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COST Action CA18120

Reliable roadmap for certification of bonded primary structures

Training School 2

October 17-19, 2022

University of Minho – Guimarães, Portugal

Editors: José Sena Cruz, Sofia Teixeira de Freitas, Chiara Bedon,
Pier Giovanni Benzo, Guilherme Gontijo, Marco Abreu Filho

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The online line version of this book is available at:
https://certbond.eu/category/activities/events/training-school/

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About COST

The European Cooperation in Science and Technology (COST) is a funding organisation for the creation of research networks, called COST Actions. These networks offer an open space for collaboration among scientists across Europe (and beyond) and thereby give impetus to research advancements and innovation.

COST is bottom up, this means that researchers can create a network – based on their own research interests and ideas – by submitting a proposal to the COST Open Call. The proposal can be in any science field. COST Actions are highly interdisciplinary and open. It is possible to join ongoing Actions, which therefore keep expanding over the funding period of four years. They are multi-stakeholder, often involving the private sector, policymakers as well as civil society.

Since 1971, COST receives EU funding under the various research and innovation framework programmes, such as Horizon 2020.

COST funding intends to complement national research funds, as they are exclusively dedicated to cover collaboration activities, such as workshops, conferences, working group meetings, training schools, short-term scientific missions, and dissemination and communication activities. For more information, please go to the Funding section of the COST website (https://www.cost.eu/).

The COST Association places emphasis on actively involving researchers from less research-intensive COST Countries (Inclusiveness Target Countries, ITC[1]). Researchers from Near Neighbour Countries and International Partner Countries can also take part in COST Actions, based on mutual benefit. For more information, please visit the global networking page (https://www.cost.eu/).

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[1] Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Macedonia, Hungary, Latvia, Lithuania, Luxembourg, Malta, Montenegro, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Turkey

COST Action CA18120

With the increasing pressure to meet unprecedented levels of eco-efficiency, aircraft industry aims for superlight structures and towards this aim, composites are replacing the conventional Aluminium. The same trend is being followed by civil, automotive, wind energy, naval and offshore industry, in which the combination (or replacement) of steel with composites can increase the strength-to-weight ratio. However, the joining design is not following this transition. Currently, composites are being assembled using fasteners. This represents a huge weight penalty for composites, since holes cut through the load carrying fibres and destroy the load path.

Adhesive bonding is the most promising joining technology in terms of weight and performance. However, its lack of acceptance is limiting its application to secondary structures, whose failure is not detrimental for the structural safety. In primary (critical-load-bearing) structures, fasteners are always included along bondlines, as “back-up” in case the bond fails. The main reasons for this lack of acceptance are the limited knowledge of their key manufacturing parameters, non-destructive inspection techniques, damage tolerance methodology and reliable diagnosis and prognosis of their structural integrity.

The Action aims to deliver a reliable roadmap for enabling certification of primary bonded composite structures. Despite the motivation being aircraft structures, which is believed to have the most demanding certification, it will directly involve other application fields in which similar needs are required. This Action will tackle the scientific challenges in the different stages of the life-cycle of a bonded structure through the synergy of multi-disciplinary fields and knowledge transfer.

General information

Start of Action: 04/04/2019
End of Action: 03/04/2023

Main Contacts

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Action website: https://certbond.eu/
Domain website: https://www.cost.eu/actions/CA18120

Action Management Committee

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Action Working Groups

WG 1 - Adhesive and interface chemistry
Leader: Ana MARQUES
Vice-leader: Åsa LUNDEVALL

- Evaluate current common practice in industry: adhesive chemistries and surface treatment processes for bonded joints.
- Collect the requirements and needs of the stakeholders and certification agencies, in terms of regulations (REACH).
- Propose novel non-toxic and environmentally friendly surface treatment processes and adhesive chemistries.
- Evaluate the quality of the new proposed eco-friendly solutions.

WG 2 - Design phase
Leader: Konstantinos TSERPES
Vice-leader: Norbert BLANCO

- Explore new design concepts (geometrical configurations and new crack arresting design features).
- Compare testing procedures for bondline characterization and models validation (under static, fatigue and impact loading, creep phenomena, imperfect bonding and environmental effects).
- Evaluate different design methodologies for the structural behaviour and progressive damage analysis of adhesively bonded structures.

WG 3 - Manufacturing phase
Leader: Nicolas CUVILLIER
Vice-leader: Rūta RIMAŠAUSKIENĖ

- Specify and select the key-parameters that influence the manufacturing process on an industrial scale.
- Evaluate destructive and non-destructive testing for quality control of manufacturing process.
- Propose novel embedded sensing solutions for the evaluation of adhesion strength.
- Evaluate of the effect of different manufacturing defects on the bondline performance.

WG 4 - In-service life phase
Leader: Wieslaw OSTACHOWICZ
Vice-leader: Theodoros LOUTAS

- Propose diagnostic tools for the structural integrity assessment of the bonded structure.
- Propose prognostic tools for the remaining useful life of the bonded structure.
- Develop guidelines towards bonded repairs application.

WG 5 - Disassembly phase
Leader: Laurent BERTHE

- Description of the state-of-the-art about disassembly technologies.
- Evaluation of the technologies and selection of the most promising technology.

WG 6 - Certification
Leader: Thomas KRUSE-STRACK
Vice-leader: Ranko PETKOVIC

- Define common nomenclature for all WG’s activities and deliverables.
- Integrate the outcomes and build the roadmap.
- Establish contact with relevant certification bodies and large industry manufacturers in naval, civil, offshore, automotive and wind energy and disseminate the progress of the Action and the roadmap.

Training School

Training Schools Coordinator: Chiara BEDON

Context

The **second CERTBOND Training School** (TS2) targets young talented researchers and aims to increase their participation in the Action activities. Practical and theoretical activities in support of the characterization and certification of primary bonded composite structures will be offered by international experts. Under the theme **Sustainable Composite Bonded Joints**, the TS2 offers a series of relevant activities, namely, (i) **Keynote Lectures from International Experts**, (ii) **Teambuilding activities with trainers**, (iii) **Social activities**, (iv) **Workshop** and (v) **Visit to the Labs** of the **Institute for Sustainability and Innovation in Structural Engineering** – ISISE (https://isise.net/), during **3 days**.

Who is eligible to take part in TS

PhD candidates and researchers are welcome. There are no registration fees to attend the Training School. However, a limited number of applicants will be selected by the organizing committee and will receive the financial support from COST.

Important Dates

- **June 15th:** deadline for registration of candidates & research abstract submission (online form - Click Here)
- **August 1st:** notification of accepted trainees
- **September 15th:** submission deadline for 1 page research summary ("short report template" available at: https://certbond.eu/templates/)
- **October 17 to 19th:** Training School - 3 full days

For any request on your application, please contact the Training School coordinator. Applicants are also requested to consult the COST Vademecum Chapter 6 for the updated information about TSs.

Organizing Committee

José Sena Cruz (Science Communication Coordinator), University of Minho

Sofia Teixeira de Freitas (Action Chair), Delft University of Technology

Chiara Bedon (Training School Coordinator), University of Trieste

Pier Giovanni Benzo, University of Minho

Guilherme Gontijo, University of Minho

Marco Abreu Filho, University of Minho

Overall Agenda

The Training School 2 involves students in technical lectures, practical activities, as well as technical visits to strategic labs & facilities in UMinho. Special care is spent for the active contribution of students that will be able to interact in the "Workshop" sessions.

Time	Day 1 – 17/10	Day 2 – 18/10	Day 3 – 19/10
Morning	Registration/ Welcome	Keynote Lecture 3	Teambuilding activity III
	Keynote Lecture 1	Teambuilding activity II	
	Coffee-break	Coffee-break	Coffee-break
	Keynote Lecture 2	Visit to the labs	Teambuilding activity IV
	Teambuilding activity I		
Break	Lunch	Lunch	Lunch
Afternoon	Workshop of CertBond Trainees I	Visit to the downtown	Workshop of CertBond Trainees III
	Coffee-break		Coffee-break
	Workshop of CertBond Trainees II		Workshop of CertBond Trainees IV

Guimarães and North of Portugal

The province of Minho, in the Northwest of Portugal, is full of scenic and historical sites, being particularly famous for the production of wine. To the North of the region, you will find the National Park of Peneda-Gerês with its rock-mountains, cascades, lakes and abundant wildlife.

To the East, you have the famous Douro river valley, where the Port wine grapes are grown. To the South, you will find the city of Porto, with its international airport, featuring an impressive architecture in the banks of the Douro River, the famous bridges and the Port wine cellars.

The city of Guimarães is famous for its architectural heritage, including worthwhile visits to: the historical centre, where its unique atmosphere of narrow streets and squares provides a meaning to the cultural heritage, which is the everyday reality for the local population; the palace of the House of Bragança, with its rare roofs and 39 large brick chimneys, that once was one of the most sumptuous residences in the Iberian Peninsula; the medieval castle, where the Portuguese history began; the Monastery of Santa Maria da Costa and the Penha Sanctuary, with a beautiful landscape.

The Guimarães municipality, with an area of 241 km^2, is located in Braga district in Northern Portugal. Elevated to the category of city in 1853, it is divided in 20 parishes with a total population of 158.000 inhabitants. The population of Guimarães is one of the youngest in Europe.

Guimarães is also considered the "Cradle of Portuguese nationality", where the country was founded in the 9th century ('Condado Portucalense', between 868 and 1143) by King D. Afonso I (1109-1185), Portugal's first ruler. The value of the historic heritage of Guimarães has been potentiated over the years. Guimarães was declared a World Heritage Site in 2001 by UNESCO due to its Middle Age historical monuments.

Guimarães offers private accommodation for the participants at very reasonable prices. Participants can easily walk from the UMinho venue to the city centre and hotels.

"Aqui nasceu Portugal" (Here was born Portugal)

Castle of Guimarães

City walls

Oliveira Square

Duques Palace

Feira Garden

Houses at Saint Tiago square

Penha

Venue

Founded in the year of 1973, **University of Minho** (UMinho) - https://www.uminho.pt/EN/ - welcomed its first students in the academic year of 1975/76. Today, UMinho is recognised for the competence and quality of its academic staff, the excellence of its research activity, its dynamism, large range of undergraduate and postgraduate degree programmes, ability for leadership and intervention, and its high degree interaction with other institutions.

The UMinho considers itself to be a complete university, offering degrees which span from Medicine, Sciences and Technology, to Arts, Humanities and Law. Some facts and figures: 20.000 students, 1.100 academic staff, 650 other staff, 1.000 researchers, 12 schools, 31 R&D Units.

Located in the North of Portugal, in the province of Minho, UMinho has two campi (https://whereis.uminho.pt/), one located in Braga and other the in Guimarães, which are 20 kilometres apart.

The Training School will take place at **Campus de Azurém, Guimarães** (figure below – left side)**, in the meeting room no. 2.09 of Building no.2 of the Department of Civil Engineering** (figure below – right side): https://whereis.uminho.pt/CA-19.html?room=CA-02-02-32-09.

Local host (contact details): José SENA-CRUZ (jsena@civil.uminho.pt)

How to reach Guimarães:

The nearest airport to Guimarães is the **Francisco Sá Carneiro Airport in Porto**, (https://www.aeroportoporto.pt/en/opo/home) which is about 50 km from Guimarães - around 30 min by car or 50 min by bus. The Francisco Sá Carneiro Airport operates with 73 destinations and 20 airlines, fly directly to Porto.

A direct shuttle bus (https://www.getbus.eu/en/) can conveniently be taken from the arrivals terminal to Guimarães. A one-way ride is 8,00€, the round trip 14,00€ and can be booked online.

Meals & Accommodation

Meals & coffee breaks

Lunches, drinks and coffee breaks will be provided by the local organiser.

Note: if you have any restrictions (e.g. any dietary preferences and/or allergies), please take care of these details when filling the online form.

