Core Project/Innovation Fellow Final Report

Project Title: Powder-Epoxy Carbon Fibre Towpreg for High Speed, Low-Cost Automated Fibre Placement
PI name: Dr. Colin Robert
Research staff/students (*include % of time*): Thomas Noble (Student/RA, 100% time)
Thomas Noble started his master project under my supervision on instrumentation of the tapeline right before the pandemic stroke. His project was originally very experimental (working on tension, speed and temperature sensors), we decided to amend it so he would work more on the coding of the user interface. As he did an excellent job on this part during his master project, I asked him to keep working with me on the tapeline as a research assistant. The complementary approaches and skillsets of Thomas and I allowed for this tapeline to become what it is now. Thomas is still working with me, on the follow-up projects described below (in the associated research grant section).
Partners (include support from industry): Swiss CMT, FreiLacke, Toray, Coriolis Composites (Originally).
Start date:01/10/2019
End date:31/01/2022 (3 months furlough due to pandemic)

Identify benefits to Industrial Partners:
Production of powder prepreg commercial spools (Figure 1): new applications previously unknown to industrial partners.

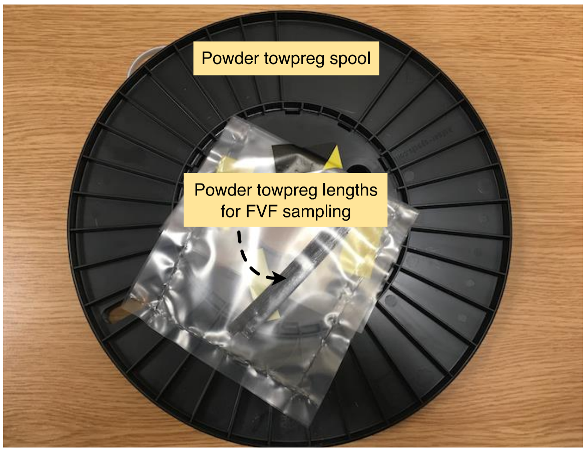

Figure 1: Powder towpreg spools produced using the tapeline

Low manufacturing costs inherent to the technology developed: commercial edge for industry.
High speed production: high volumes ability.

Associated research grants awarded (title and value):

- COMPrinting (figure 2), in collaboration with Dr. Dongmin Yang from the University of Edinburgh (CIMCOMP Feasibility study, £62.5K).

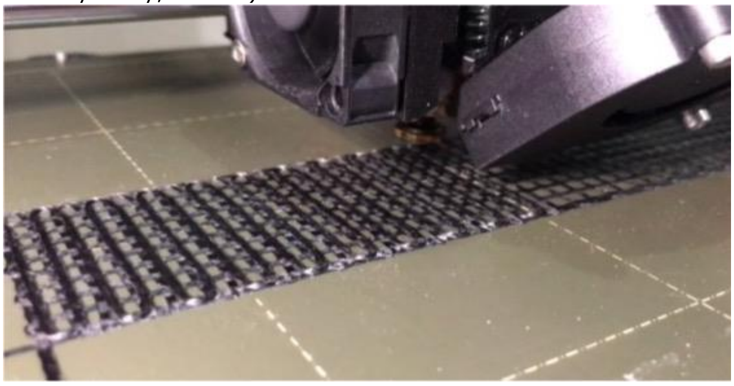

Figure 2: COMPrinting - 3D printing of continuous CF powder based towpreg

- Powder Epoxy for One-Shot Cure, Out-of-Autoclave Applications: Lap Shear Strength and Z-Pinning Study (figure 3), in collaboration with Dr. Edward Archer from Ulster University (CIMCOMP synergy study, £18K).

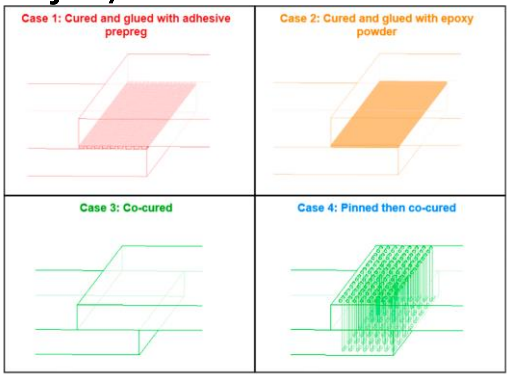

Figure 3: Concept of Powder Epoxy for One-Shot Cure, Out-of-Autoclave Applications: Lap Shear Strength and Z-Pinning Study

- Furthering the uptake of Carbon Fibre Recyclates by converting into Robust Intermediary Materials suitable for Automated Manufacturing (CIMCOMP Feasibility study, £62.5K).
- Towpreg to pressure vessel: A commercial demonstrator of low-cost, high-speed pilot powder epoxy tapeline for automated fibre placement processing, (Figure 4) in collaboration with James Kuligoski (Edinburgh innovations IAA commercialisation project, £40K).

