ECCM 20

26-30 JUNE 2022

LAUSANNE SWITZERLAND

Proceedings of the 20th European Conference on Composite Materials

COMPOSITES MEET SUSTAINABILITY

Vol 5 – Applications and Structures

Editors : Anastasios P. Vassilopoulos, Véronique Michaud

Organized by :

EPFL

Under the patronage of :

CCLAB Composite Construction Laboratory

LPAC Laboratory for Processing of Advanced Composites

ESCM EUROPEAN SOCIETY FOR COMPOSITE MATERIALS

Proceedings of the 20th
European Conference on Composite Materials
ECCM20
26-30 June 2022,
EPFL Lausanne Switzerland

Edited By :

Prof. Anastasios P. Vassilopoulos, CCLab/EPFL
Prof. Véronique Michaud, LPAC/EPFL

Oragnized by:

Composite Construction Laboratory (CCLab)
Laboratory for Processing of Advanced Composites (LPAC)
Ecole Polytechnique Fédérale de Lausanne (EPFL)

ISBN: 978-2-9701614-0-0
DOI: http://dx.doi.org/10.5075/epfl-298799_978-2-9701614-0-0

Published by :

Composite Construction Laboratory (CCLab)
Ecole Polytechnique Fédérale de Lausanne (EPFL)
BP 2225 (Bâtiment BP), Station 16
1015, Lausanne, Switzerland

https://cclab.epfl.ch

Laboratory for Processing of Advanced Composites (LPAC)
Ecole Polytechnique Fédérale de Lausanne (EPFL)
MXG 139 (Bâtiment MXG), Station 12
1015, Lausanne, Switzerland

https://lpac.epfl.ch

Cover:

Swiss Tech Convention Center
© Edouard Venceslau - CompuWeb SA

Cover Design:

Composite Construction Laboratory (CCLab)
Ecole Polytechnique Fédérale de Lausanne (EPFL)
Lausanne, Switzerland

Editorial

This collection gathers all the articles that were submitted and presented at the 20th European Conference on Composite Materials (ECCM20) which took place in Lausanne, Switzerland, June 26-30, 2022.

ECCM20 is the 20th edition of a conference series having its roots back in time, organized each two years by members of the European Society of Composite Materials (ESCM).

The ECCM20 event was organized by the Composite Construction laboratory (CCLab) and the Laboratory for Processing of Advanced Composites (LPAC) of the Ecole Polytechnique Fédérale de Lausanne (EPFL).

The Conference Theme this year was "Composites meet Sustainability". As a result, even if all topics related to composite processing, properties and applications have been covered, sustainability aspects were highlighted with specific lectures, roundtables and sessions on a range of topics, from bio-based composites to energy efficiency in materials production and use phases, as well as end-of-life scenarios and recycling.

More than 1000 participants shared their recent research results and participated to fruitful discussions during the five conference days, while they contributed more than 850 papers which form the six volumes of the conference proceedings. Each volume gathers contributions on specific topics:

Vol 1 – Materials

Vol 2 – Manufacturing

Vol 3 – Characterization

Vol 4 – Modeling and Prediction

Vol 5 – Applications and Structures

Vol 6 – Life Cycle Assessment

We enjoyed the event; we had the chance to meet each other in person again, shake hands, hold friendly talks and maintain our long-lasting collaborations. We appreciated the high level of the research presented at the conference and the quality of the submissions that are now collected in these six volumes. We hope that everyone interested in the status of the European Composites' research in 2022 will be fascinated by this publication.

The Conference Chairs

Anastasios P. Vassilopoulos, Véronique Michaud

Hosting Organizations

Composite Construction Laboratory (CCLab)
Laboratory for Processing of Advanced Composites (LPAC)
Ecole Polytechnique Fédérale de Lausanne (EPFL)

Venue

Swiss Tech Convention Center (https://www.stcc.ch)

Conference Chairs

Chair : Prof. Anastasios P. Vassilopoulos, EPFL, Switzerland
Co-Chair: Prof Véronique Michaud, EPFL, Switzerland

