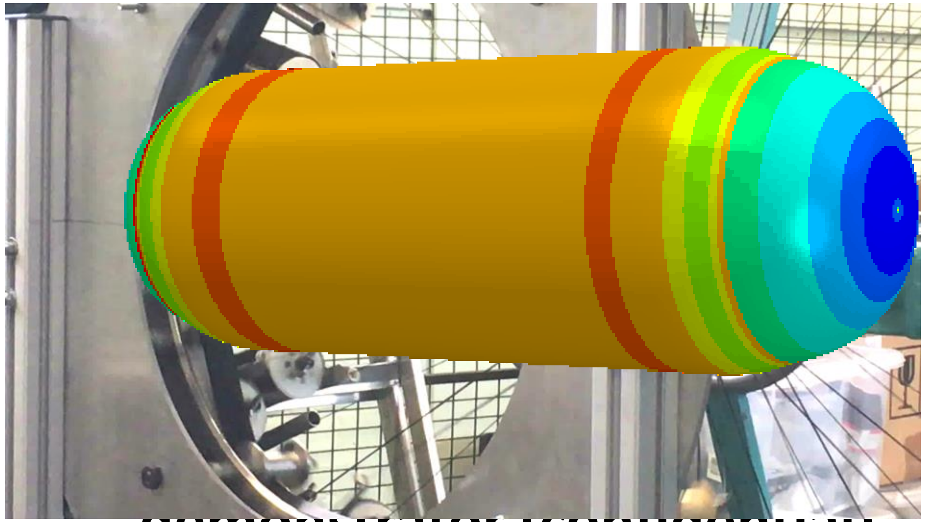
- Braid-winding preforming combines two processes
- The techniques allow creation of multi-axial braided preform with 0°, ±θ and 90° yarn orientations
- Optimisation framework was applied to predict optimum layup
- Several demonstrators of gas cylinders have been manufactured and will be tested

Predicted stress intensity levels

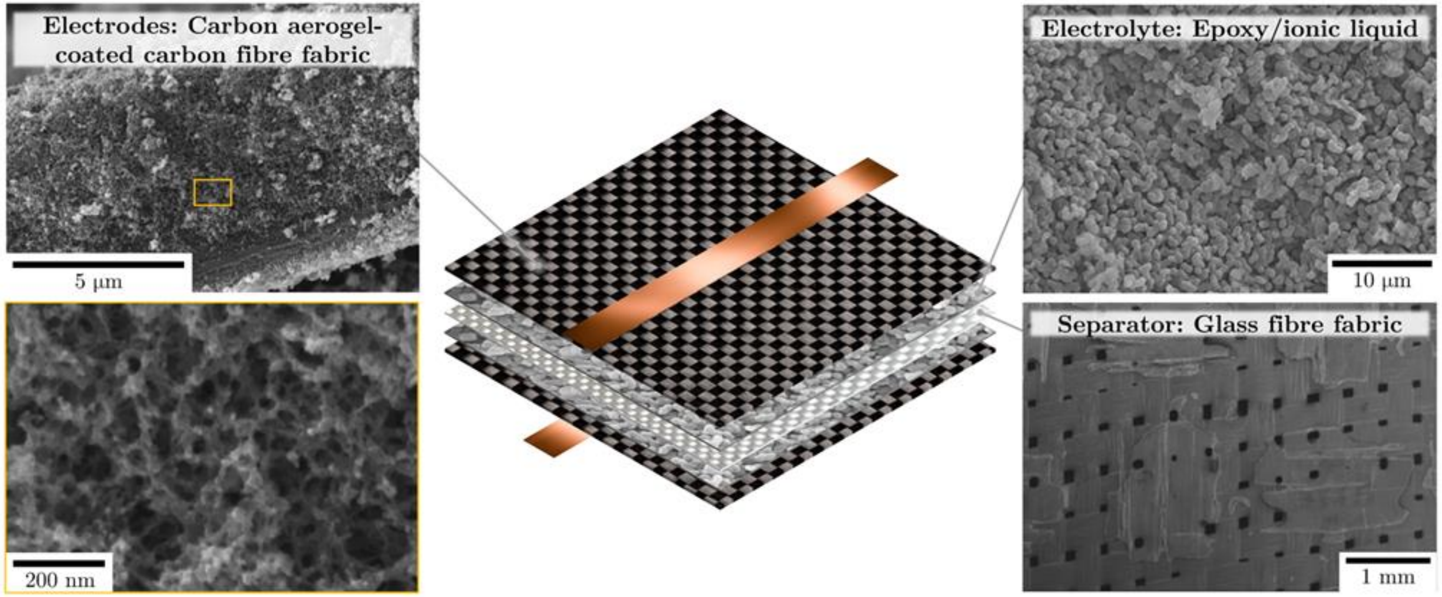
Braid-winding process

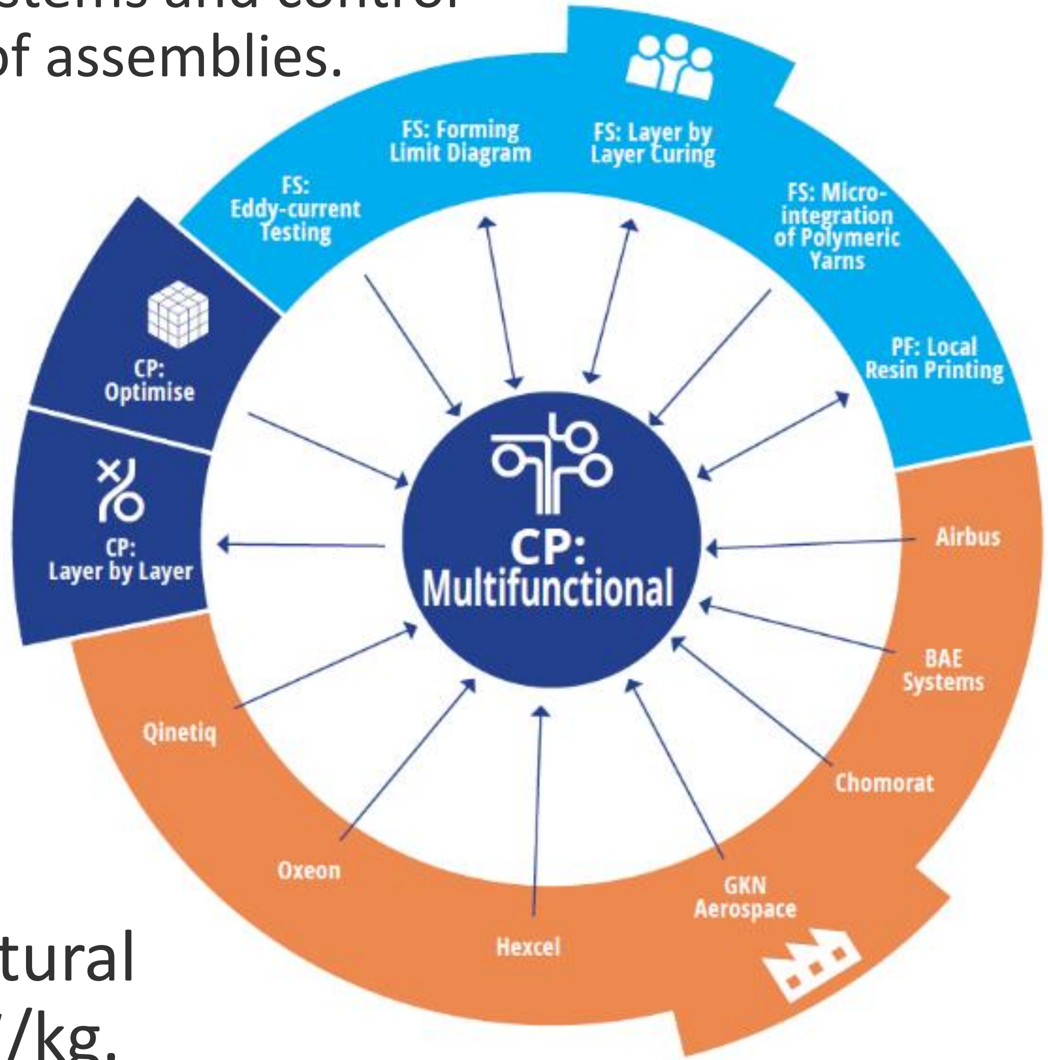


demonstrator (confidential)

WS3: Multifunctional Structures

Multifunctional composite structures have the potential to replace power systems, wiring, actuators, health monitoring systems and control systems, significantly reducing complexity and weight of assemblies.