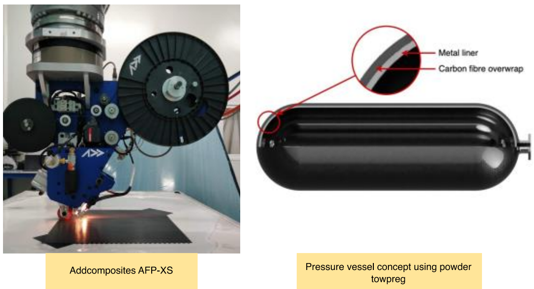

Figure 43: Addcomposites AFP-XS and the concept pressure vessel

- SPRe-IE PhD project: Sustainable, low-cost composites for net-zero infrastructure: Green hydrogen pressure vessels for self-sufficient rural and off-gas grid detached homes, in collaboration with Hexcel (£50K cash contribution, £100K total).
- EPSRC Impact Acceleration Account December 2022 Open Funding Call - collaborative projects: Powder Thermoplastic Tapeline for High-Performance Applications, submitted 13-12-2022 in collaboration with Hexcel (£50K cash contribution, £110K total).
- Last but not least: this project gave me the gravitas to apply and successfully get a 5-year chancellor fellowship at the University of Edinburgh in a highly competitive environment. The package comprised a PhD student (£100K), a £50K initial start up funding as well as my own salary (around £280K) in five years, not counting overheads, for a total of £430K.

<u>Accounting for all above (not counting the IAA project submitted), the total funding raised far is about £713K.</u>

Publications & conferences directly stemming from the innovation fellowship:

Çelik, M.; Maguire, J.; Noble, T.; Robert, C; Ó Brádaigh, C.M. Numerical and Experimental Investigation of Joule Heating in a Carbon Fibre Powder Epoxy Towpregging Line, Composites A, Volume 164, January 2023, 107285, link

Hasrin, H.; Çelik, M.; Noble, T.; Maguire, J.; Ó Brádaigh, C.M.; Robert, C. "Influence of Powder-Epoxy Towpregging Line Processing Parameters On Towpreg Consolidation". SAMPE Europe 2022, Hamburg, Germany, link

Çelik, M.; Noble, T.; Jorge, F.; Jian, R.; Ó Brádaigh, C.M.; Robert, C. "Influence of Line Processing Parameters on Properties of Carbon Fibre Epoxy Towpreg." J. Compos. Sci. 2022, 6, 75. link

Çelik, M.; Noble, T.; Haseeb, A.; Maguire, J.; Ó Brádaigh, C.M.; Robert, C. "Contact Resistance Heating of Unidirectional Carbon Fibre Tows", Plastics Rubber & Composites: Macromolecular Engineering ICMAC special edition, https://www.tandfonline.com/doi/full/10.1080/14658011.2022.2108982.

"Automated Tapeline System for Production of Towpregs for Automated Fibre Placement Process", Murat Çelik, Poster presentation at the poster competition in SAMPE UK & Ireland Chapter; Annual Technical Seminar: The Sky Is Not the Limit, Bristol, UK.

"Optimised Joule Heating of Carbon Fibres in a Low-cost, High-speed Powder-Epoxy Towpregging Pilot Production Line", Murat Çelik, Thomas Noble, James Maguire, Colin Robert, Conchúr M. Ó Brádaigh, Poster presentation at SAMPE Europe Conference 2021 Baden/Zürich – Switzerland.

Core Project/Innovation Fellow Final Report

"Contact Resistance Heating of Unidirectional Carbon Fibre Tows", M. Çelik, T. Noble, A. Haseeb, J. Maguire, C. Robert, C.M. Ó Brádaigh, Oral presentation at International Conference on Manufacturing of Advanced Composites (ICMAC 2021), Edinburgh, UK.