Accommodation

Guimarães offers private accommodation for the participants at very reasonable prices. Participants can easily walk from city centre and hotels to the UMinho venue (Campus de Azurém).

Detailed Programme

Day 1 – October 17th 2022

08:45 – 09:00	**Registration**
09:00 – 09:30	**Welcome** José Sena Cruz, Sofia Teixeira de Freitas
09:30 – 10:30	**Keynote Lecture 1** [Moderator: Anastasios Vassilopoulos] *Durability and lifetime prediction for a sustainable environment* Sotirios Grammatikos, Norwegian University of Science and Technology
10:30 – 11:00	**Coffee-break**
11:00 – 12:00	**Keynote Lecture 2** [Moderator: Sofia Teixeira de Freitas] *Additive manufacturing of bio-inspired & living composites* Kunal Masania, Delft Technical University
12:00 – 13:00	**Teambuilding activity I** J. Sena Cruz, S. Teixeira de Freitas, A. Vassilopoulos, K. Masania
13:00 – 14:30	**Lunch**
14:30 – 16:00	**Workshop of CertBond Trainees I** [Moderator: Sotirios Grammatikos]
16:00 – 16:30	**Coffee-break**
16:30 – 18:00	**Workshop of CertBond Trainees II** [Moderator: Kunal Masania]

Day 2 – October 18th 2022

09:00 – 10:00	**Keynote Lecture 3** [Moderator: José Sena Cruz] *European TS FprCEN/TS 19101 - Design of Fibre-Polymer Composite Structures* João Ramôa Correia, University of Lisbon
10:00 – 10:30	**Coffee-break**
10:30 – 11:30	**Teambuilding activity II** J. Sena Cruz, S. Teixeira de Freitas, A. Vassilopoulos, K. Masania
11:30 – 12:30	**Visit to the labs** J. Sena Cruz, P. Giovanni Benzo, G. Gontijo, M. Abreu Filho
12:30 – 14:00	**Lunch**
14:00 – 17:00	**Visit to Guimarães' downtown**

Day 3 – October 19th 2022

08:30 – 10:30	**Teambuilding activity III** J. Sena Cruz, S. Teixeira de Freitas, A. Vassilopoulos
10:30 – 11:00	**Coffee-break**
10:00 – 12:30	**Teambuilding activity IV** J. Sena Cruz, S. Teixeira de Freitas, A. Vassilopoulos
12:30 – 14:00	**Lunch**
14:00 – 15:30	**Workshop of CertBond Trainees III** [Moderator: Anastasios Vassilopoulos]
15:30 – 16:00	**Coffee-break**
16:00 – 17:45	**Workshop of CertBond Trainees IV** [Moderator: Sofia Teixeira de Freitas]
17:45 – 18:00	**Closure of Training School & Best Presentation announcement and Best Project** José Sena Cruz, Sofia Teixeira de Freitas, Anastasios Vassilopoulos

Keynote Speakers

SOTIRIOS A. GRAMMATIKOS
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Department of Manufacturing & Civil Engineering
NTNU - Norwegian University of Science and Technology

Sotirios Grammatikos is a Professor in Polymer Composites at the Department of Manufacturing and Civil Engineering of NTNU – Norwegian University of Science and Technology, Norway. Sotirios is the Scientific Director of the ASEM lab - Laboratory of Advanced and Sustainable Engineering Materials (www.asemlab.no) and Leader of the Research Group Sustainable Composites at NTNU. Sotirios is also an Affiliated Professor at Chalmers University of Technology in Sweden collaborating in the field of lightweight materials and infrastructure physics and also Visiting Scientist at the Hellenic Mediterranean University of Greece, collaborating in the field of nanocomposites. His main research interests are smart features of composites, non-destructive evaluation, recycling and durability aspects. Before joining NTNU, he worked at Chalmers, the University of Bath, UK and the University of Ioannina, Greece. Sotirios holds a PhD in Materials Engineering specialized in Structural Integrity of Aerostructures (2009-2013) and has received training in lightweight aerospace composites from the Hellenic Aerospace Industry (HAI). He is currently author/co-author of approximately 80 publications with 18 h-index (Google scholar) and invited member of the International Advisory Board (IAB) of 2 International Journals. Currently (as of Oct 2022) supervises /co-supervises 4 MSc, 10 PhD and 2 Post-doctoral students. He is PI for NTNU of 11 externally financed research projects of which 7 are EU-funded and 4 funded by the Research Council of Norway (of which 2, he is coordinator). Sotirios will be the Chairman of ECCM22, that will take place in Oslo, in June 2026.

Keynote Lecture: Durability and lifetime prediction for a sustainable environment

Whilst the design, manufacturing and material constituents of structural fibre-reinforced polymer composites have been largely improved the past years, there are still major issues pertaining to degradation especially in challenging operational conditions such as in the offshore. Coupled environmental aging with service-induced degradation lead to significant deterioration during operation. Moisture, rain & sand erosion, UV radiation, lightning strikes, impact damage as well as thermomechanical fatigue are the major causes of degradation. As the effects of the aforementioned conditions (which in most cases act in combination) are not always fully understood, unexpected behavior during service often results in structural failures, which are challenging to predict. This undoubtedly reduces the reliability of composites as structural elements making investors and stakeholders reticent in long-term investing in lightweight structures. The problem of long-term performance and lifetime prediction is more pronounced for the case of bio-based composites and also reclaimed /recycled polymer-based products, due to their inherent hydrophilicity and unknown service history, respectively. A complete analysis of why lifetime prediction of composites is a challenge, how is this affecting the new generation of bio-based polymer composites and also what is the impact to the environment, will be presented, along with ideas, solutions and latest trends.

KUNAL MASANIA
k.masania@tudelft.nl
Shaping Matter Lab
Faculty of Aerospace Engineering
TU Delft

Dr. Kunal Masania is an Associate Professor at the Faculty of Aerospace Engineering. After studying Mechanical Engineering at the University of Loughborough, Kunal carried out his PhD at Imperial College London on size effects and nanoscale toughening of thermosetting polymers. At the University of Applied Sciences of Northwestern (FHNW) Switzerland he developed a variety of advanced processing approaches for high-performance composites, such as rheo-kinetic control, compression RTM, highly reactive polymers, discontinuous composites and natural-fibre thermoplastic composites. Then Kunal joined the Complex Materials Group at ETH Zürich, to develop new bio-inspired materials, 3D printing of biological materials and nacre-like composites.

His group at TU Delft now re-imagine how composites are made today, with an emphasis on structuring hierarchical materials in three dimensions using design inspiration from the natural world. With the clear goal of producing structural details with complexities that are only possible with additive manufacturing, his group that works on topics from material synthesis, additive manufacturing of bio-inspired and living composite materials and their structures - to mechanics and mechanical behavior. Having co-founded two startups, he very much likes to push breakthrough science to applications that can impact society.

Keynote Lecture: Additive manufacturing of bio-inspired & living composites

Composite materials in nature exhibit heterogeneous architectures that are tuned to fulfill the functional demands of the surrounding environment. Examples range from the cellulose-based organic structure of plants to highly mineralized collagen-based skeletal parts like bone and teeth. Because they are often utilized to combine opposing properties such as strength and low-density or stiffness and wear resistance, the heterogeneous architecture of natural materials can potentially address several of the technical limitations of artificial homogeneous composites. However, current man-made manufacturing technologies do not allow for the level of composition and fiber orientation control found in natural heterogeneous systems. In this talk, I will show that additive manufacturing (AM) routes might offer a new exciting pathway for the fabrication of biologically-inspired composite materials with unprecedented heterogeneous architectures. Proof-of-principle examples will be presented to illustrate the potential of AM technologies for the fabrication of composites with widely-tunable properties and functionality.

JOÃO RAMÔA CORREIA
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CORE Group (https://coregroup.tecnico.ulisboa.pt)
Instituto Superior Técnico
University of Lisbon

João Ramôa Correia is Full Professor at the Department of Civil Engineering of Instituto Superior Técnico (IST), University of Lisbon, where he coordinates a research group (CORE, http://coregroup.tecnico.ulisboa.pt/) that conducts research, development and teaching activities on advanced fibre-reinforced polymer (FRP) composite systems for civil engineering applications. The main research areas of the CORE group are the mechanical behaviour of FRP composites systems, connection technology, long-term performance, durability, fire behaviour and sustainability. Members of the CORE group also participated in relevant FRP projects in Portugal, namely (i) the São Mateus Footbridge (2013, hybrid GFRP-steel); (ii) the São Silvestre Footbridge (2015, hybrid GFRP-concrete); and (iii) the Clickhouse (2015, all-GFRP modular housing system). João Ramôa Correia serves in the Editorial Board of the following journals: Journal of Composites for Construction (Associate Editor), Composite Structures and Fire Safety Journal. From 2018 to 2022, he was leader of CEN TC250 Project Team WG4.T2 "FRP Structures", which recently completed the Technical Specification (future Eurocode) for the Design of Fibre-Polymer Composite Structures. In 2012, he was the recipient of the IABSE Prize, attributed by the International Association for Bridge and Structural Engineering (IABSE), and in 2016 he received the IIFC Distinguished Young Researcher Award, attributed by the International Institute for FRP in Construction (IIFC).

The future European Technical Specification for the Design of Fibre-Polymer Composite Structures, CEN/TS 19101: 2022

In July 2022, the European Committee for Standardization (CEN) approved the Technical Specification CEN/TS 19101, "Design of fiber-polymer composite structures". This document was developed by Project Team WG4.T2, in close collaboration with Working Group 4 ("FRP Structures") of CEN Technical Committee 250 (TC250), between July 2018 and October 2021. The document should be published in 2023. In this lecture, a brief presentation of the technical specification will be made, describing: (i) the scope, (ii) the structure of the document, which is already in line with that of the new generation of Eurocodes, and (iii) the principles that were in the basis of its development. Some specific aspects will be described in greater detail, such as the resistance format adopted and how the effects of temperature, humidity and creep were considered, as well as the respective rationale. In the final part of the lecture, two complementary documents will also be briefly presented: (i) the Background Document (about 1000 pages), which provides additional information for each of the most relevant paragraphs of the technical specification, indicating the references considered and justifying the options taken, and (ii) the Worked Examples, which illustrate the application of the technical specification to different case studies.

Workshop of CertBond Trainees

The **Workshop of Certbond Trainees** consists on a series of PowerPoint oral presentations of the research carried out by the trainees. Each presentation last **10 minutes** (sharp!), followed by a discussion up to **5 minutes**. **All the PPT presentations shall be sent by the 17th of October to the Organizing Committee through the following e-mail address:** certbond.ts2@gmail.com (neither pen drives nor personal computers are permitted!).