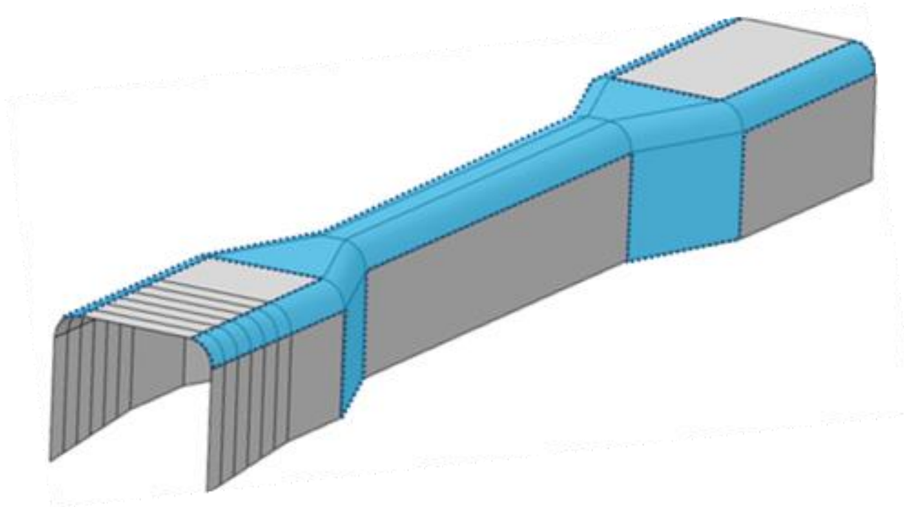


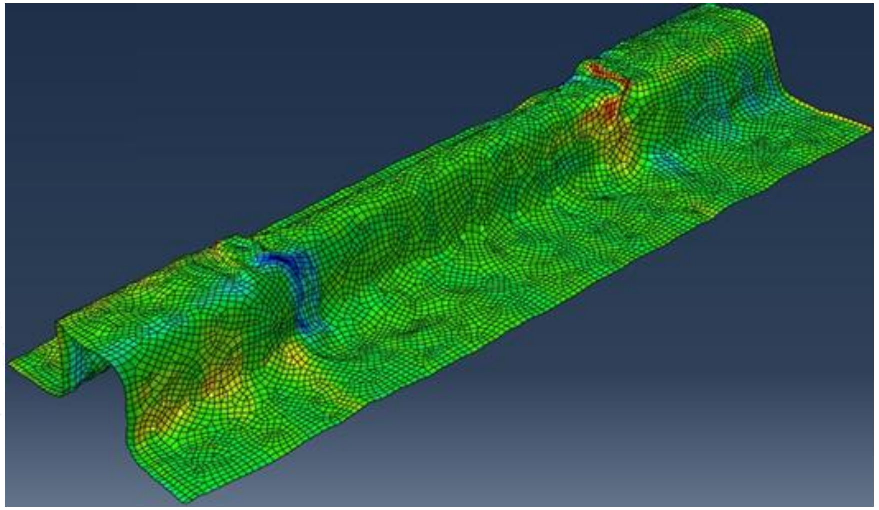
Work Stream Impact

The Multifunctional Core Project has developed composite materials that exceed the target structural supercapacitor performance: 1.4 Wh/kg & 1.1 W/kg.

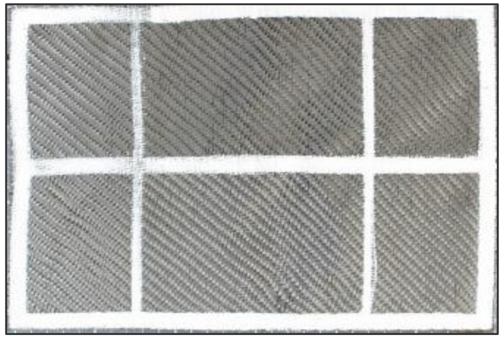
WS3: Manufacture and demonstration of curved structural power components

- Collaboration between ICL/UoB led to successful demonstration of masking and barriers to facilitate curved structures
- Developed scale-up for current collection, encapsulation, multicell assembly and demonstration

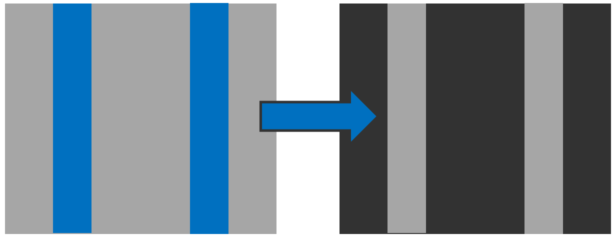


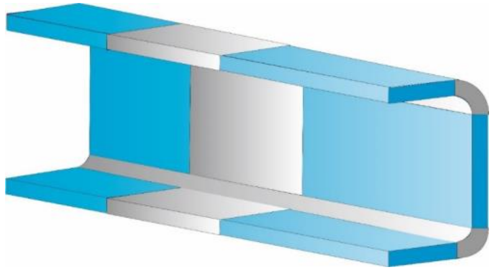


PLA mask



Polylactic acid (PLA) mask

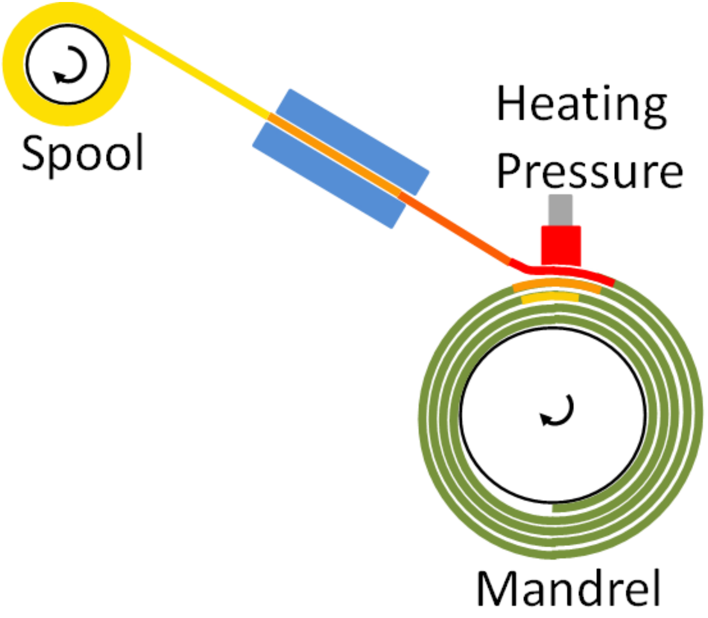


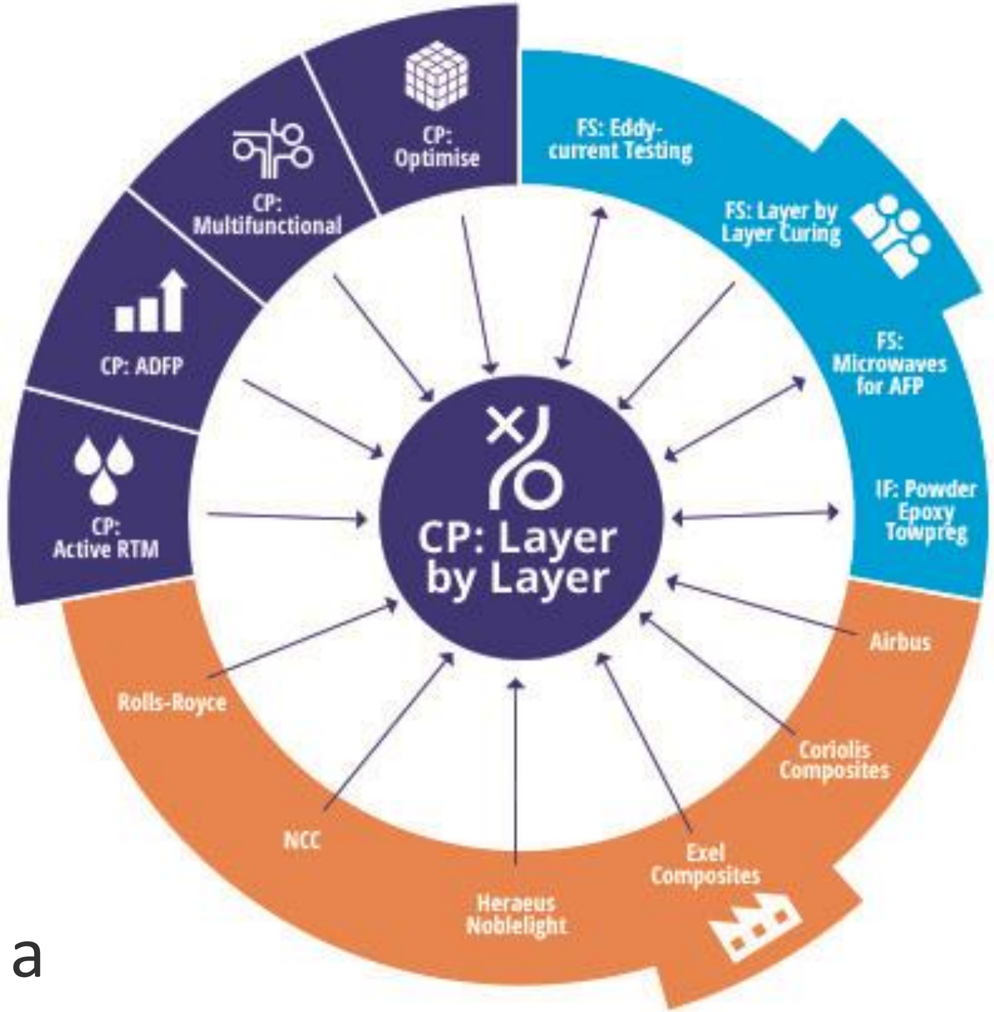


Multifunctional web and cap

WS4: Online Consolidation

Consolidation and/or cure time is a major bottleneck for fibre deposition technologies, with slow cure cycles limiting manufacturing rate.





Work Stream Impact

The Layer By Layer Feasibility Study demonstrated a ~50% saving in cure times for thick components.