International Scientific Committee

Prof. Malin Åkermo SE
Dr. Emmanuel Baranger FR
Prof. Christophe Binetruy FR
Prof. Pedro Camanho PT
Prof. Konstantinos Dassios GR
Prof. Brian Falzon UK
Prof. Kristofer Gamstedt SE
Prof. Sotiris Grammatikos NO
Prof. Christian Hochard FR
Prof. Marcin Kozlowski PL
Prof. Stepan Lomov BE
Dr. David May DE
Prof. Stephen Ogin UK
Prof. Gerald Pinter AT
Prof. Silvestre Pinho UK
Prof. Yentl Swolfs BE
Dr. Julie Teuwen NL
Dr. Panayota Tsotra CH
Prof. Wim van Paepegem BE
Prof. Dimitrios Zarouchas NL
Dr. Andrey Aniskevich LV
Prof. Christian Berggreen DK
Dr. Nicolas Boyard FR
Prof. Valter Carvelli IT
Prof. Klaus Drechsler DE
Prof. Bodo Fiedler DE
Dr. Nathalie Godin FR
Prof. Roland Hinterholzl AT
Prof. Ian Kinloch UK
Dr. Thomas Kruse DE
Prof. Theodoros Loutas GR
Prof. Veronique Michaud CH
Prof. Alessandro Pegoretti IT
Prof. Joao Ramoa Correia PT
Prof. Jose Sena-Cruz PT
Prof. Antonio T. Marques PT
Prof. Thanasis Triantafillou GR
Prof. Albert Turon ES
Prof. Anastasios P. Vassilopoulos CH
Prof. Martin Fagerström SE
Dr. Alexandros Antoniou DE
Prof. Lars Berglund SE
Prof. Michal Budzik DK
Prof. Lucas Da Silva PT
Dr. Andreas Endruweit UK
Prof. Mariaenrica Frigione IT
Dr. Larissa Gorbatikh BE
Dr. Martin Hirsekorn FR
Prof. Vassilis Kostopoulos GR
Prof. Jacques Lamon FR
Prof. Staffan Lundstrom SE
Prof. Peter Mitschang DE
Dr. Soraia Pimenta UK
Prof. Paul Robinson UK
Dr. Olesja Starkova LT
Prof. Sofia Teixeira de Freitas NL
Dr. Stavros Tsantzalis GR
Prof. Danny van Hemelrijck BE
Prof. Michele Zappalorto IT
Dr. Miroslav Cerny CZ

Local Organizing Committee

Prof. Anastasios P. Vassilopoulos, EPFL
Prof. Véronique Michaud, EPFL
Angélique Crettenand and Mirjam Kiener, Lausanne Tourisme
And all those who helped, colleagues who reviewed abstracts and chaired sessions, and CCLab and LPAC students and collaborators who worked hard to make this conference a success.

Sponsors

SHIMADZU
Excellence in Science

Bristol Composites Institute

JEC GROUP

suprem

Surface Measurement Systems
World Leader in Sorption Science

INSTRON

9T LABS

Anton Paar

DIA-STRON
DELIVERING MEASUREMENT SOLUTIONS

AΞLER

HRC

ICCM 23
BELFAST 2023
30 JULY - 4 AUGUST

TEIJIN

Functional Composite Materials

materials
an Open Access Journal by MDPI

ELSEVIER

frontiers | Research Topics
ECCM Research Topic on Advanced Manufacturing of Composites
Open for submissions ›

Supporting partners

JEC

CertBond
COST Action CA18120

EsSENce

Switzerland Tourism.

SWISS

SBB CFF FFS

sampe
Switzerland

CU
COMPOSITES UNITED
SWITZERLAND

canton de vaud

Lausanne

Contents

POLYMER COATED MATERIAL FOR INNOVATIVE REVERSIBLE DISSIMILAR COMPOSITE-METAL JOINING FOR AUTOMOTIVE APPLICATIONS

Faranak, Bahrami[a], Sadik, Omairey[a], Gareth, Bone[b], Michael, Matthews[b], Chris, Worrall[c], Sofia, Sampethai[c], Neelmanee, Sarin[c], Faisel, Almudaihesh[c], Sophie, Cozien-Cazuc[d], Joaquín, Piccini[e], Nithin, Jayasree[a], Mihalis, Kazilas[a,c]

a: Brunel Composites Centre, Brunel University London – Faranak.Bahrami@brunel.ac.uk
b: Gestamp, UK
c: TWI Ltd, UK
d: Far-UK Ltd, UK
e: Gestamp- Autotech Engineering, Spain