"Toward Streamlining Towpregging Tapeline and Automated Fibre Placement for Quicker and Cheaper Composite Manufacturing", Colin Robert, Murat Celik, Thomas Noble, Edward D. McCarthy, Conchúr M. Ó Brádaigh, Oral presentation at International Conference on Manufacturing of Advanced Composites (ICMAC 2021), Edinburgh, UK.

Publications & conferences associated with powder epoxy technology and/or tapeline development:

Alapati, A.K.; Cameron, J.; Çelik, M.; Noble, T.; Bajpai, A.; Schubiger, M.; Ó Brádaigh, C.M.; Robert, C.; Influence Of Crosslinking Density On The Mechanical Properties Of Different Powder Epoxies For Composites Applications. SAMPE Europe 2022, Hamburg, Germany.

Haoqi Zhang, Jiang Wu, Colin Robert, Conchúr M. Ó Brádaigh, Dongmin Yang, 3D printing and epoxy-infusion treatment of curved continuous carbon fibre reinforced dual-polymer composites, Composites Part B: Engineering, Volume 234, 2022, 109687, ISSN 1359-8368, https://doi.org/10.1016/j.compositesb.2022.109687.

James R. Davidson, James A. Quinn, Claudia Rothmann, Ankur Bajpai, Colin Robert, Conchúr M. Ó Brádaigh, Edward D. McCarthy, Mechanical characterisation of pneumatically-spliced carbon fibre yarns as reinforcements for polymer composites, Materials & Design, Volume 213, 2022, 110305, ISSN 0264-1275, https://doi.org/10.1016/j.matdes.2021.110305.

Noble, T.; Davidson, J.R.; Floreani, C.; Bajpai, A.; Moses, W.; Dooher, T.; McIlhagger, A.; Archer, E.; Ó Brádaigh, C.M.; Robert, C. Powder Epoxy for One-Shot Cure, Out-of-Autoclave Applications: Lap Shear Strength and Z-Pinning Study. J. Compos. Sci. 2021, 5, 225, https://doi.org/10.3390/jcs5090225.

Floreani, C.; Robert, C.; Alam, P.; Davies, P.; Ó Brádaigh, C.M. Mixed-Mode Interlaminar Fracture Toughness of Glass and Carbon Fibre Powder Epoxy Composites—For Design of Wind and Tidal Turbine Blades. Materials 2021, 14, 2103. https://doi.org/10.3390/ma14092103.

Hassan, E.; Zekos, I.; Jansson, P.; Pecur, T.; Floreani, C.; Robert, C.; Ó Brádaigh, C.M.; Stack, M.M. Erosion Mapping of Through-Thickness Toughened Powder Epoxy Gradient Glass-Fiber-Reinforced Polymer (GFRP) Plates for Tidal Turbine Blades. Lubricants 2021, 9, 22. https://doi.org/10.3390/lubricants9030022.

Colin Robert, Toa Pecur, James M. Maguire, Austin D. Lafferty, Edward D. McCarthy, Conchúr M. Ó Brádaigh, A novel powder-epoxy towpregging line for wind and tidal turbine blades, Composites Part B: Engineering, Volume 203, 2020, 108443, ISSN 1359-8368, https://doi.org/10.1016/j.compositesb.2020.108443.

"Characterization of mode I interlaminar properties of novel composites for tidal turbine blades", Christophe Floreani, Colin Robert, Parvez Alam, Peter Davies, Conchúr M. Ó Brádaigh, 13th European Wave and Tidal Energy Conference, 2019, Napoli.

"Tidal Turbine Blade Composites Using Basalt Fibre Reinforced Powder Epoxy", Colin Robert, Toa Pečur, Edward D. McCarthy, Conchúr M. Ó Brádaigh, ICCM22, 2019, Melbourne, Autralia.

"Powder Epoxy Based UD-CFRP Manufacturing Routes For Turbine Blade Application", Colin Robert, Dimitrios Mamalis, Parvez Alam, Austin D. Lafferty, Edward D. McCarthy, Conchúr M. Ó Brádaigh, Gearóid Breathnach, Cormac Ó Cadhain. SAMPE Europe Conference 2018 Southampton, UK.

Identify sustainability impact (if any):

There is a strong emphasis on potential applications in renewable energies (especially tidal & wind turbine blades, hydrogen) for powder epoxy technology.