WS4: Thick Laminate Digital Twin

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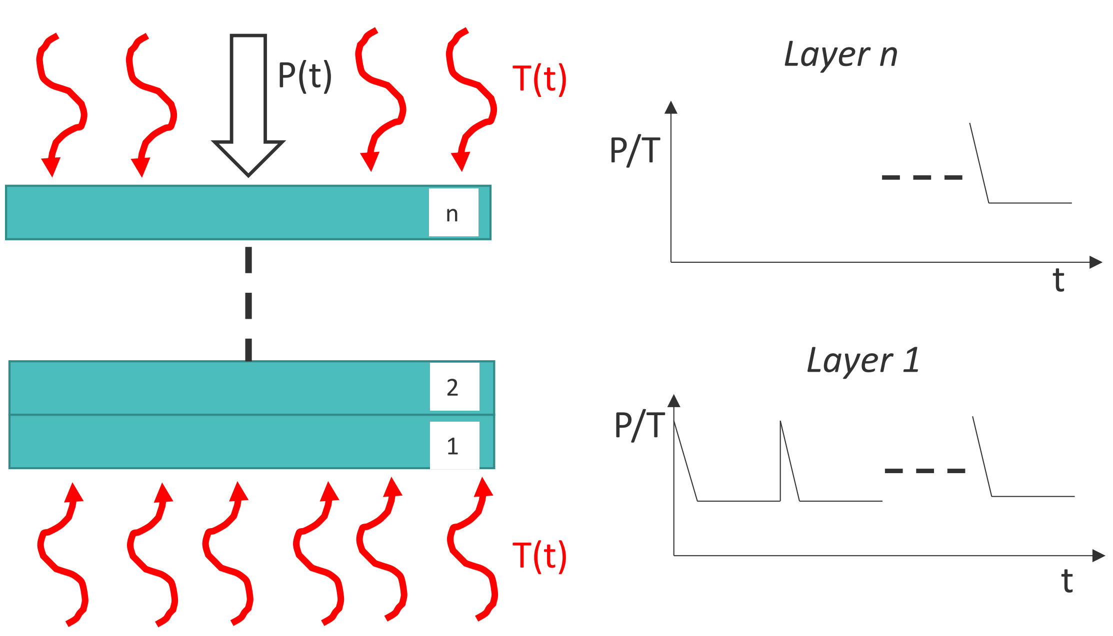
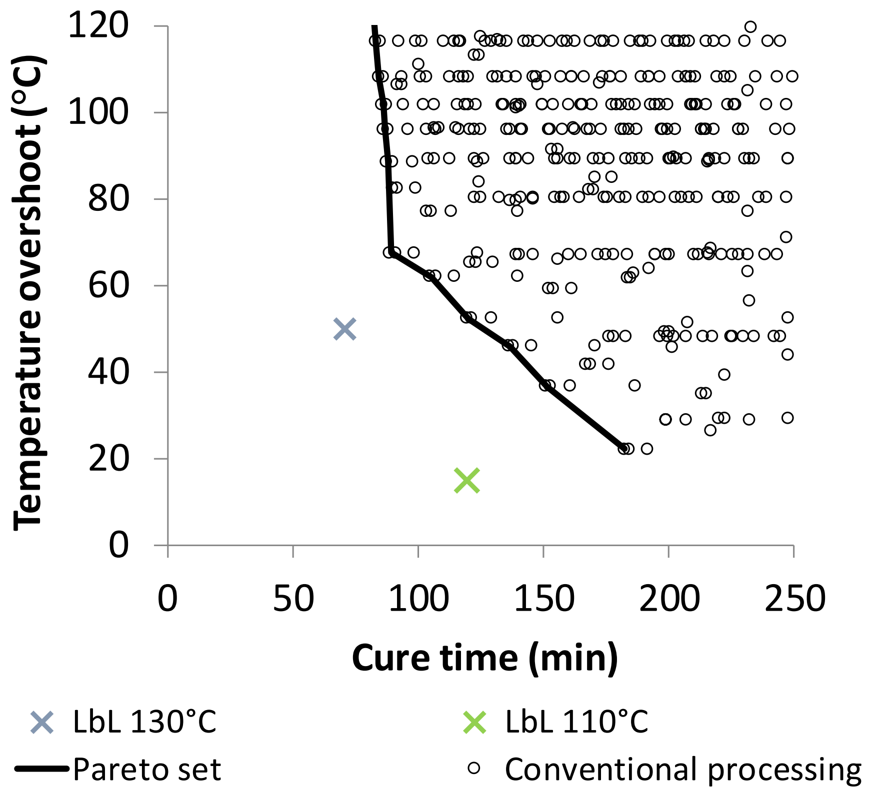
- Integrated consolidation and cure model

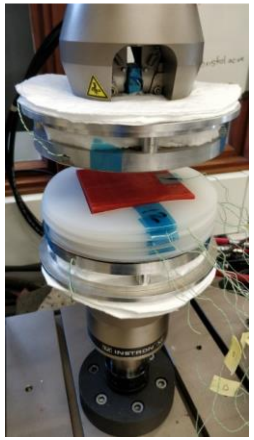


Sub-laminate solution



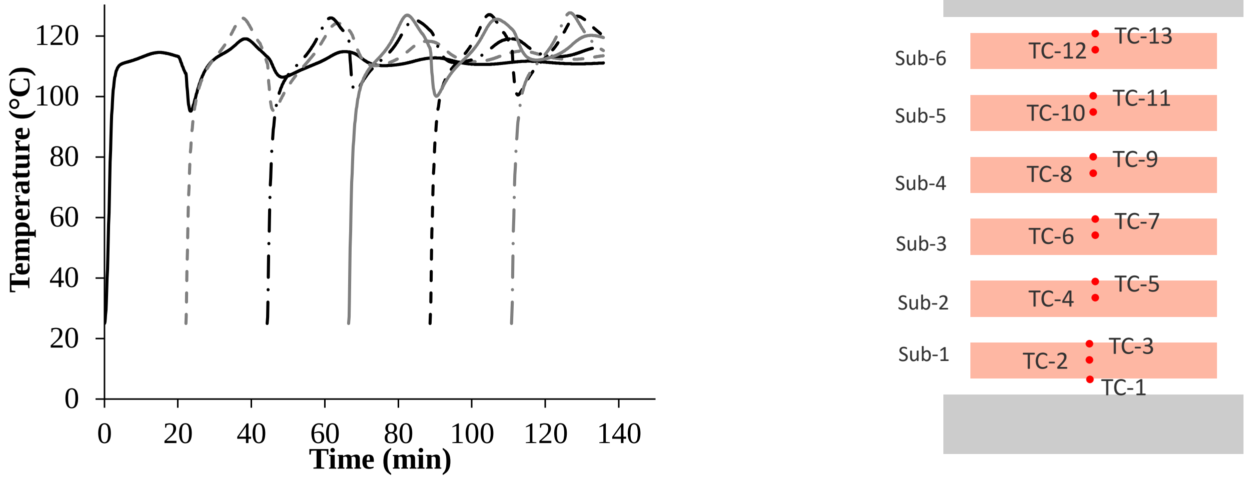
WS4: Thick Laminate Proof-of-Concept

- Interlaminar properties preserved up to gel for 300 ply laminate V_f ~ 55%

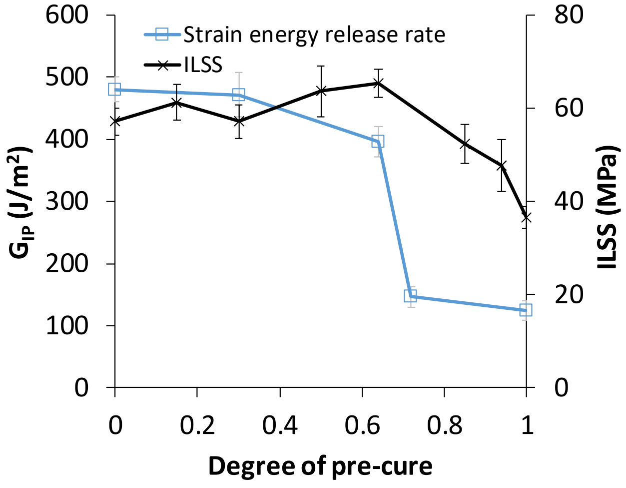


Implementation

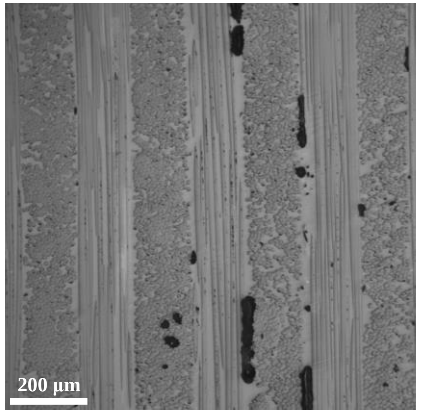
Cured laminate



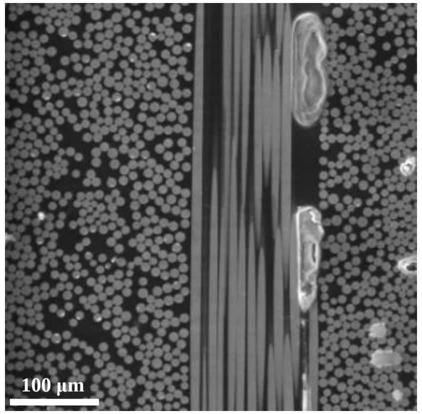
Measured laminate temperature centre



(Degree of cure of previous layer)



