Introduction to the EPSRC Future Composites Manufacturing Research Hub

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Overview of Hub, Spokes, structure and organisation
Hub Vision

- 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**.
Industrial Partners – 25
Industrial Supporters - 14

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

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

Precise fibre placement free from winkles

High integrity matrix free from voids

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

Hub Grand Challenges

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
Hub Research Themes

- 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
The Hub Work Streams
WS1: Automated Fibre Deposition Technologies

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

**Traditional method**

- **Design requirements**
  Geometry & Composite Layups

- **3rd Party CAE add-on**
  Turn the laminates into trajectories for the deposition hardware using assumptions about material behaviour (DFM data)

- **Quality Control**
  After production check the manufactured part against defined quality standards

- **CAE software**
  Turn the surface geometry into laminates, manufacturability check, iterative procedure

- **Machine Hardware**
  Turn the post-processed data into axis commands and make the composite

- **Break in feedback**

**Our method - a true Digital Twin**

- **Design requirements**
  Geometry & Composite Layups

- **3rd Party CAE add-on**
  Turn the laminates into trajectories for the deposition hardware using assumptions about material behaviour (DFM data)

- **Data collection**
  Store real-time sensor data about the resulting deposition

- **Feedback to software**
  HDF5 data can be fed back to any stage, allows inline QC checks

- **CAE software**
  Turn the surface geometry into laminates, manufacturability check, iterative procedure define nominal paths for deposition

- **Machine hardware**
  Use a virtual machine model to generate toolpaths and deposit

- **Data storage**
  HDF5 database file 'Digital Twin' stores both 'as designed' and 'as manufactured' part data in a unified format

- **Downstream processes enabled**
  Rapid feedback enabled via re-deposited data. All visualisation of performance in real-time
WS1 ADFP Lab-Scale Rig
WS1: 2D Fibre Steered + 3D Forming

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

- **Unwind**
  - Magnetic tension brake
  - + tension sensor

- **Powder deposition**
  - Controlled flow for electrostatic powder gun
  - + excess powder vacuum extraction

- **Joule heating**
  - Infrared temperature measurement + Joule heating via copper rollers

- **Re-wind**
  - 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

• 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
**WS2: 3D multi-axial reinforcements**

**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 (NCFs)
WS2: Braid-winding of tubular preforms

- 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
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
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

- Integrated consolidation and cure model

![Diagram showing integrated consolidation and cure model with layers and temperature profiles.](image)

![Graph showing temperature overshoot vs. cure time with data points for LbL 130°C, LbL 110°C, Pareto set, and conventional processing.](image)
WS4: Thick Laminate Proof-of-Concept

- Interlaminar properties preserved up to gel for 300 ply laminate $V_f \sim 55\%$

Implementation

Cured laminate

Measured laminate temperature centre

Optical micrograph

SEM micrograph
WS5: Liquid Moulding Technologies

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

Lead: Institut für Verbundwerkstoffe
In-plane permeability measurement (unsaturated, radial injection)
22 participants

Lead: National Physical Laboratory
Through-thickness permeability measurement (all approaches)
30 participants

In-plane permeability, scatter between participants

Institute for Composites Manufacturing Research Hub
WS5: Active RTM

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

Flow front is faster in this region due to a defect (race tracking)
WS6: Composite Forming Technologies

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

**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

![Diagram showing fabric over-shear, fibre compression, poor conformity, and defect level](image)
WS6: Process improvements

Motivation: innovations in processing can improve formability and reduce defects

- Pre-form stabilisation
- Friction modification
- Intra-ply stitch removal

ViscoTec system

Dry forming

Reference: No removal
Pattern 1
Pattern 2
WS7: Microwave Processing Technologies

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 straightforward 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.
Thank you

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