The development of an automated manufacturing tapeline for the epoxy technology brings us closer to renewable applications. In this respect, Edinburgh Innovation agreed with the PI vision by granting an IAA commercialisation project in collaboration with Addcomposites, a low-cost Automated Fibre Placement company, in order to build a low CAPEX & OPEX hydrogen tank demonstrator.

List patent applications, disclosures, other IP generated:

None for now, but in discussion with our innovation department. The next step for the tapeline technology will be to stem a spinoff, working commercially with Industrial collaborators, first of which Hexcel who is happy to subsidise us £100K on 2 different projects (SPRE-IE PhD, and IAA collaboration project).

During the IAA project, we intend to patent the tapeline system.

Have you engaged/or will engage with HVMCs and/industry: – *please provide details (name of organisation, in-kind contributions)*

Yes. Apart from the 4 companies involved in the fellowship initially, multiple collaborations have started with a special scope on industry, specifically Original Equipment Manufacturers (OEMs). See below the list of collaborators, first active and then sought, with involvement details). Please consider all mentioned below in the paragraph as confidential.

Active collaborators:

- Freilacke (original powder epoxy manufacturer, spool sent)
- Swiss CMT (powder system design)
- Toray (carbon fibre provider)
- Add Composites (involved in IAA commercialisation project on Hydrogen pressure vessel demonstrator – low cost AFP system, provides AFP laid plates and type 3 pressure vessel demonstrator)

- Luxfer (OEM, involved in IAA commercialisation project on Hydrogen pressure vessel demonstrator – low cost AFP system, provided 6 Hydrogen pressure vessel liners)
- Hexcel (OEM, SPRe-IE PhD project: Sustainable, low-cost composites for net-zero infrastructure: Green hydrogen pressure vessels for self-sufficient rural and off-gas grid detached homes; IAA open call collaboration project) £100K cash commitment on the tapeline technology between the 2 projects.
- Notthingam University (feasibility study on recycled carbon fibre, spool sent)
- Ulster University (synergy study – ability to stitch through thickness)

Potential future collaborators:

- Advanced Research Manufacturing Centre (Spool sent for filament winding trials)
- Nexam chemicals (willing to pay 10K to towpreg their system via consultancy scheme)
- AFPT (Advanced fibre placement technology, scaling up purpose)
- Roth (filament winder manufacturer for hydrogen pressure vessel, OEM, scaling up purpose)
- Suprem (Tape manufacturer, scaling up purpose)
- Duo Gamma (Pregging company previously involved with powder epoxy manufacturing – potential for scaling up)
- EMS Chemie (Chemistry company for scaling up purpose)
- Cevotech (Fibre patch placement technology, new development)
- 3D Core (Composite foam company, new development)
- Carbon Axis (AFP startup)
- Bayreuth University (equipment for merging towpreg and AFP capabilities – scaling up potential – spool sent)
- Bristol University (interest in Eric Kim steering technology work for new synergy study)

Have you sought further funding from EPSRC, Innovate UK or other funding body? – *please provide details (value£, was it successful, proposal title and number)*

Yes, as per the Associated research grants awarded listing. 4 EPSRC research grants were awarded in direct relation with the innovation fellowship for a total of about £183K. On top of that, Hexcel has been very interested in this technology and was happy to provide £50K contribution on a SPRe-IE PhD project (£100K in total). Lately we have been looking for funding to build a thermoplastic tapeline with them. In this regards, we have just sent in a proposal to an IAA open call (EPSRC), for a budget of £110K including a £50K contribution from Hexcel.

In the future, we will definitely look more into Innovate UK proposal as we further advance, the tapeline technology will be more and more de-risked (as per the IAA demonstrator project), thus industrial collaborators will feel more comfortable to take the lead on collaborative projects.

Finally, we are also discussing the creation of a spin off with Hexcel as first client, should the proposal gets accepted and the project goes as well as we hope.

Executive Summary

Please provide a short summary of the project and how it fits with the Hub's overall aim/objectives.

The main project objective was to develop automation of a towpregging tapeline (TPTL, Figure 1), producing low-cost powder-based epoxy carbon fibre composite with a high deposition rate for use on automated fibre placement (AFP) machines. This project increased the versatility of this manufacturing method, to bring forward a faster, more controlled and optimised way to manufacture composites.