Optical micrograph



SEM micrograph

WS5: Liquid Moulding Technologies

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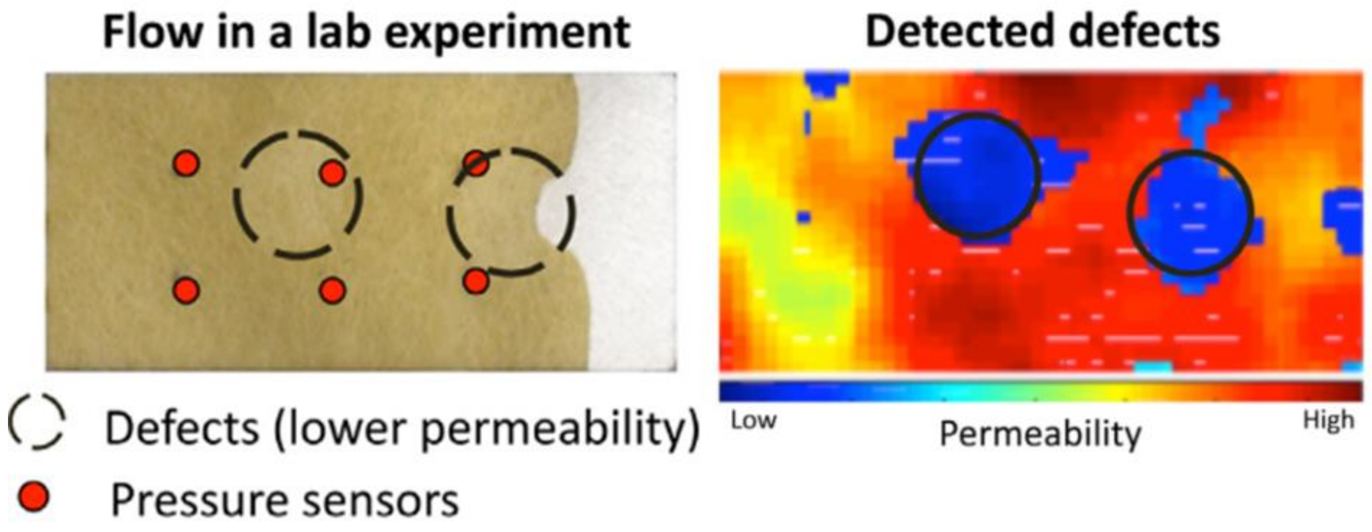
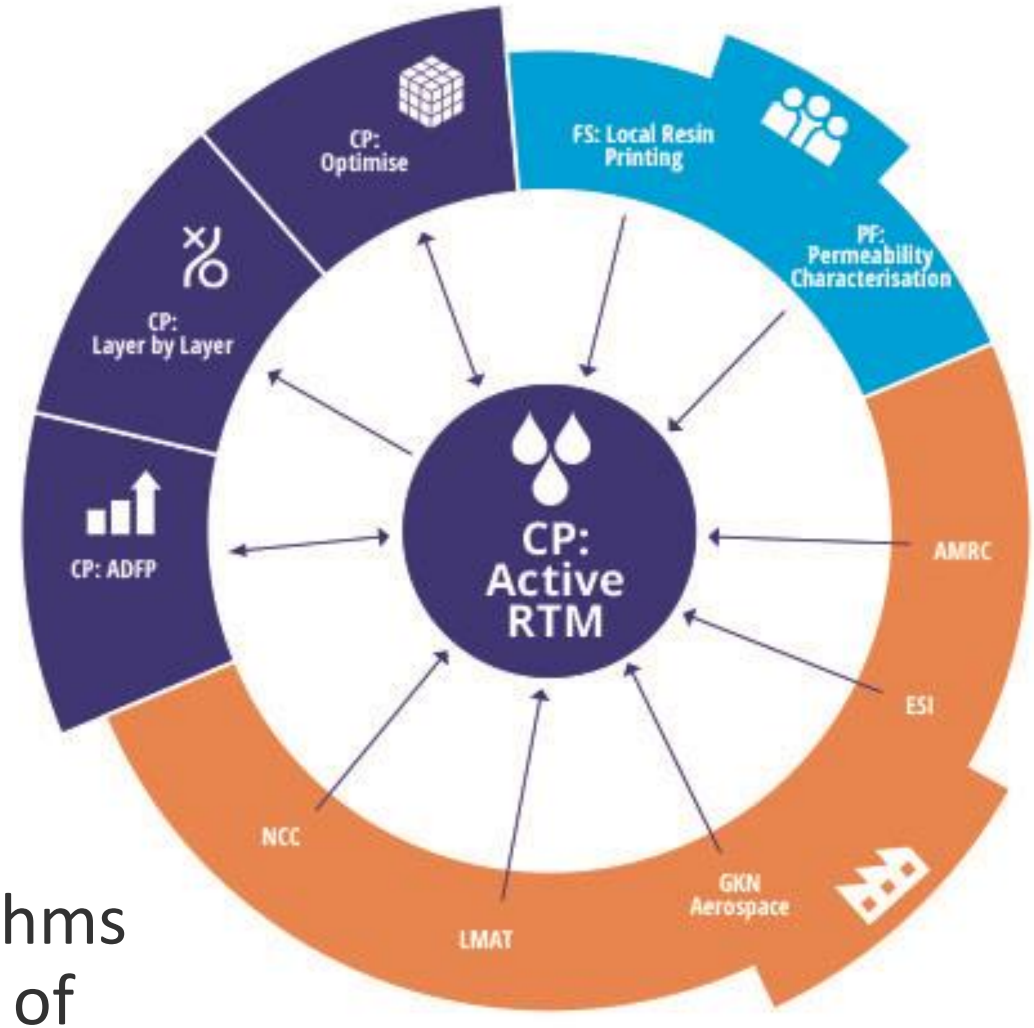
LMTs offer great potential but require robust, repeatable processes with minimal possibility for defects.





Work Stream Impact

Virtual and laboratory testing of Bayesian algorithms has accurately estimated the location and shape of defects, including race tracking.

WS5: Worldwide Benchmarking Activities

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Lead: Institut für Verbundwerkstoffe

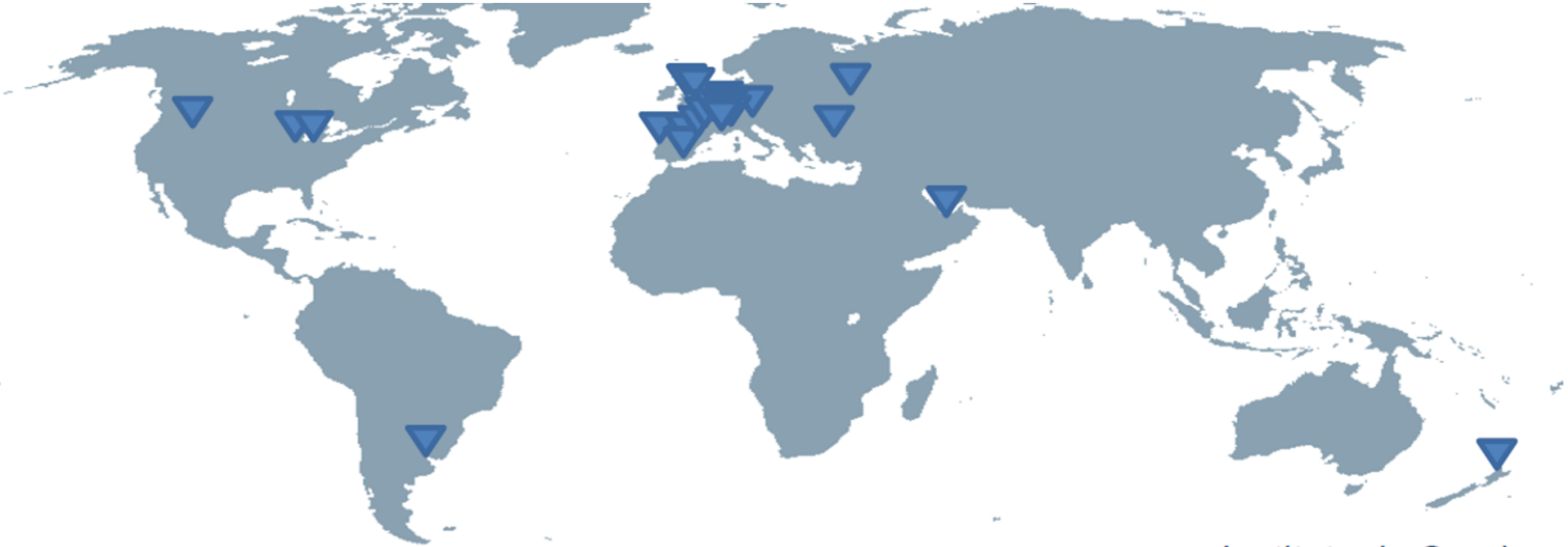
In-plane permeability measurement (unsaturated, radial injection)

22 participants

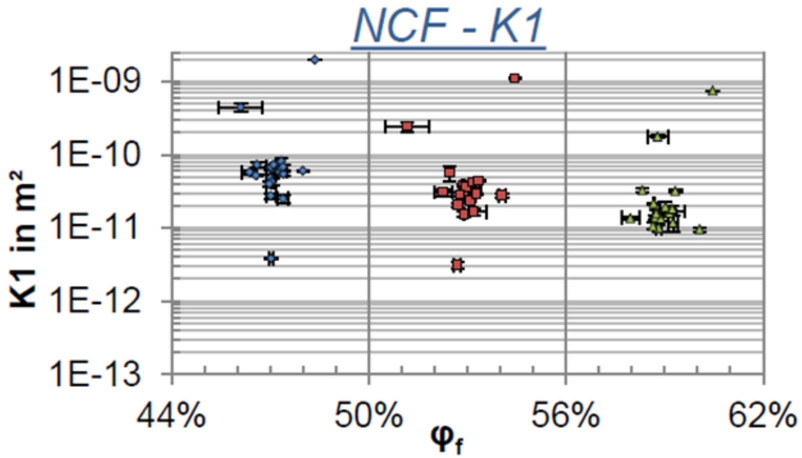
Lead: NPL National Physical Laboratory

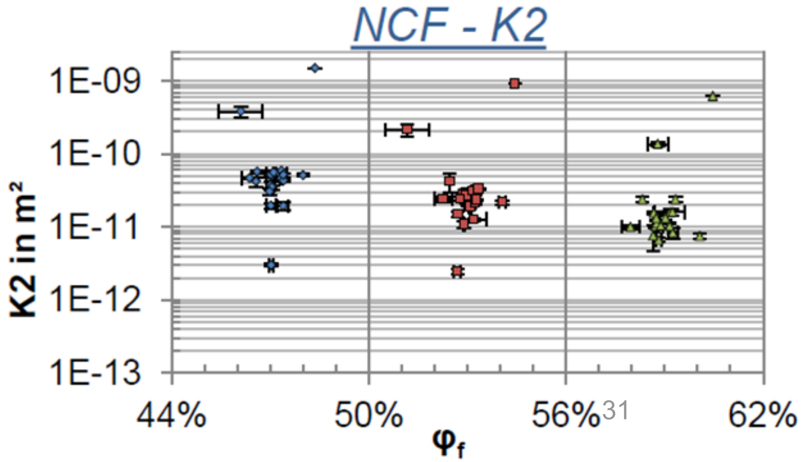
Through-thickness permeability measurement (all approaches)