Workshop of CertBond Trainees I - October 17th 2022 | 14:30 to 16:00

14:00 – 14:15 *Interface optimization in metal/thermoplastic composite hybrid joints*
A. Adelinia, J. Zanjani, D. Matthews, A. Yerokhin, M. de Rooij

14:15 – 14:30 *Environmental laser paint stripping process*
M. Ayad, S. Ünaldi, L. Berthe

14:30 – 14:45 *A non-intrusive study on factors affecting the operation of bonded fiber optic sensors inside a structure*
K. Balasubramaniam, R. Soman, P. Malinowski

14:45 – 15:00 *Fiber reinforced polymer composites in civil engineering*
I. Drobnjak

15:00 – 15:15 *Joining technology as a key to multi-material design application*
A. Đurić

15:15 – 15:30 *Durability of CFRP-Concrete bond in EBR and NSM systems under natural ageing for a period of four years*
A. Dushimimana, L. Correia, R. Cruz, J. Pereira, J. Sena-Cruz

Workshop of CertBond Trainees II - October 17th 2022 | 16:30 to 18:00

16:00 – 16:15 *Development of formaldehyde-free adhesive systems for use in the manufacturing process of particleboards*
D. Gonçalves, A. Marques, R. dos Santos

16:15 – 16:30 *Test specimen and accompanying test strategy for the comprehensive characterization of potting and insulation materials*
C. Gundlach, S. Hartwig

16:30 – 16:45 *Failure behaviour of multiscale toughened co-cured composite laminate joints subjected to quasi-static loading*
O. İnal, P. Potluri, C. Soutis, K. Katnam

16:45 – 17:00 *Integrated manufacturing and toughening of composite joints using a PEI film*
C. Innis, T. Pardoen

17:00 – 17:15 *Research and development of 3D printed continuous carbon fiber reinforced polymer composite structures*
T. Kuncius, M. Rimašauskas

17:15 – 17:30 *Mechanical and adhesive joining procedures for hybrid aluminum and Carbon Fibre Reinforced Polymer components*
N. Lázaro, D. Padró, J. Balanzat

Workshop of CertBond Trainees III - October 19th 2022 | 14:00 to 15:30

14:00 – 14:15 *Acoustic emission damage characterisation in toughened CFRP bonded joints*
R. Lima, R. Tao, A. Bernasconi, M. Carboni, N. Carrere, S. Teixeira de Freitas

14:15 – 14:30 *Advances in isocyanate microencapsulation for new ecological and mono-component adhesives*
M. Loureiro, A. Aguiar, I. Pinho, J. Bordado, A. Marques

14:30 – 14:45 *Bonded connection for decoupled masonry infill walls in RC frames*
M. Marinković

14:45 – 15:00 *A highly efficient use of the VCCT to simulate fatigue crack propagation in bonded joints*
L. Martulli, M. Carboni, A. Bernasconi

15:00 – 15:15 *Finite Element numerical modelling of monolithic glass fitted with ASF under out-of-plane bending setup*
S. Mattei, C. Bedon

15:15 – 15:30 *Design of test methods for mode I testing of adhesively bonded joints*
E. Meulman, J. Renart, L. Carreras, J. Zurbitu

Workshop of CertBond Trainees IV - October 19th 2022 | 16:00 to 17:45

16:00 – 16:15 *The effect of the SiC reinforcement and moisture absorption on the thermo-mechanical properties of the carbon/epoxy composites*
V. Obradović, D. Bajić, P. Sejkot, B. Fidanovski, K. Machalická, M. Vokáč

16:15 – 16:30 *Towards circular cast glass assemblies: Evading permanent bonding*
F. Oikonomopoulou, T. Bristogianni

16:30 – 16:45 *Adhesive bonding of glass and concrete – Development of application and construction methods*
S. Sartipi, J. Belis, R. Wan-Wendner

16:45 – 17:00 *Toward progressive failure of adhesively bonded composite joints through surface patterning and adhesive tailoring*
R. Tao, S. Teixeira De Freitas

17:00 – 17:15 *Laboratory tests of adhesively bonded aluminium angle cleat connections*
A. Valčić1, D. Skejić, J. Košćak, I. Duvnjak

17:15 – 17:30 *Application of embedded laminated connections for glass structures*
M. Zdražilová, Z. Sokol, M. Eliášová

17:30 – 17:45 *Adhesives for glass load-bearing structures*
M. Zikmundová, M. Eliášová

Workshop of CertBond Trainees Abstracts

Interface optimization in metal/thermoplastic composite hybrid joints

Atiyeh Adelinia[1]; Jamal Seyyed Monfared Zanjani[1]; Dave Matthews[1]; Aleksey Yerokhin[2]; Matthijn de Rooij[1];

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Objectives / Description / Main outcomes

The main objective of this project is to improve the bonding performance in metal/thermoplastic composite hybrid joints. Since the joining of such dissimilar entities with distinctive characteristics is a challenging task, surface treatments are required to increase the robustness and reliability of the bonding. This project aims to use plasma electrolytic oxidation (PEO) as the surface treatment method.

PEO is a promising surface treatment method to create a porous metal-oxide film on metallic substrates via applying high current density to the immersed metal in an electrolyte. Currently, there is a knowledge gap in the adaptation of the PEO process for improving the bonding performance of hybrid structures. This method is capable of creating a unique microstructure called “undercuts” as shown in Figure 1-2. These features are able to improve the bonding between metal and thermoplastic through mechanical interlocking. It is noteworthy that PEO layer characteristics are dependent on the process parameters, such as electrical parameters and electrolyte composition. Therefore, optimization is required concerning the bonding application.

So far, the effects of PEO process parameters including electric current, control mode, current density, frequency, and process duration on the surface microstructure of the PEO layer on aluminium alloy 5754 have been studied. Our experiments showed that pulsed DC mode offers higher process controllability compared to AC mode which is necessary to tune the PEO microstructure for bonding in mechanical interlocking. Moreover, we found that the constant current (CC) control mode results in more surface features which are necessary to form mechanical interlocking in the bonding stage (Figure 1-2). The PEO-treated sample was also bonded to polypropylene (PP) prepreg via a hot-press process as seen in Figure 3.

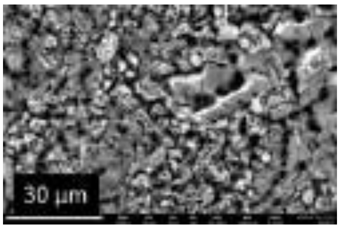

Figure 1: *PEO coating surface morphology under SEM*

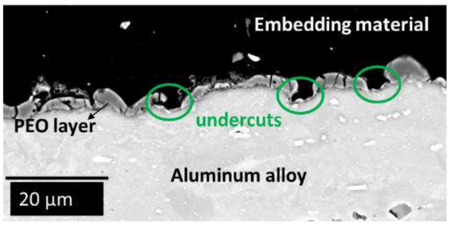

Figure 2: *Cross-sectional SEM image of PEO coating*

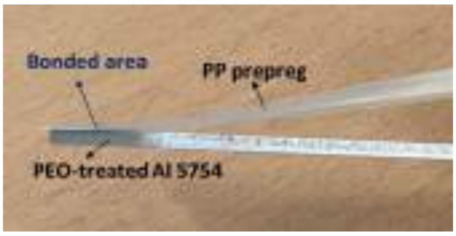

Figure 3: *Bonding between a PEO-coated sample and a PP prepreg*

Environmental laser paint stripping process

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Objectives / Description / Main outcomes

Currently, paint adhesion in aeronautical structures is a hot topic in the community in order to investigate the aircrafts' paint sustainability. A quantitative approach is mandatory to evaluate the adhesion level since above the adhesion threshold the external aircraft coatings will be stripped from the substrate. In direction of obtaining clean aviation system, paint removal and recycling are important subjects and should be investigated in detail. In this study, we use laser shock to remove the paint from Aluminium (AA 2024-T3) substrate by applying the laser on the coated side (Figure 1). Experiments have been performed at Hephaistos laser facility located at PIMM laboratory, Paris. Simulation of the high strain rate process has been established using the explicit software LS-DYNA. To that scope, high strain rate material model for metal and polymer has been used and validated with the measured experimental results at low power density (0.4 GW/cm²) as shown in Figure 2. We proved that for the first time, the laser paint stripping process (LPSP) is possible by applying the laser on paint side via Aluminium tape to protect the paint from thermal ablation, which will be produced by the laser during the operation. Finally, we showed that after applying the laser on the aluminium tape, the paint was collected directly from the aluminium tape as shown in Figure 3. This study is a key step towards the development of a selective and validated environmentally friendly recycling process of the paint and other polymers.

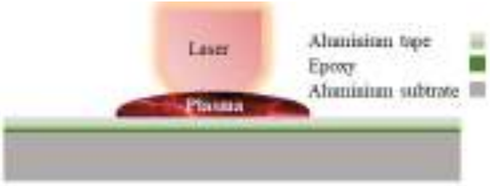

Figure 1: *Laser shock process on epoxy-aluminium substrate using aluminium tape*

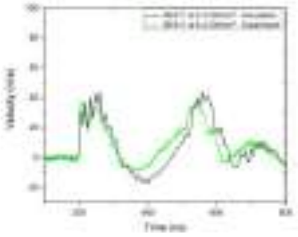

Figure 2: *Validation of the Aluminium tape, epoxy, and substrate numerical model*

Figure 3: *Collection of paint after Laser paint stripping process*

A non-intrusive study on factors affecting the operation of bonded fiber optic sensors inside a structure

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Objectives / Description / Main outcomes

Fiber Bragg grating (FBG) sensors are of small size, embedded into structures, and hence are widely used in the health monitoring of structures in various fields. FBG-based structural health monitoring applications are being used in different types of damage identification, localization, and lifecycle analysis. FBG can serve as an effective sensor for data monitoring applications as it can withstand harsh environmental conditions. The research aims to study the effect of change in guided waves (GW) relative magnitude based on the adhesive bond and bond length when applied on top of the FBG sensor. The paper compares the signal amplitudes between the directly bonded and remotely bonded FBG in the structure. Apart from this, a parametric study was also conducted based on signal attenuation to show the change in the bond length affecting the GW and wavelength shift. The bond length wave attenuation-based studies were done by applying glue at various distances from the FBG sensor and glue of various spread lengths to facilitate the concept of remote and direct bonding effects. The study is conducted on the subsystem-level aluminium specimen. A numerical finite element model was also made to test the effects of GW sensed with FBG embedded inside the structure. The research outcomes were then transferred into the actual embedding of FBGs inside glass fibered reinforced polymer (GFRP) composites for monitoring.

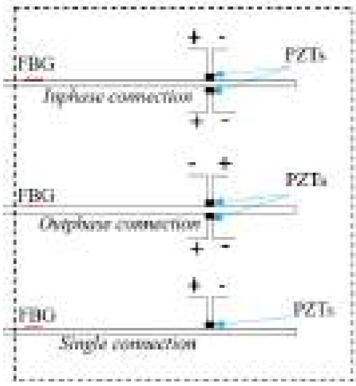

Figure 1: *PZT connection types for exciting GWs*

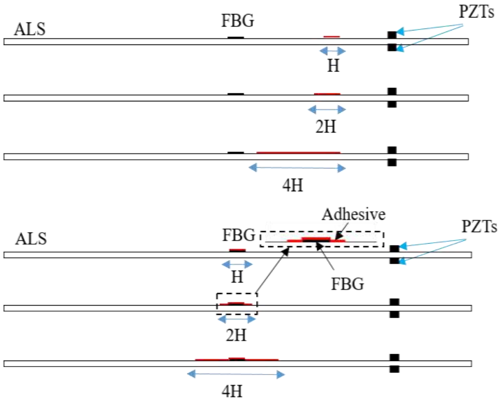

Figure 2: *Remote and Direct bonding*

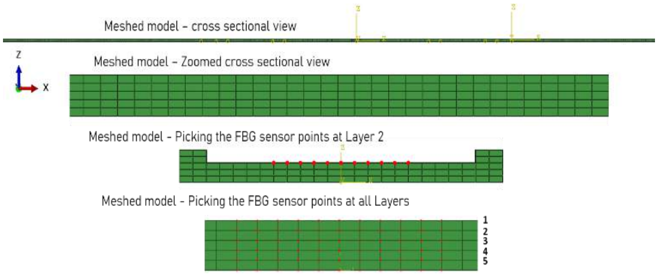

Figure 3: *Numerical model – FBG embedding*

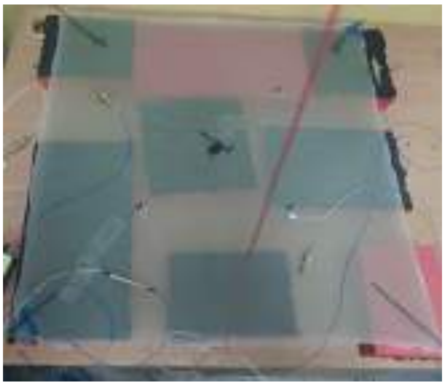

Figure 4: *FBG embedded inside the GFRP*

Fiber Reinforced Polymer Composites in Civil Engineering

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Objectives / Description / Main outcomes

The main aim of the presentation is to deliver information about the use of Fiber Reinforced Polymer Composites (FRP) in the field of Civil Engineering. FRP composites have been widely used for decades in different kinds of engineering, such as civil engineering. Their mechanical properties enable significant achievements in the functionality, safety, and economy of construction. The main advantages are high strength-to-weight and stiffness-to-weight ratios, corrosion resistance, lightweight, and potentially high durability. Different FRP shapes are used in civil engineering applications: profiles for new constructions, rebar, and strengthening systems.

