EPSRC FUTURE COMPOSITES MANUFACTURING RESEARCH HUB

UK Composites Research Challenge Landscape Report – High Rate Deposition & Conversion

Abstract

A research driven roadmap for future composite manufacturing development covering 18 high-rate deposition and conversion technologies identifying key challenges for academia

CIMCOMP Strategic Development Committee

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Foreword – Nick Warrior, CIMCOMP Hub Director

It is a pleasure to introduce the outputs from the Hub's UK Composites Research Challenge Landscape in High-rate deposition and conversion. Since the launch of the Hub in 2017, our vision has been to deliver research advances in cost reduction and rate increase, whilst improving process robustness for current and future composites manufacturing processes. Our programme of research is wide ranging but the theme of high rate deposition has proved to be the most popular area for investigation, following our open funding calls.

This document concludes the first in a series of landscaping exercises looking at fundamental research challenges for composites manufacturing from an academic, low Technology Readiness Level perspective. This study represents a significant resource for the UK composites community, recording almost 600 fundamental challenges in composite manufacturing science and technology. We hope that these data help the community to better address the process challenges that will lead to increased revenue for the UK composites supply chain.

Finally, I want to express my thanks to those from across the community who have given up their time to engage with the Hub in the preparation of this landscape.

Prof. Nick Warrior - Director

With thanks to all contributors without whom this report would not have been possible.

Introduction

The EPSRC-funded Future Composites Manufacturing Research Hub plays a key role in funding fundamental composites manufacturing research in the UK. The aim of the Composites Research Challenge Landscape is to develop a process for identifying and ranking fundamental research challenges for composites manufacturing to be addressed within the next 20 years. This will enable the Hub and the wider composites community to remain up to date with research trends and fund the most critical and timely research. It is envisaged that the data collected, and the analysis contained herein will play a key role in:

- Informing future funding decisions and shape calls for Hub Feasibility Studies
- Ensuring that Hub research themes remain relevant
- Identification of areas of research synergy between technology areas and Hub projects
- Underpinning knowledge & technology transfer into the High Value Manufacturing Catapult (HVMC) Centres
  Justification of resource needs for research projects

Scope

Process rate is a key area of focus for the Hub, in line with one of our Grand Challenges (see https://cimcomp.ac.uk/about/) to develop high rate processing technologies for high quality structures. This is also the area best represented within the Hub's current research portfolio.

This landscape study therefore focuses on *high rate deposition and rapid processing technologies*. Within this area of interest, individual technologies and processes will be addressed, rather than overarching themes. This will allow industrial process chains to be represented, from hardware to finished component, and better define how and where challenges are manifested in a manufacturing environment. The technologies addressed are described below:

	Technology	Includes:
1	Multi-ply Preforming Assembly	Cutting, joining and automated handling of plies and preforms
2	2D-3D Preforming	Automated net-shape preforming of fabrics for subsequent moulding or infusion
3	2D Weaving	Weaving of two orthogonal sets of yarns, warp 0° and weft 90°
4	3D Weaving	Weaving of weft, warp and binder fibres in the X, Y and Z directions
5	Braiding	Biaxial and triaxial braiding of fibres
6	Discontinuous Fibres	Use of discontinuous fibres (in any format)
7	Non-Wovens	Manufacturing using non-woven fabrics including non-crimp fabric (NCF)
8	ATL/AFP/ADFP	Automated deposition of tapes or fibres onto a tool or substrate
9	Pultrusion	Continuous manufacturing of constant-profile composite components
10	Filament Winding	Winding filaments under tension over a rotating mandrel
11	Overmoulding	Injection moulding over continuous fibre composite reinforcement
12	Thermoplastic Stamping	Stamping or press forming of thermoplastic blanks
13	Injection Moulding	Injection moulding of parts using discontinuous fibre filled thermoplastic polymers
14	Resin Transfer Moulding	Resin injection using a closed mould and positive pressure e.g. HP-RTM, VARTM, Gap RTM
15	Autoclave Prepreg	Autoclave (heat and pressure) curing of prepregs materials
16	Out-of-Autoclave Prepreg	Curing of prepregs using vacuum-only consolidation on single-sided tooling in an oven
17	Liquid Resin Infusion	Infusion of fabrics using a single-sided tool and vacuum bagging
18	Compression Moulding	Compression moulding of moulding compounds (e.g. SMC, DMC, BMC)

Methods

Data Collection

Challenges were captured through a series of meetings and workshops with academics and HVM Catapult engineers, held between April and September 2019. Prior to this, a draft data set was developed by the Hub team using peer-reviewed literature relevant to the 18 processes. This generated over 170 challenges, forming a basis for discussion with the wider composites community.

Meetings followed a framework based on an Institute for Manufacturing (IfM) roadmapping approach where participants identified challenges and scored them according to perceived severity on a scale of 1-10, reflecting the urgency with which they need to be addressed. Participants were also invited to suggest a different score for existing challenges, moderating the scores and ensuring that these reflect the views of all respondents. The final scores presented are an average of all responses.

Challenges were also classified terms of their potential impact to the technology in question or to the wider sector. These classifications are considered key drivers behind decision making in composites manufacturing and are therefore relevant to a range of applications. The five impacts reflect the **cost** of the process, the process **rate**, increased **uptake** of composites or specific processes, component **quality**, and **applicability** of a process to a specific industry need.

For example, the challenge 'sandwich panel forming without core crushing or thinning' has been classed as having potential impacts on both rate and cost. As a result, if the challenge were to be addressed then it is anticipated that the process would benefit from both a cost saving and a reduction in processing time.

Data Reduction

Following data collection and validation, challenges were categorised according to the position within the manufacturing process where their effect is experienced (Machinery & Hardware, Material format, Material Deposition & Part Applicability & Geometry). Challenges were further classified into those specific to a process, and those with cross-process relevance. The generic categories developed were as follows:

- Process Modelling – Any challenge relating to understanding or modelling of manufacturing processes
- Automation / Hardware / Robotics
- Tooling
- Design for Manufacture – Anything relating to data required to drive more intelligent manufacturing
- Industry 4.0, Digital, Future Automation, Machine Learning, Artificial Intelligence
- Metrology / sensing / inspection – Quality assurance methods
- Material handling
- Material binding & joining
- Material cutting
- Certification, testing, standards – barriers to uptake of a particular technology due to compliance with current methods
- Material / Manufacturing interface – the relationships between the material and the process
- Smart systems integration – embedding sensors or instrumentation into composite components
- Augmented Reality / Virtual Reality / usability & visualisation – user interface and machine / human interaction

A general tag was added, if this was preferred to a process-specific one, in order to prevent bias. If this was not possible, the challenge was labelled as 'process specific' and an indication of the type of work required to address the challenge given – low-TRL research (TRL 1-3), or mid-TRL research (TRL 4-6).

Results

Results are shown in full in the following table:

	Area	Challenge	Severity	Cost	Rate	Uptake	Quality	Appl.	Keyword
Multi-ply preforming	Inf. & env.	High level of investment required	7	•		•			Financial / investment
		Lack of i4.0 compatibility	4			•			Can't categorise - general non-specific desire
		Dedicated & relevant workforce skills	6					•	General - Skills
		Need for reliable & robust manufacturing process models	7			•	•		Process Modelling
	Machine hardware	Handling of low shear resistance materials	6			•	•		Specific technical issue - more research required - TRL4-6
		Need to maintaining fabric tension to avoid defect introduction	8			•	•		Specific technical issue - more research required - TRL4-6
		Repeatability of process	9			•	•		Specific technical issue - more research required - TRL1-3
		Optimised cutting to reduce wastage and improve nesting efficiency	4	•					Process Modelling
		Gripper configuration and optimisation to improve flexibility and reduce disturbance of other plies	9			•	•		Specific technical issue - more research required - TRL4-6
		Slow cycle hold times for thermoset binder heating and cooling	5		•				Specific technical issue - more research required - TRL1-3
		Contamination-free handling required	3			•	•		Material handling
		Defect introduction from cutting tool contact	3			•	•		Specific technical issue - more research required - TRL1-3
		Preventing movement of ply whilst cutting	7				•		Material handling
		Need accuracy of measurement to ensure reduction in variability	6				•		Metrology / sensing / inspection
		Need for single stage forming and trimming	6	•	•	•			Material handling
		Need a means to measure movement of individual small reinforcement plies in complex architectures	6		•	•			Material handling
		Reducing loose waste from cut edge and stray fibres	6	•			•		Material handling
		Programmability, flexibility & versatility of automated handling equipment	7			•	•	•	Automation / Hardware / Robotics
	Material format	Material wrinkling/buckling/shearing due to handling	8			•	•		Material handling
		Stitching to improve drapability complicates handling	6			•	•		Material handling
		Comparable joint design	4			•			Design for Manufacture
		No standard technique for measuring degree of binding of preforms	8				•		Material binding & joining
		Need for high rate binder application	9		•				Material binding & joining
		Need for continuously steered 3D fibres	7			•		•	Specific technical issue - more research required - TRL1-3
		Integrating smart systems within components (e.g. SHM, energy harvesting)	5					•	Smart systems integration
	Material deposition	Positional accuracy of placement	9			•	•		Metrology / sensing / inspection
		Gap/overlap tolerance	9			•	•		Metrology / sensing / inspection
		Correct fibre angles after laydown	9			•	•		Metrology / sensing / inspection
		Long bonding/joining cycle time	6	•	•				Material binding & joining
		Preform inspection	8				•		Metrology / sensing / inspection
		Automated manufacturability of fillers for curved/joint interface (e.g. skin stringers)	6			•			Automation / Hardware / Robotics
		Need for certification of interventional processes (e.g. Z-pinning, bonding)	8			•			Certification, testing, standards
		Poor understanding of inter-ply shear with or without TTR/stitching	7				•		Specific technical issue - more research required - TRL1-3
		Need for bespoke & often expensive preform handling rigs	5	•					Can't categorise - general non-specific desire
		Difficulty in cutting along fibre direction	3				•		Material cutting
		Edge of ply stability	3				•		Specific technical issue - more research required - TRL4-6
	Part app	Limit to scale of component that can be handled	8			•			Specific technical issue - more research required - TRL4-6
		Geometry of component (must be relatively planar)	7			•		•	Can't categorise - general non-specific desire
		Parasitic weight & other adverse effects from ply joining method	7	•		•			Can't categorise - general non-specific desire

	Area	Challenge	Severity	Cost	Rate	Uptake	Quality	Appl.	Keyword
		Design flexibility	8			•			Can't categorise - general non-specific desire
		Thermal pre-stressing to eliminate spring-back in formed components	5				•		Specific technical issue - more research required - TRL1-3
		Manufacturability of integrated parts with elastic-tailoring	9			•		•	Specific technical issue - more research required - TRL1-3
		Better understanding of 3D reinforcement in regions of high-curvature	6			•	•	•	Specific technical issue - more research required - TRL1-3
		Need for improved shear control from the material boundary	7				•		Specific technical issue - more research required - TRL1-3
		Robust & reliable predictive simulation models for part performance	9				•		Design for Manufacture
		Understanding of joint permeability for downstream processing	7				•	•	Specific technical issue - more research required - TRL1-3
2D - 3D Preforming	Inf. & env.	Lack of DFM database – limited part applicability prediction	9	•		•		•	Design for Manufacture
		High level of investment required - press, tooling	5	•		•			Financial / investment
		UK supply chain infancy	5			•			General - Supply chain needs
		Lack of flexibility of bespoke hardware	7			•			Automation / Hardware / Robotics
	Machine hardware	Handling of low shear resistance materials	4			•	•		Material handling
		Need for forced cooling to increase throughput and control distortion	5		•				Specific technical issue - more research required - TRL4-6
		Machine learning	5			•			Industry 4.0, Digital, Future Automation, ML, AI
		Gripping/clamping arrangements to improve controlled material draw	9	•	•	•			Specific technical issue - more research required - TRL4-6
		Heating mechanisms for TP and prepreg - reduce cycle time, improve uniformity	5		•				Specific technical issue - more research required - TRL1-3
		High cost of tooling	2	•		•			Tooling
		Tooling/process design to reduce forming forces and improve component quality	9			•		•	Specific technical issue - more research required - TRL4-6
		Simulation accuracy and reliability for complex components	9					•	Process Modelling
		Forming system development - DDF, DF etc.	10			•			Automation / Hardware / Robotics
		Forming simulation & flattening plies can be an 'art form' not a science	8				•		Process Modelling
	Material format	Fabric repeatability/consistency	4		•		•		Material / Manufacturing interface
		Reduced material wastage	9	•		•			Can't categorise - general non-specific desire
		Knowledge of defect mechanisms, significance and mitigation required	6			•			Process Modelling
		Trade-off between formability and stability during handling	5				•	•	Material handling
		Understanding of Inter-ply friction effects to improve forming of multi-ply preforms	8			•			Specific technical issue - more research required - TRL1-3
		Sandwich panel forming without core crushing/thinning	9	•	•			•	Specific technical issue - more research required - TRL1-3
		Standardised material tests to evaluate fabric shear compliance	4			•			Certification, testing, standards
		Tailored preform with variable thickness	6					•	Specific technical issue - more research required - TRL4-6
		Understanding mixed-material architectures to optimise component structure	10					•	Design for Manufacture
		Anchoring part of preform using 3D stitching	6			•			Material binding & joining
		Thermoset binders	5					•	Material binding & joining
		Effects of material behaviour during preforming on VF	7				•		Specific technical issue - more research required - TRL1-3
		Tolerance stack up and influence on VF/infusability	7					•	Specific technical issue - more research required - TRL1-3
		Need for net shape processes	9		•	•			
		Waste 'build-up' during processing (e.g. production 5%, cutting 35%, preform edge trimming 5%)	9	•					
		Handling & thickness effects	7			•			Material handling
		Understanding how stitch limits formability	7					•	Material handling
		Flexible manufacturing processes at a large scale to cope with a range of performance related microstructures	8						Automation / Hardware / Robotics

	Area	Challenge	Severity	Cost	Rate	Uptake	Quality	Appl.	Keyword
		Understanding how stitch tension limits formability	7					•	Material handling
	Material deposition	Layup rate is low	4		•				Can't categorise - general non-specific desire
		Limited ability to correct fibre placement on the fly	4			•	•		Automation / Hardware / Robotics
		Accuracy of ply placement for large components	5			•	•		Specific technical issue - more research required - TRL4-6
		Part inspection during deposition	9		•		•		Metrology / sensing / inspection
		Nesting efficiency	4	•					Can't categorise - general non-specific desire
		Fibre cutting	2		•				Material cutting
		Design for manufacturing to optimise nesting and architecture	9	•		•			Design for Manufacture
		Pick-and-place speed and accuracy need improvement	8		•		•		Automation / Hardware / Robotics
		Understanding forming parameters to understand defect significance	7				•		Process Modelling
	Part applicability & geometry	Residual stresses and warpage	5			•			Can't categorise - general non-specific desire
		Complex double curvature components	9			•		•	Process Modelling
		Limited information on geometrical constraints	10			•		•	Design for Manufacture
		Lack of reliable predictive tools - thick preforms, rate effects, temp effects	8			•		•	Process Modelling
		Understanding of forming limits for a given fabric / component geometry	8			•		•	Process Modelling
		Part inspection during and after forming	6	•		•	•		Metrology / sensing / inspection
		Overreliance on performance or rate-driven design, rather than manufacturing-driven	7	•			•	•	Design for Manufacture
		Understanding of time dependency effects on forming rate & quality	7		•		•		Process Modelling
2D Weaving	Inf. & env.	High level of investment required	7	•		•			Financial / investment
	Mach. hard.	Time to load fibres into machine	6		•				Automation / Hardware / Robotics
		Inline fabric defect monitoring	9			•	•		Metrology / sensing / inspection
		Multi-axial weavability (machine modification required)	7			•			Automation / Hardware / Robotics
	Material format	Limited in-plane fibre orientations due to current weaving looms	5			•			Specific technical issue - more research required - TRL4-6
		Material variability due to defects caused by handling/shipping	7				•		Specific technical issue - more research required - TRL4-6
		High material wastage - trim waste from loom	5	•		•			Can't categorise - general non-specific desire
		Crimp introduced during yarn interlocking - reduced in-plane mechanical performance	6				•		Specific technical issue - more research required - TRL1-3
		Crimp introduced during yarn interlocking - affected out-of-plane mechanical performance	7				•		Specific technical issue - more research required - TRL1-3
		Material is unstable around cut edges, leading to variability and increased wastage (EOP vs MEOP)	4				•		Specific technical issue - more research required - TRL4-6
		Print through on cosmetic/painted surfaces due to fibre crimp	2				•		Specific technical issue - more research required - TRL1-3
		Need for high tow-count weaving without reducing mechanical properties	9	•			•		Specific technical issue - more research required - TRL4-6
		Understanding performance benefits of mixed-material weaving	8			•		•	Specific technical issue - more research required - TRL1-3
		Need a digital system to measure and confirm visual quality of finish	7			•	•		Metrology / sensing / inspection
		Raw material cost	8	•		•			Financial / investment
		Understanding influence of manufacturing post-processing (e.g. infusion, moulding etc.) on defect introduction	9				•		Process Modelling
		Control/prediction of fibre architecture upon draping over complex geometry	5					•	Process Modelling
		Theoretical maximum VF achievable (glass ceiling)	4			•	•		Can't categorise - general non-specific desire
		Inherent waviness (compliance)	4				•		Can't categorise - general non-specific desire