A novel powder-based epoxy from FreiLacke was used in this study. The powder epoxy has significant advantages compared to its liquid equivalents: low minimal viscosity, low exotherm, ability to preshape different parts and co-cure them in a one-shot process and stability at ambient temperature (no refrigeration requirement). These advantages result in lower manufacturing costs and quicker production of mechanically superior composite parts compared to standard liquid epoxy-based composites.

Regarding fitting the hub vision, the project aimed to produce a fully automated low-cost, high-speed tapeline to produce powder-based carbon fibre towpreg (fit to Hub Priority Area 1; HPA1). The tapeline process would be controlled via a Human Machine Interface enabling auto correction depending on the parameters inputs (HPA2).

During this fellowship, the tapeline was designed and built, with the main developments including:

- Build the structure using movable and versatile aluminium sections (KJN aluminium profiles), allowing for changes as we sent along.
- Laser cut PMMA panels were included for safety protection for both the powder deposition and the heating sections.
- Powder box for electrostatic powder deposition with vacuum outlet to ensure negative pressure so the powder never leaves through the slitted sections of the box (compulsory to let the carbon fibre tow in and out).
- A magnetic particle brake and a tension sensor synchronised with a PID system for tension for dynamic tension information and control.
- A DC generator providing joule heating from the carbon fibre to the powder epoxy, with the temperature controlled using three infrared temperature sensors and a PID.
- A linear encoder acted as speed sensor, and was synchronised with the rewinding motor for speed control, again via PID.

Core Project/Innovation Fellow Final Report

- All PID systems were instrumented using National Instruments modules and securely placed in an enclosed electric box. A comprehensive picture of the overall electronic system is included in Figure 2.
- All sensors data and controls were logged and monitored via a custom-made user interface panel via LabView software (Figure 3).
- Two in-line controls were also included to ensure the tape quality and homogeneity: a FLIR to check the temperature homogeneity and a camera system (Raspberry Pi high quality camera with telecentric lens) to check the width at all times (figure 4).

