CIMComp EPSRC Future Composites Manufacturing Research Hub

Feasibility Study Final Report

Project Title: **AD**vanced **D**ynamic **RE**pair **S**olutions for **S**ustainable Composites (**ADDRESS**)

PI name: Ian Hamerton, Janice Barton, Marco Longana, Dmitry Ivanov (PI)

Research staff/students (*include name and % of time they worked on the FS*): Dominic R. Palubiski, 100% time for 5 months

Partners (include support from industry): Mallinda Inc. (CAN resin at the first stage of the project has been supplied in kind), Inductive Coil Solutions (the company produced bespoke coil designed by UoB and offered advice on the coil manufacturability).

Institutional Support: (number of PhDs supported and value £): University of Bristol covered the time of jury service of PDRA (three weeks). Standard lab/technicians provisions were put in place.

Start date: 22 Nov 2021. **End date**: 22 July 2022

Identify benefits to Industrial Partners: (1) Validation the feasibility of creating multi-matrix continuously-reinforced composites (MMCRC) with CAN polymers, (2) validation the feasibility of repair using low pressure / moderate temperature requirements (acceptably for in-field repair), (3) validation of new coil designs for composite applications.

Associated research grants awarded (title and value): In preparation

Publications: In preparation

Conference papers: Dominic R. Palubiski, Macro Longana, Janice M. Dulieu-Barton, Ian Hamerton, Dmitry S. Ivanov, Multi-matrix continuously-reinforced composites for repair applications, ICMAC-2022

Conferences attended: ICMAC-2022 – in preparation.

Identify sustainability impact: The developed concept will enable to prolong the service life of structures with energy-efficient and simple repair.

List patent applications, disclosures, other IP generated: n/a

Have you engaged/or will engage with HVMCs and/industry: The plan is to align the follow-up activities with the NCC Core Project on Modular Infusion. The results of the Feasibility Study have been presented to Rolls-Royce UTC on 12/05/2022, at Vestas-NSS-UoB annual meeting on 17/05/2022, and the NCC Research Committee Meeting on 07/07/2022.

Have you sought further funding from EPSRC, Innovate UK or other funding body? EPSRC proposal in preparation, not yet submitted. A related topic (modular forming of MMCRC) is investigated in Composites Manufacturing Hub project at UoB.

Executive Summary

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The ambition of this work is to develop *design for repair* strategy by means of manufacturing multi-matrix continuously-reinforced composites (MMCRC). The concept, pursued in this Feasibility Study, enables composite structures combining domains of Covalent Adaptive Networks (CANs) and conventional established resins. CAN's can change their topology without decreasing their connectivity and hence present a great potential for repair. On the other hand, CAN's are far less processable and present manufacturing challenges: high viscosity, short processing window, demanding consolidation requirements.

Designing repair with MMCRC right at the manufacturing stage allows bringing new and existent resin in an integral material assembly. Instead of relying on the adhesive bonding of repair patches the novel manufacturing concept creates fibre bridged interphases ensuring better structural integrity and reliability of repair. Such concept circumvents both the manufacturability challenges and lack of confidence associated with conventional forms of repair. Moreover, it has been shown that MMCRC structures do not demand excessive processing requirements for repair and can be dealt with tools available in-field. Inductive coil with new architecture has been designed specifically for the non-planar shape and aim at localised targeted and uniform heating.

The project demonstrated successful manufacturing of CAN-epoxy MMCRC for corner geometries and subsequent mechanical testing to generate controlled level of matrix damage. It has been shown that with relatively low processing requirements, which can be available in-field, the repair fully restores the mechanical performance of the MMCRC. Resultant approach offers sustainable solution to improve life of complex composite structures, thus contributing to the priority Hub themes of "Reycling/Reuse". This brings closer the creation of circular economy and more efficient recovery of materials.

Background

Composites design offer significant cost savings by reducing parts counts and joining operations. However, when a composite component is damaged it is difficult to replace a part that is co-bonded or co-cured in a larger structure, often resulting in disposal of a large asset. Currently, repairs are cumbersome and time-consuming with low confidence in their efficacy for primary structures. This is critical barrier to a more sustainable approach to composite asset management.