	Area	Challenge	Severity	Cost	Rate	Uptake	Quality	Appl.	Keyword
	Material deposition	Material wastage due to poor nesting	6	•		•			Can't categorise - general non-specific desire
	Material deposition	Slow deposition rates (compared with other processes e.g. NCF)	6		•				Automation / Hardware / Robotics
	Material deposition	Reduced component quality due to material variability (in-plane shear)	7				•		Can't categorise - general non-specific desire
	Material deposition	Yarn abrasion due to continuous tension variations	5				•		Specific technical issue - more research required - TRL1-3
	Part appl. & geo.	High levels of automation limited to relatively simple planar parts	6			•			Automation / Hardware / Robotics
	Part appl. & geo.	Structures produced from 2D fabrics are prone to delamination and local disbonding	7				•		Specific technical issue - more research required - TRL1-3
	Part appl. & geo.	Structures difficult to repair without adding parasitic weight	5			•	•		Can't categorise - general non-specific desire
3D Weaving	Infrastructure & environment	High level of investment required (depending on thickness & width)	9	•		•			Financial / investment
3D Weaving	Infrastructure & environment	Need an integrated supply chain - fabric supplier is closer to becoming Tier 1	6			•			General - Supply chain needs
3D Weaving	Infrastructure & environment	Need a large space for the machine	6	•					Specific technical issue - more research required - TRL4-6
3D Weaving	Infrastructure & environment	Poor understanding by end-users of 3D weaving architectures, mechanical performance and cost limits uptake	8	•		•			Can't categorise - general non-specific desire
3D Weaving	Infrastructure & environment	Need for reliable cost models for 3D weaving business case	10	•					Design for Manufacture
3D Weaving	Machine hardware	Width restriction of fixed weaving area	4			•			Specific technical issue - more research required - TRL4-6
3D Weaving	Machine hardware	Time to load machine	9		•				Specific technical issue - more research required - TRL4-6
3D Weaving	Machine hardware	Need for automated loading of fibres - adopting textile processes into composites manufacture	7			•			Specific technical issue - more research required - TRL4-6
3D Weaving	Machine hardware	Inline fabric defect and quality monitoring	9				•		Metrology / sensing / inspection
3D Weaving	Machine hardware	Influence of weaving geometry on fibre degradation	4				•		Specific technical issue - more research required - TRL1-3
3D Weaving	Machine hardware	Need accurate tension control	9			•			Material handling
3D Weaving	Machine hardware	Complex (often manual) preform trimming, especially in thick parts	7			•			Material cutting
3D Weaving	Material format	Crimp introduced during yarn interlocking = reduced inplane mechanical performance	6				•	•	Specific technical issue - more research required - TRL1-3
3D Weaving	Material format	Need to understand links between weave design and permeability	7				•		Specific technical issue - more research required - TRL1-3
3D Weaving	Material format	Difficult to cut thick weaves accurately	5		•		•		Material cutting
3D Weaving	Material format	Understanding how to introduce binder to stabilise 3D woven preforms	8			•			Material binding & joining
3D Weaving	Material format	Understanding performance benefits of mixed-material weaving	8			•		•	Specific technical issue - more research required - TRL1-3
3D Weaving	Material format	Ability to weave fibres at ±45°	7			•		•	Specific technical issue - more research required - TRL4-6
3D Weaving	Material format	Formation of large resin rich regions	5				•		Specific technical issue - more research required - TRL1-3
3D Weaving	Material format	Micro-cracking of matrix around z-fibres and understanding their extent	6				•		Specific technical issue - more research required - TRL1-3
3D Weaving	Material format	What are best practice edge stabilisation techniques	8			•			Specific technical issue - more research required - TRL1-3
3D Weaving	Material format	Understand impact of toughness/impact resistance	3					•	Specific technical issue - more research required - TRL1-3
3D Weaving	Material deposition	Yarn abrasion due to continuous tension variations	5				•		Specific technical issue - more research required - TRL4-6
3D Weaving	Material deposition	Need for bespoke preform handling rigs	4			•			Tooling
3D Weaving	Material deposition	Ensuring 3D woven preforms with good handlability, and methods to handle them automatically	6			•			Material handling
3D Weaving	Material deposition	Weaving at rates in line with other processes	8		•				Automation / Hardware / Robotics
3D Weaving	Part appl. & geo.	Understanding preform geometry - what is the machine capable of?	8			•			Specific technical issue - more research required - TRL4-6
Braiding	Inf. & env.	High level of investment required for large structures	8	•		•			Financial / investment
Braiding	Inf. & env.	Lack of virtual machines	5			•			Process Modelling

Area	Challenge	Severity	Cost	Rate	Uptake	Quality	Appl.	Keyword
	Need to understand complexity of structures that can be braided	8						Design for Manufacture
Machine hardware	Time to load machine	8		•				Specific technical issue - more research required - TRL4-6
	High levels of machine downtime	6		•				Specific technical issue - more research required - TRL4-6
	Lack of automated bobbin change overs or fibre splicing	6		•				Specific technical issue - more research required - TRL4-6
	Time to load a mandrel and gather fibres to initiate braid	5		•			•	Specific technical issue - more research required - TRL4-6
	Time to terminate a part and remove mandrel	5		•			•	Specific technical issue - more research required - TRL4-6
	Limited processing speed due to rotary inertia of bobbins	4		•				Specific technical issue - more research required - TRL4-6
	Lack of remote bobbins/creels off the machine	5		•				Specific technical issue - more research required - TRL4-6
	Inline defect detection	8				•		Metrology / sensing / inspection
	Bobbin capacity - larger increases rate but also cost	8	•	•				Specific technical issue - more research required - TRL4-6
	Mandrel manipulation through the braider, esp. if mandrels are weak/flexible	7			•			Specific technical issue - more research required - TRL4-6
	In-line fibre breakage detection system	8				•		Metrology / sensing / inspection
Material format	Voids and defects	4				•		Metrology / sensing / inspection
	Fibre fuzzing and fibre damage	8				•		Material handling
	Permeability low and not well characterised	6				•		Design for Manufacture
	Ability to use spread tow to produce low areal weight preforms	7				•		Specific technical issue - more research required - TRL4-6
	Ability to use stiff preimpregnated fibres to avoid resin infusion stage	7		•		•		Specific technical issue - more research required - TRL4-6
	Excessive bulk factor/crimp, preventing mould closure	6				•		Specific technical issue - more research required - TRL1-3
	Tension control of fibres can impact on visual quality of preform	5				•		Specific technical issue - more research required - TRL4-6
	Processability of comingled yarns	7					•	Specific technical issue - more research required - TRL1-3
	Hybrid braiding of other materials e.g. wires, shape memory alloys, sensors etc.	7					•	Specific technical issue - more research required - TRL1-3
	Comingled CF/TP braids have high bulk factors, limiting control of defects, wrinkles	7				•	•	Specific technical issue - more research required - TRL1-3
Material deposition	Fibre deposition rate severely affected by changes in curvature and cross-section	6		•			•	Automation / Hardware / Robotics
	Slow machine reversal to create ply drops	6		•			•	Automation / Hardware / Robotics
	Fibre fixation on the mandrel to prevent slippage	7				•		Specific technical issue - more research required - TRL4-6
	Lack of inline sensing for fibre angle	7				•		Metrology / sensing / inspection
	Lack of fibres in the hoop direction (90°)	6					•	Specific technical issue - more research required - TRL4-6
	Dependency on resin infusion step - Can resin be introduced cost effectively at the braiding stage?	8		•			•	Specific technical issue - more research required - TRL1-3
	Lack of inline curing	3		•			•	Specific technical issue - more research required - TRL1-3
	Multi-ply tooling solutions	8						Specific technical issue - more research required - TRL4-6
	Braiding preforms which require post-braid shaping operation before moulding	5					•	Specific technical issue - more research required - TRL4-6
	Mandrel wear in slip regions	3	•					Specific technical issue - more research required - TRL4-6
	Mandrel surface materials to aid slip/grip	3			•			Specific technical issue - more research required - TRL4-6
	Stability of fibre angles when off mandrel	2				•		Specific technical issue - more research required - TRL4-6
	Anchoring at start/end of a braid path	1			•			Specific technical issue - more research required - TRL4-6
Part applicability & geometry	Lack of simulation tools to predict fibre path on complex parts	8			•		•	Process Modelling
	Poor geometric accuracy	7				•	•	Specific technical issue - more research required - TRL4-6
	Lack of structural optimisation tools considering braiding manufacturing constraints	9					•	Design for Manufacture

	Area	Challenge	Severity	Cost	Rate	Uptake	Quality	Appl.	Keyword
		High specific density of mandrel materials to resist crushing	5					•	Specific technical issue - more research required - TRL4-6
		Ability to produce open-sections	7					•	Specific technical issue - more research required - TRL4-6
		Issues with near-90° bends	8					•	Specific technical issue - more research required - TRL4-6
		Integration of insert e.g. holes, near net-shape	6			•			Specific technical issue - more research required - TRL4-6
		Accurate thickness prediction tools	7			•			Process Modelling
		Combined braiding with 3D stitching	7			•			Specific technical issue - more research required - TRL4-6
		Differential between inner & outer arc length creates VF differential	5				•		Specific technical issue - more research required - TRL4-6
Discontinuous	Inf. & env.	Limited DFM database - limited part applicability	9			•			Design for Manufacture
		UK supply chain infancy - lack of Tier 1 moulders	2			•			General - Supply chain needs
		Need for robust & reliable predictive models for performance	8						Process Modelling
		Weak tooling supply chain & design understanding of tool features	5						Tooling
	Machine hardware	Blade wear of fibre choppers	4	•					Material cutting
		Machine down-time due to fibre blockages	7	•					Specific technical issue - more research required - TRL4-6
	Material format	Low permeability, leading to high void content (>1%)	7			•	•		Specific technical issue - more research required - TRL1-3
		High material variability, leading to mechanical property variations (±20%)	9				•		Specific technical issue - more research required - TRL1-3
		Size and scale dependencies. Poor mechanical properties for thin structures	8			•	•		Specific technical issue - more research required - TRL1-3
		No dedicated carbon fibre chopper rovings - poor distribution and wetout	3				•		Specific technical issue - more research required - TRL4-8
		Limited mechanical strength, due to fibre stress concentrations	8			•	•		Specific technical issue - more research required - TRL1-3
		Limited ceiling fibre volume fraction (ca.55%)	7			•	•		Specific technical issue - more research required - TRL1-3
		Formability of discontinuous fibre systems with non-standard angles	8					•	Specific technical issue - more research required - TRL1-3
		Poor understanding of flow in process. Poor flow for long fibres	6					•	Specific technical issue - more research required - TRL1-3
		Low fibre alignment (different to control)	6				•		Specific technical issue - more research required - TRL1-3
		Use of recyclate	6	•					Specific technical issue - more research required - TRL1-3
		Impact of tooling surface roughness on material flow	2		•				Specific technical issue - more research required - TRL1-3
		Low cost AFP tapes from discontinuous long fibres	8	•					Specific technical issue - more research required - TRL1-3
		Use of NCF offcuts	8	•					Specific technical issue - more research required - TRL4-6
	Mat'l dep'n	Material wastage due to overspray (poor fibre positional control)	4	•					Process Modelling
		Fibre alignment due to flow in processing is poorly understood	6				•		Process Modelling
	Part appl. & geo	Unsuitable for large components (>1m2) due to pressures involved (>100 bar)	5					•	Can't categorise - general non-specific desire
		Unsuitable for large planar areas due to warpage (difficult to control fibre architecture)	4					•	Can't categorise - general non-specific desire
		Understanding of geometric features to stiffen and 'hold flat'	4						Design for Manufacture
Non-Wovens	Inf. & env.	High level of investment required	6	•		•			Financial / investment
		Large amount of space required	5	•					Can't categorise - general non-specific desire
		Need suppliers for wide-format and tailored width material	8			•			General - Supply chain needs
	Machine hardware	Large amounts of machine downtime (typically XXkg/hr compared to YYkg/hr for weaving)	5	•	•				Automation / Hardware / Robotics
		Width of material limited by machine bed	6			•		•	Can't categorise - general non-specific desire
		Improve machine design to improve flexibility of layer angles	6					•	Specific technical issue - more research required - TRL4-6

	Area	Challenge	Severity	Cost	Rate	Uptake	Quality	Appl.	Keyword
		Inline fabric defect and quality monitoring	9				•		Metrology / sensing / inspection
		Consistent stitch tensioning on wide format material	4					•	Specific technical issue - more research required - TRL4-6
	Material format	Potential for fibre breakage during intra-ply stitching	4		•		•		Specific technical issue - more research required - TRL4-6
		Reduction in in-plane properties due to stitch	6				•		Specific technical issue - more research required - TRL1-3
		Limited standard fibre orientations (0/90, ±45....), rather than non-standard angles (some machines can do 60 degs)	8			•		•	Specific technical issue - more research required - TRL4-6
		Complexity of forming due to intra-ply stitches	9				•	•	Specific technical issue - more research required - TRL1-3
		Asymmetric shear behaviour due to some stitch patterns	9				•	•	Specific technical issue - more research required - TRL1-3
		Choice of stitch material to suit mechanical performance	6					•	Specific technical issue - more research required - TRL4-6
		Impact performance not well understood	4			•		•	Specific technical issue - more research required - TRL1-3
		Understanding performance benefits of mixed-material non-wovens	8			•		•	Specific technical issue - more research required - TRL1-3
		Consistency of material production (e.g. gaps)	7				•		Industry 4.0, Digital, Future Automation, ML, AI
		Spreading the 0 deg fibres	7					•	Specific technical issue - more research required - TRL4-6
		Theoretical VF limit (glass ceiling)	8				•		Specific technical issue - more research required - TRL1-3
		Material format width limits (large component applicability)	8					•	Specific technical issue - more research required - TRL4-6
		Wide tolerance on thickness	8				•	•	Specific technical issue - more research required - TRL4-6
	Material deposition	High material wastage due to machine trim waste (outside of edge stitch)	7	•					Specific technical issue - more research required - TRL4-6
		Limited suitability for net-shape preforming (i.e. waste)	10	•				•	Specific technical issue - more research required - TRL4-6
		Formability vs stability of ply geometry in handling/depositing	7					•	Specific technical issue - more research required - TRL1-3
		High tolerance ply cutting needed	8				•	•	Material cutting
		Temperature requirements for fixing/binding application in large preforms	8					•	Material binding & joining
	Part appl. & geo.	Geometry limited to relatively planar components with single curvature for multiaxials	3					•	Can't categorise - general non-specific desire
ATL-AFP-ADFP	Infrastructure & environment	Level of investment required - tool and hardware	9	•		•			Financial / investment
		Lack of DFM database – limited part applicability prediction	10	•		•		•	Design for Manufacture
		Lack of reliable cost modelling tools for part cost prediction	8			•		•	Design for Manufacture
		Programming route not i4.0 compatible	6	•					Industry 4.0, Digital, Future Automation, ML, AI
		Limited software suppliers, High cost of software, Offline	5	•		•			General - Supply chain needs
		Supply chain infancy	3			•			General - Supply chain needs
		Supply chain size (number of suppliers)	4	•		•			General - Supply chain needs
		Supplier and machine format often linked	5	•		•			General - Supply chain needs
		Need for design & analysis tools for TFP parts	8						Design for Manufacture
	Machine hardware	High levels of machine stand-still during process	10	•	•				Industry 4.0, Digital, Future Automation, ML, AI
		Time to load machine	8	•	•				Automation / Hardware / Robotics
		Axis speed & acceleration limits , TCP speed & acceleration limits	6		•				Automation / Hardware / Robotics
		Data rate for sensors & network	5		•				Industry 4.0, Digital, Future Automation, ML, AI
		Lots of alternative machine formats e.g. location of creels	5			•			Can't categorise - general non-specific desire
		Hardware accuracy (knowledge of TCP position)	5					•	Automation / Hardware / Robotics
		Hardware rigidity limits part accuracy	4		•				Automation / Hardware / Robotics

	Area	Challenge	Severity	Cost	Rate	Uptake	Quality	Appl.	Keyword
		Big data and data processing in real time	5		•				Industry 4.0, Digital, Future Automation, ML, AI
		Processing speed – synchronisation of motion & sensor data	5		•				Industry 4.0, Digital, Future Automation, ML, AI
		Lack of standardisation of AFP machine systems & interfaces	9			•		•	Certification, testing, standards
		High cost of parts and maintenance - need standard parts	7	•		•			Financial / investment
	Material format	Fibre fuzzing	9		•				Material handling
		Binder functions not well understood	8		•				Material binding & joining
		Permeability not well characterised	9			•			Design for Manufacture
		Material is expensive	9	•					General - Supply chain needs
		No common material format or generic options	7	•		•			Certification, testing, standards
		Addition of veil leads to less steerable material	7					•	Specific technical issue - more research required - TRL1-3
		Lack of steerability of material	7					•	Specific technical issue - more research required - TRL1-3
		Inconsistency of tape width	5					•	Industry 4.0, Digital, Future Automation, ML, AI
		Resin-rich areas in stitched UD tow-preg	7			•			Specific technical issue - more research required - TRL1-3
		Secondary processes to tape vs online activities (e.g. binder application)	7	•					Specific technical issue - more research required - TRL1-3
		Lack of standard material architecture for dry fibre	9			•		•	Certification, testing, standards
		Cost benefits of dry fibre need better understanding	9	•		•			Design for Manufacture
		Effect of stitch material & quantity not understood in TFP, especially on bottom surface of base material	8					•	Specific technical issue - more research required - TRL1-3
	Material deposition	Limited ability to predict optimum processing conditions	9	•				•	Process Modelling
		Tack level required and tack changes with rate	7		•				Specific technical issue - more research required - TRL1-3
		Shear stiffness of material limits steering capability	8					•	Specific technical issue - more research required - TRL1-3
		Heating mechanisms – lack of understanding of relative advantages/disadvantages of each	7			•			Specific technical issue - more research required - TRL4-6
		Course thickness inconsistency & bulk factor	8	•				•	Industry 4.0, Digital, Future Automation, ML, AI
		Low deposition head speed limit	5		•				Automation / Hardware / Robotics
		Speed, quality and consistency of fibre cutting is low	4		•				Material cutting
		Control of heating profile (heat/cool cycle) within TP tape laying to control tack & constrain warpage	8		•		•		Process Modelling
		Thermal cycle history, early deposited layers experience more heating/cooling cycles leading to degradation	7				•		Process Modelling
		Stitch material remains in moulded part in TFP	7				•		Specific technical issue - more research required - TRL4-6
	Part applicability & geometry	Layup and production rates are low	10		•				Specific technical issue - more research required - TRL4-6
		Need for part inspection during deposition	8	•	•				Metrology / sensing / inspection
		Issues with corners	7					•	Specific technical issue - more research required - TRL4-6
		Infusion step lengthy, risky and limited simulation capability	8		•	•			Specific technical issue - more research required - TRL4-6
		Limited ability to adjust process on the fly	7		•				Industry 4.0, Digital, Future Automation, ML, AI
		Limited part production accuracy	6					•	Industry 4.0, Digital, Future Automation, ML, AI
		Lack of information on geometrical capabilities	6			•		•	Specific technical issue - more research required - TRL4-6
		Limited understanding of material relaxation resulting in need for part inspection after deposition	5	•	•				Specific technical issue - more research required - TRL1-3
		Limited ability to steer	5					•	Specific technical issue - more research required - TRL4-6
		Uncertainty over process flow options e.g. - 2D + drape or 3D?	3			•			Design for Manufacture
		Understanding sectoral limitations and understanding potential applications	10			•			Design for Manufacture
		Need design tools for TFP parts that drape 'severely'	7					•	Design for Manufacture