30 participants



In-plane permeability, scatter between participants





WS5: Active RTM

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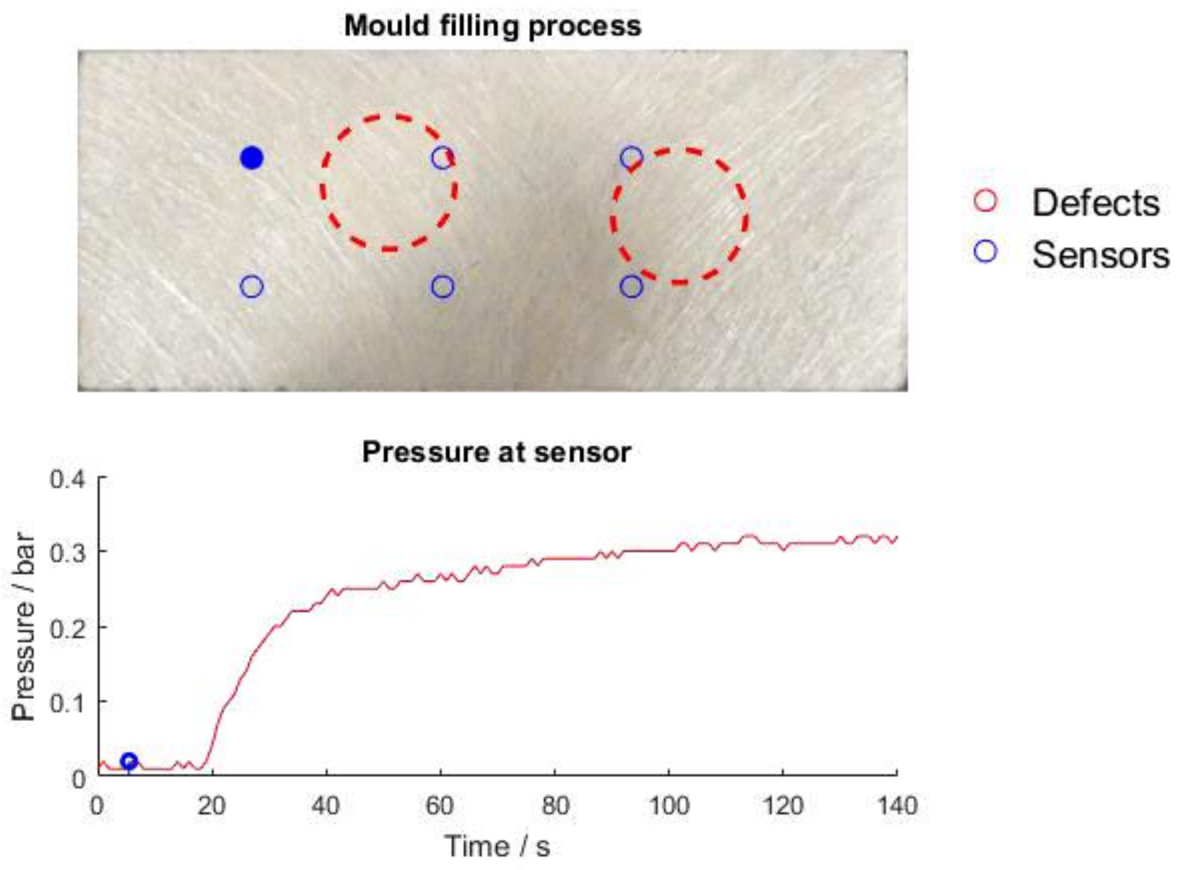
- Bayesian inversion algorithm, takes sensor readings as input and predicts position of defects
- Synergy of Engineering and Applied Mathematics
- Predicted position and severity of defects will be used for process control

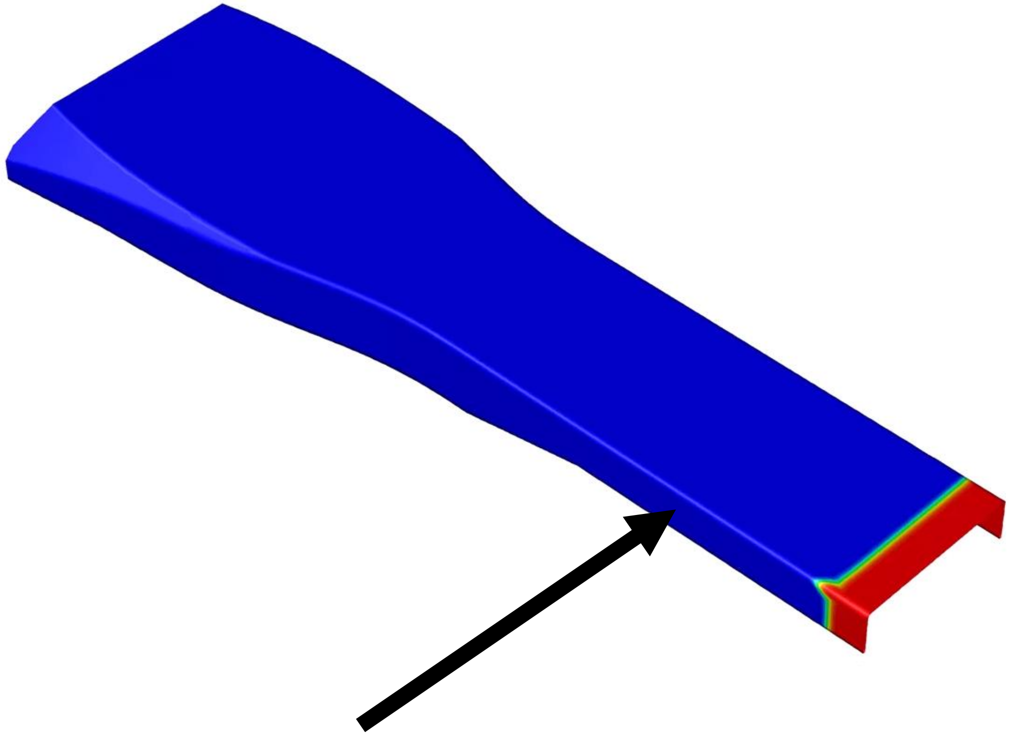


WS5: Active RTM

- The novel inversion algorithm also works with 3D geometries
- The algorithm can cope with more localised but still important defects (e.g. race-tracking)

Sensors are emulated in simulations

Defect detection algorithm



Flow front is faster in this region due to a defect (race tracking)