Abstract: *While the cost of composites has dropped over the past decade, the effective joining of these materials to conventional metal parts in the automotive sector remains a significant challenge. Existing joining solutions present several limitations, with major manufacturers inclined to use mechanical fasteners or adhesive bonding. In this study, Polymer Coated Material (PCM) joining process is adapted for thermoplastic composite to metal assembly. This joining method uses induction welding to join a thermoplastic composite to a metallic substrate pre-coated with a compatible thermoplastic polymer film. Compared to mechanical fastening, PCM does not induce stress concentrations in the parts, and as the materials are not pierced, the risk of water damage is reduced. Compared to adhesives, PCM solution is not subject to curing times or shelf-life restrictions. Furthermore, the use of PCM enables easy recyclability of the parts; at the end-of-life, the parts can be disassembled through a reversal heat process.*

Keywords: Induction Welding; Dissimilar Material Joining; Thermoplastic Composite; Disassembly; Automotive

1. Introduction

Compared to metals, fibre-reinforced polymer (FRP) composites offer improved stiffness to weight ratio, thermal/electrical properties, and corrosion resistance. These properties are interesting for advanced industries and applications. For example, the aerospace sector exploits these benefits by replacing metal alloys with composites in primary structures [1, 2]. Similarly, the automotive industry is replacing more conventional materials with lighter and stiffer alternatives that offer higher performance and meet regulating bodies' tighter regulations and restrictions to produce environmentally friendly cars [3-6]. The benefit of light-weighting expands beyond the drive for using composites in electric vehicles (EVs) and fuel cell electric vehicles (FCEVs) where weight reduction is crucial to extend range but also benefits internal combustion engine vehicles (ICEVs) where it is estimated that up to 700 litres of fossil fuel can be saved over the lifetime of an ICEV for every 100kg weight reduction [7]. A state-of-the-art automotive application of thermosetting composites is implemented in BMW's i3 hatchback. However, poor energy absorption, high production cost, long production time, limited recyclability and end of life options of thermosets question their advantages and sustainability with full-body implementations. Hence, although weight reduction is an important aspect, the use of metals remains technically and economically sustainable, especially as metals allow manufacturers to meet the EU's reuse and recycling of ≥ 85 % and reuse and recovery of ≥ 95% (EU Directive 2000/53/EC). As a result, manufacturers seek to increase the stiffness of the vehicle structure at specific locations utilising the available design space. For instance, Jaguar

  doi:10.5075/epfl-298799_978-2-9701614-0-0

Land Rover (JLR) in the Tucana project [8] are replacing the rear section of the body-in-white (BIW) aluminium and steel with composites capable of handling the increased torque generated by high-performance batteries, while improving range efficiency and reducing CO_2 impact. In another example, Hexcel Composites developed thermosetting fibre reinforced patches that can be bonded to aluminium subframes using adhesive to reduce noise, vibration and harshness (NVH) [9]. Nevertheless, these applications do not change the fact that the circular economy for thermosetting composites remains a challenge. Instead, manufacturers are shifting to thermoplastic composites as they offer excellent material options thanks to their weldability, low density, low overall production cost, improved fracture toughness, and recyclability. This is explored in projects such as MAI Skelett [10] (BMW as an end-user partner) to replace the i3's CFRP roof structure with a composite thermoplastic version. Extruded thermoplastics sections combined with overmoulding achieved better overall stiffness responses, and energy absorption in crash load cases outperformed the Carbon fibre reinforced polymer (CFRP), creating a ductile failure mode. Conversely, FlexHYjoin [11] project focused on joining an application-oriented multi-material roof stiffener, namely thermoplastic composite roof crossbar with Cant rail via steel brackets. The project used laser joining to undercuts the steel brackets, then applying pressure and laser beam to initiate induction welding of the thermoplastic to the steel bracket with a primary focus on automation aspects and bond strength via non-destructive testing (NDT).