	Area	Challenge	Severity	Cost	Rate	Uptake	Quality	Appl.	Keyword
Pultrusion	Inf. & env.	High level of investment required	5	•		•			Financial / investment
		Volatile emissions	3			•			Specific technical issue - more research required - TRL1-3
	Machine hardware	Long set up times - not suitable for short production runs	5	•	•				Automation / Hardware / Robotics
		Dedicated machinery required	2	•		•			Automation / Hardware / Robotics
		High scrap levels during machine setup and calibration	3	•					Industry 4.0, Digital, Future Automation, ML, AI
		Larger components require larger hardware setups	3		•				Can't categorise - general non-specific desire
		Tooling wear	2	•					Tooling
		Tooling heating, esp. for floating mandrel can limit rate	4		•				Tooling
	Material format	Anisotropic material properties	2					•	Specific technical issue - more research required - TRL1-3
		Poor control of resin content	3				•		Specific technical issue - more research required - TRL1-3
		Fabric plies need to be tailored to the dimensions of the component	3	•					Specific technical issue - more research required - TRL1-3
		Understanding use of various fibre formats/webs for feed stability	6			•			Specific technical issue - more research required - TRL1-3
		Heating/cooling rates for TP injection (in situ polymerisation)	5		•				Specific technical issue - more research required - TRL1-3
	Material deposition	Pulling speed is dependent on the reaction time of the resin	3		•				Specific technical issue - more research required - TRL4-6
		Complex thermomechanical models required to simulate process	3			•			Process Modelling
		Asymmetric designs may cause bending during cooling phase	7				•		Specific technical issue - more research required - TRL4-6
		Poor fibre impregnation	5				•		Specific technical issue - more research required - TRL1-3
		Dimensional tolerance - pultruded sections typically not straight	7				•	•	Specific technical issue - more research required - TRL4-6
		Rate dependent on part thickness	5		•			•	Specific technical issue - more research required - TRL4-6
		1-3m/min max. rate. Multiple machines required to meet demand	8		•				Specific technical issue - more research required - TRL4-6
		Ability to use CF/PEEK	8					•	Specific technical issue - more research required - TRL1-3
	Part appl. & geo.	Limited to constant cross-section	7					•	Can't categorise - general non-specific desire
		Typically limited to straight sections	7					•	Can't categorise - general non-specific desire
		Radial pultrusion relatively immature but possible	7			•			
		Post-forming processes following pultrusion	7					•	Specific technical issue - more research required - TRL1-3
Filament winding	Machine hardware	Touch labour required to initiate and terminate winding	3		•				Automation / Hardware / Robotics
		Separate oven-cure step required	4		•				Specific technical issue - more research required - TRL4-6
		Mandrel extraction limits geometry or increases cost	8	•				•	Specific technical issue - more research required - TRL4-6
	Material format	Doesn't support diverse fibre types	7			•			Specific technical issue - more research required - TRL1-3
		High surface porosity	7				•		Specific technical issue - more research required - TRL1-3
		Low viscosity resins required leading to lower mechanical properties	8				•		Specific technical issue - more research required - TRL1-3
		Dependency on using solvents to clean equipment between batches	3	•	•				Specific technical issue - more research required - TRL4-6
		Fibre damage during dry fibre winding	6				•		Specific technical issue - more research required - TRL4-6
		Need for diverse resin types	6					•	Specific technical issue - more research required - TRL4-6
		Need for co-mingled CF/Thermoplastics	5					•	Specific technical issue - more research required - TRL4-6
	Material deposition	Unable to wind reverse curvature	5			•		•	Specific technical issue - more research required - TRL4-6
		Unable to easily change fibre path within a layer	5			•			Specific technical issue - more research required - TRL4-6

	Area	Challenge	Severity	Cost	Rate	Uptake	Quality	Appl.	Keyword
		Difficult to place fibres parallel to the mandrel axis (min 10deg required)	7			•	•		Specific technical issue - more research required - TRL4-6
		Winding speed dependent on fibre placement accuracy required - limited to 30m per min for precise requirements	4		•				Industry 4.0, Digital, Future Automation, ML, AI
		Batch processing due to limited resin pot life	3			•			Specific technical issue - more research required - TRL4-6
		Limit to how much the tow can be spread due to continuous tension	8		•	•			Specific technical issue - more research required - TRL4-6
		Availability of a robust programming solution	8			•			Process Modelling
	Part applicability & geometry	Part configuration must facilitate mandrel extraction - limits complex geometries	7			•			Can't categorise - general non-specific desire
		Poor external surface finish	3				•		Specific technical issue - more research required - TRL4-6
		Poor material uniformity	6				•		Specific technical issue - more research required - TRL1-3
		Mandrel deflection for large structures	3					•	Specific technical issue - more research required - TRL1-3
		Inertial effects for large mandrels = limited speed	3		•				Can't categorise - general non-specific desire
		Short life for collapsible mandrels to facilitate complex components	3	•					Specific technical issue - more research required - TRL4-6
		High residual stresses due to fibre winding tension, leading to fibre buckling at ID.	7				•		Specific technical issue - more research required - TRL1-3
		Residual fibre stresses due to mandrel expansion during cure	6				•		Specific technical issue - more research required - TRL1-3
		Limited part applicability - closed section, cylindrical or prismatic	7					•	Specific technical issue - more research required - TRL4-6
		Typically used for thicker structures - not applicable for thinwalled parts	5			•		•	Specific technical issue - more research required - TRL4-6
Overmoulding	Inf. & env.	Supply chain infancy	7			•			General - Supply chain needs
		Small supply chain size	7	•		•			General - Supply chain needs
	Machine hardware	Large clamping forces required due to high injection pressures (limiting process to small parts)	7			•			Can't categorise - general non-specific desire
		Challenge of net-shaped forming, avoiding wastage (clamping etc.)	5	•	•				Can't categorise - general non-specific desire
		Heating mechanisms for TP and prepreg - reduce cycle time, improve uniformity	10		•		•		Specific technical issue - more research required - TRL4-6
		Clamping mechanisms to locate and constrain fibre inserts within tool	8			•	•		Specific technical issue - more research required - TRL4-6
		Relaxation/sagging of blank during heating	6				•		Specific technical issue - more research required - TRL4-6
		Modifications required to existing injection moulding equipment	7			•			Specific technical issue - more research required - TRL4-6
		High complexity (therefore cost) of tooling	8	•		•			Tooling
		Tooling/process design to reduce forming forces and improve component quality	8			•		•	Design for Manufacture
		Poor control of temperature distribution within tooling	8		•		•		Tooling
		Rapid heating/cooling of tooling needed	10		•				Tooling
	Material format	Material wrinkling due to overmoulding step	5				•		Specific technical issue - more research required - TRL1-3
		Material washing/migration due to overmoulding step	5				•		Specific technical issue - more research required - TRL1-3
		Wastage of expensive organosheet material	7	•					Specific technical issue - more research required - TRL4-6
		Metal part introduction and tooling for multi-material components	9					•	Specific technical issue - more research required - TRL4-6
		Organosheet is uniform thickness - needs ramps etc.	9					•	Specific technical issue - more research required - TRL4-6
		Behaviour/performance of dissimilar material interface	6				•	•	Specific technical issue - more research required - TRL1-3
	Material deposition	Distortion/warpage control due to unbalanced laminates	9				•		Process Modelling
		Distortion/warpage control due to flow induced fibre alignment	9				•		Process Modelling
		Unwanted flow induced alignment due to injection strategy and tool design	8				•		Process Modelling
		Sink marks/print through	8				•		Process Modelling
		Transition from heating platform to press or minimising distance	3		•				Automation / Hardware / Robotics

	Area	Challenge	Severity	Cost	Rate	Uptake	Quality	Appl.	Keyword
		Surface activation to encourage bond line	7				•		Specific technical issue - more research required - TRL1-3
		Accurate process modelling to predict warpage	7				•		Process Modelling
	Part applicability & geometry	Poor mechanical performance at material interfaces - temp effects	9				•		Specific technical issue - more research required - TRL1-3
		Lack of reliable flow-based modelling tools, accounting for fabric inserts	8					•	Process Modelling
		Stress concentrations due to large local stiffness gradients at material transitions	8				•		Financial / investment
		Availability of design data is limited, leading to long development times, high cost	8	•	•			•	Specific technical issue - more research required - TRL1-3
		Simulation tools to compensate injection mould tools to account for shrinkage	6				•		Design for Manufacture
		Limited scalability due to large injection pressures - high viscosity polymers	7					•	Specific technical issue - more research required - TRL4-6
		Part complexity limited by thermoforming operation	6					•	Specific technical issue - more research required - TRL4-6
		Thickness limitations	5					•	Specific technical issue - more research required - TRL4-6
Thermoplastic Stamping	Infrastructure & environment	Challenge of net-shaped forming, avoiding wastage (clamping etc.)	6	•					Specific technical issue - more research required - TRL1-3
		Heating mechanisms for TP - reduce cycle time/dwell time, improve uniformity	10		•				Specific technical issue - more research required - TRL1-3
		Need for a low cost, bespoke organosheet	9	•					General - Supply chain needs
		Prediction of defect formation	9			•	•		Process Modelling
		Higher tooling & processing costs compared with thermoset materials	8	•					Tooling
	Machine hardw.	Tooling/process design to reduce forming forces and improve component quality	8			•			Tooling
		Forming of thick blanks (process control)	7					•	Industry 4.0, Digital, Future Automation, ML, AI
		Need for actuated/bespoke tooling to minimise wrinkling & defects	10				•		Specific technical issue - more research required - TRL4-6
	Material format	Wastage through trimming (25% minimum)	5	•					Can't categorise - general non-specific desire
		Clamping mechanisms to locate and constrain fibre inserts within tool	9			•	•		Specific technical issue - more research required - TRL1-3
		Relaxation of blank during heating	6				•		Specific technical issue - more research required - TRL1-3
		Wastage of expensive organosheet material	6	•					Can't categorise - general non-specific desire
		Need to control crystallinity (accurate thermal management)	10			•			Specific technical issue - more research required - TRL1-3
		Difficult control of fibre architecture upon forming	8				•		Specific technical issue - more research required - TRL1-3
		Tailored blanks manufactured in high volumes/rates	7	•	•				Automation / Hardware / Robotics
	Material deposition	Need to increase speed of compaction pressure and temperature introduction without use of matched-tooling	7		•				Specific technical issue - more research required - TRL1-3
		Overheating of sheet to compensate for cooling during transfer to press	7					•	Specific technical issue - more research required - TRL1-3
		Monitoring of temperature through the thickness	7			•			Metrology / sensing / inspection
		Heating through to centre of laminates	10			•			Specific technical issue - more research required - TRL1-3
		Difficult to form over complex geometry (low-radius tapers, double curvatures etc.)	9					•	Specific technical issue - more research required - TRL1-3
	Part appl. & geo.	Part complexity limited by thermoforming operation (depth of draw)	8					•	Specific technical issue - more research required - TRL1-3
		Component forms limited by limited fibre-shearing in blank	9					•	Specific technical issue - more research required - TRL1-3
		Geometric limitations due to blank draft and radius to prevent tearing	8					•	Specific technical issue - more research required - TRL1-3
		Need to introduce ramps	8					•	Specific technical issue - more research required - TRL1-3
Injection	Inf. & env.	Large clamping forces required due to high injection pressures (limiting process to small parts)	8	•		•			Can't categorise - general non-specific desire
		High level of investment required	8	•					Financial / investment

	Area	Challenge	Severity	Cost	Rate	Uptake	Quality	Appl.	Keyword
		Need for prototype tooling as a low-cost option	8	•					Specific technical issue - more research required - TRL1-3
	Machine hardw.	High complexity and lack of versatility of tooling	8	•					Can't categorise - general non-specific desire
	Machine hardw.	Tooling/process design to reduce forming forces and improve component quality	8			•		•	Specific technical issue - more research required - TRL1-3
	Machine hardw.	Poor control of temperature distribution within tooling	8				•		Specific technical issue - more research required - TRL1-3
	Material format	Wastage from 'flash' material	5	•					Can't categorise - general non-specific desire
	Material format	Management of melting point of precursors for reactive systems to prevent solidification within system	10	•					Specific technical issue - more research required - TRL1-3
	Material format	Fibre orientation due to flow	5				•		Process Modelling
	Material format	Need for moisture control	6				•		Specific technical issue - more research required - TRL1-3
	Material format	Increased fibre length	3			•			Specific technical issue - more research required - TRL1-3
	Material format	Viscosity management effects (e.g. incomplete fill, voids, flash)	8				•		Process Modelling
	Material deposition	Incomplete mould filling	7				•		Process Modelling
	Material deposition	Formation of weld lines	5				•		Process Modelling
	Material deposition	Voids and air traps leading to performance reduction	7				•		Specific technical issue - more research required - TRL1-3
	Material deposition	Void and cavitation control required	4				•		Process Modelling
	Material deposition	Flow distance	4				•		Specific technical issue - more research required - TRL1-3
	Part appl. & geo.	Inefficient for larger components	7					•	Can't categorise - general non-specific desire
RTM/HP-RTM/VARTM/Wet Press	Machine hardware	High moulding pressures required leading to machine cost increases (HP-RTM)	8	•		•			Financial / investment
RTM/HP-RTM/VARTM/Wet Press	Machine hardware	H&S issues around highly reactive resins	3			•			Material / Manufacturing interface
RTM/HP-RTM/VARTM/Wet Press	Machine hardware	Optimised tool design for predictable flow	7			•			Tooling
RTM/HP-RTM/VARTM/Wet Press	Machine hardware	High tool cost & lead time	9	•					Tooling
RTM/HP-RTM/VARTM/Wet Press	Machine hardware	Tool design for complex geometry (e.g. sliding tools)	6			•			Tooling
RTM/HP-RTM/VARTM/Wet Press	Machine hardware	Versatility and modularity of tooling	9	•		•			Tooling
RTM/HP-RTM/VARTM/Wet Press	Machine hardware	Need for optimised vent/gate design to produce a peripheral vacuum	7			•			Tooling
RTM/HP-RTM/VARTM/Wet Press	Machine hardware	Tooling design to optimise tool closure during Gap RTM	8			•			Tooling
RTM/HP-RTM/VARTM/Wet Press	Machine hardware	Need for more intelligent flow and pressure management	8		•	•			Industry 4.0, Digital, Future Automation, ML, AI
RTM/HP-RTM/VARTM/Wet Press	Machine hardware	Need for moisture controls to facilitate reactive thermoplastic resins in RTM process	8			•		•	Specific technical issue - more research required - TRL1-3
RTM/HP-RTM/VARTM/Wet Press	Material format	Process and tool design for net-shape moulding	9			•			Automation / Hardware / Robotics
RTM/HP-RTM/VARTM/Wet Press	Material format	Understanding defect significance (especially resin-rich areas)	10				•		Specific technical issue - more research required - TRL1-3
RTM/HP-RTM/VARTM/Wet Press	Material format	Ability to introduce toughening phase (e.g. interleaves, veils)	7					•	Specific technical issue - more research required - TRL1-3
RTM/HP-RTM/VARTM/Wet Press	Material format	Design of resin application for use of snap-cure and fast-cure resins	7					•	General - Supply chain needs
RTM/HP-RTM/VARTM/Wet Press	Material format	Need for an efficient & high-rate preforming process prior to moulding	10		•	•			Automation / Hardware / Robotics
RTM/HP-RTM/VARTM/Wet Press	Material format	Binder and resin interaction	7			•			Material binding & joining
RTM/HP-RTM/VARTM/Wet Press	Material format	Mixing of drapeable and high-stiffness materials affecting impregnation	8				•	•	Specific technical issue - more research required - TRL1-3
RTM/HP-RTM/VARTM/Wet Press	Material format	Embedding of metallic inserts (complicates tooling and process)	8					•	Specific technical issue - more research required - TRL1-3
RTM/HP-RTM/VARTM/Wet Press	Material format	Foam cores leading to complication of resin flow	8					•	Specific technical issue - more research required - TRL1-3
RTM/HP-RTM/VARTM/Wet Press	Material format	Embedded sensors	2				•		Smart systems integration
RTM/HP-RTM/VARTM/Wet Press	Material format	Resins with tailorable cure profile for short cycles	7					•	General - Supply chain needs
RTM/HP-RTM/VARTM/Wet Press	Material format	Pot life of resins	6	•				•	General - Supply chain needs

	Area	Challenge	Severity	Cost	Rate	Uptake	Quality	Appl.	Keyword
		High exotherms of thick components	7			•			Specific technical issue - more research required - TRL1-3
	Material deposition	Racetracking	8				•		Specific technical issue - more research required - TRL1-3
		Air entrapment resulting in dry spots and understanding significance	8				•		Specific technical issue - more research required - TRL1-3
		Microvoids leading to performance reduction	7				•		Specific technical issue - more research required - TRL1-3
		Fibre-wash at higher pressures resulting in lower VF and poor architecture control	6				•		Specific technical issue - more research required - TRL1-3
		Fibre clamping	7				•		Specific technical issue - more research required - TRL1-3
		Ability to produce net edge	9			•			Specific technical issue - more research required - TRL1-3
		Robust models to predict permeability & resin flow	8			•			Process Modelling
		In-process cure monitoring	5			•			Metrology / sensing / inspection
		Cavity pressure management and monitoring (wet press)	7			•			Metrology / sensing / inspection
		Preform variability	4				•		Industry 4.0, Digital, Future Automation, ML, AI
		Dose heat design, how to clean out snap cure systems	5			•			Specific technical issue - more research required - TRL4-6
		Understanding level of cure required	6					•	Specific technical issue - more research required - TRL1-3
		Resin cracking and resin-rich zones	2				•		Specific technical issue - more research required - TRL1-3
		Seal design high risk to process	8			•			Specific technical issue - more research required - TRL4-6
		Better understanding of vacuum during tool closure	6			•			Specific technical issue - more research required - TRL1-3
		Tooling design - how to compensate for tolerances of preform weight and dose volume	6					•	Tooling
	Part applicability & geometry	Impact performance due to use of untoughened resins	8				•		Specific technical issue - more research required - TRL1-3
		Warpage due to resin flow/shrinkage	8				•		Specific technical issue - more research required - TRL1-3
		Large amount of wastage due to off-cuts	7	•					Specific technical issue - more research required - TRL1-3
		Removal of peel ply causing component damage	6				•		Specific technical issue - more research required - TRL1-3
		Core integration in sandwich panels (single-shot curing)	5					•	Specific technical issue - more research required - TRL1-3
Autoclave Prepreg	Infrastructure & environment	Level of investment required	9	•		•			Financial / investment
		Address material and process variability in simulation	8		•	•	•	•	Process Modelling
		Long preparation time prior to cure (e.g. bagging)	3		•				Specific technical issue - more research required - TRL4-6
		Long material outlife	3	•					Material / Manufacturing interface
		Investment costs grow exponentially with size	9	•					Financial / investment
		Automation mimicking laminator -know how	9			•			Industry 4.0, Digital, Future Automation, ML, AI
	Machine hardw.	Component size, shape restricted by autoclave size	6	•				•	Can't categorise - general non-specific desire
		Wastage of consumables (e.g. vacuum bags)	2	•					Can't categorise - general non-specific desire
		Need for reusable/recyclable consumables	8	•		•			General - Supply chain needs
	Material format	Need for low-temp curing resin with medium-temp properties without need for post-cure	8	•	•	•		•	General - Supply chain needs
		Consistent resin impregnation	6		•		•		Industry 4.0, Digital, Future Automation, ML, AI
		Online inspection	7	•	•	•	•	•	Metrology / sensing / inspection
		Material format for automated deposition	7	•	•	•	•	•	General - Supply chain needs
		Material quality along tape lengths to reduce waste	9	•					Industry 4.0, Digital, Future Automation, ML, AI
		Use of sustainable/alternative materials	3	•		•			General - Supply chain needs
		Heat-up/cool-down time is too long	8		•				Specific technical issue - more research required - TRL1-3