FRP use in repairing and retrofitting structures has seen significant growth over the last two decades. It is one of the most challenging ones in the civil industry. These composites can be applied to strengthen the beams, columns, and slabs of buildings and bridges. The connection of beam and column (beam-column joints) are very vulnerable portions of RC buildings, especially during occurrences of earthquakes. Traditional retrofitting methods do not always provide reliable solutions, unlike composite materials (e.g. FRP) as the present durable retrofitting solution.

It is very clear that the volume of repair and retrofit structures with FRP will increase substantially in the future with its significant growth in the last decades and its superiority in many ways to conventional construction materials. This requires more education and training in the design, manufacture, and use of composites and FRP composites in different kinds of engineering, such as civil engineering.

Sources for Figures: https://www.horseen.com/; https://ascelibrary.org/doi/10.1061/%28ASCE%29CC.1943-5614.0000590

Figure 1: *Beam strengthening*

Figure 2: *Column strengthening*

Figure 3: *Slab strengthening*

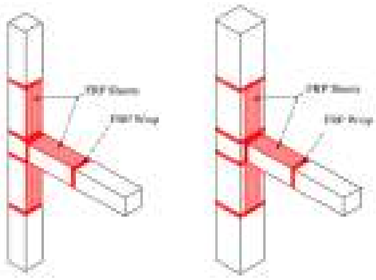

Figure 4: *Beam-column joints strengthening*

Joining technology as a key to multi-material design application

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Objectives / Description / Main outcomes

A proven way to reduce fuel consumption is to reduce the weight of the vehicle (weight reduction leads to fuel savings, and thus CO_2 emissions), and this can again be achieved by replacing the steel structures with a structure made of light materials. It is to be expected that the complete replacement of steel with light materials is not possible. Multi-material design is developed as a modern concept to achieve a lightweight structure. This implies primarily the use of dissimilar lightweight materials such as AHSS steel, aluminum alloys and carbon fibre reinforced polymer composites (CFRP) in one structure (Fig 1). The structure of different materials has a good perspective for application in the automotive and aerospace industries but only if is possible to achieve a quality joint between dissimilar materials. Sheet metal joining technologies can generally be divided into four basic groups: welding, mechanical joining, adhesion and hybrid technologies (Fig. 2).

The one of most used technology for joining sheets materials is Resistance spot welding (RSW). Due to different mechanical, physical and chemical properties, the joining of different materials by RSW technology does not provide a quality joint, and accordingly, alternative technologies for joining different materials have emerged. Resistance element welding (REW) was developed to enable different materials to join. This technology does not require significant modification of existing equipment in factory, which is its great advantage. Welding technologies suitable for joining dissimilar materials include friction stir welding, ultrasonic welding and laser welding.

Mechanical clinching (MC) is another alternative technique for joining sheets, but without an additional element and without introducing heat. This method of cold forming has performed by the process of local deformations with the punch and die. When it comes to modern mechanical joining technologies with additional components, then the dominant research is in terms of joining materials with self-piercing rivets (SPR) and Flow drilling screws (FDS).

The adhesive joint also can be used for joining dissimilar materials. This way of joining meets the requirements of mechanical load, with high reliability of the product, and in connection with the production and climatic conditions. On the other way, the mechanical characteristics of the joint can be significantly improved by combining the adhesive joint with welding and mechanical joining technologies (hybrid technologies).

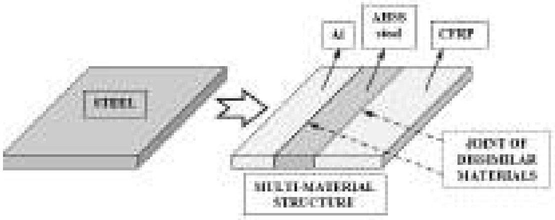

Figure 1: *An example of multi-material design*

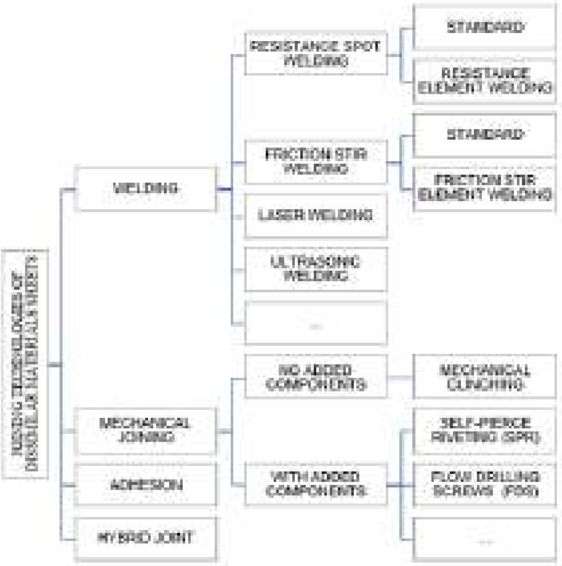

Figure 2: *Sheet metal joining technologies*

Durability of CFRP-Concrete bond in EBR and NSM systems under natural ageing for a period of four years

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[1]University of Minho, ISISE/IB-S, Guimarães, Portugal

Objectives / Description / Main outcomes

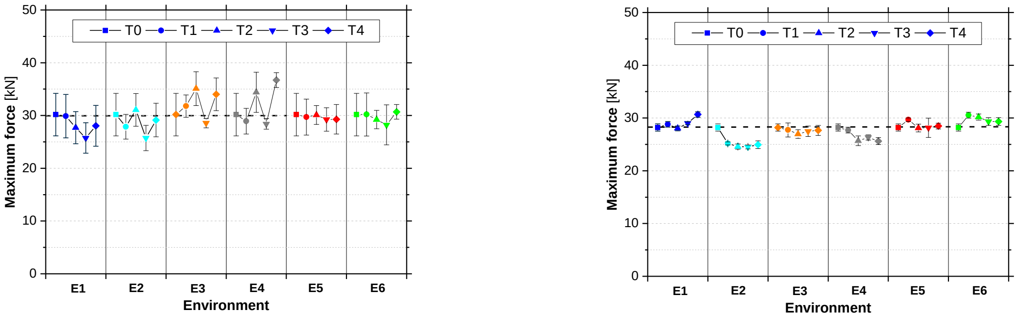
Existing reinforced concrete structures can be strengthened with Carbon Fibre Reinforced Polymer (CFRP) composites to increase their life span and serviceability performance. The application of the CFRP composites is mainly performed with Externally Bonded Reinforcement (EBR) and Near Surface Mounted (NSM) techniques.

Most of the existing studies on the durability of structures strengthened EBR- and NSM-CFRP systems have been conducted under laboratorial conditions using accelerated ageing protocols, and little is known on whether such conditions can provide an appropriate estimate of what normally happens in the real (natural) outdoor conditions.

The main objective of the current work was to provide insights on the durability of the bond between concrete and CFRP reinforcements installed using EBR and NSM techniques, under the effects of ageing induced by natural outdoor conditions (see Fig. 1) for a period of four years. The specimens were located in four different natural outdoor environments with ageing mainly induced by carbonation (E3), freeze-thaw attacks (E4), elevated temperatures (E5), and airborne chlorides from seawater (E6). The bond behaviour for specimens was investigated through pull-out-tests (see Fig.2). Besides, for comparison purpose, the study also included a reference environment (E1: ≈20 °C / 55% RH) and another environment with the specimens continuously immersed in water (E2: ≈20 °C / immersion). The results from pull-out tests performed on the specimens collected from the above environments (see Fig. 3) showed that the concrete-adhesive-CFRP bond strength in outdoor environments had some noticeable fluctuations with time especially in E3&E4 for EBR and E4 for NSM, while other outdoor environments showed irrelevant variations. Owing to the fact that the highest bond strength reductions are less than 10% for NSM and 9% for EBR, it can generally be concluded that the bond strength had a small degradation with time and environmental exposure.

Figure 1: *EBR (left) and NSM (right) specimens exposed to outdoor environments*

Figure 2: *Pull-out tests: EBR (left) and NSM (right) specimens*



a) *b)*

Figure 3: *Bond strength variation up to 4 years (Ti stands for year i, i =0,..4): a) EBR; b) NSM*

Development of formaldehyde-free adhesive systems for use in the manufacturing process of particleboards

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Objectives / Description / Main outcomes

The wood-based panels (WBPs) market is expected to increase in size due to the rising demand across the globe for more sustainable materials. This growth prospect also presents the opportunity to improve the manufacturing lines of WBPs, increasing the quantity of renewable materials used during the manufacturing process. The production lines for manufacturing of WBPs like particleboards, plywood and OSB, depend mainly on petrochemical-based adhesive systems, such as phenol-formaldehyde (PF), melamine-urea-formaldehyde (MUF), and MDI. The use of these types of adhesive systems have some significant downsides, such as the release of volatile specimens, like unreacted formaldehyde, that pose significant human health concerns. As such, the main objective for this research work consists in the production of a formaldehyde-free adhesive system for use in the manufacture of particleboards. Presently, our research is mainly focused on protein-based adhesives. We are currently working with whey proteins, but intend to also study other protein sources, such as soy, cottonseed, and hemp.

The use of protein-based adhesive systems in WBPs manufacture also present some significant obstacles, specifically the board's water resistance, board swelling in humid environments, and low bio-resistance to fungi and bacteria caused degradation.

As such, the present work aims the development and implementation of a crosslinker (cr) that can be then added to the adhesive formulation to increase its water resistance, whilst not negatively affecting any other physical and mechanical properties. The cr synthesis system currently being studied uses a mixture of a polyol diglycidyl ether with a bio-based tetramine, of which some results are shown in figure 1. These crosslinkers were added to the whey-protein adhesive system, figure 2, and used in the manufacture of samples of the typical sandwich particleboards, an example of which is shown in figure 3.

Currently, we aim to improve the adhesive system formulation, by optimizing the amounts of crosslinker added, water present in its formulation and study different protein sources. With these changes we aim to reduce the costs for the large-scale implementation of this manufacturing process, whilst increasing the amount of renewable-sourced raw materials used in it and keep the physical and mechanical properties of the manufactured WBPs.

***Figure 1:** Example of the crosslinkers used*

***Figure 2:** Whey-Protein based adhesive*

***Figure 3:** Side view of a sandwich-type particleboard*

Test specimen and accompanying test strategy for the comprehensive characterization of potting and insulation materials

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Objectives / Description / Main outcomes

Moulding is a common approach to protect components like electronic devices on circuit boards, battery cells in a module or coils in an electric engine from environmental influences and to increase their performance according to aspects like heat transfer. In order to ensure the correct design of the multi-material structure for long-lasting operation, the impact of the individual material parameters and their interaction on aging and failure mechanisms under different loads in service have to be considered and – in the best case – fully characterized before the component's final design. This creates demand for simple testing techniques that are able to map the multi-directional and multi-domain loads in a moulded hybrid part as accurately as possible.