WS6: Composite Forming Technologies

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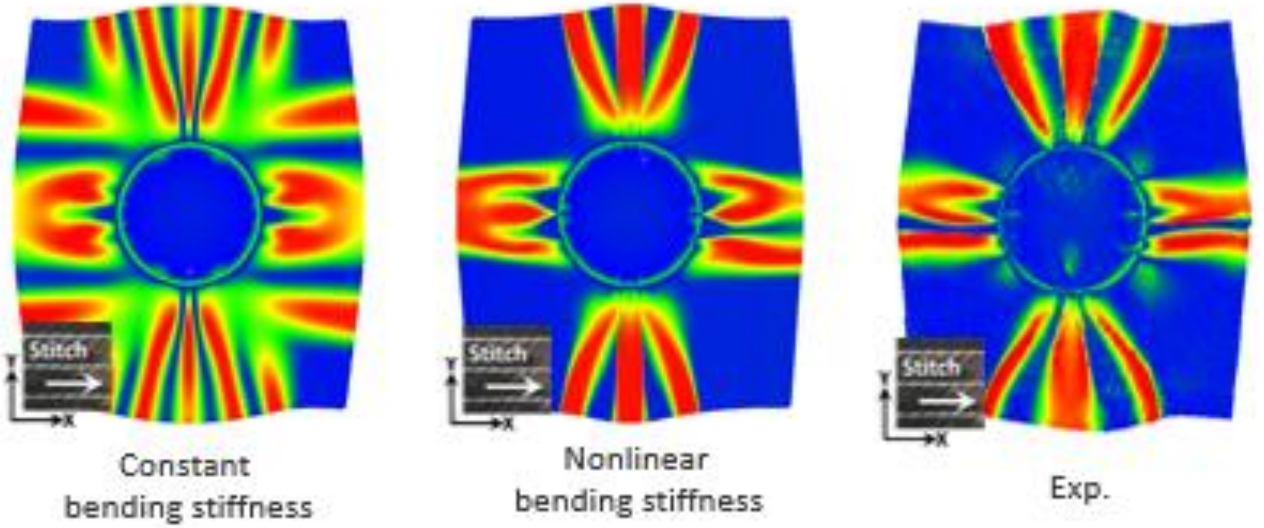
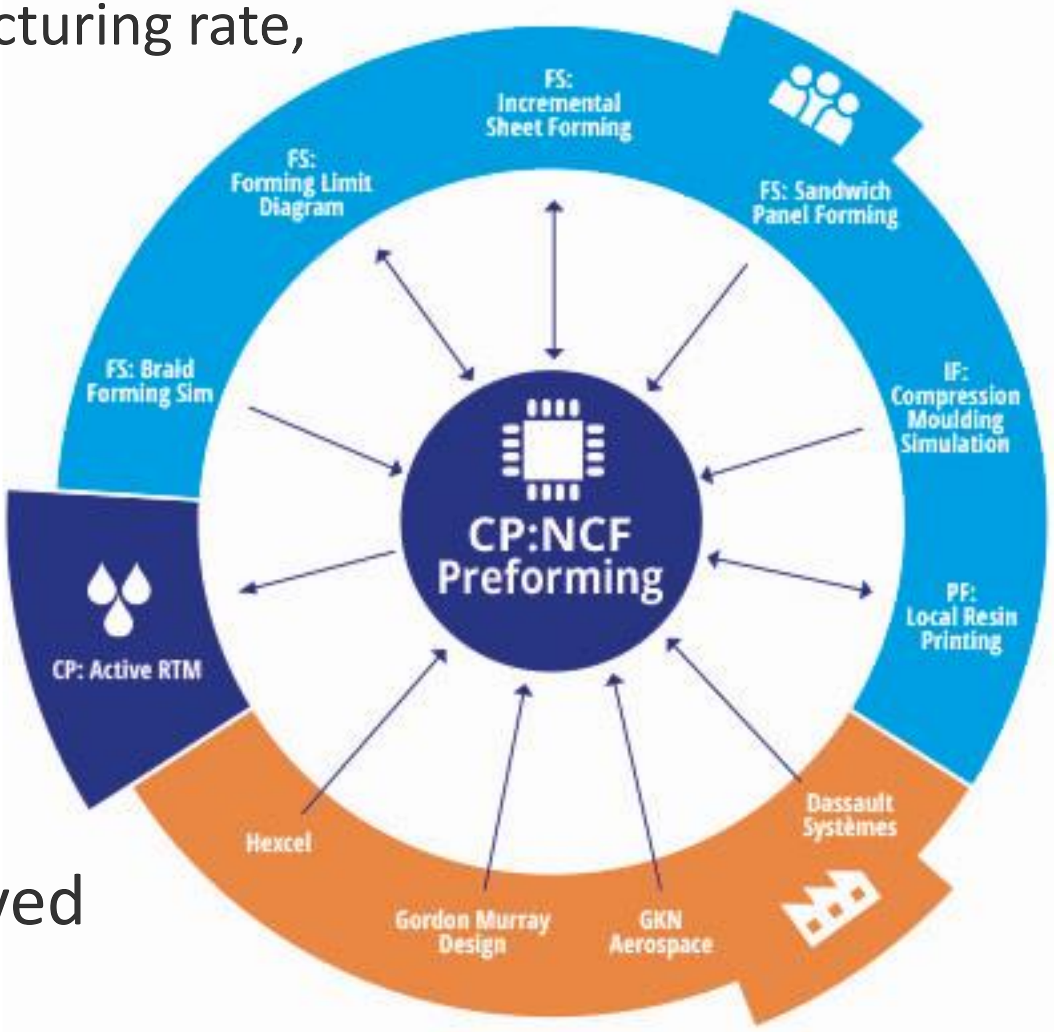
Composite forming is recognised as an important enabling technology, with significant improvements on manufacturing rate, volume and quality.





Work Stream Impact

The Feasibility Study ‘Forming Simulation of curved sandwich panels’ developed a numerical tool to optimise net-shape forming for industry.

WS6: Global-to-Local Modelling

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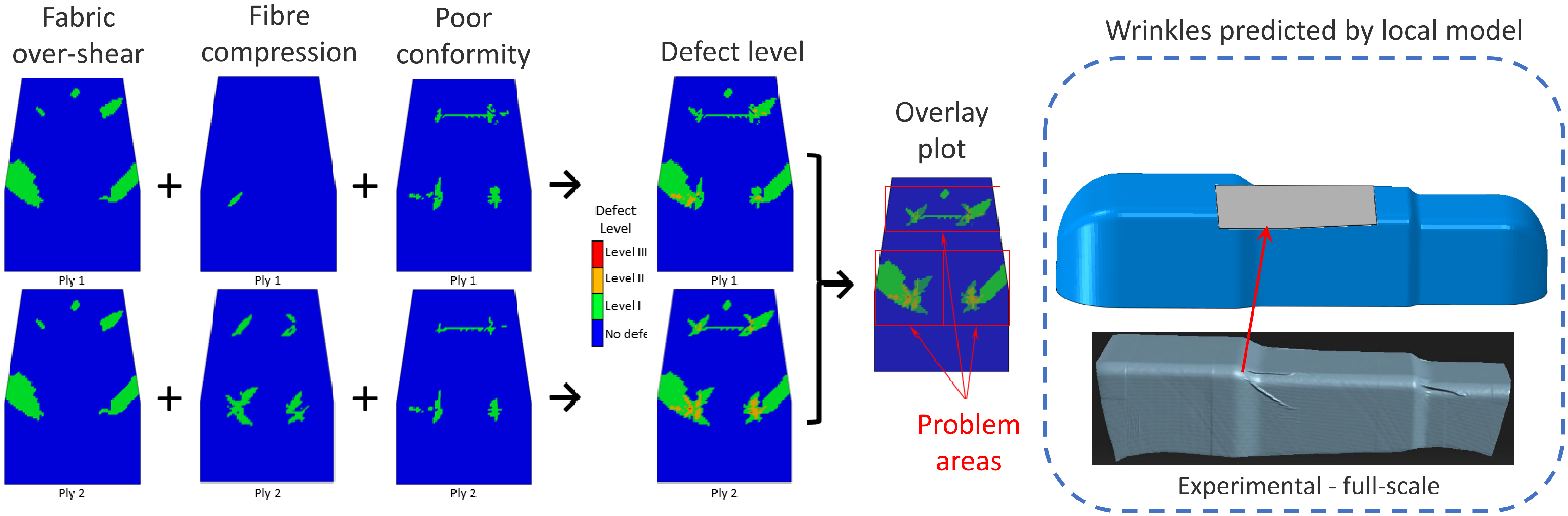
Motivation: prediction of small-scale defects using FE analysis impractical with large structures

- Global modelling using membrane-only approach to identify problem areas
- Local modelling using shell-based approach to predict the shape of defects



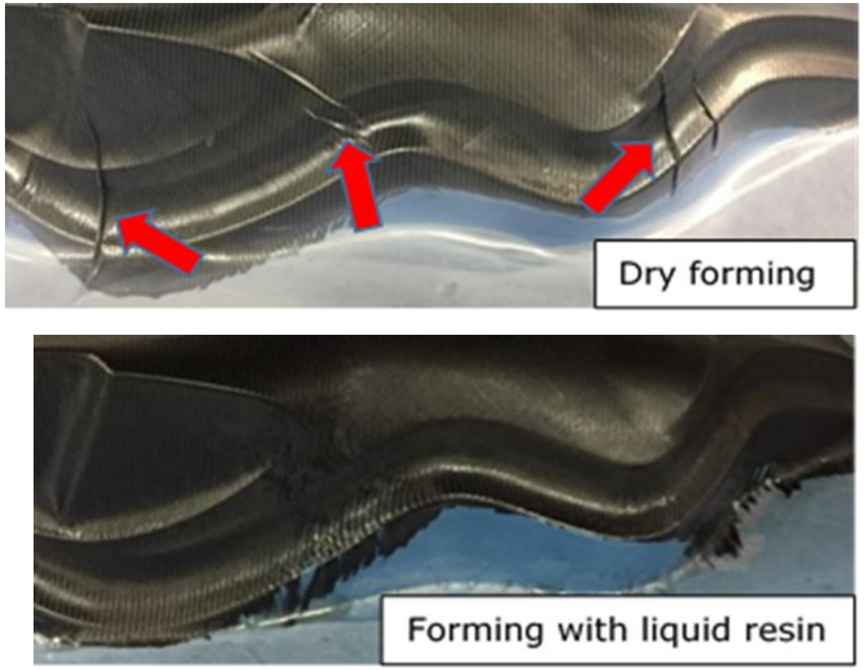
WS6: Process improvements

CIMComp
EPSRC
Future Composites
Manufacturing Research Hub

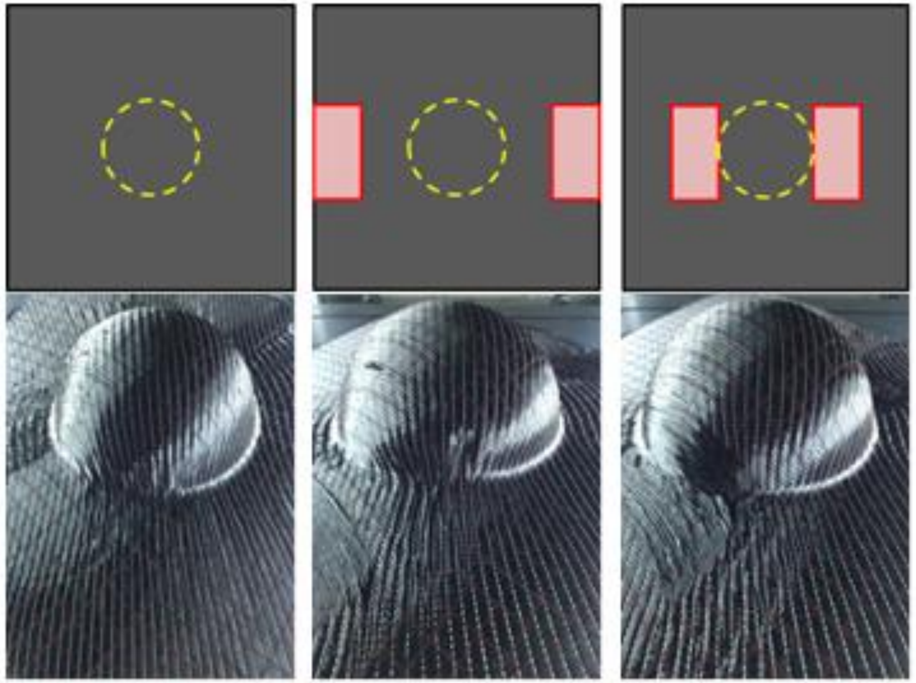
Motivation: innovations in processing can improve formability and reduce defects