	Area	Challenge	Severity	Cost	Rate	Uptake	Quality	Appl.	Keyword
	Material deposition	Automated deposition of fabric materials	7	•	•		•		Automation / Hardware / Robotics
		Reduction or reprocessing lay-up waste	7			•			Specific technical issue - more research required - TRL1-3
		Tailored heated tooling	3	•	•		•		Tooling
		Automated layup of high-performance thermoplastics	7					•	Automation / Hardware / Robotics
		Manual skills retention for experienced laminators	7			•			General - Skills
		Difficult to automate or replicate lamination process maintaining flexibility	8			•			Automation / Hardware / Robotics
	Part appl. & geo	Issues with complex shapes	9				•	•	Specific technical issue - more research required - TRL1-3
		Poor/non-industrialised tools for predicting creep/deformation of plies within autoclave	4			•	•		Process Modelling
		Accurate process model to avoid springback and avoid the need for shimming	9			•	•		Process Modelling
Out of Autoclave Prepreg	Infra. & env.	Address material and process variability in simulation	8		•	•	•	•	Process Modelling
		Long preparation time prior to cure (e.g. bagging)	3		•				Specific technical issue - more research required - TRL4-6
	Machine hardw.	Ability to handle out-of-autoclave materials	3		•	•			Automation / Hardware / Robotics
		Wastage of consumables (e.g. vacuum bags)	3	•		•			Can't categorise - general non-specific desire
		Need for reusable/recyclable consumables	8	•		•			General - Supply chain needs
	Material format	Poor through-thickness evacuation in thick laminates	7				•		Specific technical issue - more research required - TRL1-3
		Process deviations leaving to changes in resin viscosity and reduced void suppression	7				•		Process Modelling
		Air entrapment in sandwich panel cores	6				•		Can't categorise - general non-specific desire
		Out-gassing of adhesives under vacuum leading to foaming	6				•		Material / Manufacturing interface
		Wrinkling and fibre-bridging resulting from large degrees of cure compaction	6				•		Specific technical issue - more research required - TRL1-3
		Need for low-temp curing resin with medium-temp properties without need for post-cure	8	•	•	•		•	General - Supply chain needs
		Consistent resin impregnation	7		•		•		Specific technical issue - more research required - TRL1-3
		Online inspection	7	•	•	•	•	•	Metrology / sensing / inspection
		Material format for automated deposition	6	•	•	•	•	•	General - Supply chain needs
		Functionalised additives	4			•		•	General - Supply chain needs
		Outlife limitations	8	•		•			General - Supply chain needs
	Material deposition	Maximum achievable fibre volume fraction of ~50-55%	5				•	•	Specific technical issue - more research required - TRL1-3
		Long cure cycle and vacuum hold times	3		•				Specific technical issue - more research required - TRL1-3
		Low in-plane permeability leading to dry spots	7				•		Specific technical issue - more research required - TRL1-3
		Automated deposition of prepreg materials	7	•	•		•		Automation / Hardware / Robotics
		Reduction or reprocessing lay-up waste	6			•			Specific technical issue - more research required - TRL1-3
		Tailored heated tooling required	3	•	•		•		Tooling
	Part appl. & geo	Low bulk factors	4				•		Specific technical issue - more research required - TRL1-3
		Poor conformance to complex forms (e.g. tight corners)	6				•	•	Specific technical issue - more research required - TRL1-3
		Poor surface porosity above core sections	4				•		Specific technical issue - more research required - TRL1-3
		Wrinkling at corners due to laminate buckling	4				•		Specific technical issue - more research required - TRL1-3
Liquid Resin	Infra. & env.	Long preparation time prior to infusion (e.g. bagging)	5		•				Automation / Hardware / Robotics
		Specific infusion tooling design	5					•	Tooling
	Machine	Wastage of consumables (e.g. vacuum bags)	2	•		•			General - Supply chain needs

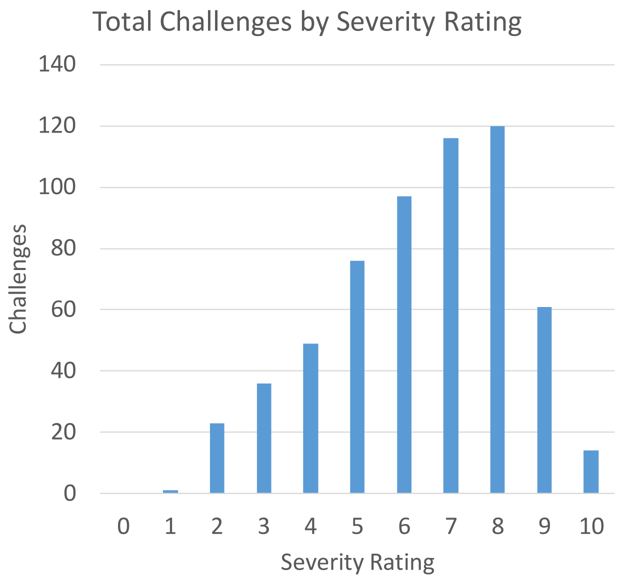
	Area	Challenge	Severity	Cost	Rate	Uptake	Quality	Appl.	Keyword
		Rapid heating & cooling of tooling required when using snap-cure resins	7		•				Tooling
		Faster/smarter heating and cooling	8		•	•			Tooling
		Need for reusable/recyclable consumables	7	•		•			General - Supply chain needs
		Mix ration control & verification for aero certification	5					•	Industry 4.0, Digital, Future Automation, ML, AI
	Material format	Channels forming due to fibre bridging causing a non-uniform front	6				•		Specific technical issue - more research required - TRL1-3
		Understanding defect significance (especially resin-rich areas)	8			•	•		Design for Manufacture
		Limited flow-length when using snap-cure or fast-cure resins	7					•	General - Supply chain needs
		Infusion of multi-material parts	3					•	Specific technical issue - more research required - TRL1-3
		Moisture uptake	6				•		General - Supply chain needs
	Material deposition	Racetracking	8				•		Specific technical issue - more research required - TRL1-3
		Air entrapment resulting in dry spots and understanding significance	7				•		Process Modelling
		Microvoids leading to performance reduction	7				•		Design for Manufacture
		Optimisation of infusion strategy for sector specific applications	6					•	Industry 4.0, Digital, Future Automation, ML, AI
		Fundamental understanding of a variety of infusion processes	7			•		•	Specific technical issue - more research required - TRL1-3
		Spatial management of heating within tool required to enhance flow, curing and stresses	3	•	•		•		Tooling
		Resin 'boiling' resulting from reduced pressure at flow-front and leading to gas production and entrapment	6				•		Specific technical issue - more research required - TRL1-3
		Filtering and distribution of resin additives resulting in performance gradient	8				•	•	Specific technical issue - more research required - TRL1-3
		Phase separation between blends	9				•		Specific technical issue - more research required - TRL1-3
		Flow front management	9			•			Industry 4.0, Digital, Future Automation, ML, AI
		Degassing (pre and during infusion)	5				•		Specific technical issue - more research required - TRL4-6
		Pre-infusion de-risking - low fidelity, fast response simulation needed	8			•			Process Modelling
		LRI specific NDT & defect characterisation	7				•		Metrology / sensing / inspection
		Resin pot life	6			•			General - Supply chain needs
		B-stage infusion/cure	9			•			General - Supply chain needs
		Micro-cracking in resin around z-fibres	5				•		Specific technical issue - more research required - TRL1-3
		Effect of z-fibre buckling due to compaction of a bulky, dry preform	4				•		Specific technical issue - more research required - TRL1-3
	Part applicability & geometry	Decompaction during infusion leading to unpredictable fibre-volume fraction	7				•		Process Modelling
		Maximum achievable fibre volume fraction of ~50-55%	4			•		•	Specific technical issue - more research required - TRL1-3
		Fibre print through	5				•		Specific technical issue - more research required - TRL1-3
		Process induced brittleness of parts when using certain resin systems (e.g. phenolic resins)	5				•		Specific technical issue - more research required - TRL1-3
		Near net edge	9			•			Specific technical issue - more research required - TRL1-3
		Sector specificity of processing parameter importance	4					•	Specific technical issue - more research required - TRL1-3
		Scale up and maintain quality	7					•	Specific technical issue - more research required - TRL4-6
Compression Moulding	Infrastructure & environment	High level of investment required - press, tooling	5	•		•			Financial / investment
		Poor maturity of tooling supply chain	8	•		•			General - Supply chain needs
		Thermal expansion, tooling geometry	2					•	Tooling
		Twist of tooling resulting in male & female tool parts misaligning and fighting the press	9				•	•	Tooling
		Tooling lead times	7	•	•	•			General - Supply chain needs
	Mac hine	High cost of tooling	3	•		•			Financial / investment

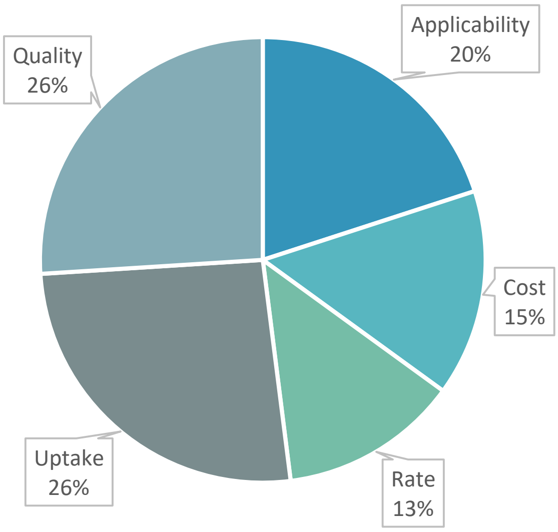
	Area	Challenge	Severity	Cost	Rate	Uptake	Quality	Appl.	Keyword
		Optimised tool design required for compaction pressure and temperature management	7					•	Tooling
		Durability and versatility of tooling	7			•			Tooling
		Intelligent, conforming tooling to adapt with the part during moulding to limit shrinkage	8			•	•	•	Tooling
		Tooling wear over lifetime of project	2	•					Tooling
		Low cost tooling needed for prototypes/small production runs	8	•					Tooling
		Thermal cycling of tool could maintain geometry upon part ejection	3				•	•	Specific technical issue - more research required - TRL1-3
	Material format	Reinforcement migration	7				•		Specific technical issue - more research required - TRL1-3
		Racetracking of charge resulting in weld lines and voids	8				•		Process Modelling
		Poor fibre impregnation leading to voids and air entrapment	7				•		Specific technical issue - more research required - TRL1-3
		Need for models to accurately predict SMC flow	6			•			Process Modelling
		Structural and physical properties affected by flow-induced phenomena (e.g. fibre bundling)	6				•		Process Modelling
		Need for an efficient preforming process prior to moulding	9	•		•			Automation / Hardware / Robotics
		Better understanding and control of draping	9					•	Process Modelling
		Better use of recyclate	8	•		•			Specific technical issue - more research required - TRL1-3
	Material deposition	Out-of-plane flow during rib filling resulting in fibre entanglement and resin-rich regions	8				•		Specific technical issue - more research required - TRL1-3
		Design of tooling/charge placement to target specific fibre angles and flow	9					•	Process Modelling
		Fibre alignment due to flow being poorly understood	8				•		Process Modelling
		Impact of charge location	5					•	Process Modelling
		How to move weld line location? Flow management required	5				•	•	Process Modelling
	Part applicability & geometry	Restricted to relatively non-complex geometries	5					•	Specific technical issue - more research required - TRL1-3
		In-mould flow to fill complex areas can result in defects	8				•		Process Modelling
		Preferential flow resulting in fracture	7				•		Process Modelling
		Fibre-matrix separation susceptibility	7				•		Specific technical issue - more research required - TRL1-3
		Mechanical weakness resulting from component 'hard points' (e.g. fasteners, fixings)	8				•		Specific technical issue - more research required - TRL1-3
		Part shrinkage and springback	7				•		Design for Manufacture
		Dimensional stability when ejected above Tg	4				•		Specific technical issue - more research required - TRL1-3
		UD/discontinuous mix - need to keep UD in place whilst chopped fibres flow	7					•	Specific technical issue - more research required - TRL1-3

Assessing Challenge Severity

Challenges were rated by contributors on a 10-point severity scale. This ranking is intended to identify the urgency with which they should be addressed, where 10 represents a significant pain point which requires critical attention and 1 represents the least severe and hence the least necessary to resolve in the short term.

Overall, there is a trend towards high severity challenges with a median score of 8 (195 challenges; 33% of the total). Challenges at or above this level are considered serious, although scores of 9 and 10 appear to have been reserved for the most significant issues in a particular process. This bias should be taken into account if performing further analysis. However, this also suggests that the process of moderation has successfully limited the number of challenges receiving the highest scores ensuring a balanced spread of severity scores.

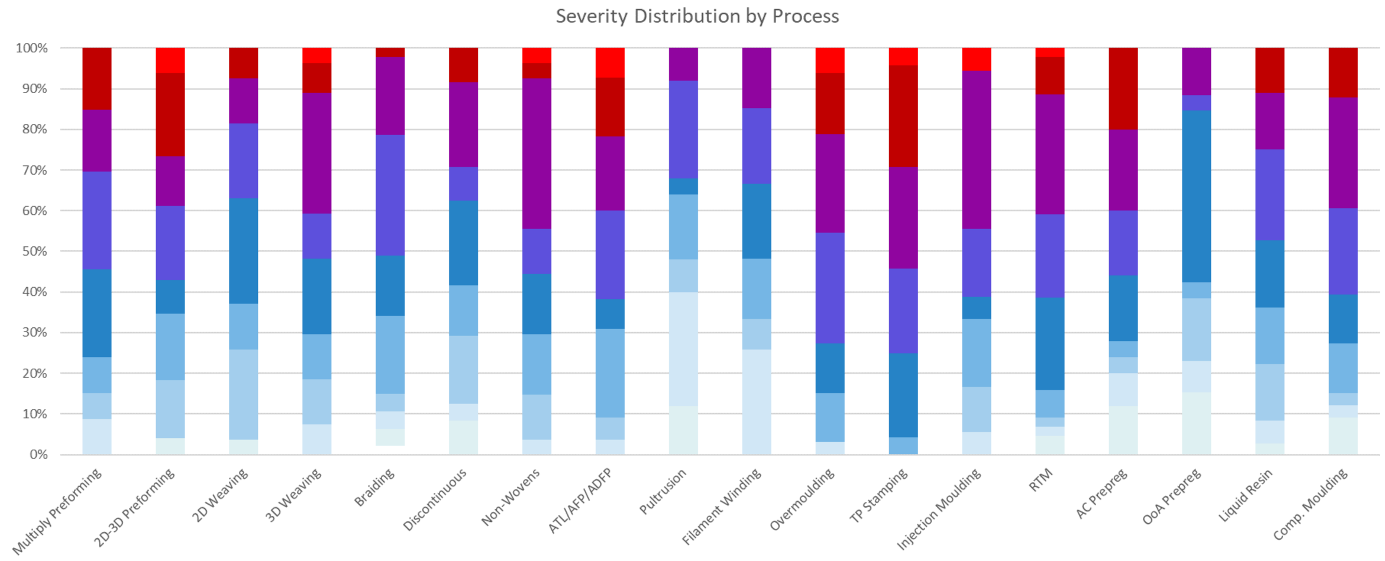




The classification of challenges according to their potential impact is shown in the pie chart on the left. The two most commonly occurring impacts were Quality and Uptake (26%). Conversely, the least commonly occurring impacts were Cost (15%) and Rate (13%). Since cost and rate are frequently cited as drivers for innovation in composites manufacturing, this is a potentially surprising result. However, this reflects the low-TRL nature of the challenges collected during the exercise. Highly fundamental research often aims to prove processes have sufficient quality to meet industrial manufacturing needs and to introduce composites to new applications, which is reflected in the results. Whereas cost and rate are typically associated with process optimisation, which occurs higher up the Technology and Manufacturing Readiness levels.

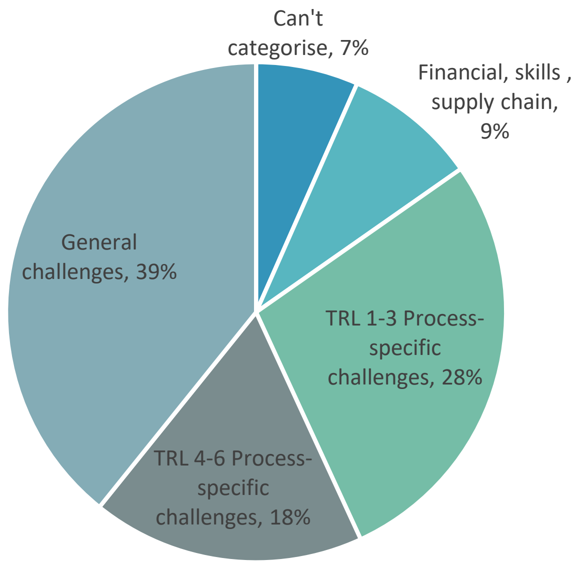
Process by Process Analysis

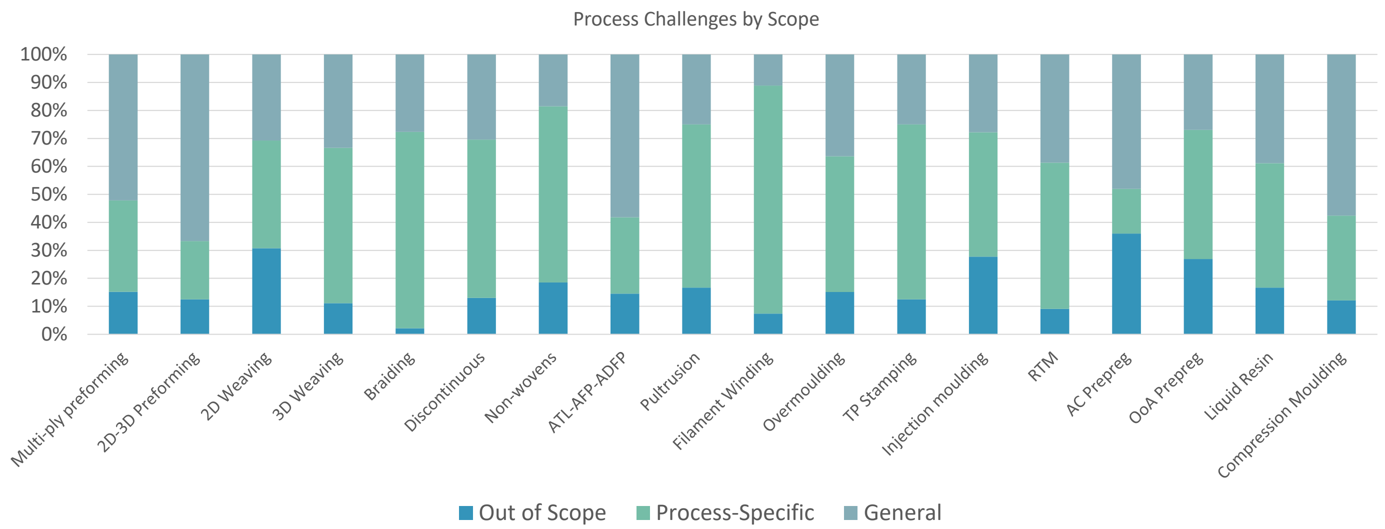
All processes had a wide distribution of challenge severities and this is shown in the figure below. However, newer processes such as Automated Fibre Placement were generally identified to have a larger number of high severity challenges (the centre of the distribution, shown by the darker coloured areas, is lower) in contrast to those in more established processes such as Pultrusion and Filament winding, which show fewer severe challenges. As expected, this suggests that in less established processes, fundamental, low-TRL research is necessary. In more established processes, the types of challenges that are defined are potentially more incremental, or require a less fundamental approach to solve.