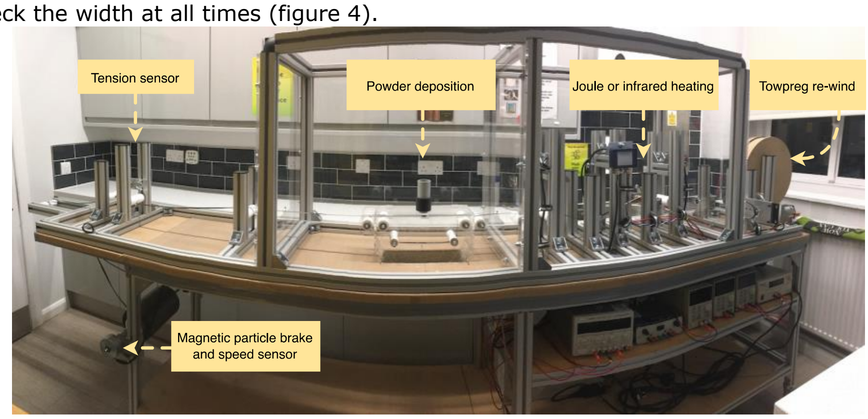

Figure 1 4: Automated Powder Epoxy Tapeline

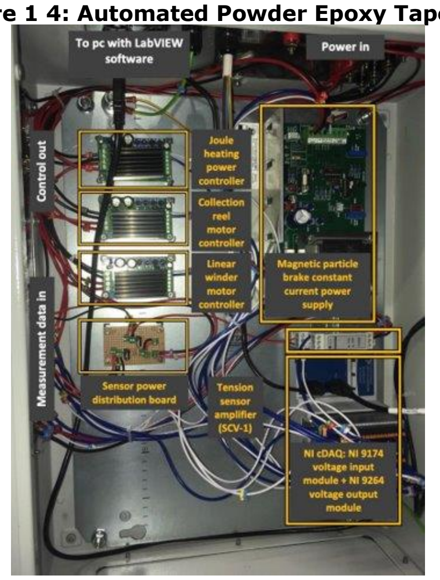

Figure 2: Automated tapeline electronic system

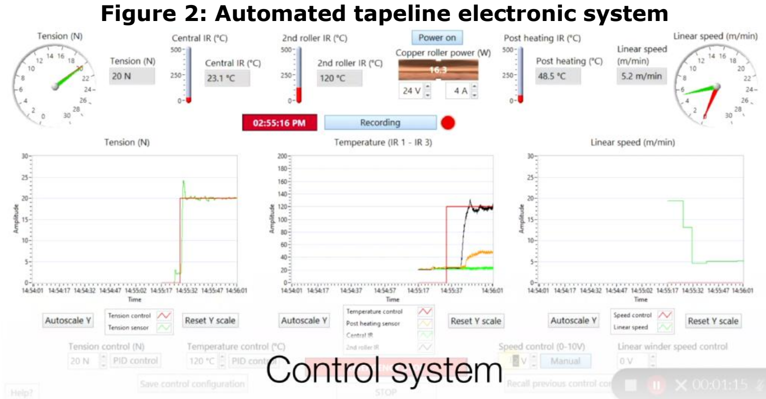

Figure 3: Custom made User Interface with LabView (National Instruments)

Core Project/Innovation Fellow Final Report

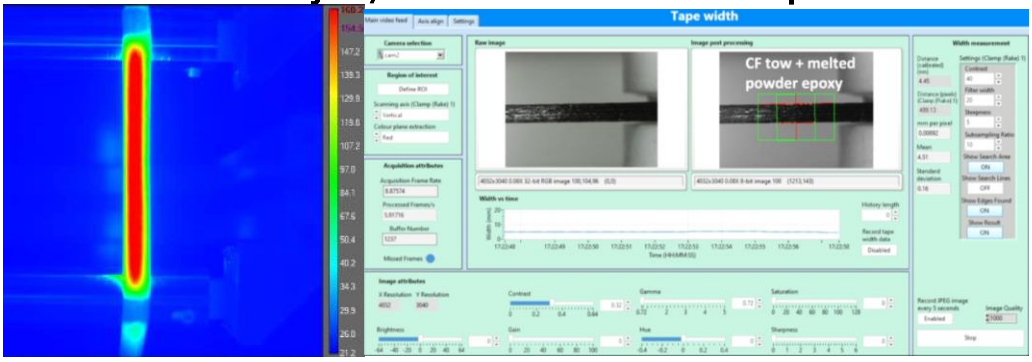

Figure 4: In-line dynamic controls: temperature homogeneity via FLIR and Tow width control via Machine Vision (Raspberry Pi high quality camera with telecentric lens).

Did you successfully answer your research question?

The overall aim of this fellowship was to build a robust, industrial-ready towpregging tapeline system for low-cost & high-speed production of powder epoxy tape.

At the start of my fellowship, the original proof of concept tapeline had no dynamic information over tension, temperature and speed, making the tape produced unusable in an industrial setting from quality insurance and safety standpoint.

The new tapeline built during the fellowship addressed all these issues: Tension, temperature and speed are now fully controlled and logged. Adding in-line dynamic controls as shown in figure 4, allowed for further control over the system.

First and foremost, the robustness of the tapeline enables to be confident of the tape quality and homogeneity. Then, it also allowed to go much faster than previously, while retaining the quality, which was impossible before automation. Automation and speed it allowed to drive the production cost down, thanks to a lower operator cost and higher production speed. Finally, innovative aspects of the powder towpregging tapeline, such as the use of electrostatic deposition of powder epoxy (allowing for high-speed production); and the use of joule heating (using 50 times less energy than a 1KW IR lamp); allowed for low-cost production.

Overall, I think the fellowship has been a frank success and a critical steppingstone in my career, as per the 6 projects stemming from this fellowship can attest.

Background

Please summarise the project's aim and objectives and discuss the industrial application or interest

The project aimed to produce a fully automated low-cost, high-speed tapeline to produce powder-based carbon fibre towpreg. The tapeline process aimed to be controlled via a Human Machine Interface enabling auto correction depending on the parameters inputs.

In short, some industrial advantages of this method are listed below:

- High volume manufacturing capabilities.
- Low cost of the towpregging process: powder is inexpensive (c. £8/kg). As the tape is completely stable at ambient temperatures, there is no need for sub-zero environment storage.
- Full automation of the whole process: labour cost reduced and more reliability.
- A new panel of powder-based epoxy systems that can be tailored depending on the application: "slow" to "flash" cure, incorporation of toughening and hardening agents.
- Tow to composite process: crimp due to weaving or stitching is avoided and fibres are always kept under tension, leading to better alignment and mechanical properties.