The above projects demonstrated thermoplastics potential in terms of welding ability. Yet, the scope of the state-of-the-art use of advanced composites is still limited by the number of joining techniques, the areas where these techniques were implemented, commercial feasibility, and disassembly for end-of-life recycling. Therefore, the BRACE project aims to use an advanced joining technique for fibre reinforced thermoplastic composites to lightweight and improve the performance of chassis components while emphasising: 1) the design for disassembly by using polymer-coated materials (PCM) joining technique in which joints can be separated by heat application without damaging any of substrates, 2) the use of thermoplastic patches that are compatible with PCM and offer improved performance and recycling options, and 3) commercial feasibility as PCM process can be integrated with existing manufacturing line and do not require additional time for cure cycle.

2. PCM joining approach

Joining dissimilar materials is challenging as it involves different mechanical properties, surface behaviour and thermal expansion coefficients. Traditional joining technologies for metallic components such as welding, mechanical fastening, and riveting are not directly transferable to fibre reinforced composites because drilling or punching composites with post-manufacture mechanical fasteners or rivets damage the reinforcement [12]. Hence, adhesives are widely adopted for dissimilar joining as they offer several advantages over mechanical fastening, such as uniform stress distribution along the bonded area, sealing and electrical insulation, excellent fatigue strength, damping, and shock absorption, in addition to commercial benefits. However, despite their benefits, the performance of adhesively bonded joints is affected by various types of defects that are hard to inspect and require a high level of quality control. Recently, attention is increasing towards the importance of sustainability and end-of-life recycling by designing products that can be easily disassembled for efficient in-service repair, reuse, and end-of-life recycling. Consequently, using adhesives limits the disassembly opportunity as they are hard to separate once set and hard to remove from the substrates without damaging them. Prototypes for developing a disbanding solution for adhesively bonded joints include the use of thermally expandable microspheres to separate joint substrates were investigated. However, separated joints using this approach will still have adhesive remains on joint interfaces, and bond strength is slightly reduced with the introduction of microspheres [13].

On the other hand, BRACE project aims to remove the need for adhesives by utilising the weldability of thermoplastics by adopting an innovative PCM joining approach [14]. PCM involves using thermoplastics as structural adhesives where the final assembly operation is a polymer weld. For example, in the manufacture of a joint between dissimilar materials with one of the substrates being thermoplastic based composite, the non-thermoplastic component is first coated with a compatible thermoplastic before both components are welded together using heat and pressure action. As for disassembly, heat application is repeated until the interface reaches the glass transition temperature and the joint separates efficiently without damaging substrates. A schematic illustration for the PCM joint and Carbon/PEEK to aluminium joint demonstrations can be seen in Figure 1 and Figure 2, respectively.

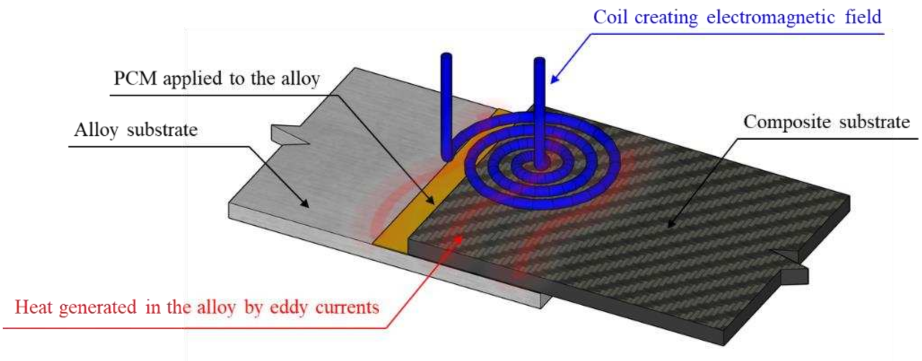

Figure 1 Schematic cross-section through a PCM joint.