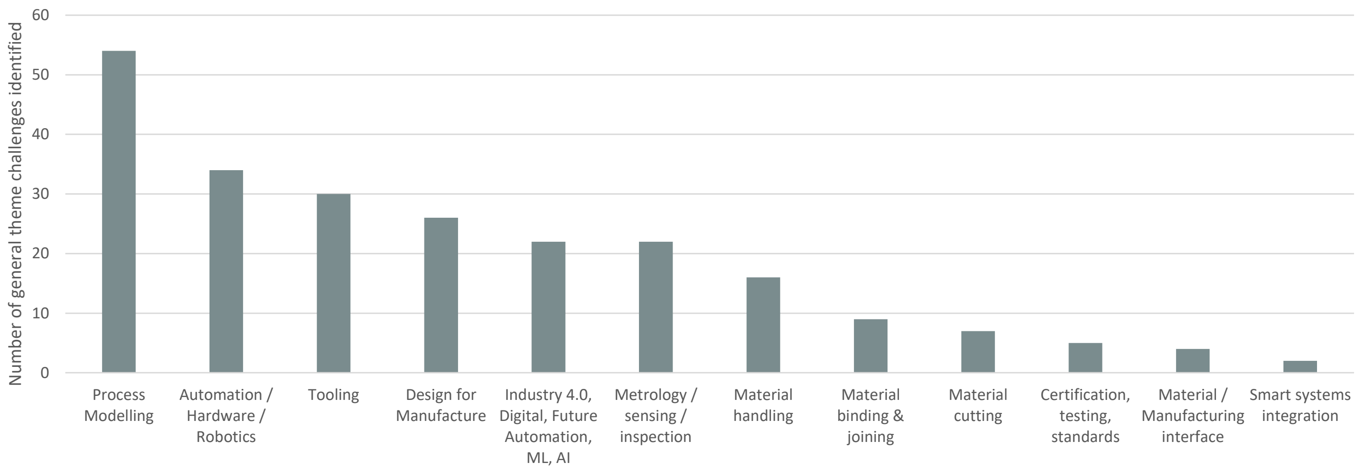
Theme by Theme Analysis

The majority of challenges captured in the landscape (268 challenges; 45% of the total) were technically focused and process specific. However, a number of general (non-process-specific) challenges were also identified (281 challenges; 48%). These challenges are potentially relevant across multiple processes and therefore offer opportunities for cross-process learning and synergy. Finally, several challenges were considered 'Out of Scope' (90 challenges, 15%). These challenges typically referred to financial or investment issues, supply chain needs, or skill shortages that could not be addressed through Hub research projects. The classification for the whole data set and for the distribution of classification across the 18 technologies is shown below:





General challenges were ranked by keyword analysis according to their incidence across all 18 technologies. Specific themes were then investigated by grouping relevant challenges together. The number of challenges related to the resulting themes is outlined below:



Although the identified themes represent clusters of related challenges, it is clear that they also vary in breadth. Material cutting, for instance, fits the requirement of a cross-process specific area of universal interest whereas process modelling, whilst relevant to multiple processes may only be specific to a single area. The 6 most populated themes are described in greater detail in the first section of the results below.

Navigating this Report

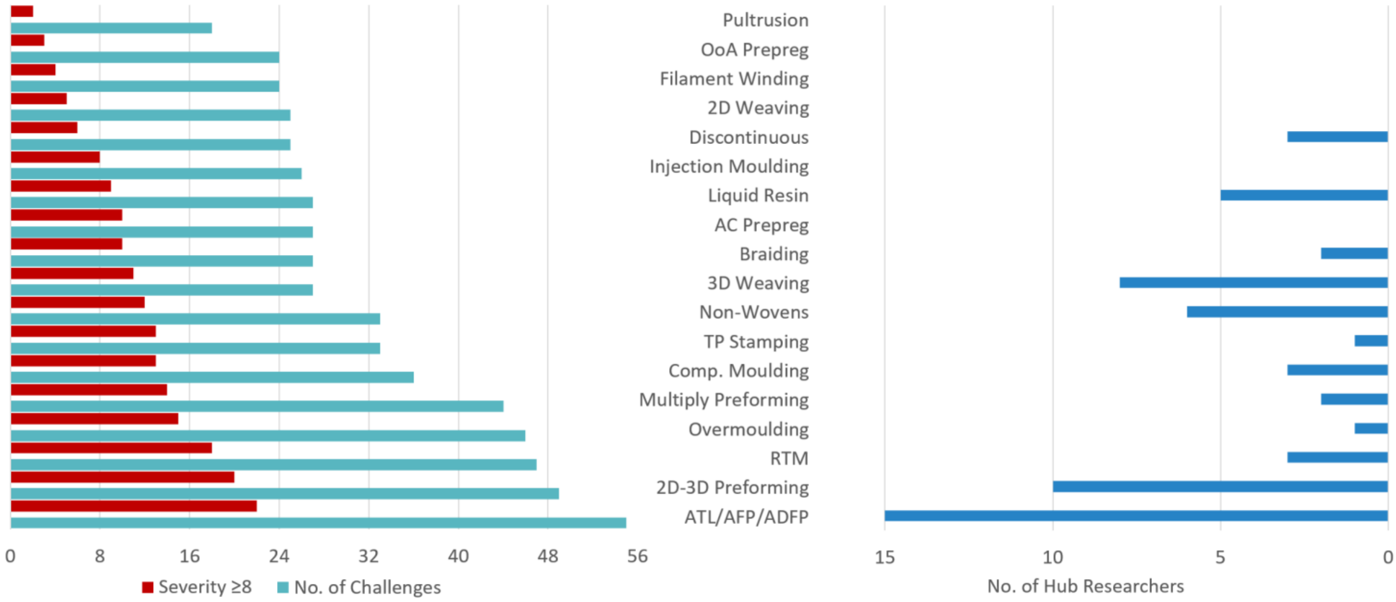
For the purposes of this report, the data has been divided into two sections for ease of presentation: Theme by Theme, and Process by Process. This will allow readers to find the most relevant results for their requirements. The 'Theme by Theme' results include challenges that have been classified as 'generic' regardless of technology, ranked by severity. These have been used to identify potential themes of interest to the Hub for each area. The 'Process by Process' results include challenges that have been classified as process specific (the challenges already identified in the Theme by Theme section are not repeated here). These have been used to identify emergent future research topics that could be addressed through fundamental research projects. The full, raw data are available for download at: https://cimcomp.ac.uk/research-landscape.

Summary

The landscaping exercise has identified almost 600 manufacturing challenges across 18 high-rate composite deposition and conversion technologies, classified by their severity. This demonstrates a considerable opportunity for the UK's composites community to develop step-changing solutions through fundamental research. The results of the study have been presented in a way that highlights key trends and drivers, whilst allowing the reader the opportunity to see each challenge collected. It is hoped that these challenges will inspire new research ideas and highlight areas in need of funding allocation and research activity. Classification of the data further shows that a number of challenges (39%) can be considered 'general' rather than process specific. This suggests that there is scope for cross-process data and knowledge sharing to solve some of the challenges presented.

Hub Relevance

The figure below shows the 18 technologies assessed ranked by number of challenges collected (left). In addition, the number of challenges with a severity score of greater than 8 is overlaid. The right side of the figure shows the number of postgraduates and researchers working on Hub funded projects in each of these areas. Comparing the two sides shows that there is a similar trend in both graphs. Hub resources are high in technologies with a greater number of challenges, in particular in automated deposition and preforming which are the two most populated. Comparing resource allocation with areas of need suggests that the research programme is relevant, and that funded projects are responsive to current needs. Understanding the challenges presented in this study will enable the Hub to continue to meet relevant challenges and conduct step-changing research.



Industry Relevance

The landscape focuses primarily on fundamental, low-TRL research which are of direct relevance to industrial needs. Of the 6 dominant themes identified within the data, the majority correspond to pain points cited by industry. Inspection for example, is a critical part of aerospace component manufacturing processes, and is typically conducted as a separate stage at the end of the production line. This adds considerable time and cost, ultimately affecting manufacturing volume. The ability to assess component quality in-line would eliminate this step, streamlining the manufacturing process and delivering real-time quality insight to the operator. This corresponds with the Process Modelling, Design for Manufacture and Industry 4.0 themes, aimed at delivering a fully integrated manufacturing ecosystem. Finally, tooling is an essential part of the manufacturing process but is costly, labour intensive and often has a long lead-time.

Innovation in these areas is directly relevant to industrial needs and offers a pathway to greater integration with the High-Value Manufacturing Catapult Centres, who play a key role in pulling technologies through from low-TRL to commercial readiness.

Results – Theme by Theme

Theme 1 – Process Modelling

16 of the 18 processes analysed mentioned one of the areas captured by the 'Process Modelling' keyword. This was the most popular generic theme and could potentially encompass the following topics:

- Advanced process control
- Simulation techniques
- Simulation accuracy or efficacy
- Process optimisation or Defect detection and analysis

This theme overlaps with both the 'Automation' and 'Design for Manufacture' themes as there is clear synergy between simulation outputs and design tools, whilst automation provides the interface with the manufacturing process itself. Some typical research challenges are shown below (ordered by priority):

Process	Challenge	Priority
2D Weaving	Understanding influence of manufacturing post-processing (e.g. infusion, moulding etc.) on defect introduction	9
2D-3D	Simulation accuracy and reliability for complex components	9
2D-3D	Complex double curvature components	9
AC Prepreg	Accurate process model to avoid springback and avoid the need for shimming	9
ATL-AFP-ADFP	Limited ability to predict optimum processing conditions	9
Compression Moulding	Better understanding and control of draping	9
Compression Moulding	Design of tooling/charge placement to target specific fibre angles and flow	9
Overmoulding	Distortion/warpage control due to unbalanced laminates	9
Overmoulding	Distortion/warpage control due to flow induced fibre alignment	9
TP Stamping	Prediction of defect formation	9
2D-3D	Forming simulation & flattening plies can be an 'art form' not a science	8
2D-3D	Lack of reliable predictive tools - thick preforms, rate effects, temp effects	8
2D-3D	Understanding of forming limits for a given fabric / component geometry	8
ATL-AFP-ADFP	Control of heating profile (heat/cool cycle) within thermoplastic tape laying to control tack & constrain warpage	8
Compression Moulding	Racetracking of charge resulting in weld lines and voids	8
Compression Moulding	Fibre alignment due to flow being poorly understood	8
Compression Moulding	In-mould flow to fill complex areas can result in defects	8
Filament Winding	Availability of a robust programming solution	8
Injection moulding	Viscosity management effects (e.g. incomplete fill, voids, flash)	8
Liquid Resin	Pre-infusion de-risking - low fidelity, fast response simulation needed	8
Overmoulding	Unwanted flow induced alignment due to injection strategy and tool design	8
Overmoulding	Lack of reliable flow-based modelling tools, accounting for fabric inserts	8
RTM	Robust models to predict permeability & resin flow	8
AC Prepreg	Address material and process variability in simulation	7.5
Braiding	Lack of simulation tools to predict fibre path on complex parts	7.5
Discontinuous	Need for robust & reliable predictive models for performance	7.5
OoA Prepreg	Address material and process variability in simulation	7.5
Overmoulding	Sink marks/print through	7.5
2D-3D	Understanding forming parameters to understand defect significance	7
2D-3D	Understanding of time dependency effects on forming rate & quality	7
ATL-AFP-ADFP	Thermal cycle history, early deposited layers experience more heating/cooling cycles leading to degradation	7
Braiding	Accurate thickness prediction tools	7
Compression Moulding	Preferential flow resulting in fracture	7
Injection moulding	Incomplete mould filling	7
Liquid Resin	Air entrapment resulting in dry spots and understanding significance	7
Liquid Resin	Decompaction during infusion leading to unpredictable fibre-volume fraction	7
Multiply preforming	Need for reliable & robust manufacturing process models	7
Overmoulding	Accurate process modelling to predict warpage	7
OoA Prepreg	Process deviations leaving to changes in resin viscosity and reduced void suppression	6.5
2D-3D	Knowledge of defect mechanisms, significance and mitigation required	6
Compression Moulding	Need for models to accurately predict SMC flow	6
Compression Moulding	Structural and physical properties affected by flow-induced phenomena (e.g. fibre bundling)	6
Discontinuous	Fibre alignment due to flow in processing is poorly understood	6
2D Weaving	Control/prediction of fibre architecture upon draping over complex geometry	5
Braiding	Lack of virtual machines	5
Compression Moulding	Impact of charge location	5
Compression Moulding	How to move weld line location? Flow management required	5
Injection moulding	Fibre orientation due to flow	5
Injection moulding	Formation of weld lines	5
AC Prepreg	Poor/non-industrialised tools for predicting creep/deformation of plies within autoclave	4
Discontinuous	Material wastage due to overspray (poor fibre positional control)	4
Injection moulding	Void and cavitation control required	4
Multiply preforming	Optimised cutting to reduce wastage and improve nesting efficiency	4
Pultrusion	Complex thermomechanical models required to simulate process	3

It's obvious from this wide range of challenges that improved process models are required for all steps of the composite production chain. Some of the lack of optimisation could be overcome by a simple increase in simulation speed to allow more automated operation of the simulation process. Other areas relate to needing to capture more of the physics of the process or to capture aspects such as material variability. Most of these areas are being addressed by current research but the table above does indicate some priority areas:

- Improved distortion modelling to support advanced laminate designs or complex geometries which have complex orientation fields (e.g. those created by flow induced alignment)
- Improved understanding of defect generation methods and their incorporation into process models so that their impact can be assessed rapidly
- Development of inverse models for a variety of processes - forming / charge location, tool design, cure cycle optimisation etc.

Theme 2 – Automation/Hardware/Robotics

16 of the 18 processes analysed mentioned one of the areas captured by the 'Automation/Hardware/Robotics' keyword. This area could encompass the following topics:

- Advanced process control
- Automation programming & Hardware setup
- Hardware operation parameters (e.g. accuracy, component size etc.)
- Increasing production rate
- Manufacturing process flexibility

Some typical research challenges are shown below:

Process	Challenge	Priority
2D-3D	Forming system development - DDF, DF etc.	10
RTM	Need for an efficient & high-rate preforming process prior to moulding	9.5
Compression Moulding	Need for an efficient preforming process prior to moulding	9
RTM	Process and tool design for net-shape moulding	9
2D-3D	Flexible manufacturing processes at a large scale to cope with a range of performance related microstructures	8
2D-3D	Pick-and-place speed and accuracy need improvement	8
3D Weaving	Weaving at rates in line with other processes	8
AC Prepreg	Difficult to automate or replicate lamination process maintaining flexibility	8
ATL-AFP-ADFP	Time to load machine	8
2D Weaving	Multi-axial weavability (machine modification required)	7
2D-3D	Lack of flexibility of bespoke hardware	7
AC Prepreg	Automated layup of high-performance thermoplastics	7
Multiply preforming	Programmability, flexibility & versatility of automated handling equipment	7
TP Stamping	Tailored blanks manufactured in high volumes/rates	7
AC Prepreg	Automated deposition of fabric materials	6.5
OoA Prepreg	Automated deposition of prepreg materials	6.5
2D Weaving	Time to load fibres into machine	6
2D Weaving	Slow deposition rates (compared with other processes e.g. NCF)	6
2D Weaving	High levels of automation limited to relatively simple planar parts	6
Braiding	Slow machine reversal to create ply drops	6
Multiply preforming	Automated manufacturability of fillers for curved/joint interface (e.g. skin stringers)	6
ATL-AFP-ADFP	Axis speed & acceleration limits, TCP speed & acceleration limits	5.5
Braiding	Fibre deposition rate severely affected by changes in curvature and cross-section	5.5
ATL-AFP-ADFP	Hardware accuracy (knowledge of TCP position)	5
ATL-AFP-ADFP	Low deposition head speed limit	5
Non-wovens	Large amounts of machine downtime (typically XXkg/hr compared to YYkg/hr for weaving)	5
Pultrusion	Long set up times - not suitable for short production runs	5
Liquid Resin	Long preparation time prior to infusion (e.g. bagging)	4.5
2D-3D	Limited ability to correct fibre placement on the fly	4
ATL-AFP-ADFP	Hardware rigidity limits part accuracy	4
Filament Winding	Touch labour required to initiate and terminate winding	3
Overmoulding	Transition from heating platform to press or minimising distance	3
OoA Prepreg	Ability to handle out-of-autoclave materials	2.5
Pultrusion	Dedicated machinery required	2

Automation is typically viewed as an area for higher TRL investigation. Many of the challenges in the table above could be addressed by incremental improvements of existing processes. Some potential areas of investigation are in the area of real-time control, design of flexible / reconfigurable manufacturing systems for composites and the incorporation of e.g. global metrology systems. Many of the rate-related issues should be dealt with through improved process modelling.

Theme 3 – Tooling Development

Although there are manufacturing process-specific issues for tooling design there may be value in a general effort to improve composite tooling design and manufacture. Tooling was the third highest ranked keyword and featured in the research challenges for 11 out of 18 processes.

Process	Challenge	Priority
Overmoulding	Rapid heating/cooling of tooling needed	10
Compression Moulding	Twist of tooling resulting in male & female tool parts misaligning and fighting the press	9
RTM	High tool cost & lead time	9
RTM	Versatility and modularity of tooling	9
Compression Moulding	Intelligent, conforming tooling to adapt with the part during moulding to limit shrinkage	8
Compression Moulding	Low cost tooling needed for prototypes/small production runs	8
Liquid Resin	Faster/smarter heating and cooling	8
Overmoulding	High complexity (therefore cost) of tooling	8
Overmoulding	Poor control of temperature distribution within tooling	8
RTM	Tooling design to optimise tool closure during Gap RTM	8
TP Stamping	Higher tooling & processing costs compared with thermoset materials	8
TP Stamping	Tooling/process design to reduce forming forces and improve component quality	8
Compression Moulding	Optimised tool design required for compaction pressure and temperature management	7
Compression Moulding	Durability and versatility of tooling	7
Liquid Resin	Rapid heating & cooling of tooling required when using snap-cure resins	7
RTM	Optimised tool design for predictable flow	7
RTM	Need for optimised vent/gate design to produce a peripheral vacuum	6.5
RTM	Tool design for complex geometry (e.g. sliding tools)	6
RTM	Tooling design - how to compensate for tolerances of preform weight and dose volume	6
Discontinuous	Weak tooling supply chain & design understanding of tool features	5
Liquid Resin	Specific infusion tooling design	5
3D Weaving	Need for bespoke preform handling rigs	4
Pultrusion	Tooling heating, especially for floating mandrel can limit rate	4
Liquid Resin	Spatial management of heating within tool required to enhance flow, curing and stresses	3
AC Prepreg	Tailored heated tooling	2.5
OoA Prepreg	Tailored heated tooling required	2.5
2D-3D	High cost of tooling	2
Compression Moulding	Thermal expansion, tooling geometry	2
Compression Moulding	Tooling wear over lifetime of project	2
Pultrusion	Tooling wear	2

Tooling is a highly experienced-based industry with high costs due one-off production, costly raw materials alongside a lack of predictive tools. The data above suggests that there is a need for new tooling concepts (particularly in the area of tool heating) and cost reduction as well as improved predictive models for thermal expansion and thermal conductivity aspects. Many of the other areas are covered by the process modelling theme (e.g. a reduction in clamping forces through better understanding of charge behaviour).