Results/Deliverables/Outcomes

Please present results clearly against the project's original aims, objectives and deliverables including any challenges you faced – Highlight significant results and where objectives/deliverables have not been met, explain why these have not been achieved

Milestone 1: Production of carbon fibre tape "as is" for Coriolis Composites.

The first major milestone of the project will be to deliver a substantial length (over 200 meters) of tape of the right width (12.7mm) with a consistent FVF, for initial trials on Csolo©.

Tape "as is" (from the old original tapeline) was produced be December 2019 and delivered in hands to Coriolis Composites on the third of January 2020. Soon after, the pandemic hit and Coriolis Composites had to severely reduce its personal (30% staff cut) and focus on their core work. The contact person (Matthew Frost) was made redundant, thus halting the collaboration.

Following this, a greater emphasis was given to produce a more robust tape with the new tapeline before sending industrial ready spools with powder tape to many industrial and academics collaborators.

Achieving this step (Milestone 2) took some significant time as the tapeline had to be built and troubleshooted, as well as the tape homogeneity characterised before sending it. We started producing the spools around November-December 2021.

I will refer to the industry engagement section for the exhaustive list of interested parties.

Core Project/Innovation Fellow Final Report

Some academic collaborators examples:

- Nottingham: (Tom Turner & Adam Joesbury) We had a successful feasibility study bid on towpregging recycled carbon fibres and is ongoing.
- Ulster: (Ed Archer) Initial synergy study to investigate through thickness reinforcement on one shot cure abilities. We are now looking for a £250K follow-on synergy study.
- Bristol: (Eric Kim) Initial interest from the spool sent recently that convinced him to participate in the £250K follow-on synergy study. Eric has a great understanding of what is needed for the tape to be competitive.

D2.1: Increase TPTL temperature control: an array of non-contact infrared sensors will be added to carefully monitor the temperature at the melting and cooling stations.

The infrared sensors were selected, installed and working by September 2020, according to my original schedule despite a 4-month hiatus due to not being able to access the lab.

D2.2: Increase TPTL tension control: controlling the tension will be paramount in this project. First, tension meters will monitor the tension applied on the carbon fibres. The towpreg tension will also be monitored using force gauges. Finally, a tachometer will be placed on the reel to ensure a constant speed.

Tension and speed sensors & regulators were fully installed by November-December 2020, with a small lag mainly due to airport customs holding our package coming from US without informing us.

D2.3: Automation of the tapeline: centralise the TPTL parameters using a HMI system such as LabVIEW.

The LabVIEW system was well operational with full control of temperature, tension and speed by March 2021. The LabVIEW system is always being improved as we modify/optimise the system (PID controls, new sensors for fibre volume fraction calculations).

Overall, before the Fellowship the tape produced was very inhomogeneous and therefore not usable as continuous tape. There was no control over the whole process, but eye observation and gut feelings on the tension, temperature and fibre volume fraction. This was fine for an early proof of concept, which is what the original tapeline was, but definitely not good enough for industry.

All the deliverables above ensure the tape homogeneity and higher quality, as well as traceability of all experimental details, which in time allowed for better understanding on the co-dependencies of the different experimental parameters.

Milestone 3. Manufacture AFP grade tape and CFRP parts; compare cost and mechanical properties of TPTL based-CFRP to standard process-based CFRP and technology transfer.

D3.1: Manufacture plates with commercial out-of-autoclave prepreg with the same carbon fibres (T700s© from Toray) and investigate mechanical properties.

This work has recently been submitted (31/01/2022) and will soon be published. Extra work on the influence of fibre volume fraction was added.

D3.2: Compare mechanical properties to plates originally manufactured with AFP processing with the original non-optimised towpreg.

Due to Coriolis stepping away from the project, this deliverable was delayed. However we recently got a new funding with AddComposites and we will publish the results by the end of this year.

D3.3: Optimization of process: manufacture plates and perform mechanical testing of CFRP samples depending on TPTL processing settings to reach the optimal TPTL manufacturing conditions.

This is part of the work recently published, where we investigate the influence of FVF on the mechanical properties (https://doi.org/10.3390/jcs6030075). In a nutshell, the findings are that a more speed led to a higher FVF and more porosity. The higher FVF samples also allowed for a higher interfacial porosity ratio, leading to lower delamination strength, while retaining better tensile strength overall.