- Pre-form stabilisation

- Friction modification



- Intra-ply stitch removal



Reference: No removal

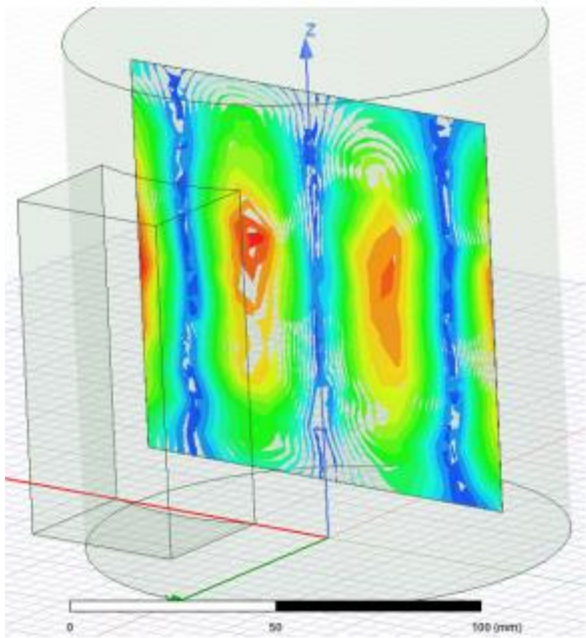
Pattern 1

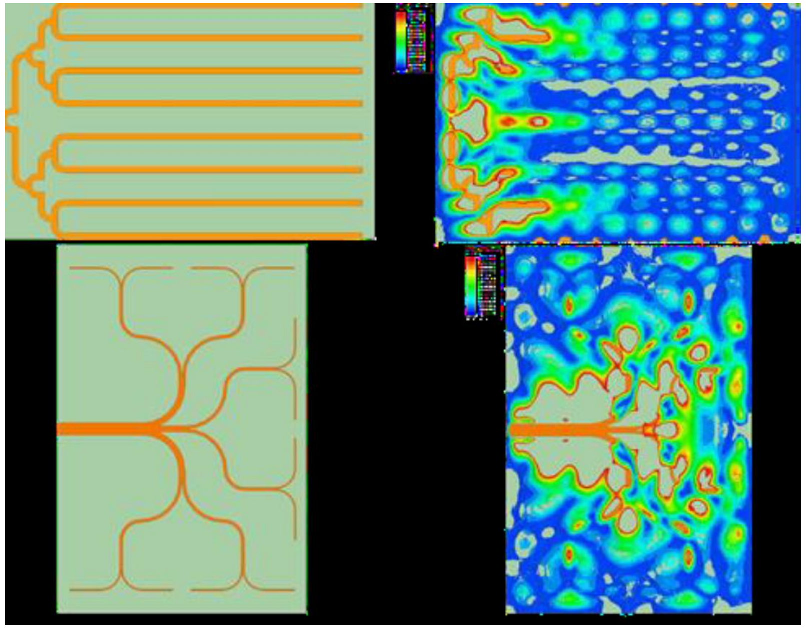
Pattern 2

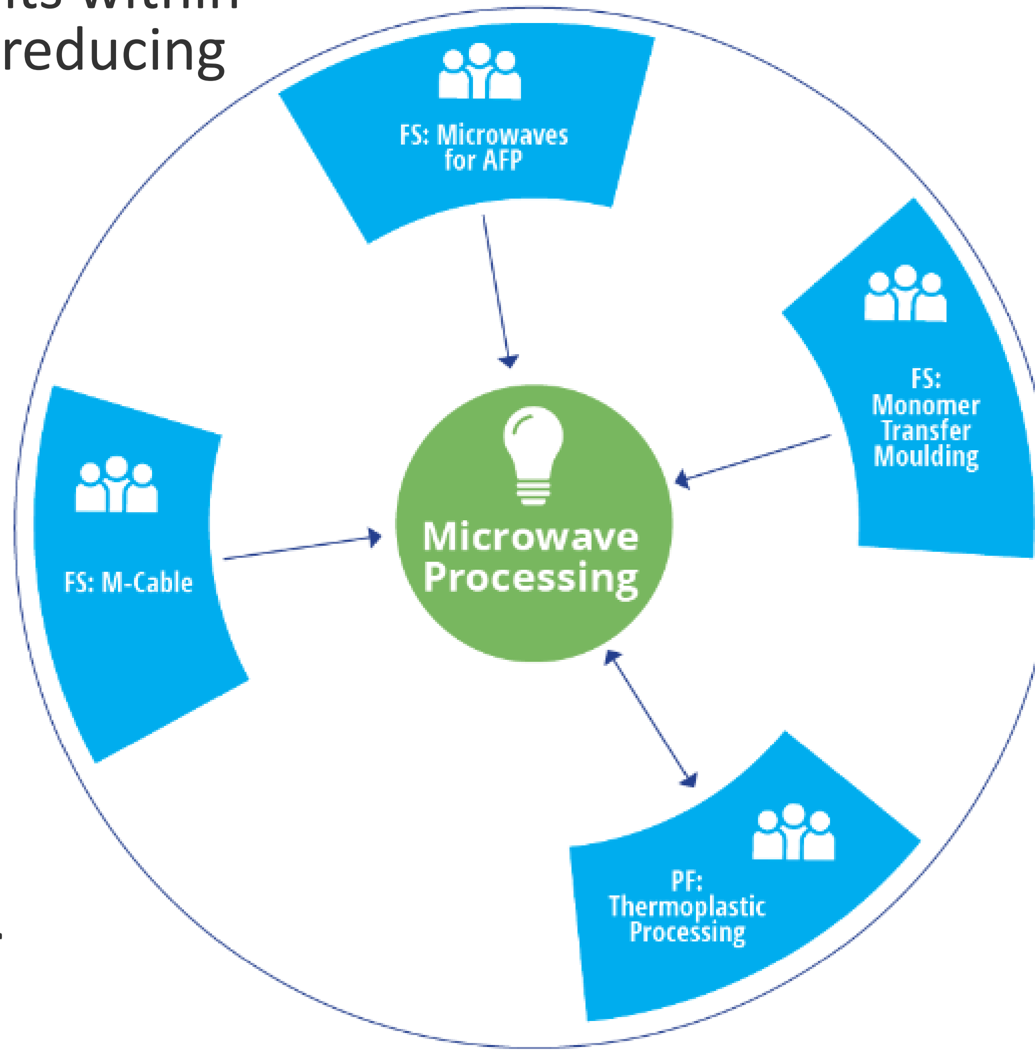
WS7: Microwave Processing Technologies

CIMComp
EPSRC
Future Composites
Manufacturing Research Hub

Microwave volumetric heating can greatly increase the rate of polymerisation, overcoming undesirable thermal gradients within tooling, reducing cure cycles from hours to minutes and reducing energy consumption.