Theme 4 – Design for Manufacture

Design for Manufacture (DFM) challenges are reflected in 9 out of 18 process areas. This area includes challenges relating to:

- Process applications
- Component geometry
- Material processing parameters (e.g. permeability, drapeability)
- Post-processing challenges (e.g. spring-back, shrinkage)

Process	Challenge	Priority
2D-3D	Understanding mixed-material architectures to optimise component structure	10
2D-3D	Limited information on geometrical constraints	10
3D Weaving	Need for reliable cost models for 3D weaving business case	10
ATL-AFP-ADFP	Lack of DFM database – limited part applicability prediction	10
ATL-AFP-ADFP	Understanding sectoral limitations and understanding potential applications	10
2D-3D	Design for manufacturing to optimise nesting and architecture	9
ATL-AFP-ADFP	Permeability not well characterised	9
ATL-AFP-ADFP	Cost benefits of dry fibre need better understanding	9
Braiding	Lack of structural optimisation tools considering braiding manufacturing constraints	9
Discontinuous	Limited DFM database - limited part applicability	9
Multiply preforming	Robust & reliable predictive simulation models for part performance	9
2D-3D	Lack of DFM database – limited part applicability prediction	8.5
ATL-AFP-ADFP	Lack of reliable cost modelling tools for part cost prediction	8
ATL-AFP-ADFP	Need for design & analysis tools for TFP parts	8
Braiding	Need to understand complexity of structures that can be braided	8
Liquid Resin	Understanding defect significance (especially resin-rich areas)	8

Overmoulding	Tooling/process design to reduce forming forces and improve component quality	8
2D-3D	Overreliance on performance or rate-driven design, rather than manufacturing-driven	7
ATL-AFP-ADFP	Need design tools for TFP parts that drape 'severely'	7
Liquid Resin	Micro voids leading to performance reduction	7
Compression Moulding	Part shrinkage and spring-back	6.5
Braiding	Permeability low and not well characterised	6
Overmoulding	Simulation tools to compensate injection mould tools to account for shrinkage	6
Discontinuous	Understanding of geometric features to stiffen and 'hold flat'	4
Multiply preforming	Comparable joint design	4
ATL-AFP-ADFP	Uncertainty over process flow options e.g. - 2D + drape or 3D?	3

DFM covers a large area, but the challenges can be split into property / performance characterisation and process capability. There is a clear need for cost-based models which allow more accurate process selection and optimisation. This would necessarily include detailed models of process capability in order to allow assessment of part/process compatibility. Many of the other challenges are also related with the process modelling theme.

Theme 5 – Industry 4.0 & Digitalisation

9 of the 18 processes analysed mentioned one of the areas captured by the 'Industry 4.0' keyword. This area could encompass the following topics:

- Advanced process control
- Machine learning, Artificial Intelligence
- Digital & Digitalisation
- Other areas under the Industry 4.0 umbrella - Big Data & Analytics, Digital Twin, Location detection, Human machine interfaces – including Augmented Reality and Virtual Reality, Smart machines & systems

This theme overlaps with general automation hardware since this is the interface with the actual manufacturing process. Some typical research challenges are shown below:

Process	**Challenge**	**Priority**
ATL-AFP-ADFP	High levels of machine stand-still during process	10
AC Prepreg	Automation mimicking laminator -know how	9
AC Prepreg	Material quality along tape lengths to reduce waste	9
Liquid Resin	Flow front management	9
ATL-AFP-ADFP	Course thickness inconsistency & bulk factor	8
RTM	Need for more intelligent flow and pressure management	8
ATL-AFP-ADFP	Limited ability to adjust process on the fly	7
Non-wovens	Consistency of material production (e.g. gaps)	7
TP Stamping	Forming of thick blanks (process control)	7
AC Prepreg	Consistent resin impregnation	6
ATL-AFP-ADFP	Programming route not i4.0 compatible	6
ATL-AFP-ADFP	Limited part production accuracy	6
Liquid Resin	Optimisation of infusion strategy for sector specific applications	6
2D-3D	Machine learning	5
ATL-AFP-ADFP	Data rate for sensors & network	5
ATL-AFP-ADFP	Big data and data processing in real time	5
ATL-AFP-ADFP	Processing speed – synchronisation of motion & sensor data	5
ATL-AFP-ADFP	Inconsistency of tape width	5
Liquid Resin	Mix ratio control & verification for aero certification	5
Filament Winding	Winding speed dependent on fibre placement accuracy required - limited to 30m per min for precise requirements	4
RTM	Preform variability	4
Pultrusion	High scrap levels during machine setup and calibration	3

Some suggested areas for research investigation are given below:

- Improvements in machine reliability – develop intelligent machine learning based algorithms for defect prediction
- Automation process capability mapping – rapid determination of applicability of particular parts to a range of processes
- More intelligent processes - Development of real-time control methods and optimisation strategies
- Increased use of the capabilities of new industrial control systems to increase data rate and potential for machine learning
- Process agnostic online quality assessment

Theme 6 – Metrology, Sensing & Inspection

12 out of 18 technologies included some form of inspection challenge whether related to in-process, or off-line inspection. Challenges in this area include:

- Quality inspection
- Tolerance
- Positional accuracy of the manufacturing process
- Surface finish
- Defect detection

Process	Challenge	Priority
2D-3D	Part inspection during deposition	9
3D Weaving	Inline fabric defect and quality monitoring	9
Multiply preforming	Positional accuracy of placement	9
Multiply preforming	Gap/overlap tolerance	9
Multiply preforming	Correct fibre angles after laydown	9
Non-wovens	Inline fabric defect and quality monitoring	9
2D Weaving	Inline fabric defect monitoring	8.5
ATL-AFP-ADFP	Need for part inspection during deposition	8
Braiding	Inline defect detection	8
Braiding	In-line fibre breakage detection system	8
Multiply preforming	Preform inspection	7.5
2D Weaving	Need a digital system to measure and confirm visual quality of finish	7
Braiding	Lack of inline sensing for fibre angle	7
Liquid Resin	LRI specific NDT & defect characterisation	7
RTM	Cavity pressure management and monitoring (wet press)	7
AC Prepreg	Online inspection	6.5
OoA Prepreg	Online inspection	6.5
TP Stamping	Monitoring of temperature through the thickness	6.5
2D-3D	Part inspection during and after forming	6
Multiply preforming	Need accuracy of measurement to ensure reduction in variability	6
RTM	In-process cure monitoring	5
Braiding	Voids and defects	4

Metrology challenges can be split into sensor development, data reduction and the development of methods to enable correction of the process. Development of sensors is widespread across manufacturing and composites implementation should focus on the specific challenges of

- Composite specific sensing methods
- Edge / feature detection with difficult to image dry fibre materials
- Incorporation of metrology systems into existing processes (AFP, Curing process, braiding)
- Development of methods to correct processes in real-time – e.g. multi-ply preforming, 3D Weaving

Results – Process by Process

Multi-ply preforming

Introduction

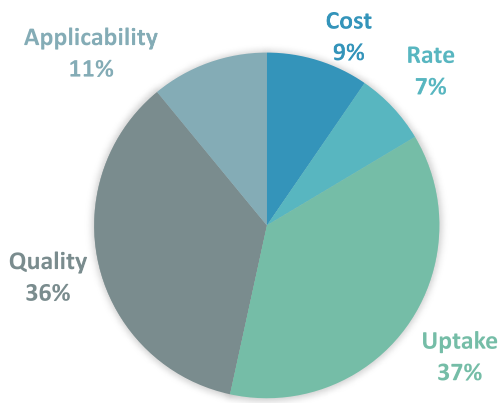
Multi-ply preforming encompasses all aspects of the preforming process including cutting, joining, handling and the automation of these areas. 46 challenges were captured for this process, there is some overlap with the 2D-3D preforming process and hence some potential synergy. Most severe challenges were as follows (these were all ranked with a severity of 9):

- Repeatability of the process
- Gripper configuration & optimisation to improve flexibility and reduce disturbance of other plies
- Need for high-rate binder application
- Positional accuracy of placement
- Gap / overlap tolerance
- Correct fibre angles after laydown
- Manufacturability of integrated parts with elastic tailoring
- Robust and reliable predictive simulation models for part performance

Future research areas

The following list of potential research themes is based on the process-specific areas listed in the table below and is ordered by perceived TRL with fundamental science closer to the top.

- Handling of low shear resistance materials – maintaining tension in automated processes and gripping process optimisation
- Improved understanding of the fundamental mechanisms of binder / material interaction
- Improved understanding of final part performance including joint permeability and structural integrity
- Parts integration and multi-material formats



Analysis

22% of challenges were rated as 'out of scope', 28% process-specific and 50% potentially general and of interest to several processes. The most severe challenges listed above appear to be process specific with many of the lower severity challenges finding their way into the generic themes of Material Handling and Metrology, Inspection & Sensing (see previous section).

Raw data – Process-specific challenges only

Area	Challenge	Current	Cost	Rate	Uptake	Quality	Applicability
Machine hardware	Handling of low shear resistance materials	6			•	•	
	Need to maintaining fabric tension to avoid defect introduction	8			•	•	
	Repeatability of process	8.5			•	•	
	Gripper configuration and optimisation to improve flexibility and reduce disturbance of other plies	9			•	•	
	Slow cycle hold times for thermoset binder heating and cooling	5		•			
	Defect introduction from cutting tool contact	3			•	•	
Material format	Need for continuously steered 3D fibres	5.5			•		•
Material deposition	Poor understanding of inter-ply shear with or without TTR/stitching	5.5				•	
	Edge of ply stability	3				•	
Part applicability & geometry	Limit to scale of component that can be handled	8			•		
	Thermal pre-stressing to eliminate spring-back in formed components	5				•	
	Manufacturability of integrated parts with elastic-tailoring	9			•		•
	Better understanding of 3D reinforcement in regions of high-curvature	6			•	•	•
	Need for improved shear control from the material boundary	7				•	
	Understanding of joint permeability for downstream processing	7				•	•

2D – 3D Preforming

Introduction

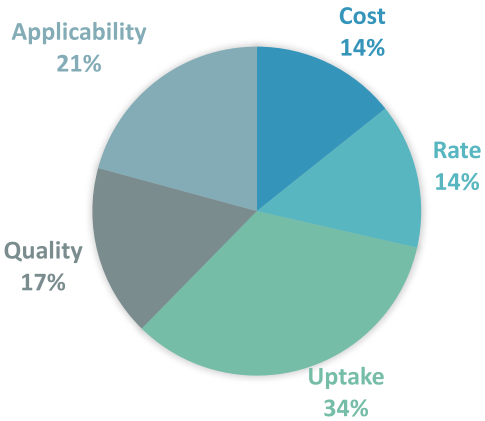
2D-3D Preforming includes processes related to the automated net-shape or near-net-shape preforming of fabrics for subsequent moulding or infusion. 48 challenges were captured for this process, there is some overlap with the multiply preforming challenges and hence some potential synergy. Most severe challenges were as follows (these were all rated 9):

- Gripping/clamping arrangements to improve controlled material draw
- Forming system development
- Simulation accuracy and reliability for complex components
- Tooling/process design to reduce forming forces and improve component quality
- Understanding mixed-material architectures to optimise component structure
- Need for net shape processes
- Limited information on geometrical constraints
- Delivery of complex double curvature components
- Part inspection during deposition
- Design for manufacturing to optimise nesting and architecture
- Waste 'build-up' during processing

Future research areas

The following list of potential research themes is based on the process-specific areas and is ordered by perceived TRL with fundamental science closer to the top:

- Understanding of the impact of forming on permeability and structural performance
- Forming of complex multi-material stacked structures including sandwich cores
- One-shot forming of thick preform stacks over complex geometry
- Prediction improvement to reduce waste and improve net-shape performance



Analysis

13% of challenges were out of scope, 21% process-specific and 67% potentially general and of interest to several processes. Many of the general challenges relate to Process Modelling and Material Handling themes.

Raw data – Process-specific challenges only

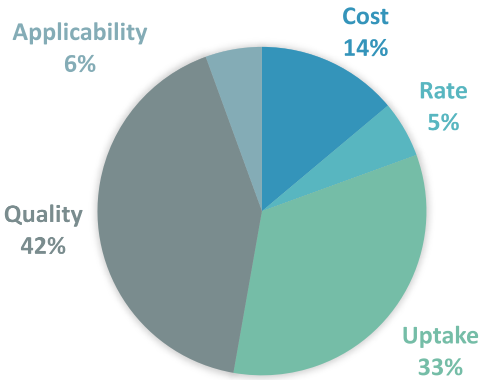
Area	Challenge	Current	Cost	Rate	Uptake	Quality	Applicability
Machine hardware	Need for forced cooling to increase throughput and control distortion	5		•			
	Gripping/clamping arrangements to improve controlled material draw	9	•	•	•		
	Heating mechanisms for TP and prepreg - reduce cycle time, improve uniformity	5		•			
	Tooling/process design to reduce forming forces and improve component quality	9			•		•
Material format	Understanding of Inter-ply friction effects to improve forming of multi-ply preforms	8			•		
	Sandwich panel forming without core crushing/thinning	9	•	•			•
	Tailored preform with variable thickness	6					•
	Effects of material behaviour during preforming on VF	7				•	
	Tolerance stack up and influence on VF/infusability	7					•
Material deposition	Accuracy of ply placement for large components	5			•	•	

2D Weaving

Introduction

2D Weaving refers to processes which involve the weaving of two orthogonal sets of yarns, warp 0° and weft 90°. 26 challenges were captured for this process, there is overlap with the 3D Weaving process. Most severe challenges were as follows (these were all rated 9):

- Inline fabric defect monitoring
- Need for high tow-count weaving without reducing mechanical properties
- Understanding influence of manufacturing post-processing on defect introduction
- Understanding performance benefits of mixed-material weaving



Future research areas

The following areas are suggested as potential future research:

- Detailed models of how fibre / tow performance is affected by the weaving process
- Enhanced models of fibre-fibre interactions at the meso scale
- Development of existing processes to improve handling of high tow count materials

Analysis

31% of challenges were out of scope, 38% process-specific and 31% potentially general and of interest to several processes. Most of the process-specific challenges identified relate to material format and lie on the interface between material and manufacturing – this is clearly a key area for weaving processes.

Raw data – Process-specific challenges only

Area	Challenge	Current	Cost	Rate	Uptake	Quality	Applicability
Machine hardware	Limited in-plane fibre orientations due to current weaving looms	4.5			•		
	Material variability due to defects caused by handling/shipping	6.5				•	
Material format	Crimp introduced during yarn interlocking - reduced in-plane mechanical performance	6				•	
	Crimp introduced during yarn interlocking - affected out-of-plane mechanical performance	7				•	
	Material is unstable around cut edges, leading to variability and increased waste (EOP vs MEOP)	4				•	
	Print through on cosmetic/painted surfaces due to fibre crimp	2				•	
	Need for high tow-count weaving without reducing mechanical properties	9	•			•	
	Understanding performance benefits of mixed-material weaving	8			•		•
Material deposition	Yarn abrasion due to continuous tension variations	4.5			•		•
Part applicability & geometry	Structures produced from 2D fabrics are prone to delamination and local disbonding	7				•	

3D Weaving

Introduction

3D Weaving includes processes involving the weaving of weft, warp and binder fibres in the X, Y and Z directions. 27 challenges were captured for this process, there is some overlap with the 2D Weaving process and hence some potential synergy.

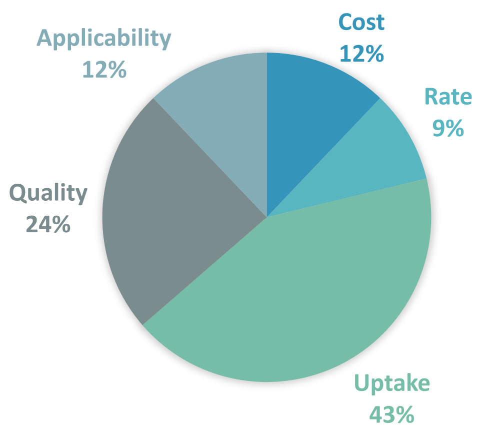
Most severe challenges were as follows:

- Need for reliable cost models for 3D weaving business case (score & location)
- Inline fabric defect and quality monitoring
- Need for accurate tension control
- Time to load machine

Future research areas

See also suggestions for 2D weaving above.

- Development of automated loading / changeover processes for existing looms – improve ability to rapidly reconfigure or change designs
- Understanding process capability – where is the optimum window of opportunity for this process?



Analysis

11% of challenges were out of scope, 56% process-specific and 33% potentially general and of interest to several processes. As with 2D weaving, most of the challenges relate to material issues

Raw data – Process-specific challenges only

Area	Challenge	Current	Cost	Rate	Uptake	Quality	Applicability
Infrastructure & environment	Need a large space for the machine	6	•				
Machine hardware	Width restriction of fixed weaving area	3.5			•		
	Time to load machine	9		•			
	Need for automated loading of fibres - adopting textile processes into composites manufacture	7			•		
	Infuence of weaving geometry on fibre degradation	4				•	
Material format	Crimp introduced during yarn interlocking = reduced inplane mechanical performance	5.5				•	•
	Need to understand links between weave design and permeability	6.5				•	
	Understanding performance benefits of mixed-material weaving	8			•		•
	Ability to weave fibres at ±45°	7			•		•
	Formation of large resin rich regions	5				•	
	Micro-cracking of matrix around z-fibres and understanding their extent	6				•	
	What are best practice edge stabilisation techniques	8			•		
	Understand impact of toughness/impact resistance	3					•
Material deposition	Yarn abrasion due to continuous tension variations	5				•	
Part applicability &	Understanding preform geometry - what is the machine capable of?	8			•		

Braiding

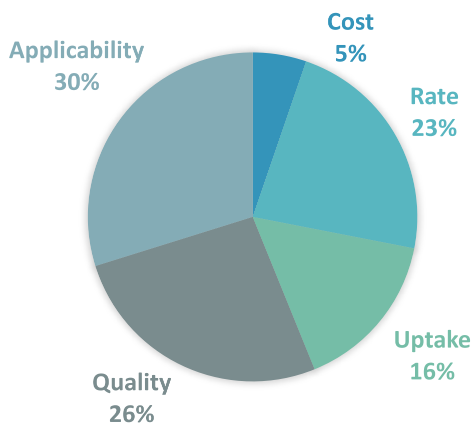
Introduction

Braiding includes both the biaxial and triaxial braiding of fibres into a preform. 47 challenges were captured for this process. Most severe challenges were as follows:

- Lack of structural optimisation tools considering braiding manufacturing constraints
- High level of investment required for large structures
- Need to understand complexity of structures that can be braided
- Time to load machine
- Inline defect detection
- In-line fibre breakage detection system
- Fibre fuzzing and fibre damage
- Lack of simulation tools to predict fibre path on complex parts

Future research areas

See also development areas proposed for 3D Weaving – these processes share issues with automation and materials handling. There is also the opportunity for some work developing physics-based process models for braiding including fibre path simulation and property knock-downs for materials as they are deposited.