The objective of my research is an application-oriented test methodology for potting and insulation materials in multi-material structures, which mainly involves evaluating ageing and failure behaviour on a new test specimen. According to the current state of the art, different geometries and test strategies are suggested but seem to be limited in terms of flexibility, intensity, reproducibility and temporal distinctiveness in terms of failure of different materials. In order to solve these issues, a cylindrical test specimen using a specially shaped metal insert encased with the potting material is suggested. With this approach, mechanical stresses arising from exposure to temperature changes are concentrated. The amount of aging of the potting material due to thermal cycling is characterized in particular in the form of delamination phenomena as well as crack initiation and propagation on the test specimen. The results allow comparing different moulding materials according to their thermo-mechanical performance and delivering robust material recommendations.

The application of non-destructive testing methods on the test specimen extends the amount of results drawn from testing. Induction based thermography is used for checking the inlay's position after production and for detecting possible changes in the thermal conductivity of the potting material due to thermal cycling. Additionally, with a vibration-based technique it is possible to perform a continuous structural health monitoring of the specimen during the ageing experiment. Effects like cracks, delamination and stiffness reductions can be detected without the need for interrupting the ageing experiment. The knowledge about the application and evaluation of non-destructive testing methods gained in combination with the specimen is currently adapted to the use with adhesively and fusion bonded joints over their whole life cycle in laboratory and practical environments.

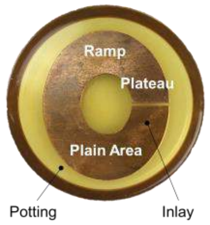

Figure 1: *Structure of the test specimen*

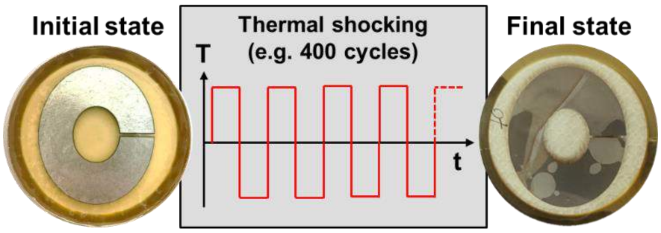

Figure 2: *Ageing of the test specimen with thermal shocks and possible failure pattern after experiment*

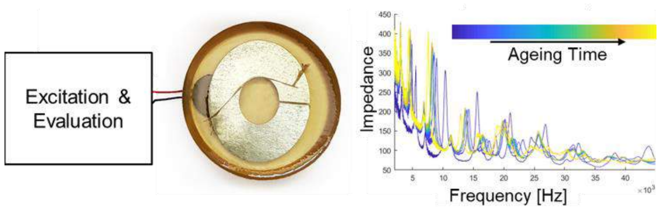

Figure 3: *Structural Health Monitoring of the test specimen during an ageing experiment using a vibration-based technique*

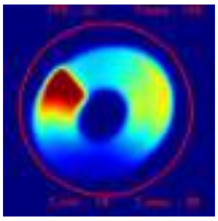

Figure 4: *Thermography image of the test specimen heated by induction*

Failure behaviour of multiscale toughened co-cured composite laminate joints subjected to quasi-static loading

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Objectives / Description / Main outcomes

The adhesive bonding of composite structures has many advantages, such as weight-saving and better load/stress transfer, over conventional mechanical fasteners. Essentially, adhesive bonding can be practised between cured/solidified parts (i.e. secondary bonding), between a cured/solidified part and an uncured part (i.e. co-bonding), and between two uncured parts (i.e. co-curing). Among them, co-curing offers cost savings by reducing the number of manufacturing steps as the curing and bonding of the composite parts are carried out in a single manufacturing step without the need for surface preparation. The resin of the composite material system could maintain the bonding between composites—eliminating the need for an additional adhesive agent. However, the most used matrix material in advanced composites is the thermosetting epoxies that are susceptible to fracture due to their inherent brittleness (i.e. low fracture toughness)—making the co-cured bondline susceptible to failure without warning. Thus, enhancing the fracture properties of the co-cured bondline is paramount to improve the mechanical behaviour of co-cured composite assemblies.

This study investigates the effect of bondline fracture toughness on the static failure behaviour of out-of-autoclave co-cured joints. Three different joint geometries (i.e. single lap, stepped and skin-stiffener) are manufactured using four different material systems. These material systems are selected as follows: (1) untoughened (i.e. reference), (2) toughening with core-shell rubber particles (i.e. resin toughening), (3) toughening with thermoplastic non-woven veil (i.e. interlaminar toughened), and (4) toughening with both particle and non-woven veil (i.e. multiscale toughened). Firstly, the quasi-static mode-I and mode-II fracture properties of different material systems are evaluated. Then, the joint strength tests are carried out in combination with a 3D-digital image correlation system (i.e. 3D-DIC), followed by the post-fracture surface analysis. As a result, it is observed that the mode-mixity of the debonding/delamination in the co-cured bondline should be considered when selecting a toughening route. Further, 3D-DIC demonstrated that the accumulation and the growth of debonding/delamination could be delayed/arrested by toughening the co-cured bondline.

In summary, this study demonstrated that the commercially available tougheners could be strategically exploited to enhance the mechanical behaviour of out-of-autoclave co-cured composite structure assemblies without sacrificing manufacturability and geometry. Further details will be shared in the conference meeting.

Integrated manufacturing and toughening of composite joints using a PEI film

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Objectives / Description / Main outcomes

The intensive use of Carbon Fibre Reinforced Polymer (CFRP) Composites in aerospace is motivated by their high strength to weight ratio. However, the manufacturing of complex aeronautic structures combining metallic and composite parts requires an efficient, ideally integrated, bonding process. Bonding through classical adhesives suffer from low to moderate toughness and the process requires multiple steps separating the manufacturing of the composite parts and the bonding.

In order to reduce the manufacturing time of the joints, integrated manufacturing is the new target in the field. Integrated manufacturing means that composite curing and bonding are performed in a single step. Recent work of Voleppe et al. [1] focussed on the curing of an epoxy resin with a PEI film, resulting in a tough interface (880 J/m²) and crack trapping due to the development of a morphological gradient (figure 1). Hence, the current objective is to make use of this principle in the context of integrated manufacturing of tough composite joints by inserting a PEI film between the two composite adherends.

This works aims at introducing a PEI film at composite midplane before the Resin Transfer Molding (RTM) process (figure 2a). During composite curing, the contact between epoxy resin and the PEI film allows for the development of the morphological gradient resulting in a tough interface. In order to determine the fracture toughness of these joints Double Cantilever Beam tests are performed. In addition, fractographic analyses reveal the failure mechanisms taking place in the joints in order to further improve the joint fracture toughness.

First, it is observed that the PEI film thickness has an influence on the joint fracture toughness. However, even if the morphological gradient resulting in a high toughness in the work of Voleppe et al. develops, inserting a PEI film results in a lower fracture toughness (< 300 J/m²) than compared to composite delamination (400 J/m²). This decrease is due to the intimate contact between the carbon fibres and the PEI film. In order to create a spacing between the film and the fibres, polyethylene (PE) fishing lines are inserted (figure 2b). The influence of the spacing between the fishing lines is investigated. The lower the spacing the higher the fracture toughness due to the larger number of fishing lines acting as bridging ligaments. However, compared to thermoplastic veils the amount of thermoplastic fibres is limited, but the joint fracture toughness increases at least by a factor 2 compared to joints made of a single PEI film. Fractography also reveals that the fishing line spacing influences the failure mechanism.

[1] Q. Voleppe et al. (2021) « Enhanced fracture resistance of thermoset/thermoplastic interfaces through crack trapping in a morphology gradient », Polymer, 218

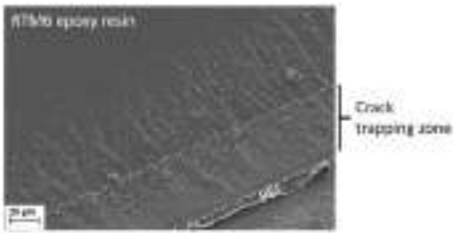

Figure 1: RTM6-PEI interphase allowing for high fracture toughness and crack trapping

Figure 2: Composite bonding with (a) PEI and (b) PEI and fishing lines

Research and development of 3D printed continuous carbon fiber reinforced polymer composite structures

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Objectives / Description / Main outcomes

The research is focused on the applicability of the Fused Deposition Modeling (FDM) technology for printing composite structures by reinforcing thermoplastic matrix structures with continuous carbon fiber (CCF). The main aim of the scientific research is to develop and validate an FDM technology for the rapid fabrication of complex geometry CCF-reinforced composite structures. To achieve this aim, an innovative method for the impregnation of CCF before the printing process was developed and tested. A new printing module has also been designed and manufactured, capable of printing composite structures reinforced with CCF. Developed printing module and the printing process based on Fused Deposition Modeling has been experimentally tested. Tensile, flexural and shear tests were carried out in order to determine the main mechanical characteristics of the printed material. Adhesion between individual layers, and between the matrix and the reinforcing material, was also determined. Two different methods, computed tomography and dissolution of the matrix material were used in order to determine, the volume of air void and the percentage of carbon fiber in the printed structures In order to reduce the volume of air cavities and improve mechanical properties, secondary impregnation of printed composite structures in epoxy resin has been developed and tested. The manufacturing methodologies and equipment developed during this research can be used for the production of complex structural design continuous carbon fiber reinforced composite functional parts. The results of technological development, such as various impregnation techniques, printing modules and the identification of the most suitable FDM process conditions as well as parameters can be used for rapid fabrication of customized lightweight functional components employed in the automotive and aviation industries or medical sectors and any other newly emerging scope of applications including autonomous robotics, human assistive devices, vehicle or aircraft parts where the mass-to-stiffness ratio is of top importance. The mechanical properties and print quality characterizations of printed composite structures provide valuable information and knowledge for the further technological development of the process.

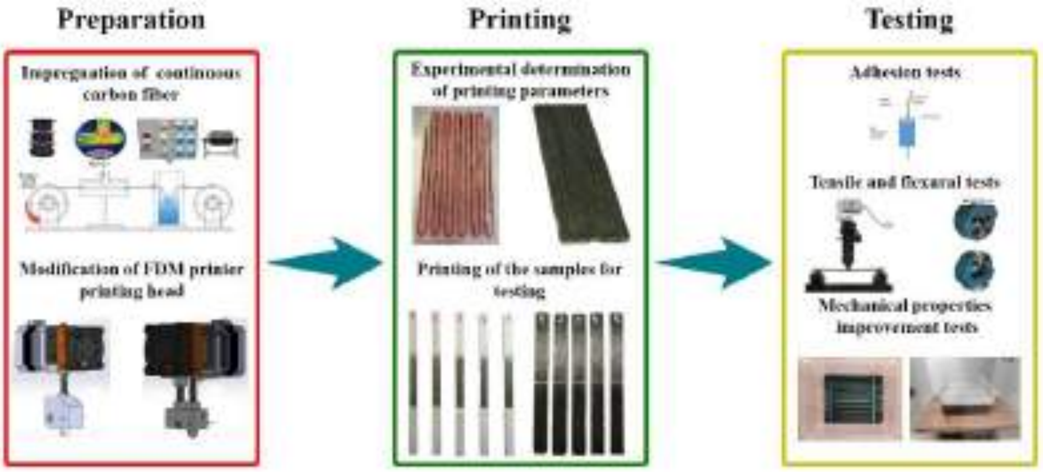

Figure 1: *Research experimental setup*

Mechanical and adhesive joining procedures for hybrid aluminum and Carbon Fibre Reinforced Polymer components

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Objectives / Description / Main outcomes

The joints between different lightweight materials play a significant role in multi-material design of structural components for automotive industry, aiming to reduce the vehicle’s weight without compromising performance or safety. Yet, conventional mechanical joining technologies between metals and carbon fibre reinforced polymers either create the need of drilling a hole in the composite material, leading to damages which reduce the load bearing capacity, or increase the weight of the part due the incorporation of fasteners. At the same time, alternative mechanical joining methodologies involve complex and costly processing, hindering their industrial application.