D3.4: Dissemination of the technology: the applicant intend to communicate on the technology in two proceeding conferences as well as a peer review paper. The NCC have a notable experience in finding the best routes to application. As such, they will host a consortium on the subject of TPTL process, in which industrial and academics stakeholders will be present.

I'll refer to the publication list above, where 6 peer review papers and 7 conference papers are mentioned (not to mention the 2 studies recently submitted for peer review).

D3.5: If successful, the candidate will propose a follow-through to this study. With the help of NCC, this technology will be transferred into both industrial and commercial environments via an industrial transfer-based scheme such as the Technology Pull-Through programme, which is hosted by the NCC.

This is still to be done. As my timeline changed significantly since last year (and the chancellor fellowship awarded), I first want to de-risk my product (powder epoxy tape) as much as possible before going ahead with a big proposal. This is why the IAA feasibility study is so timely. Once we have a demonstrator, the industrial actors will be more enthusiastic about potential collaborations and our chances of success for an innovate UK will also be much better.

Future Direction/Impact

What are the next steps for this research (e.g. further grant funding, Technology Pull Through, Industry Exploitation?)

The bid on is to start a spinoff company with the ability to towpreg both thermoset and thermoplastics, with Hexcel benevolent help as first client.

Before that, we will be constructing a high-performance thermoplastic powder tapeline (Hexcel provides £100K over a PhD and a collaborative project on this topic).

What opportunities have you identified?

A big topic for tomorrow's composite industry is pressure vessels. The Towpreg to pressure vessel research grants awarded will highlight the ability to use of Powder-Epoxy Carbon Fibre Towpreg for hydrogen pressure vessels.

The ability to co-cure and stitch through uncured powder epoxy parts as per the CIMCOMP synergy study with Dr. Archer. This is a great potential for out-of-autoclave one shot cure applications. There will definitely be more scope for this in the future.

There is much potential coming from this low viscosity, non-tacky tape in terms of additive manufacturing with Dr. Yang, with whom I am working a lot on this technology (see recent papers above).

What potential impact has been/ will be generated?

We believe the technology developed during the fellowship is disruptive, and were glad to see that Hexcel is thinking alike. It will create a step change in processing of epoxy based towpregs and will permeate in new markets allowing for new applications thanks to a low CAPEX and OPEX. We will use the IAA study with AddComposite to prove this assertion and de-risk the technology.

Synergy with other Hub projects

Have you worked/supported any of the current Hub funded projects?

Have you identified any future opportunities to work with other Hub members?

(You can find more information on Hub projects in the latest annual report and on our website https://cimcomp.ac.uk)

The hub has been a fantastic support for my work and we participated in 3 collaborative projects with hub members, directly in relation with the powder epoxy tapeline.

- CIMCOMP synergy study: Powder Epoxy for One-Shot Cure, Out-of-Autoclave Applications: Lap Shear Strength and Z-Pinning Study, in collaboration with Dr. Edward Archer from Ulster University.
- COMPrinting: Novel 3D Printing of Curved Continuous Carbon Fibre Reinforced Powder-based Epoxy Composites, in collaboration with Dr. Dongmin Yang from UoE.
- CIMCOMP feasibility study: Furthering the uptake of Carbon Fibre Recyclates by converting into Robust Intermediary Materials suitable for Automated Manufacturing, in collaboration with the University of Nottingham.

Metrics Summary

Please complete the following table:

(For Innovation Fellowship)

		Target	
	Project duration (yrs)	2	2
	Project Value	£ 220,000	£273,888.00
Project Metrics	**PhD students**	0	0
	PDRAs (FTE per year)	1	1
	Person years	2	2
	Project based partners	2	Originally:4 Now: 8
	Institutional support	£ -	
	Industry support (Letters of Support)	£ 50,000	£ 100,000
	Additional leveraged grant income	£ 400,000	£ 713,000 (+ £110,000 submitted)
	Additional industry leveraged income	£ 200,000	£0 (Nexam chemicals interest in giving £10K for consultancy – ongoing)
	Journal publications	3	3
	Conference papers	4	5
	Patent applications	1	None yet
	New collaborative research activity	0	Within CIMCOMP: 3 Outside: 2