Analysis

2% of challenges were out of scope, the majority of challenges identified (70%) were braiding-specific and 28% potentially general and of interest to several processes. Challenges are equally spread between the areas and machine hardware has a number of issues related to downtime or machine loading. Many of the issues are related to continuous operation to achieve high rate on real parts.

Raw data – Process-specific challenges only

Area	Challenge	Current	Cost	Rate	Uptake	Quality	Applicability
Machine hardware	Time to load machine	8		•			
	High levels of machine downtime	6		•			
	Lack of automated bobbin change overs or fibre splicing	6		•			
	Time to load a mandrel and gather fibres to initiate braid	5		•			•
	Time to terminate a part and remove mandrel	5		•			•
	Limited processing speed due to rotary inertia of bobbins	4		•			
	Lack of remote bobbins/creels off the machine	5		•			
	Bobbin capacity - larger increases rate but also cost	8	•	•			
	Mandrel manipulation through the braider, esp. if mandrels are weak/flexible	7			•		
Material format	Ability to use spread tow to produce low areal weight preforms	7				•	
	Ability to use stiff preimpregnated fibres to avoid resin infusion stage	7		•		•	
	Excessive bulk factor/crimp, preventing mould closure	6				•	
	Tension control of fibres can impact on visual quality of preform	5				•	
	Processability of comingled yarns	7					•
	Hybrid braiding of other materials e.g. wires, shape memory alloys, sensors etc.	7					•
	Comingled CF/TP braids have high bulk factors, limiting control of defects, wrinkles	7				•	•
Material deposition	Fibre fixation on the mandrel to prevent slippage	7				•	
	Lack of fibres in the hoop direction (90°)	6					•
	Dependency on resin infusion step - Can resin be introduced cost effectively at the braiding stage?	8		•			•
	Lack of inline curing	3		•			•
	Multi-ply tooling solutions	8					
	Braiding preforms which require post-braid shaping operation before moulding	5					•
	Mandrel wear in slip regions	3	•				
	Mandrel surface materials to aid slip/grip	3			•		
	Stability of fibre angles when off mandrel	2				•	
	Anchoring at start/end of a braid path	1			•		
Part applicability & geometry	Poor geometric accuracy	7				•	•
	High specific density of mandrel materials to resist crushing	5					•
	Ability to produce open-sections	7					•
	Issues with near-90° bends	8					•
	Integration of insert e.g. holes, near net-shape	6			•		
	Combined braiding with 3D stitching	7			•		
	Differential between inner & outer arc length creates VF differential	5				•	

Discontinuous Fibre formats

Introduction

Discontinuous Fibre Formats refer to the use of discontinuous architectures, either as a mat, or as chopped fibres. 23 challenges were captured for this process.

Most severe challenges were as follows:

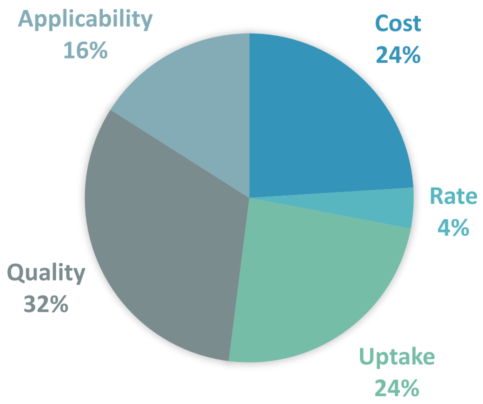
- A limited design-for-manufacturing database limiting part applicability
- Robust and reliable predictive simulation models for part performance
- High material variability, leading to mechanical property variations (±20%)
- Size and scale dependencies. Poor mechanical properties for thin structures
- Limited mechanical strength, due to fibre stress concentrations
- Formability of discontinuous fibre systems with non-standard angles
- Low cost AFP tapes from discontinuous long fibres
- Use of NCF offcuts

Future research areas

The following list is based on the process-specific areas and is ranked by perceived TRL with fundamental science closer to the top. Many of the issues with discontinuous fibre composites relate to the stochastic nature of the material and the prediction of properties for real applications (e.g. design data or basis values) as well as the certification of these materials in high performance applications. Discontinuous fibre formats are a potential avenue of reuse for fibres recovered from recycling processes but the area captures a wide variety of scales from platelet style meso-scale materials down to single fibre formats.

- Multi-physics simulations approaches capturing multiple effects simultaneously e.g. fibre flow and mechanical performance
- A certification process which captures the stochastic nature of discontinuous fibre formats
- Development of a dedicated fibre formats for discontinuous materials – including AFP
- Development of processes able to use recovered fibres or NCF trim scrap in high performance applications

Analysis



13% of challenges were out of scope, 57% process-specific and 30% potentially general and of interest to several processes. A large number of the challenges are related to quality due to the stochastic nature of the materials.

Raw data – Process-specific challenges only

Area	Challenge	Current	Cost	Rate	Uptake	Quality	Applicability
Machine hardware	Machine down-time due to fibre blockages	7	•				
Material format	Low permeability, leading to high void content (>1%)	7			•	•	
	High material variability, leading to mechanical property variations (±20%)	9				•	
	Size and scale dependencies. Poor mechanical properties for thin structures	8			•	•	
	No dedicated carbon fibre chopper rovings - poor distribution and wetout	3				•	
	Limited mechanical strength, due to fibre stress concentrations	8			•	•	
	Limited ceiling fibre volume fraction (ca.55%)	7			•	•	
	Formability of discontinuous fibre systems with non-standard angles	8					•
	Poor understanding of flow in process. Poor flow for long fibres	6					•
	Low fibre alignment (different to control)	6				•	
	Use of recyclate	6	•				
	Impact of tooling surface roughness on material flow	2		•			
	Low cost AFP tapes from discontinuous long fibres	8	•				
	Use of NCF offcuts	8	•				

Non-wovens

Introduction

Non-wovens encompass all manufacturing using non-woven fabrics, including non-crimp fabrics (NCF). 27 challenges were captured for this process.

Most severe challenges were as follows:

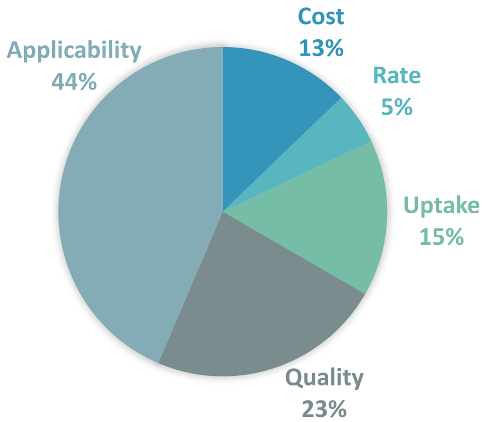
- Inline fabric defect and quality monitoring
- Complexity of forming due to intra-ply stitches
- Asymmetric shear behaviour due to some stitch patterns
- Limited suitability for net-shape preforming (i.e. waste)

Future research areas

The following list is based on the process-specific areas and is ranked by perceived TRL with fundamental science closer to the top.

- Stitch placement optimisation methods
- Improved models for forming behaviour (speed, accuracy, ability to handle large material stacks)
- Developing routes for re-use of edge trim waste
- Improved understanding of the process window for NCF materials

Analysis



19% of challenges were out of scope, 63% process-specific and 19% potentially general and of interest to several processes.

Raw data – Process-specific challenges only

Area	Challenge	Current	Cost	Rate	Uptake	Quality	Applicability
Machine hardware	Improve machine design to improve flexibility of layer angles	4					•
	Consistent stitch tensioning on wide format material	6					•
Material format	Potential for fibre breakage during intra-ply stitching	8		•		•	
	Reduction in in-plane properties due to stitch	9				•	
	Limited standard fibre orientations (0/90, ±45....), rather than non-standard angles (some machine	9			•		•
	Complexity of forming due to intra-ply stitches	6				•	•
	Asymmetric shear behaviour due to some stitch patterns	4				•	•
	Choice of stitch material to suit mechanical performance	8					•
	Impact performance not well understood	7			•		•
	Understanding performance benefits of mixed-material non-wovens	8			•		•
	Spreading the 0 deg fibres	7					•
	Theoretical VF limit (glass ceiling)	8				•	
	Material format width limits (large component applicability)	8					•
	Wide tolerance on thickness	8				•	•
Material deposition	High material wastage due to machine trim waste (outside of edge stitch)	6.5	•				
	Limited suitability for net-shape preforming (i.e. waste)	10	•				•
	Formability vs stability of ply geometry in handling/depositing	7					•

Automated Deposition

Introduction

Automated deposition encompasses technologies such as ATL, AFP and ADFP which deposit tapes or fibres onto a tool or substrate. 55 challenges were captured for this process, many of them are general and appear in the research themes section.

Most severe challenges were as follows:

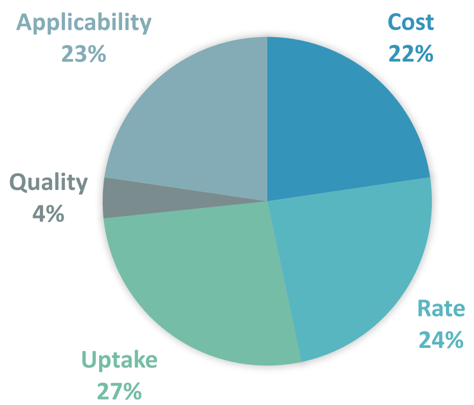
- Repeatability of the process
- Level of investment required - tool and hardware
- Lack of DFM database – limited part applicability prediction
- High levels of machine stand-still during process
- Lack of standardisation of AFP machine systems & interfaces
- Fibre fuzzing
- Permeability not well characterised
- Material is expensive
- Lack of standard material architecture for dry fibre
- Cost benefits of dry fibre need better understanding
- Limited ability to predict optimum processing conditions
- Layup and production rates are low
- Understanding sectoral limitations and understanding potential applications

Future research areas

- Steering – developing more steerable materials and developing better models of steering behaviour
- Improved simulation tools for the infusion step
- Development of a manufacturer-neutral assessment of different in-process heating methods
- Physics based models of material relaxation and tack behaviour with a view to speeding-up deposition

Analysis

15% of challenges were out of scope, 27% process-specific and 58% potentially general and of interest to several processes. Quality appears to be of little concern but the other areas of applicability, cost, uptake and rate are equally split.



Raw data – Process-specific challenges only

Area	Challenge	Current	Cost	Rate	Uptake	Quality	Applicability
Material format	Addition of veil leads to less steerable material	7					•
	Lack of steerability of material	7					•
	Resin-rich areas in stiched UD tow-preg	6.5			•		
	Secondary processes to tape vs online activities (e.g. binder application)	7	•				
	Effect of stitch mat & quantity not understood in TFP, especially on bottom surface of base matl	8					•
Material deposition	Tack level required and tack changes with rate	7		•			
	Shear stiffness of material limits steering capability	8					•
	Heating mechanisms – lack of understanding of relative advantages/disadvantages of each	7			•		
	Stitch material remains in moulded part in TFP	7				•	
Part applicability & geometry	Layup and production rates are low	10		•			
	Issues with corners	7					•
	Infusion step lengthy, risky and limited simulation capability	8		•	•		
	Lack of information on geometrical capabilities	6			•		•
	Limited understanding of material relaxation resutling in need for part inspection after deposition	5	•	•			
	Limited ability to steer	5					•

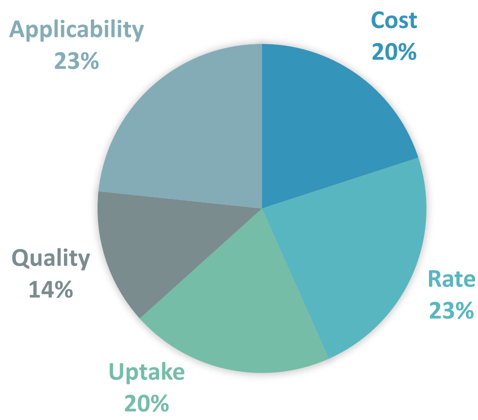
Pultrusion

Introduction

Pultrusion encompasses the continuous manufacturing of constant-profile composites components. 24 challenges were captured for this process.

Most severe challenges were as follows:

- 1-3 m/min maximum rate. Multiple machines required to meet demand
- Ability to use CF/PEEK



Future research areas

- Improved thermo-chemical models for shrinkage-induced dimensional changes
- Dynamic flow models that capture thermal and chemical effects during wet-out to improve rate and applicability of more varied materials
- Fundamental exploration of post-forming step – assessment of applicability to certain shapes and thicknesses of material

Analysis

17% of challenges were out of scope, 58% process-specific and 25% potentially general and of interest to several processes. Many of the challenges are low severity due to the relative maturity of the process.

Raw data – Process-specific challenges only

Area	Challenge	Current	Cost	Rate	Uptake	Quality	Applicability
Infrastructure & Environment	Volatile emissions	3			•		
Material format	Anisotropic material properties	2					•
	Poor control of resin content	3				•	
	Fabric plies need to be tailored to the dimensions of the component	3	•				
	Understanding use of various fibre formats/webs for feed stability	6			•		
	Heating/cooling rates for TP injection (in situ polymerisation)	5		•			
Material deposition	Pulling speed is dependent on the reaction time of the resin	3		•			
	Asymmetric designs may cause bending during cooling phase	7				•	
	Poor fibre impregnation	4.5				•	
	Dimensional tolerance - pultruded sections typically not straight	7				•	•
	Rate dependent on part thickness	5		•			•
	1-3m/min max. rate. Multiple machines required to meet demand	8		•			
	Ability to use CF/PEEK	8					•
Part applicability & geometry	Post-forming processes following pultrusion	7					•

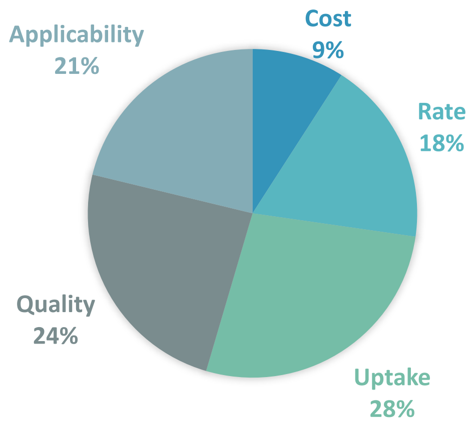
Filament Winding

Introduction

Filament Winding encompasses the winding of filaments, tows, yarns or tapes under tension over a rotating mandrel. 27 challenges were captured for this process.

Most severe challenges were as follows:

- Mandrel extraction limits geometry or increases cost
- Low viscosity resins required leading to lower mechanical properties
- Limit to how much the tow can be spread due to continuous tension
- Availability of a robust programming solution



Future research areas

Future research on Filament Winding should focus on increasing part performance and widening part applicability. They are also potential research areas in determining fibre performance knockdown during deposition (see also Braiding). Increasing the capability of the process to produce a greater range of parts may also require some fundamental research. There is also opportunity for new process development.

Analysis

7% of challenges were out of scope, the majority (81%) process-specific and 11% potentially general and of interest to several processes. Despite the relative maturity of the process Uptake is still viewed as a major barrier.

Raw data – Process-specific challenges only

Area	Challenge	Current	Cost	Rate	Uptake	Quality	Applicability
Machine hardware	Separate oven-cure step required	4		•			
	Mandrel extraction limits geometry or increases cost	8	•				•
Material format	Doesn't support diverse fibre types	7			•		
	High surface porosity	7				•	
	Low viscosity resins required leading to lower mechanical properties	8				•	
	Dependency on using solvents to clean equipment between batches	3	•	•			
	Fibre damage during dry fibre winding	6				•	
	Need for diverse resin types	6					•
	Need for co-mingled CF/Thermoplastics	5					•
Material deposition	Unable to wind reverse curvature	5			•		•
	Unable to easily change fibre path within a layer	5			•		
	Difficult to place fibres parallel to the mandrel axis (min 10deg required)	7			•	•	
	Batch processing due to limited resin pot life	3			•		
	Limit to how much the tow can be spread due to continuous tension	8		•	•		
Part applicability & geometry	Poor external surface finish	3				•	
	Poor material uniformity	6				•	
	Mandrel deflection for large structures	3					•
	Short life for collapsible mandrels to facilitate complex components	3	•				
	High residual stresses due to fibre winding tension, leading to fibre buckling at ID.	7				•	
	Residual fibre stresses due to mandrel expansion during cure	6				•	
	Lmited part applicability - closed section, cylindrical or prismatic	7					•
	Typically used for thicker structures - not applicable for thinwalled parts	5			•		•

Overmoulding

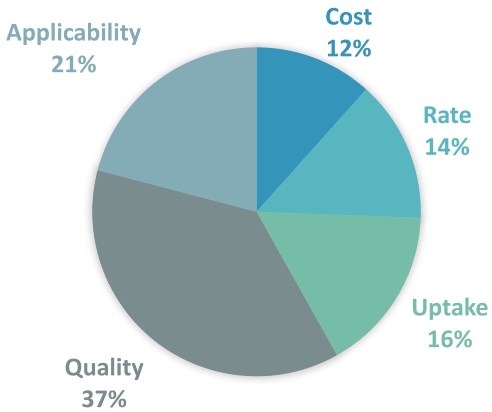
Introduction

Overmoulding is a relatively new process that encompasses injection moulding thermoplastic polymer (which may or may not be fibre reinforced) over a layered continuous composite fibre reinforcement. 33 challenges were captured for this process.

Most severe challenges were as follows:

- Heating mechanisms for TP and prepreg - reduce cycle time, improve uniformity
- Rapid heating/cooling of tooling needed
- Metal part introduction and tooling for multi-material components

- Organosheet is uniform thickness - needs ramps etc.
- Distortion/warpage control due to unbalanced laminates
- Distortion/warpage control due to flow induced fibre alignment
- Poor mechanical performance at material interfaces - temp effects



Future research areas

Since this is a relatively new process for composites applications there is considerable work required on understanding the limitations of the process and where it will prove most useful. Since this is a process most suited to higher volumes this might limit the speed of development since the costs required to advance the TRL will be high.