Therefore, the main objective of this thesis is the development of mechanical joining strategies between aluminum and carbon fibre reinforced polymers (CFRP) which are simple, cost-efficient and can be easily implemented in the automotive industry, while avoiding the incorporation of fasteners, the drilling or damaging of the composite material and complex processing. Such joints are also combined with adhesive bonding.

The developed joints were characterized through non-destructive testing, such as ultrasound inspection (US), and destructive testing, such as Single Lap Shear test (SLS). No debonding was observed during ultrasound inspection of the specimens. Moreover, load-displacement curves obtained in SLS tests (Figures 3 and 4) showed that the shear strength of the adhesive bonded specimens was increased in a 39% and the absorbed energy in a 94% with the incorporation of the developed joints, while at the same time slightly reducing weight due to material removal.

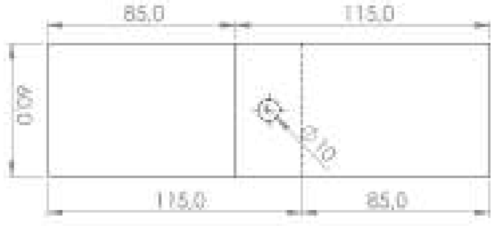

Figure 1: *SLS specimen dimensions*

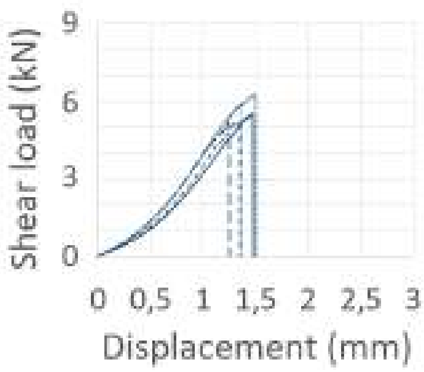

Figure 2: *Load-displacement curve for SLS performance of adhesively bonded specimens*

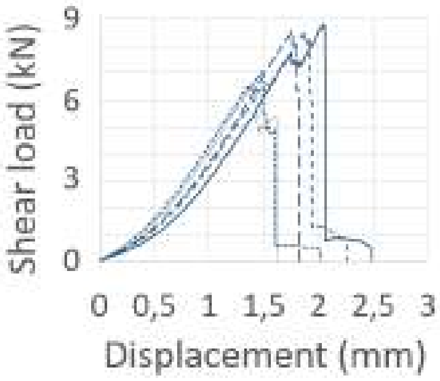

Figure 3: *Load-displacement curve for SLS performance of adhesively bonded combined with the developed joints*

Acoustic emission damage characterisation in toughened CFRP bonded joints

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Objectives / Description / Main outcomes

The acoustic emission is a promising method for structural health monitoring of adhesively bonded joints that can be used to guarantee their in-service safety and reliability by the online or on-demand diagnosis of the bonded components.

This work aims to study the feasibility of using the acoustic emission monitoring method to identify the different damage mechanisms within toughened CFRP adhesively bonded joints. For that, five types of double cantilever beam specimens with different CFRP layups ($[0]_8$, $[0/90_2/0]_S$, $[90/0_2/90]_S$, $[90/45/-45/0]_S$ and $[90/60/90/-60/0]_S$) were tested under quasi-static mode I tests. An additional camera and a travelling microscope were used to measure the crack length and observe the crack paths through the joints during the tests. Mode I fracture toughness of pure CFRP double cantilever beam specimens, and tensile tests of the used CFRP material (in 0° and 90° directions) were also performed to assess the acoustic emission signals of pure delamination phenomena, matrix cracking and fibre breaking, respectively.

An unsupervised artificial neural network was applied for patterning recognition and, combined with clustering algorithms, grouped the data considering their similarities. The main acoustic emission features used in the clustering procedure were selected based on principal component analysis.

Finally, the results showed that the acoustic emission data could be effectively clustered. The different defined groups were associated with several damage mechanisms within the various CFRP joints with the aid of the images recorded by the travelling microscopy.

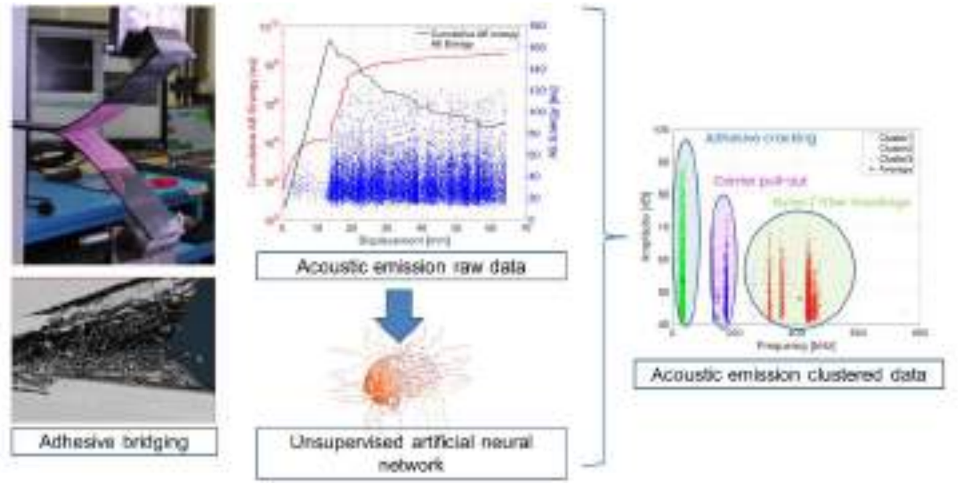

Figure 1: Graphical abstract

Advances in isocyanate microencapsulation for new ecological and mono-component adhesives

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Objectives / Description / Main outcomes

Polyurethane (PU) and polychloroprene (PCP) adhesives used in the footwear industries are typically supplied as two-component (2k) formulations, consisting of isocyanate species (cross-linkers) and a prepolymer. However, isocyanates have a high toxicity which is a concern in the adhesive application. To prevent health hazards, in February 2020, REACH approved restrictions on diisocyanates, prohibiting its commercialization as substances on their own, as a constituent in other substances or in mixtures for industrial and professional use when in concentrations above 0.1% wt. However, isocyanate-based adhesives are the ones which provide appropriate high strength quality joints needed for the footwear industry, in particular for the upper-to-sole joints. The present work aims to develop a new mono-component (1K) adhesive formulation composed by the prepolymer and microencapsulated isocyanates, only to be released during the adhesive joint preparation. The isocyanate encapsulation prevents health hazards, avoids the weighing and mixing of the two components and reduces the necessary packaging. The developed microcapsules (MCs) are designed to respond to the external stimuli of pressure and/or temperature applied during the footwear manufacture, at the same time offering enough storage stability and chemical resistance.
The solvent evaporation technique combined with a double microemulsion system was used to obtain MCs with a biodegradable shell of polycaprolactone (PCL) as well as of polyhydroxybutyrate (PHB). By using this technique it was possible to obtain MCs by a purely physical process. The newly developed MCs contrast with the polyurethane/polyurea (PU/PUa) ones, synthetized using the interfacial polymerization technique, typically used for the isocyanate microencapsulation, offering several advantages: (i) biodegradability of the PCL and PHB, which makes these MCs not a microplastic, by definition, (ii) a high hydrophobicity of the MCs ’ shell, which contributes to a longer shelf-life, (iii) and, for the MCs with a PCL shell, a low melting temperature and low melting viscosity which enables the melting process of the MCs and promotes the homogeneous distribution of the isocyanate within the adhesive joint material.The developed MCs have a core-shell morphology, and high encapsulation loads up to 74wt% of isocyanate and a narrow size distribution.

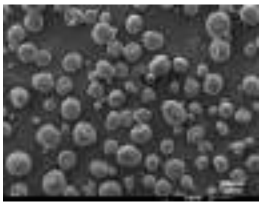

Figure 1: *SEM microphotograph of PCL MCs*

Figure 2: *SEM microphotograph MC showing a core-shell morphology*

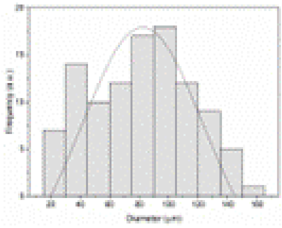

Figure 3: *PCL MCs size distribution*

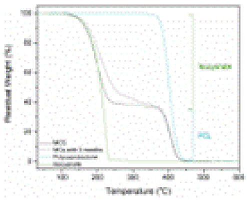

Figure 4: *Thermograms of the PCL MCs, encapsulated isocyanate and PCL*

Bonded connection for decoupled masonry infill walls in RC frames

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Objectives / Description / Main outcomes

Damage of reinforced concrete (RC) frames with masonry infill walls has been observed after many earthquakes due to brittle behaviour of the masonry infills in combination with the ductile behaviour of the RC frames. A good way to avoid negative aspects arising from this behaviour is to ensure no or low-interaction of the frame and infill wall, for instance by decoupling the infill from the frame. This can be done by applying elastomeric strips at infill/frame connection. Elastomers are glued to the bricks, thus making this bonded connection a key element in providing in-plane decoupling and at the same time a restrain for out-of-plane loads.

Main objective of this work was to investigate the capacity of glued connection between elastomers and RC frame as well as between elastomers and masonry infill wall. During the out-of-plane loading of infill, the U profiles made of elastomers are subjected to shear and bending forces. The circumferential U-shaped elastomer strips must be able to safely absorb these forces. The load is transferred by the flange of the U profile to the circumferential plastic profile. In order to test the glue bond and the load bearing capacity of the U-shaped elastomer, experimental campaign on small specimen tests was conducted. Experimental tests were performed on a brick for the connection situations corresponding to the frame columns and frame top beam. In the experiments, the elastomer U profiles were glued on both sides of the bricks and subjected to the shear load using a loading plate (Figure 1). For each installation situation, a total of four tests are conducted without any prestress. In none of the tests a failure of the glued joint or the U-Profile appeared, as the failure always occurred in the clay bricks before. The smallest shear force of 3.5 kN (Figure 2) is obtained for the connection situation at the top beam with a maximum gap of 15 mm and a reduced contact length of 10 mm (Test B3). Assuming a four-sided load transfer of the out-of-plane loads, this leads to an ultimate out-of-plane surface load of 23.0 kN/m^2. This results in a maximum attainable acceleration of 11.5 g related to a density of 5.5 kN/m^3 for the applied clay brick. The small specimen tests on the connections made of elastomeric cellular materials clearly show the potential of the newly developed connection to ensure a load transfer under combined in-plane and out-of-plane loading. This is confirmed by almost linear load-displacement curves up to the maximum load-bearing capacity that was limited by the brick failure. The load-bearing capacity can therefore be further increased by using bricks with higher strengths.

Figure 1: *Test setup for the glued connection of elastomeric U profile*

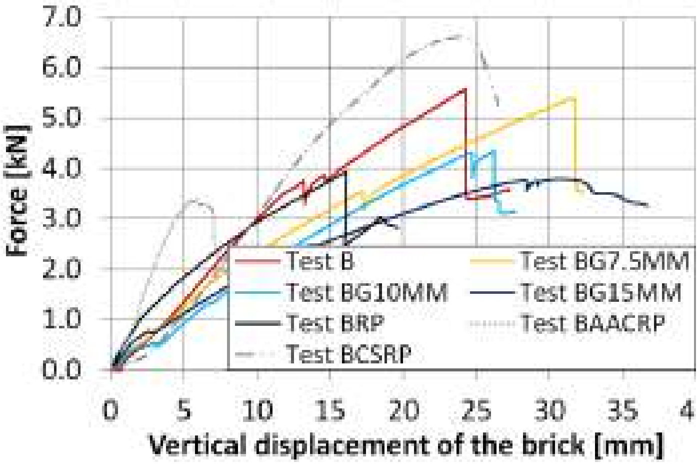

Figure 2: *Summary of force displacement curves for the test on U-shaped connections for the beam*

A highly efficient use of the VCCT to simulate fatigue crack propagation in bonded joints

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Objectives / Description / Main outcomes

In the last years, industrial interest in structural bonding has significantly grown thanks to its numerous advantages with respect to other bonding techniques. The fast expansion of this bonding technique makes the availability of numerical models to predict the fatigue response of bonded joints critical.