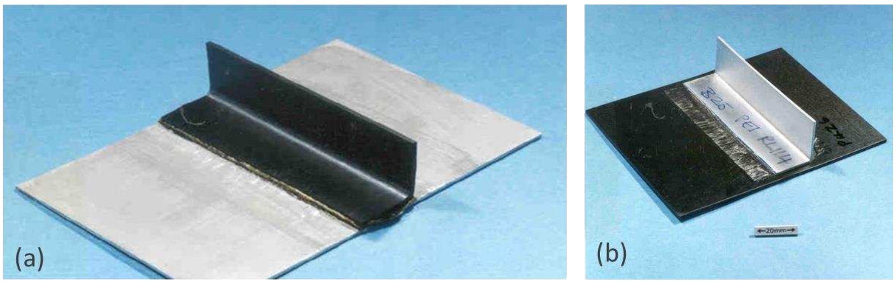

Figure 2 TWI Ltd PCM joining demonstration: a) Carbon/PEEK stiffener joined the PCM aluminium alloy panel. B) PCM Aluminum alloy stiffener joined to carbon/PEEK panel (copyright TWI).

3. Joining and disassembly steps

In this study, five main process steps are followed to achieve an effective PCM joint; these steps are:

1) **Cleaning and decontamination**: In this stage, surface preparation of the metal (laser processing, etching, surface texturing, or abrasion) takes place to prepare the metallic substrate for coating with the polymer material, PCM, see *Figure 3*(a).

2) **Coat**: a low-viscosity polymer solution is applied to the metal component by either spraying, dipping, or painting. Following effective cleaning and decontamination in the first step, the polymer solution penetrates the micro-features on the surface of the metal as it dries and adheres to the surface through a combination of attachment forces with additional chemical bonding enhancing the strength of the interface, see Figure 4.
3) **Heat**: The thermoplastic composite part is then brought into contact with the PCM applied to the metal part. A work coil is then used to heat the composite and/or metal by electromagnetically inducing eddy currents in the conductive parts of the assembly.
4) **Joint**: Fusion bonding occurs between PCM (applied to the metallic substrate) and composite as the required temperature of the PCM is reached. For effective joints, mechanical pressure is applied along with the induced heat to ensure sufficient contact between the substrates; applying this pressure can vary based on the application.
5) **Disassemble**: At the end-of-life of the product, in the same way as heat is needed to create the joining bonds, the process can also be reversed through the application of heat. The joined parts are easily released and disassembled at end-of-life for recycling, or reuse.

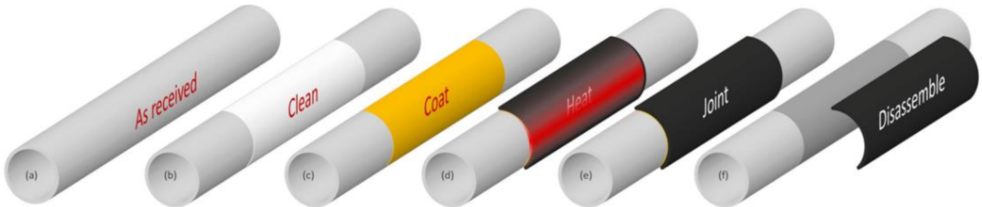

Figure 3 PCM joining (a-e) and end-of-life process (f).

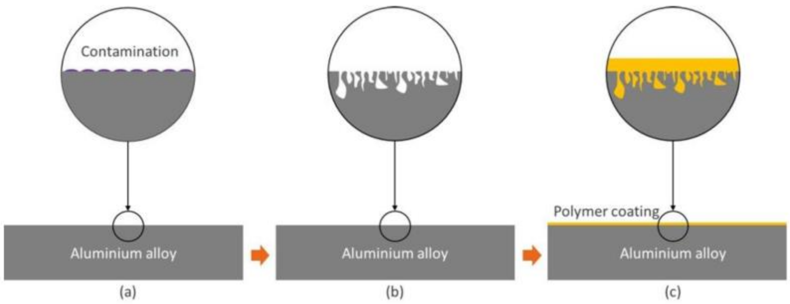

Figure 4 PCM coating process: (a) as received; (b) cleaning, texturing/pre-treatment; (c) polymer coating applied, ready for joining.

4 PCM Automotive Application

In the BRACE project, the consortium further develops the PCM joining process to adapt it for automotive chassis parts. For this purpose, three standard components manufactured by Gestamp Chassis are selected, aluminium and steel (painted and unpainted) lower control arms, see Figure 5. The aim is to apply the patch to these parts to increase their stuffiness, improve NVH for higher-end models, and explore the possibility of downgauging standard parts where economically viable weight reduction is possible. The following sections of this study present the coils developed, coating approach, planned experimental testing and numerical simulation strategy.