Adhesive repair strategies rely on the mechanical properties of relatively weak polymers. The problem is exacerbated by the complexity of the repair process. A repair procedure is generally conducted in-field, with limited resources and little opportunity for control of the processing parameters. The result is non uniform curing in complex geometries, with insufficient bonding of the repair to the hosting structure, thermal distortions, voidage, which prevent efficient load transfer across the repair. The difficulties also arise from the intrinsic composite material properties such as low through-thickness thermal conductivity, highly reactive thermosetting matrices, and thermal stresses due to the mismatch of properties. Furthermore, there are many processing problems that occur due to the intrinsic material limitations, *e.g.* thermal lag in heat transfer, run-away exothermic reactions, inefficient heating methods, and requirements for air extraction at the bonding interfaces.

Our vision is to reduce the amount of scraped non-recyclable composite components by developing a new holistic process-for-material and materials-for-process approach that enables accessible, efficient, and reliable repair techniques. The realisation of our vision will enable design for repair manufacturing strategies, which comprises the following:

i) identification of areas susceptible to operational wear, fatigue damage, or environmental degradation, which cannot be efficiently solved without the penalty of weight, cost or excessive complexity;
ii) design of replaceable patches right at the stage of manufacturing the new component and involving reformable matrix formulations such as Covalent Adaptive Networks (CANs);
iii) implementation of repair process without damaging surrounding structure and continuous composite reinforcement using limited pressure available in-field and local heating solution, such as EM induction.

Results/Deliverables/Outcomes

Various manufacturing route to create epoxy-CAN MMCRC have been explored in manufacturing trials. With the combination of compression moulding and resin infusion, seamless co-hosting of two matrices in one structure has been achieved. The produced samples exhibit acceptable quality of impregnation in the repairable area and undetectable matrix transition at the fibre-bridged interfaces, proving the feasibility of design and manufacturing integral CAN-epoxy parts.

The L-shape MMCRC have been tested in Curved Beam Strength test till failure. The tested enabled to induce controlled matrix failure in the CAN targeted region. Delamination in these regions were shown not to be affected by the interface. Thus, the mechanical performance for CAN-MMCRC was assessed in the matrix-dominated failure mode.

The repair process over the tested vacuum-bagged samples have been conducted using conventional oven heating and EM induction. A bespoke coil has been designed in the current project aiming at generating local but uniform heating over the corner areas. The performance of the coil has been assessed and found fit for repair. The samples were then retested and using optical strain measurements. The result showed a great potential of this strategy in full recovery of strength. The restoration of strength has been observed not only for perfect samples but also for the samples with various degrees of ply waviness/wrinkles.

Hence, the feasibility and the strong promise of the suggested concept has been successfully demonstrated. ADDRESS combined several novel concepts, pioneered by the project team, and devise new generic scalable repair methodologies applicable across a wide range of industries such as marine, aerospace, automotive and energy where non-recyclable polymer composites are deployed in high value assets.

Future Direction/Impact

The project will pursue several avenues for further development. First, the fundamental manufacturing potential of the CAN-MMCRC will be explored in follow-on Composites Manufacturing Hub project at UoB: "De-risking manufacturing and enhancing structural efficiency with modular sustainable multi-material", which will examine application of this concept to simplify and control forming processes. Secondly, follow-up activities with the NCC Core Project on Modular Infusion which has a potential for the integration of various aspect of modular technologies in an integral manufacturing paradigm. Some of the aspects of the current work may be explored further in the EngD NCC funded project of

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Joe Sultan. The application to an NCC Technology Pull Through is also considered. EPSRC proposal on applying repair concept for more scalable process and examining the mechanical performance of induced material features is in preparation.

Synergy with other Hub projects

In the current project we identified opportunities to co-operate with other Hub projects at the next stage of the development. For instance, the new synergy project on overmoulding of thermoplastic composites has potentially good affinity with the current follow-on project on modular forming of the MMCRC.

Metrics Summary

Please complete the following table:

		Target	Actual achievements
	Project duration (yrs)	**0.5**	**0.6**
	Project Value (80% FEC)	**£ 50,000**	**£ 50,000**
Project Metrics	**PhD students**	**0**	**n/a**
	PDRAs (FTE per year)	**1**	**5/12**
	Person years	**0.5**	**5/12**
	Project based partners	**1**	**2**
	Institutional support	**£ -**	**£ 2,854**
	Industry support (Letters of Support)	**£ 12,500**	**n/a**
	Additional leveraged grant income	**£ 125,000**	**£ -**
	Additional industry leveraged income	**£ 60,000**	**£ 1000**
	Journal publications	**0.5**	**In preparation**
	Conference papers	**1**	**1**
	Patent applications	**0**	**0**
	New collaborative research activity	**0**	**1**