Virtual Crack Closure Technique (VCCT) is a numerical tool capable of accurately predict the elastic strain energy release rate caused by a crack propagation. This technique can thus be coupled with a Paris-like crack propagation law to simulate the fatigue crack propagation in a bonded structure. VCCT is implemented in Abaqus via the “direct cyclic” algorithm, a simulation algorithm for the cyclic response of a given material. The direct cyclic constitutes one of the most used commercially available tools for the prediction of fatigue damage propagation in bonded joints. As reported in the literature, however, direct cyclic is highly computationally expensive, requiring several simulation hours even for the most simple cases.

This work presents a new more efficient VCCT-based algorithm called Sequential Static Fatigue (SSF). This method replaces the single fatigue direct cyclic simulation with a series of static simulations. In particular, a master Python code launches the static simulations and extracts the values of the strain energy release rate. Based on these values and on an input Paris law, the Python code is capable of calculating the number of cycles required to propagate the crack by a predefined length. A new static simulation is thus launched with the new crack length. A cycle counter keeps track of the elapsed cycles from the first simulation, to allow the computation of the crack propagation during the load history of the structure.

The validation of the proposed method is first performed by comparing the SSF predictions for experimental data from the literature (Asp et al., 2001). Figure 1 shows the results of this validation, proving the accuracy of the SSF. Moreover, the SSF is compared with the standard VCCT method implemented in Abaqus via the direct cyclic. While both methods lead to comparable predictions, the simulation time were reduced by factors ranging from about 200 to about 800. A drastic computational efficiency improvement was thus achieved.

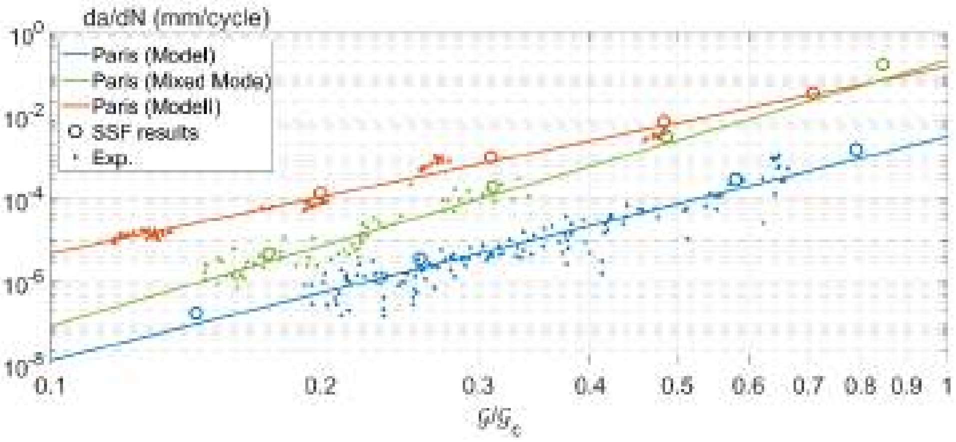

Figure 1: *SSF results over different mode-mixities*

Finite Element numerical modelling of monolithic glass fitted with ASF under out-of-plane bending setup

Silvana Mattei[1]; Chiara Bedon[1]

[1]University of Trieste, Italy

Objectives / Description / Main outcomes

The prediction of fracture and post-critical behaviour of glass elements under various loading conditions can be of great interest in a multitude of cases. In recent years, the design of glass increased significantly in complexity, from ordinary windows to curtain-walls and load-bearing systems. Several studies have been thus conducted concerning the mechanical response of this building material in the post-failure regime, as a result of its brittle characteristics and potential risks to human life. On this matter, numerous researchers proved the benefits of using anti-shatter safety films (ASF). In general, a typical safety film consists of a self-adhesive polyester (PET) film that is applied to glass surfaces and used to retrofit existing elements, especially to increase safety levels in protecting people from serious injuries from flying shards. In addition, PET has good characteristics of thermal insulation, energy conservation, ultraviolet-proof. At the same time, it is a versatile material with the ability to be remade from its polymer state through mechanical recycling and even able to provide a competitive advantage in terms of environmental impact, becoming carbon neutral in short times, compared to the possibility to replace a glass component with a new one.

The purpose of this work is to elucidate the enhanced failure mechanisms in the behaviour of ordinary glass elements by fitting of anti-shatter film. To investigate the improvement in terms of resistance and the possibility of describing the post-fracture behaviour, a Finite Element (FE) numerical model is built using the ABAQUS code, and major outcomes are examined by comparing previous experimental results. For the reference FE model, an accurate characterization of the pressure-sensitive adhesive (PSA) is carried out by means of cohesive (CZM-based) elements. The simulations of three-pointing bending (3PB) tests demonstrate a progressive failure response, which at the beginning depends on the achievement of tensile strength in the glass. Secondly, the post-failure branch relies on the traction-separation law representative of the degradation of the adhesive contribution related to the complex delamination process. In doing so, different scenarios of accelerated ageing are also considered. Overall, the predictions obtained from FE quasi-static numerical analyses are found in good agreement with the experimental results in the linear elastic part, whereas in some cases a more conservative residual flexural strength of the system is observed.

Figure 1: *Fracture pattern of glass fitted with ASF system after impact*

Figure 2: *FE numerical model of 3PB experimental setup*

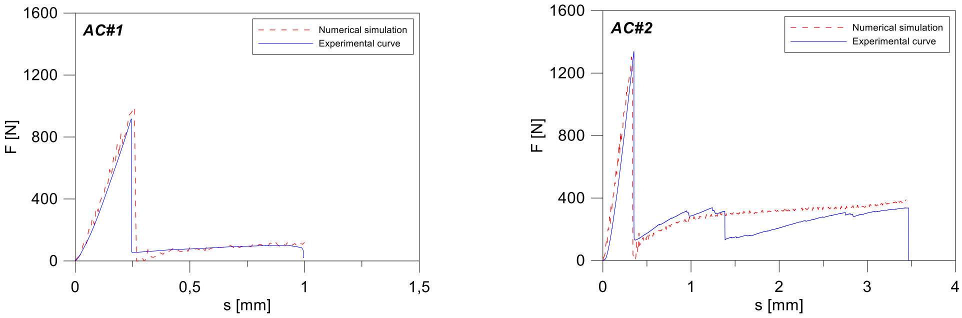

Figure 3: *Comparison between FE numerical and experimental load-displacement curves for ASF-fitted glass specimens under different ageing conditions*

Design of test methods for mode I testing of adhesively bonded joints

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[1] AMADE, Polytechnic School, University of Girona, Spain

[2] Ikerlan Technology Research Centre, Basque Research and Technology Alliance (BRTA), Arrasate-Mondragón, Spain

Objectives / Description / Main outcomes

The objective of this work is to develop a relatively small and simple mode I fracture toughness test setup with a roller wedge (Figure 1 & Figure 2). The roller wedge makes it possible to use it without a test machine, to be able to make a fast estimation of the mode I fracture toughness of a bonded joint. The developed Roller Wedge Driven (RWD) test method could potentially be an alternative mode I fracture toughness test method for bonded joints [1]. Secondly, a dead weight can be applied to the roller wedge so that a creep test with constant energy release rate can be performed. Durability tests would be possible by placing the relatively small RWD test setup inside a climate chamber. The goal is to obtain crack growth rate (da/dt) against energy release rate (G) curves.

The method has been tested with DCB-like bonded joints made out of aluminium 7075-T6 adherends bonded with methacrylate-based Araldite 2021-1 and epoxy-based Araldite 2015-1. Besides aluminium also CFRP T800S/M21 is used as an adherend material. The CFRP adherends are only bonded with Araldite 2015-1 since the fracture toughness of Araldite 2021-1 is too high and will result in interlaminar failure in the CFRP adherend. For the quasi-static fracture toughness RWD test method a threaded bar is rotated by hand to apply a force to the wedge. A load cell and displacement sensor measure the load applied and wedge displacement during the test. Before the RWD creep test is initiated, the specimen is first pre-cracked by using the RWD test setup. The roller wedge is driven into the specimen to create a 10 to 20mm pre-crack. Directly after, a weight is applied to the roller wedge. The energy release rate at the crack tip remains constant because the wedge displaces an amount of distance equal the crack length increment.

The results of DCB tests performed were used as a reference to compare the RWD test method against, obtaining close results. For aluminium adherends bonded with araldite 2021-1, creep growth rate curves have been obtained. Currently aluminium adherends bonded with epoxy-based araldite 2015-1 are being subjected to creep testing. Which will be followed by creep tests applied to the CFRP with Araldite 2015-1 bonded joints.

[1] E. Meulman, J. Renart, L. Carreras, and J. Zurbitu, "Analysis of mode I fracture toughness of adhesively bonded joints by a low friction roller wedge driven quasi-static test," Eng. Fract. Mech., vol. 271, no. May, p. 108619, 2022, doi: 10.1016/j.engfracmech.2022.108619.

Figure 1: *RWD roller wedge sketch*

Figure 2: *RWD roller wedge*

The effect of the SiC reinforcement and moisture absorption on the thermo-mechanical properties of the carbon/epoxy composites

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Objectives / Description / Main outcomes

Carbon fiber reinforced polymer (CFRP) composites are extensively employed in aircraft industry, and in other areas where outstanding mechanical performance is a requirement. In this study, the composite samples were made from the carbon fabrics impregnated with epoxy resin reinforced with the silicon carbide (SiC) microparticles or microfibers. The thermal, tensile and impact properties of the untreated specimens were compared with the ones that underwent the water absorption in duration of 72 h (immersion or high humidity) followed by desorption.

The glass transition temperatures (T_g) of the specimens were determined using the differential scanning calorimeter (DSC) device. The carbon/epoxy specimens were tested in accordance with the ASTM D5942 standard for their impact properties and ASTM D3039 standard for the tensile properties of the composite materials with the polymer matrix.

The dry carbon/epoxy specimens with the SiC microfibers or SiC particles showed a large increase in the tensile strength and tensile energy absorption (TEA), respectively, in comparison with the dry carbon/epoxy specimens while the specimens with the SiC particles had the highest value of the impact toughness. The carbon/epoxy specimens with the SiC reinforcement, which were exposed to 70% humidity or water immersed, saw the decline in T_g. The tensile strength and TEA of the water immersed carbon/epoxy specimens with the SiC reinforcement had the values decreased in comparison with the ones of their dry specimens. Contrary to this trend of results, the tensile properties values achieved a significant increase in the immersed carbon/epoxy specimens (with no reinforcement), in comparison with the dry ones. The decrease of the elastic modulus was determined in all the specimens after water immersion followed by desorption. The impact toughness values of all the specimens decreased after exposing them to the elevated humidity as well as to water immersion, compared to the values in their untreated counterparts.

