CIMComp EPSRC Future Composites Manufacturing Research Hub

Feasibility Study Final Report

Feasibility Study (FS) Title: Furthering the uptake of carbon fibre recyclates by converting into robust intermediary materials suitable for automated manufacturing.

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Partners (include support from Industry): Swiss Composite Materials & Technologies (3 days engineering time & £5000 materials). Teijin Carbon Europe GmbH, SHD Composite Materials Ltd (prepreg resin for sample manufacture)

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End date: 30/06/2022

Executive Summary

This study addresses the issue of composites sustainability by developing new manufacturing technologies to produce a high performance composite intermediate material from recycled carbon fibre. The format of this product is a powder-coated aligned short fibre tape with high mechanical properties and excellent formability. This project has excellent alignment with the aims of the Hub, addressing four critical topics: 1) Reduce the carbon footprint of composites manufacturing; by furthering the uptake of carbon fibre recyclates, therefore making end of life reuse a more viable option, and so reducing the loss of material to landfill disposal. 2) Step towards a new manufacturing technology; that aims to overcome barriers preventing the use of recycled carbon fibre in automated manufacturing processes. 3) Analytical study to understand material manufacturing parameters. 4) Increasing the manufacturing sustainability of high-performance structures; by enabling the use of aligned recycled carbon fibre in high-accuracy automated fibre placement technologies.

Overall the project has successfully demonstrated an improvement in usability of the existing aligned fibre tapes at low TRL. The programme of work highlighted some issues which were not foreseen at the bid writing stage which have limited progress somewhat compared to the original intentions. In particular, we have not been able to demonstrate use of the material in an automated process or in any end use demonstrator components, but we have uncovered some fundamental phenomena which will drive future development.

The primary impact of this feasibility study is to demonstrate that, in contrast to many existing technologies, fibres recovered from end-of-life components can be turned into a format that resembles a virgin material with manufacturing characteristics (such as the ability to be stretch formed) that enhance industrial appeal.

Background

The University of Nottingham has developed a fibre alignment process to process various forms of short fibres (e.g. end of life components, NCF Hoover waste, woven trim scrap, chopped pyrolised fabric) into 300mm wide highly aligned tapes of 100-200gsm areal weight. The viscosity modifier used imparts some strength to the final product when dried but the tapes are very moisture sensitive and have low resistance to elevated temperature, so they are not well suited to use in conventional downstream processes such as hand laminated or automated preforming.

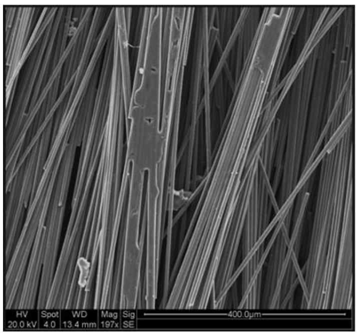
The aim of this project was to develop a binder doping methodology to provide a robust and handleable RCF-based finished product. The binder is intended to strengthen and stabilise the core of the material. As a second step the dried products are coated with an epoxy powder either as a surface binder for preforming or as a way of incorporating the totality of the matrix resin for compression moulding.

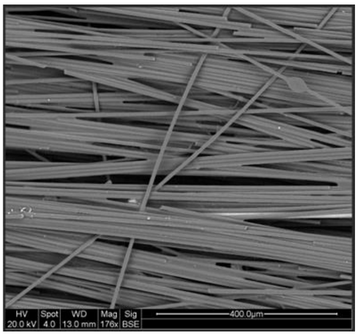
It is intended that the final products could be well suited to automated dry fibre placement or pick & place processes for either resin infusion or prepreg compression moulding.

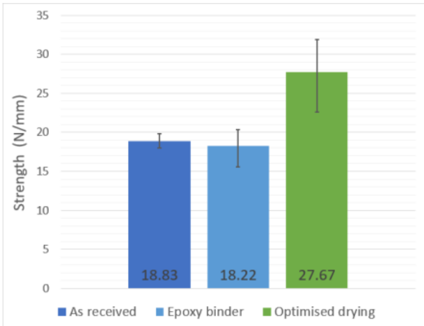
Results/Deliverables/Outcomes

Tape consolidation process
The first stage of producing rCF tapes was to process aligned rCF mats into tapes that had sufficient intrinsic properties to be accommodate downstream processing. The mat and tape processing requires aqueous processing, various drying and consolidation processes were trailed, the following are ranked from least effective to most effective: ambient conditions > heated press > heated vacuum bag > blotting press. Optimised drying and consolidation resulted in a 30% increase in FVF compared to 'As received' rCF mat.

Doping process
Accompanying the drying and consolidation study were trials of various doping methods to add an aqueous epoxy resin emulsion in an attempted to improve the properties of dry rCF tapes. The trialled processes are listed in order from least effective to most effective: saturation spray with low concentration mixture > rinsing and 'infusion' with low concentration mixture > minimal spray application of high concentration mixture. SEM images enabled observation of the displacement of residual viscosity modifier from the rCF mat manufacturing process (left image) and replacement with aqueous solution delivered epoxy (right image). Optimisation of the drying and consolidation process was found to have the greatest impact on improving dry tape strength (at ambient conditions).