Figure 5 The proposed metallic chassis components by Gestamp that will be strengthened with thermoplastic composite patches using PCM joining method.

4.1 Work coils

One of the advantages of thermoplastic over thermoset composites is that they can be melted and reshaped. Hence, they can be joined by welding, also known as fusion bonding. In induction welding, a conducting work coil is used. In this technique, a work coil connected to a high-frequency power supply is placed in close proximity to the joint. As high-frequency electric current passes through the coil, a dynamic magnetic field is generated whose flux couples with the conductive components of the part. Consequently, an electric current is induced, thus heating up the conducting material, which leads to melting of the surrounding thermoplastic. Pressure applied to the joint helps ensure that molten thermoplastic forms a strong bond [15]. In this study, several coils will be used, the first coil used is a pancake coil which mirrors the size of the joint sample. This coil was used to conduct an initial lab-scale joining demonstration, see *Figure 6*.

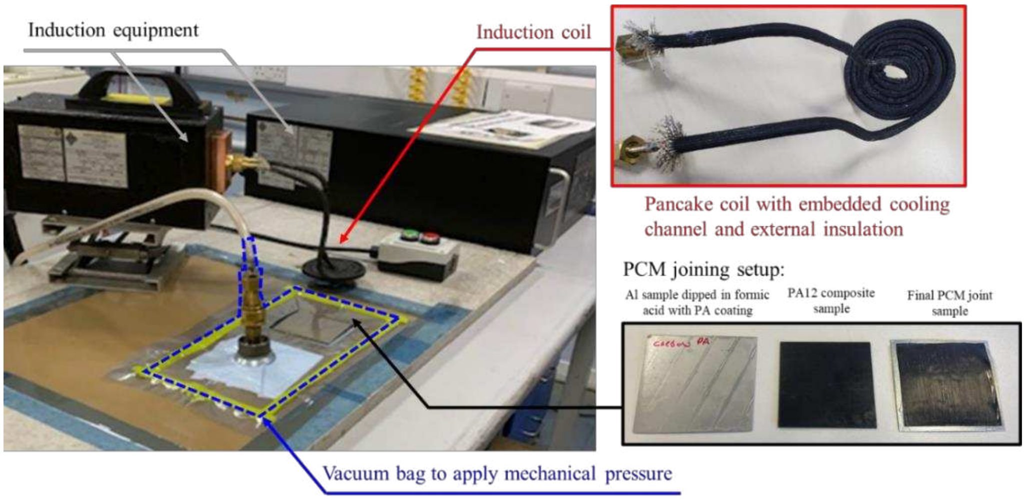

Figure 6 Lab-scale demonstration of dissimilar joining of thermoplastic-metal using PCM technology for BRACE project at TWI Ltd.

A second coil is designed to be used for the single-lap shear (SLS) test coupon samples, see Figure 7. The PCM technology will be first applied on SLS coupons to optimise the process. Then further SLS testing will be conducted to obtain mechanical property parameters, which can be used as input into the finite element analysis (FEA). A third work coil will be designed later in the project suitable for the optimised shape composite patch used for chassis parts; the movement of the coil will be automated and integrated within the production line.

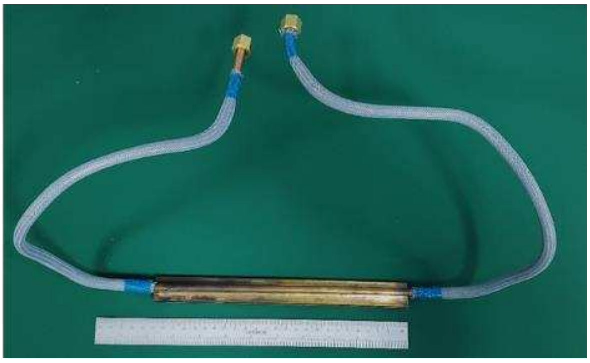

Figure 7 Work coil designed by TWI Ltd to be used in the SLS coupon manufacture using PCM technology.