Analysis

15% of challenges were out of scope, 48% process-specific and 36% potentially general and of interest to several processes. Quality of parts produced appears to be a major issue and it is perhaps surprising that uptake wasn't viewed as a greater issue.

Raw data – Process-specific challenges only

Area	Challenge	Current	Cost	Rate	Uptake	Quality	Applicability
Machine hardware	Heating mechanisms for TP and prepreg - reduce cycle time, improve uniformity	10		•		•	
	Clamping mechanisms to locate and constrain fibre inserts within tool	8			•	•	
	Relaxation/sagging of blank during heating	6				•	
	Modifications required to existing injection moulding equipment	7			•		
Material format	Material wrinkling due to overmoulding step	5				•	
	Material washing/migration due to overmoulding step	5				•	
	Wastage of expensive organosheet material	7	•				
	Metal part introduction and tooling for multi-material components	9					•
	Organosheet is uniform thickness - needs ramps etc.	9					•
	Behaviour/performance of dissimilar material interface	6				•	•
Material deposition	Surface activation to encourage bond line	7				•	
Part applicability & geometry	Poor mechanical performance at material interfaces - temp effects	9				•	
	Availability of design data is limited, leading to long development times, high cost	8	•	•			•
	Limited scalability due to large injection pressures - high viscosity polymers	7					•
	Part complexity limited by thermoforming operation	6					•
	Thickness limitations	5					•

Thermoplastic Stamping

Introduction

Thermoplastic Stamping encompasses the stamping or press forming of thermoplastic fibre-reinforced blanks. 24 challenges were captured for this process.

Most severe challenges were as follows:

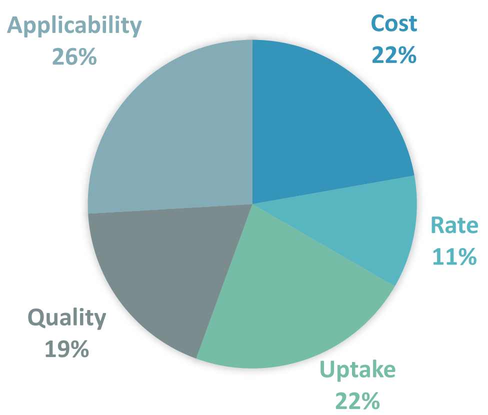
- Heating mechanisms for TP - reduce cycle time/dwell time, improve uniformity
- Need for actuated/bespoke tooling to minimise wrinkling & defects
- Need to control crystallinity (accurate thermal management)
- Heating through to centre of laminates

Future research areas

Many of the challenges relate to heating issues and there may be some potential for work on predicting the heat transfer characteristics of the materials for the various heating methods employed. The majority of the challenges are related to forming issues, blank control and wastage of material. There is therefore a clear need for process simulations to improve our predictive capability, this will also allow rapid assessment of alternative part geometries to improve our understanding of process applicability.

Analysis

Relatively few challenges were collected and 13% were deemed to be out of scope. 63% were process-specific and 25% potentially general and of interest to several processes. Rate doesn't appear to be a concern in this process which is geared towards high volume production.



Raw data – Process-specific challenges only

Area	Challenge	Current	Cost	Rate	Uptake	Quality	Applicability
Infrastructure & Environment	Challenge of net-shaped forming, avoiding wastage (clamping etc)	6	•				
	Heating mechanisms for TP - reduce cycle time/dwell time, improve uniformity	10		•			
Machine hardware	Need for actuated/bespoke tooling to minimise wrinkling & defects	9.5				•	
Material format	Clamping mechanisms to locate and constrain fibre inserts within tool	9			•	•	
	Relaxation of blank during heating	6				•	
	Need to control crystallinity (accurate thermal management)	9.5			•		
	Difficult control of fibre architecture upon forming	7.5				•	
Material deposition	Need to increase speed of comp pressure and temp introduction without use of matched-tooling	7		•			
	Overheating of sheet to compensate for cooling during transfer to press	6.5					•
	Heating through to centre of laminates	9.5			•		
	Difficult to form over complex geometry (low-radius tapers, double curvatures etc.)	8.5					•
Part applicability & geometry	Part complexity limited by thermoforming operation (depth of draw)	7.5					•
	Component forms limited by limited fibre-shearing in blank	8.5					•
	Geometric limitations due to blank draft and radius to prevent tearing	8					•
	Need to introduce ramps	8					•

Injection Moulding

Introduction

Injection Moulding encompasses the pressurised injection of a discontinuous fibre filled thermoplastic polymer into a mould or tool to produce a component. This is a very mature high volume process (particularly for unfilled polymers) and 18 challenges were captured.

Most severe challenges were as follows:

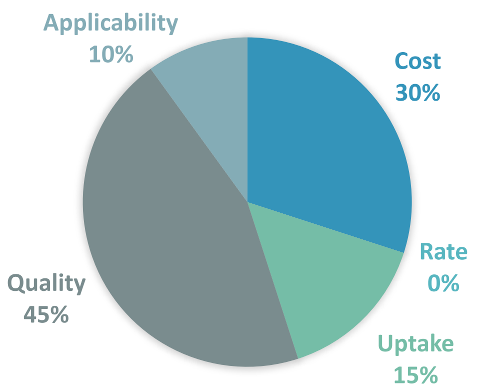
- Large clamping forces required due to high injection pressures (limiting process to small parts)
- High level of investment required
- Need for prototype tooling as a low-cost option
- High complexity and lack of versatility of tooling
- Tooling/process design to reduce forming forces and improve component quality
- Poor control of temperature distribution within tooling
- Management of melting point of precursors for reactive systems to prevent solidification within system
- Viscosity management effects (e.g. incomplete fill, voids, flash)

Future research areas

This is a mature process and process models are well established. Tooling is an area of concern and this is a high volume process which means that developments will be costly. Research developments may be related to the need for new types of material.

Analysis

28% of challenges were out of scope, 44% process-specific and 28% potentially general and of interest to several processes. No issues with rate were raised whereas part quality appears to be a major barrier.



Raw data – Process-specific challenges only

Area	Challenge	Current	Cost	Rate	Uptake	Quality	Applicability
Infrastructure & Environment	Need for prototype tooling as a low-cost option	8	•				
Machine hardware	Tooling/process design to reduce forming forces and improve component quality	8			•		•
	Poor control of temperature distribution within tooling	8				•	
Material format	Management of melt point of precursors for reactive systems to prevent solidification within sys	10	•				
	Need for moisture control	6				•	
	Increased fibre length	3			•		
Material deposition	Voids and air traps leading to performance reduction	7				•	
	Flow distance	4				•	

Resin Transfer Moulding

Introduction

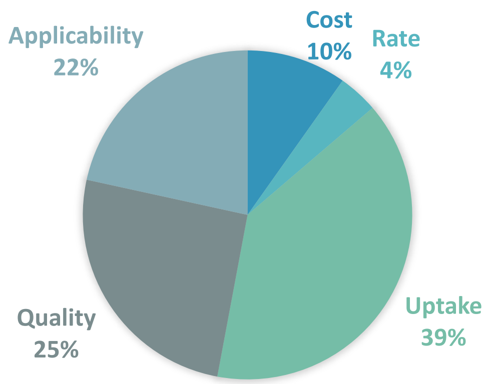
Resin Transfer Moulding (RTM) encompasses resin injection using a closed mould and positive pressure. This includes more recent process derivatives such as HP-RTM, VARTM, and Gap RTM. 44 challenges were captured for this process.

Most severe challenges were as follows:

- High tool cost & lead time
- Versatility and modularity of tooling
- Process and tool design for net-shape moulding
- Understanding defect significance (especially resin-rich areas)
- Need for an efficient & high-rate preforming process prior to moulding
- Ability to produce net edge

Future research areas

Since the widespread availability of rapid curing resin systems emphasis has shifted to the preforming process as the main process bottleneck (see the multi-ply preforming area for instance). The challenges identified are a mixture of flow issues (air entrapment, vacuum performance, fibre washing) practical issues related to implementation (seal design, material wastage, tool heating) and material / manufacturing interface – tougheners, resin cracking, exotherm management etc.



Analysis

9% of challenges were out of scope, 52% process-specific and 39% potentially general and of interest to several processes. Despite the relative maturity of the process, Uptake is seen as the main barrier and this was identified mainly against the practical issues around implementation.

Raw data – Process-specific challenges only

Area	Challenge	Current	Cost	Rate	Uptake	Quality	Applicability
Machine hardware	Need for moisture controls to facilitate reactive thermoplastic resins in RTM process	8			•		•
Material format	Understanding defect significance (especially resin-rich areas)	10				•	
	Ability to introduce toughening phase (e.g. interleaves, veils)	6.5					•
	Mixing of drapeable and high-stiffness materials affecting impregnation	8				•	•
	Embedding of metallic inserts (complicates tooling and process)	8					•
	Foam cores leading to complication of resin flow	8					•
	High exotherms of thick components	7			•		
Material deposition	Racetracking	8				•	
	Air entrapment resulting in dry spots and understanding significance	8				•	
	Microvoids leading to performance reduction	7				•	
	Fibre-wash at higher pressures resulting in lower VF and poor architecture control	6				•	
	Fibre clamping	6.5				•	
	Ability to produce net edge	8.5			•		
	Dose heat design, how to clean out snap cure systems	5			•		
	Understanding level of cure required	6					•
	Resin cracking and resin-rich zones	2				•	
	Seal design high risk to process	8			•		
	Better understanding of vacuum during tool closure	6			•		
Part applicability & geometry	Impact performance due to use of untoughened resins	8				•	
	Warpage due to resin flow/shrinkage	8				•	
	Large amount of wastage due to off-cuts	7	•				
	Removal of peel ply causing component damage	6				•	
	Core integration in sandwich panels (single-shot curing)	5					•

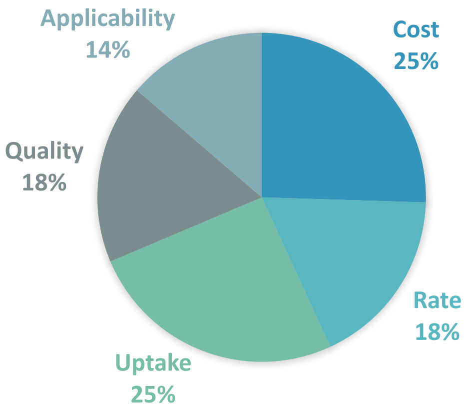
Autoclave prepreg

Introduction

Autoclave Prepreg the use of heat and pressure (within an autoclave) to cure prepreg materials. 25 challenges were captured for this process, there is some overlap with the Out of-Autoclave Prepreg and hence some potential synergy.

Most severe challenges were as follows:

- Level of investment required
- Investment costs grow exponentially with size
- Automation mimicking laminator -know how
- Material quality along tape lengths to reduce waste
- Issues with complex shapes
- Accurate process model to avoid spring-back and avoid the need for shimming



Future research areas

This area is mature and well developed. There is considerable overlap with the OoA prepreg route in terms of repurposing waste, tool conformance and cure cycle length. Process automation remains a key area for development.

Analysis

36% of challenges were out of scope, 16% process-specific and 48% potentially general and of interest to several processes.

Raw data – Process-specific challenges only

Area	Challenge	Current	Cost	Rate	Uptake	Quality	Applicability
infrastructure & Environment	Long preparation time prior to cure (e.g. bagging)	2.5		•			
Material format	Heat-up/cool-down time is too long	8		•			
Material deposition	Reduction or reprocessing lay-up waste	6.5			•		
Part applicability & geometry	Issues with complex shapes	9				•	•

Out of Autoclave Prepreg

Introduction

Out of Autoclave Prepreg encompasses the curing of prepreg materials using vacuum-only consolidation on single sided tooling in an oven. 26 challenges were captured for this process, there is some overlap with the Autoclave Prepreg process and hence some potential synergy.

Most severe challenges were as follows:

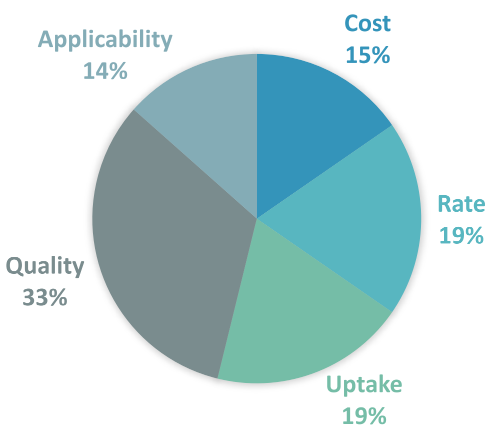
- Address material and process variability in simulation
- Need for reusable/recyclable consumables
- Need for low-temp curing resin with medium-temp properties without need for post-cure
- Outlife limitations

Future research areas

Optimising cure cycles for minimum porosity while reducing cycle time should be a key goal for development. It is likely that resin development would also be required to meet this goal. OoA manufacturing is widely used but reaches a limiting thickness and/or part area due to air evacuation limitations. Efforts to improve these issues by changing the material format have led to bulk problems in the past.

Analysis

27% of challenges were out of scope, 46% process-specific and 27% potentially general and of interest to several processes.



Raw data – Process-specific challenges only

Area	Challenge	Current	Cost	Rate	Uptake	Quality	Applicability
infrastructure & Environment	Long preparation time prior to cure (e.g. bagging)	2.5		•			
Material format	Poor through-thickness evacuation in thick laminates	6.5				•	
	Wrinkling and fibre-bridging resulting from large degrees of cure compaction	6				•	
	Consistent resin impregnation	6.5		•		•	
Material deposition	Maximum achievable fibre volume fraction of ~50-55%	4.5				•	•
	Long cure cycle and vacuum hold times	2.5		•			
	Low in-plane permeability leading to dry spots	6.5				•	
	Reduction or reprocessing lay-up waste	6			•		
Part applicability & geometry	Low bulk factors	3.5				•	
	Poor conformance to complex forms (e.g. tight corners)	5.5				•	•
	Poor surface porosity above core sections	4				•	
	Wrinkling at corners due to laminate buckling	4				•	

Liquid Resin Moulding

Introduction

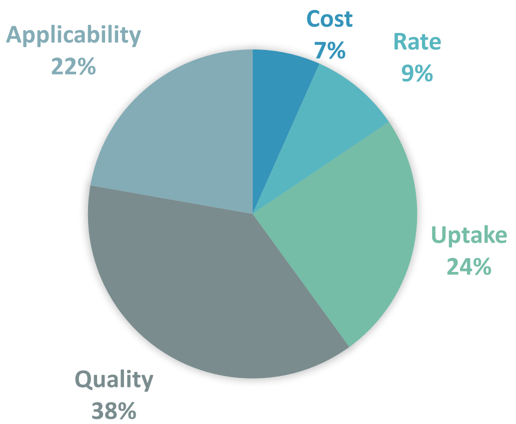
Liquid Resin Moulding encompasses the infusion of fabrics using a single-sided tool and vacuum consolidation. 36 challenges were captured for this process.

Most severe challenges were as follows:

- Phase separation between material blends
- Flow front management
- B-stage infusion/cure
- Near net edge

Future research areas

Despite the relative maturity of the process there remain several areas where understanding is lacking. The interaction between both liquid and fibrous constituent materials and the process remain a key area. Low TRL research should focus on flow aspects but should expand from the existing interest in permeability into other areas – filtration of materials, resin boiling, phase separation etc. There is also scope for further development of fibre formats with RTM-specific characteristics.



Analysis

17% of challenges were out of scope, 44% process-specific and 39% potentially general and of interest to several processes. Cost and Rate do not appear to be limiting barriers whereas Quality is the largest factor identified.

Raw data – Process-specific challenges only

Area	Challenge	Current	Cost	Rate	Uptake	Quality	Applicability
Material format	Channels forming due to fibre bridging causing a non-uniform front	6				•	
	Infusion of multi-material parts	3					•
Material deposition	Racetracking	8				•	
	Fundamental understanding of a variety of infusion processes	6.5			•		•
	Resin 'boiling' resulting from reduced pressure at flow-front and leading to gas production and ent	6				•	
	Filtering and distribution of resin additives resulting in performance gradient	8				•	•
	Phase separation between blends	9				•	
	Degassing (pre and during infusion)	5				•	
	Micro-cracking in resin around z-fibres	5				•	
	Effect of z-fibre buckling due to compaction of a bulky, dry preform	4				•	
Part applicability & geometry	Maximum achievable fibre volume fraction of ~50-55%	4			•		•
	Fibre print through	5				•	
	Process induced brittleness of parts when using certain resin systems (e.g. phenolic resins)	4.5				•	
	Near net edge	9			•		
	Sector specificity of processing parameter importance	4					•
	Scale up and maintain quality	7					•

Compression Moulding

Introduction

Compression Moulding encompasses the use of moulding compounds including SMC, BMC and DMC to produce composite components at high rate. Historically this has been a process solely using glass fibre reinforcement but is increasingly investigated for carbon fibre. 33 challenges were captured for this process.

Most severe challenges were as follows:

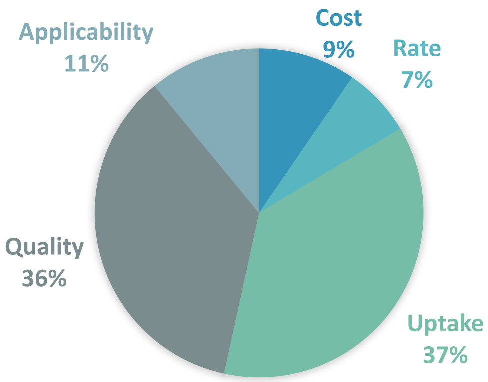
- Twisting of tooling resulting in male & female tool parts misaligning and fighting the press
- Need for an efficient preforming process prior to moulding
- Better understanding and control of draping
- Design of tooling/charge placement to target specific fibre angles and flow

Future research areas

Process models for single filament or small bundle based materials (such as conventional SMC) are well developed but meso-scale / platelet reinforcement structures are at a similar scale to the part thickness and require alternative modelling approaches. There is also a clear need for mechanical test data and more general DFM data to drive wider uptake and aid in the design process.

Analysis

12% of challenges were out of scope, 30% process-specific and 58% potentially general and of interest to several processes. As expected for a high rate process cost and rate are not major concerns, there also seems to be sufficient understanding of applicability to different parts.



Raw data – Process-specific challenges only

Area	Challenge	Current	Cost	Rate	Uptake	Quality	Applicability
Machine hardware	Thermal cycling of tool could maintain geometry upon part ejection	3				•	•
Material format	Reinforcement migration	7				•	
	Poor fibre impregnation leading to voids and air entrapment	7				•	
	Better use of recyclate	8	•		•		
Material deposition	Out-of-plane flow during rib filling resulting in fibre entanglement and resin-rich regions	8				•	
Part applicability & geometry	Restricted to relatively non-complex geometries	5					•
	Fibre-matrix separation susceptability	6.5				•	
	Mechanical weakness resulting from component 'hard points' (e.g. fasteners, fixings)	8				•	
	Dimensional stability when ejected above Tg	4				•	
	UD/discontinuous mix - need to keep UD in place whilst chopped fibres flow	7					•