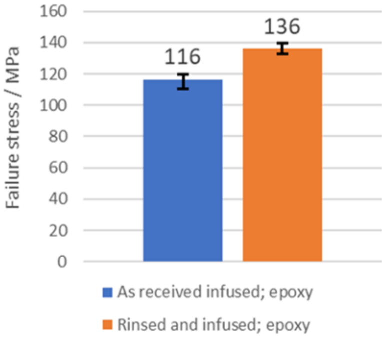




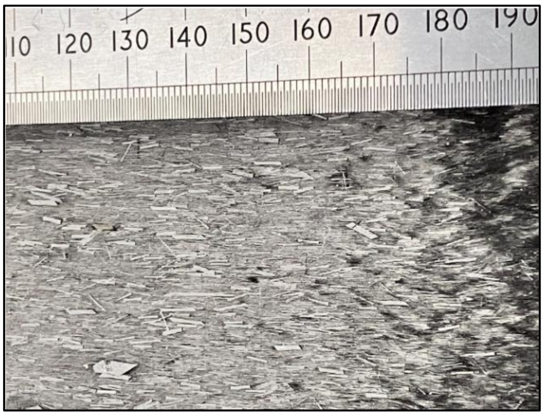
Surface modification
The second stage of the rCF tape manufacturing process was surface application of powder epoxy. The 'As received' aligned rCF tape was found to not have adequate tensile strength to be processable in the UoE powder deposition line. The addition of

aqueous binder, though found to have negligible influence on tensile strength, resulted in tapes being more stable during the powder application process.

Manual production of rCF powder-epoxy tapes (image on left), with estimated epoxy wt.% of 50 and 55, were measured to have ultimate tensile strengths of 13.9 ± 3.3 MPa. When rCF tapes were processed into laminated composites, by traditional infusion method, the off-axis strength was seen to be improved when aqueous epoxy binder was used to stabilise dry rCF tapes (chart on right).



Demonstrating use of end-of-life recycled carbon fibre



Progression of the feasibility study enabled the project scope to accommodate a trial of using carbon fibre recycled from end-of-life composites that were recovered by pyrolysis. This trial was limited to using the recycled carbon fibre in the alignment process. The image on the left shows the achieved fibre alignment. It can also be seen that fibre dispersion remains a significant challenge when end-of-life recycled fibre is used.

Several demonstration materials will be manufactured to conclude this study:

1. Baseline case with optimised washing in process (no additional treatment)
2. Epoxy binder to stabilise as described above – optimum processing conditions
3. As (2) with 3% epoxy powder for hand laminating
4. As (2) with 40% epoxy powder for compression moulding
5. As (2) with SHD prepreg epoxy for autoclave cure

Future Direction/Impact

The development within this project is related to the underlying alignment technology which is an active area of research for the group. This project has enabled a pathway towards a scaled-up process which will be added to the existing alignment process flow.

The binder application and drying process will be added to the current 300mm wide process and proved-out before scaling further.

Obvious avenues for further funding are ATI & IUK funding. We are in discussions with potential partners. We hope to develop a process operating at commercial scale to compete with the other existing and developmental processes delivering intermediates to high performance applications in aerospace interiors and automotive.

Remaining scientific challenges to be explored in future work:

- Application method – how can the location of the binder within the core of the tape be controlled
- What is the range of forming behaviour that can be achieved with different material combinations?
- What is the performance of the developed materials at different temperatures?
- Stability of material under processing parameters of downstream manufacturing processes, as well as temperature, tensile strength for material to be self-supporting (i.e., tapes will not break as they are fed though deposition machinery).
- Dewatering and removal/management of 'temporary' binder i.e., viscosity modifier.
- Chemical / Physical interactions of viscosity modifier and binder.
- Incorporate intermediate processing stage that conditions the tapes to have a topology that is more suitable for downstream manufacturing processes, i.e., flatter and smoother.
- Analysis methods for effective and efficient measurement of intra-tape binder content and localisation.
- In-process behaviour not fully characterised
- Laminate performance not fully characterised but dependent on underlying tape structure

Synergy with other Hub projects

The technology developed within this project will be employed on the Hub Synergy project ECOTOOL to develop low cost, high performance integrally heated tooling.

		Target / project	Actual achievements
	Project duration (yrs)	0.5	
	Project Value (80% FEC)	£ 50,000	
Project Metrics	**PhD students**	0	0
	PDRAs (FTE per year)	1	0.5
	Person years	0.5	0.5
	Project based partners	1	3
	Institutional support	£ -	£ -
	Industry support (Letters of Support)	£ 12,500	£ 9000
	Additional leveraged grant income	£ 125,000	£ 0 -
	Additional industry leveraged income	£ 60,000	0
	Journal publications	0.5	0
	Conference papers	1	0
	Patent applications	0	0
	New collaborative research activity	0	0