4.2 Coating process

The metal surface is activated prior to the polymer coating. The surfaces are either grit blasted or mechanical braised and are solvent wiped to remove any contamination. Post deoxidisation of the metal surface is treated with an automotive standard surface Pre-Treatment primer. Once the primer sets in, the surface of the metal is now ready to be coated. The surface can be sprayed or dip-coated with the polymer solution to get a uniformly coated polymer thickness throughout. The final coating method will be aligned with the manufacturing process of the chassis component to ensure maintaining a high production rate.

4.3 Experimental and Numerical Modelling

To design the required patch for the selected automotive parts, there is a need to obtain the mechanical properties of the joint. Hence, in the experimental stage of the study, the SLS test will be completed on both PCM and adhesively bonded coupons. The results will allow characterising the bond for use in the FEA model and comparing the two joining methods. A preliminary FEA model has been generated for the SLS coupons using the commercial FEA software Abaqus. It is assumed that the PCM joint behaves similarly to those of adhesively bonded joints. Hence, a standard solid model was created based on the traction separation method and cohesive zone section property. The cohesive zone parameters will be obtained from the experimental testing of the SLS samples. This model will also be used to optimise PCM's process parameters, i.e. power, time, pressure, coil distance, and PCM coating concentration, to maximise the joint performance. The validated and optimised high-fidelity model of the dissimilar joint section will be analysed under various loading conditions to create a low-fidelity join section that can capture the joint system properties which can then be used in the upscaled case studies.

Simultaneously, a preliminary component scale analysis using was created to assess the buckling behaviour of the chosen demonstration parts with and without the thermoplastic patches. Based on assumed joint parameters, the buckling force needed for both the steel and aluminium was increased by 13.5% and 13.9% after using the thermoplastic patch, respectively as seen in Figure 8. These models will further be calibrated in future work as testing results become available.

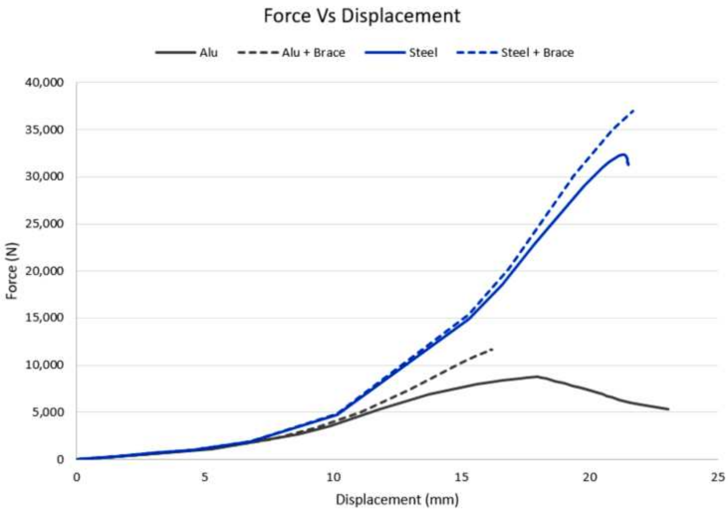

Figure 8 Preliminary simulations by Gestamp show an increase in buckling strength of the LCA after using a thermoplastic patch.

5 Conclusions

Although the cost of composites has dropped over the past decade, there are still significant challenges to effectively join these materials to conventional metal parts. Mechanical fastening and adhesive bonding are amongst the most common joining techniques. Nonetheless, both solutions present several limitations. In this study, PCM joining process is adapted for thermoplastic composite to metal assembly. This joining method uses induction welding to join a thermoplastic composite to a metallic substrate pre-coated with a compatible thermoplastic polymer film. Compared to mechanical fastening, PCM does not induce stress concentrations in the parts, and as the materials are not pierced, the risk of water damage is reduced. Compared to adhesives, PCM solution is not subject to curing times or shelf-life restrictions. Furthermore, the use of PCM enables easy recyclability of the parts; at the end-of-life, the parts can be disassembled through a reversal heat process.

The PCM method is used in conjunction with thermoplastic patches to strengthen automotive chassis parts. In order to assess the performance of PCM joints, experimental and numerical modelling has been utilised. SLS will be used for both PCM and adhesively bonded joints to allow a direct comparison between the two joining techniques. A preliminary FEA model has been completed to evaluate the buckling behaviour of the automotive demonstration parts with and without the thermoplastic patch. The results indicated that thermoplastic patches have led to an approximately 14% increase in the force required to buckle the parts. Further work is ongoing to complete the testing campaign and calibrate the models to optimise the patch geometry accordingly.