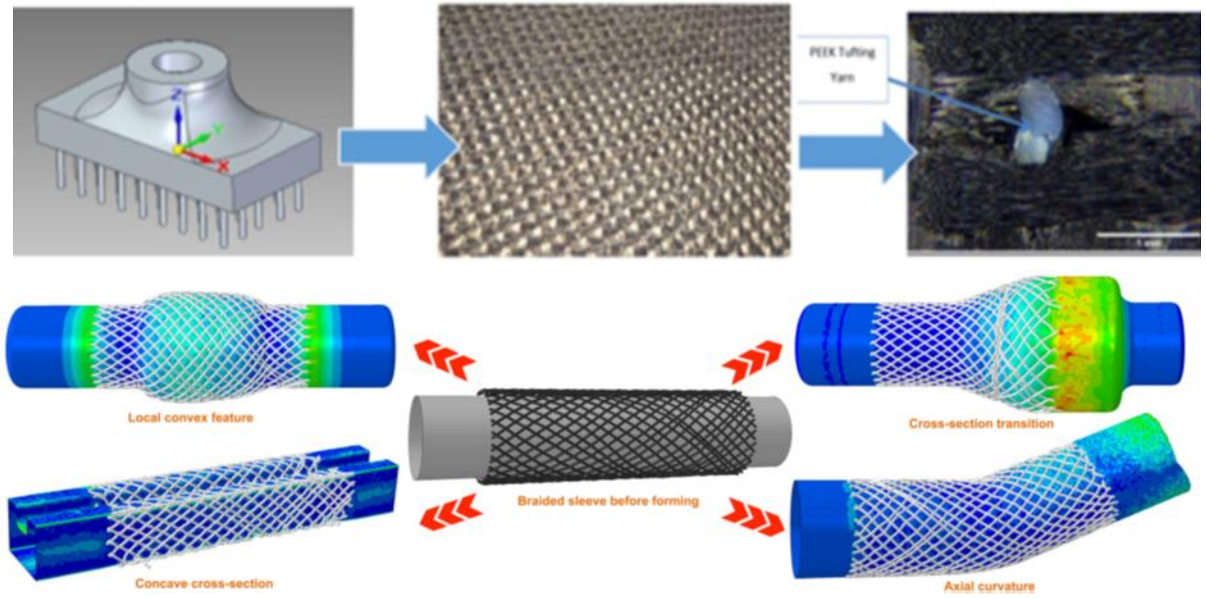


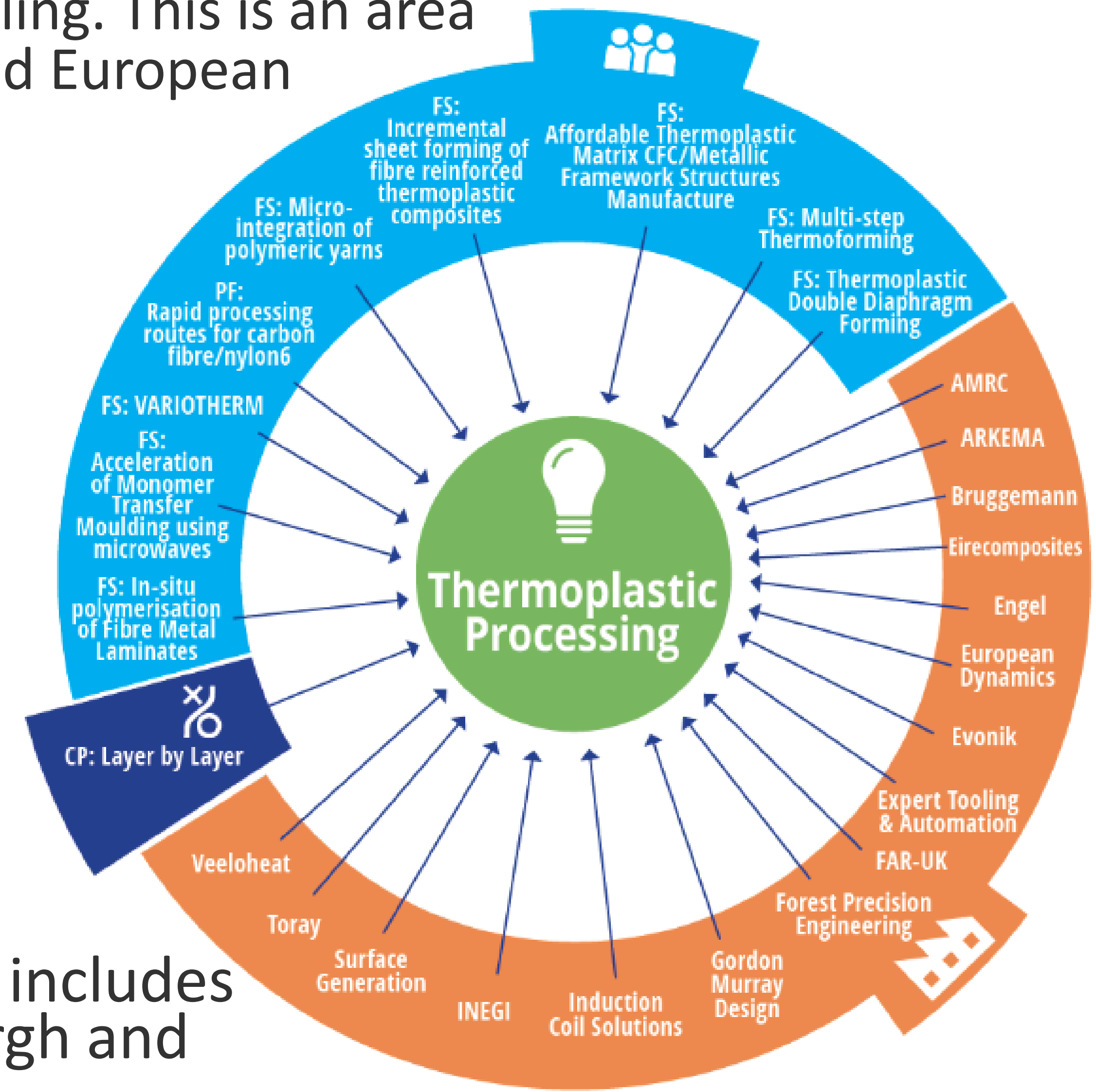
Work Stream Impact

The M-Cable project demonstrated a potential for energy savings in excess of 25% using embedded microwave heating in tools.

WS8: Thermoplastic Processing

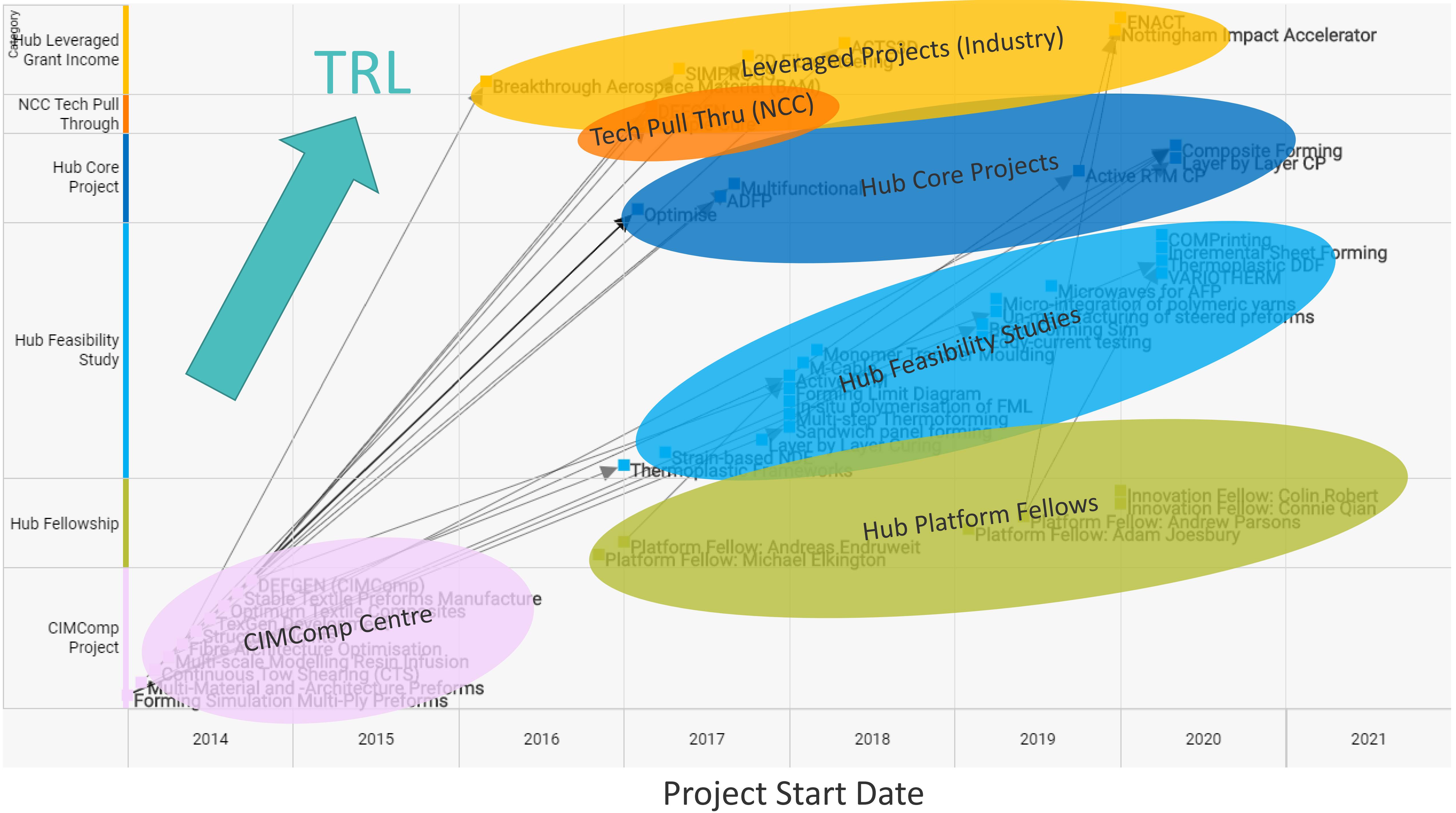
Thermoplastic composites can be rapidly processed and offer a relatively straight forward route for end of life recycling. This is an area of critical capability in which the UK is lagging behind European countries.





Work Stream Impact

A Hub Thermoplastics Working Group has been established to coordinate activity in this area and includes the Universities of Nottingham, Warwick, Edinburgh and Cranfield.



Category
Hub Leveraged Grant Income
NCC Tech Pull Through
Hub Core Project
Hub Feasibility Study
Hub Fellowship
CIMComp Project
TRL
Leveraged Projects (Industry)
Tech Pull Thru (NCC)
Hub Core Projects
Hub Feasibility Studies
Hub Platform Fellows
CIMComp Centre
Breakthrough Aerospace Material (BAM)
ENACT
Nottingham Impact Accelerator
Composite Forming
Layer by Layer CP
Active RTM CP
Multifunctional
ADFP
Optimise
COMPrinting
Incremental Sheet Forming
Thermoplastic DDF
VARIOTHERM
Microwaves for AFP
Micro-integration of polymeric yarns
Monomer Transfer Moulding
Forming Limit Diagram
In-situ polymerisation of FML
Multi-step Thermoforming
Sandwich panel forming
Layer by Layer Curing
Strain-based NDE
Thermoplastic Frameworks
Innovation Fellow: Colin Robert
Innovation Fellow: Connie Qian
Platform Fellow: Andrew Parsons
Platform Fellow: Adam Joesbury
Platform Fellow: Andreas Endruweit
Platform Fellow: Michael Elkington
DEFGEN (CIMComp)
Stable Textile Preforms Manufacture
Optimum Textile Composites
Fibre Architecture Optimisation
Multi-scale Modelling Resin Infusion
Continuous Tow Shearing (CTS)
Multi-Material and -Architecture Preforms
Forming Simulation Multi-Ply Preforms
2014
2015
2016
2017
2018
2019
2020
2021
Project Start Date

Thank you

Prof Nick Warrior

Hub Director

University of Nottingham