Acknowledgements

BRACE has secured funding from Innovate UK under EUREKA collaborative R&D programme 107471. The partners involved are: Gestamp Chassis (Lead partner), Far-UK, TWI Ltd and Brunel University London (participation through the Brunel Composites Centre).

References

1. McIlhagger A., Archer E. and McIlhagger R., (2020). 3 - manufacturing processes for composite materials and components for aerospace applications, pp.59-81. Available at: http://www.sciencedirect.com/science/article/pii/B9780081026793000034
2. Soutis C., (2020). 1 - aerospace engineering requirements in building with composites, pp.3-22. Available at: http://www.sciencedirect.com/science/article/pii/B9780081026793000010
3. Fuchs E.R.H., Field F.R., Roth R. and Kirchain, R.E., (2008). Strategic materials selection in the automobile body: Economic opportunities for polymer composite design, Composites Science and Technology, 68 (9),
4. Pradeep S.A., Iyer R.K., Kazan H. and Pilla S., (2017). 30 - automotive applications of plastics: Past, present, and future, In Kutz M., (Ed.) Applied Plastics Engineering Handbook (Second Edition) William Andrew Publishing, pp. 651-673. Available at: https://www.sciencedirect.com/science/article/pii/B9780323390408000316.
5. Seidlitz H., Kuke F. and Tsombanis N., Advanced joining technology for the production of highly stressable lightweight structures, with fiber-reinforced plastics and metal,
6. Carello M., Amirth N., Airale A.G., Monti M. and Romeo A., (2017). Building Block Approach' for Structural Analysis of Thermoplastic Composite Components for Automotive Applications, Applied Composite Materials, 24 (6), pp.1309-1320.
7. Hinte E. and Beukers A., (2020). Designing Lightness. Netherlands: nai010.
8. Advanced Propulsion Centre. 2022. APC Funding Drives UK Lightweighting - Advanced Propulsion Centre. [online] Available at: <https://www.apcuk.co.uk/apc-funding-drives-uk-lightweighting/> [Accessed 28 March 2022].
9. Hexcel's New Carbon Prepreg Patch Technology Selected as Finalist in JEC Innovation Awards 2019 [online]. Hexcel. 2019 [cited 28 March 2022]. Available from: https://www.hexcel.com/News/News-Releases/2729/hexcels-new-carbon-prepreg-patch-technology-selected-as-finalist-in-jec-innovat
10. More details on MAI Skelett design process [Internet]. Compositesworld. 2019 [cited 28 March 2022]. Available from: https://www.compositesworld.com/articles/more-details-on-mai-skelett-design-process
11. Cordis. 2018. *Flexible production cell for Hybrid Joining*. [online] Available at: https://cordis.europa.eu/project/id/677625 [Accessed 12 April 2022].
12. Omairey S, Jayasree N, Kazilas M. Defects and uncertainties of adhesively bonded composite joints. SN Applied Sciences. 2021;3(9).
13. Rapid Heat Popping Joints could revolutionise use of composites [online]. National Composites Centre. 2022 [cited 28 March 2022]. Available from: https://www.nccuk.com/news/rapid-heat-popping-joints-could-revolutionise-use-of-composites/
14. Wise R.J., Gosai K. Polymer Coated Material (PCM) Joining Technology for Manufacture and Repair of Dissimilar Material Structures [online]. TWI Global. 1999 [cited 28 March 2022]. Available from: https://www.twi-global.com/technical-knowledge/published-papers/polymer-coated-material-pcm-joining-technology-for-manufacture-and-repair-of-dissimilar-material-structures-march-1999
15. Worrall C.M., Wise R.J. Novel Induction Heating Technique for Joining of Carbon Fibre Composites. European Conference on Composite Materials [online]. Seville; 2014 [cited 25 March 2022]. Available from: http://www.escm.eu.org/eccm16/assets/0544.pdf

ECCM 20

26-30 JUNE 2022

LAUSANNE SWITZERLAND

ECCM20 - Proceedings

ISBN: 978-2-9701614-0-0
DOI: 10.5075/epfl-298799_978-2-9701614-0-0