Figure 1: *Specimens after the tensile test: carbon/epoxy/SiC microfibers (left) and carbon/epoxy (right)*

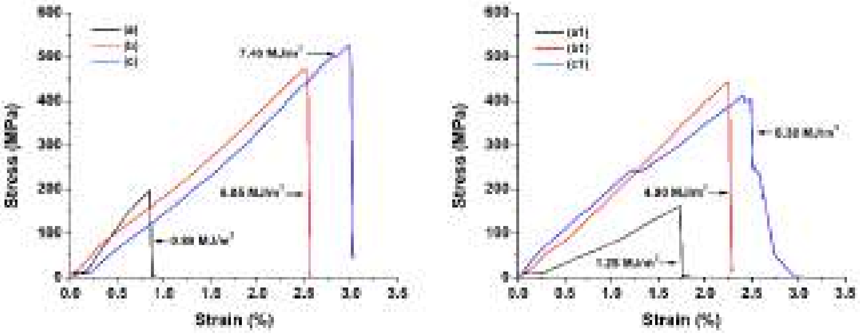

Figure 2: *Stress-strain relationship for the carbon/epoxy specimens with their TEA values: (a) neat (b) with SiC particles; (c) with SiC microfibers and immersed: (a1) neat; (b1) with SiC particles and (c1) with SiC microfibers*

Towards circular cast glass assemblies: Evading permanent bonding

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[1] Delft University of Technology, The Netherlands

Cast glass assemblies have great architectural and structural potential. Typically applied in the form of solid blocks, cast glass components can be used as repetitive units to form fully-transparent, glass masonry structures. To maximize transparency and ensure an even load distribution, the glass blocks are typically bonded together by a colourless adhesive. Key criteria for the selection of the latter include bond strength, gap-filling capability, ease-of-application and transparency level. Yet, the adhesives commonly used in cast glass assemblies result to irreversible bonding, which prevents the reuse of the glass components, and also hinders their recyclability due to undesired contamination.
The **objective** of this research is thus, to review existing adhesives and explore alternative connection methods that can allow for demountable, yet highly-transparent cast glass assemblies of satisfactory strength.

Main outcomes

A review on existing adhesives for the structural bonding of (cast) glass has not revealed an existing adhesive product that has satisfactory performance and that can be easily de-bonded. Perhaps the most evident de-bonding solution for rigid adhesives is via controllable application of heat to warm the adhesive above its glass transition temperature, in order to soften it and carefully remove it, a de-bonding method the authors developed experimentally for the Crystal Houses façade (Figure 1).
Still, further research is essential for (a) finding an adhesive that can be eventually dissolved and for (b) assessing the effect of the contamination to the glass due to remaining traces of adhesive.
The authors, together with MSc students, also developed -via prototype work and experimental testing - alternative design approaches that can evade completely, or allow for the use of a weaker, easily-to-remove adhesive. These include:
(i) The design of a dry-assembly system, utilizing interlocking cast glass components and a dry intermediate interlayer material (e.g. PU) that can evenly distribute the stresses and accommodate the size deviations of the individual blocks (Figure 2). The latter can be either a dry-interlayer or a “weaker glue” that can be eventually de-bonded.
(ii) The design of a reversible embedded mechanical connection, as described in the patent 2022/050835 A1: a mechanism utilizing magnetic balls inside an embedded connection (to the glass block) can lock and unlock the connection with the aid of a magnetic field, enabling a fully demountable, highly controllable connection (Figure 3).

Figure 1: *De-bonding method using heat developed for the Crystal Houses Façade*

Figure 2: *Prototype of the interlocking, dry-assembly system*

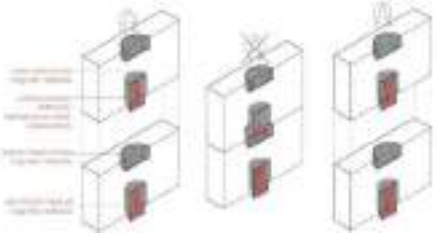

Figure 3*: Principle of the embedded reversible mechanical connection (patent number: 2022/050835 A1)*

Adhesive bonding of glass and concrete – Development of application and construction methods

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[1]Ghent University, Ghent, Belgium

Objectives / Description / Main outcomes

In the past decade, adhesives have seen a steady increase in application in the construction sector. Adhesives are already used in both the concrete and glass construction industry. In concrete construction, adhesives are commonly used for the installation of anchors and reinforcement material (i. e. FRP sheets) in the strengthening and rehabilitation of structures. Adhesives are also used in glass engineering to fashion a variety of different products such as hybrid glass-steel beams and glass-to-metal bonded facades. However, connections between concrete and glass have so far only been achieved through intermediary steel frames, typically for glazing purposes. These connections usually disrupt the continuity of the glass surface and are costly due to the metal used in the framework. Adhesive connections, however, do not require drilling of the glass and provide a more aesthetically pleasing finishing to the surface.

Due to the brittle behavior of both materials, glass and concrete are usually combined with other ductile materials such as steel in a hybrid element. The combination of two brittle materials imposes challenges with regard to displacement capacity which needs to be resolved using the intermediary adhesive. The purpose of this project is to develop possible applications and construction methods for the fabrication of the adhesive bond and the resultant hybrid element between concrete and glass. The project has started with a large experimental program ascertaining the suitability of a large number of adhesives to bond concrete and glass interfaces. The candidate adhesives will be selected based on literature and market research and compared based on the shear capacity of joints formed between glass and concrete as well as their resistance to the adverse environmental conditions of 50˚ C and 90% relative humidity. Further research on the selected adhesives will cover the material properties of adhesives, characterize the relative interfaces and characterize the short-term and long-term behavior of the resultant element. This research will provide a proper methodology for connecting and testing adhesive connections between concrete and glass and can provide the tools for a more transparent and modern design of façade structures and hybrid concrete-glass elements.

Figure 1: *The Shear Test setup*

Figure 2: *Concrete-Glass Shear Specimen*

Toward progressive failure of adhesively bonded composite joints through surface patterning and adhesive tailoring

Ran Tao[1]; Sofia Teixeira De Freitas[1]

[1]Aerospace Structures & Materials, Faculty of Aerospace Engineering, Delft University of Technology, the Netherlands

Objectives / Description / Main outcomes

Secondary adhesive bonding is one of the most efficient joining technology for carbon fiber reinforced polymers (CFRPs) as it avoids stress concentrations of open holes and ensure the structural integrity. However, it is crucial to introduce crack arresting features to slow down (or even stop) the crack growth to achieve progressive failure and broaden the applications of adhesive joints.

Our previous work directly utilized the adhesive layer to bridge the separating CFRP parts, through the extrinsic bridging of adhesive ligaments. The bridging adhesive ligaments, triggered by the patterning of distinct surface treatments, largely enhances the energy release rate (ERR) and successfully arrests the crack propagation. However, a large portion of the apparent ERR is stored elastically in the adhesive ligaments, and due to the brittleness of the thermoset epoxy adhesive material, the stored energy is released all at once after the failure of ligaments. Such ligament failure yields fast and unstable crack propagation, causing serious safety concerns to the structure, which will be exacerbated as the adhesive thickness increases.

In this study, a more ductile adhesive material was adopted to soften the joint damage behavior with the alternative patterning on CFRP substrates. Numerical investigations were conducted to compare the influence of brittle epoxy adhesive and ductile methyl methacrylate adhesive (MMA). When using brittle epoxy adhesive, as shown in *Figure 1*, the crack jumps from the bottom to the top interface, but the bridging epoxy ligament fractures quickly without the extrinsic bridging. Such observation echoed the limitation of using brittle adhesives in extrinsic bridging ligaments. As for a more ductile MMA adhesive, simulation clearly showed a large-scale extrinsic bridging ligament, illustrated with two increase stages shown in *Figure 2*. At the first stage ①, the crack propagation is arrested by the green arrest interface till the crack jumps from the bottom to the top interface. Secondly, the MMA adhesive ligament gradually extends the bridging length up to 4 mm, leading to a second rising stage of the ERR curve (stage ② in *Figure 2*). Thanks to the plastic energy dissipation, ERR could experience an extra enhancement and further slowdown the crack propagation, in contrary to the epoxy adhesive, where ligament fails during the crack jump.

In conclusion, by promoting the plastic energy dissipation, the bridging, stretching, and failure of generated adhesive ligaments demand extra energy dissipation, resulting in a more stable crack propagation. The ductile adhesive material could extend the length of bridging ligaments and expand the design space of this toughening technique, further arresting the crack propagation and improving the joint safety.

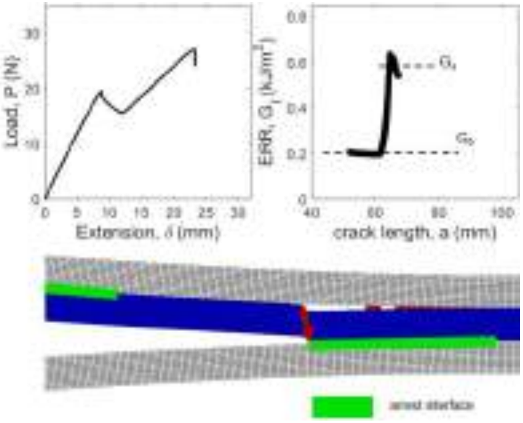

Figure 1: *Simulated load-displacement response, corresponding ERR curve, and bridging of DCB with epoxy adhesive*

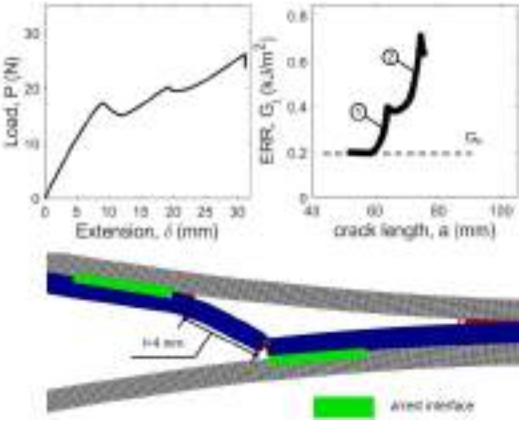

Figure 2: *Simulated load-displacement response, corresponding ERR curve, and bridging of DCB with MMA adhesive*

Laboratory tests of adhesively bonded aluminium angle cleat connections

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Objectives / Description / Main outcomes

The classical methods of joining aluminium structures have progressed in recent years, but the fundamental problems of degradation of mechanical properties are still present if welding is used as a joining technique. A different, more suitable, but not yet fully investigated, method for joining aluminium members is adhesive bonding. In this study, the application of adhesives in joining aluminium and steel components is investigated. The experimental study was carried out with the aim of characterising a bonded aluminium angle cleats connection in tension using four different types of adhesives.

The laboratory tests included a tensile (Mode I) test of the pair of aluminium angle cleats adhesively bonded to a steel plate. A total of 12 pairs of angle cleats were tested, three specimens for each of the four different adhesive types. All specimens consist of two extruded aluminium angles L 100x100x10 mm (EN AW 6060-T66), 140 mm in length, with one leg bonded to a 30 mm thick steel plate. The other angle legs are bolted (6xM12, quality 8.8) to a steel plate mounted on the static testing machine with a capacity of □ 600 kN (Fig. 1). The preparation of the surfaces and application of the adhesives was carried out by Sika Croatia staff, who provided all four types of adhesives (Fig. 2). Two ductile (SikaFast 555 L10 – label **A** and SikaPower 4720 – label **B**) and two brittle (Sikadur 330 – label **C** and Sikadur 31 CF Normal – label **D**) adhesives were applied. In addition to conventional measurement techniques such as the LVDT sensors, the entire displacement field was measured using the non-contact stereophotogrammetric 3D measurement system (Fig. 3). Due to the relatively small displacements (Fig. 4), the non-contact measurement system proved to be very beneficial in capturing the realistic behaviour of these sensitive connections.

All specimens failed over adhesives in different percentages of failure through the adhesive layer. The fracture surfaces varied for each specimen. The most consistent results were obtained for the specimens labelled **B**. The load-bearing capacity of the mentioned specimens was roughly 60 kN (Fig. 4). The results of the specimens labelled **C** and **D** were quite scattered, mainly due to the different thickness of the adhesive layer, but also to the insufficient mechanical preparation of the cleat's surface. The specimens labelled **A** showed the highest ductility, while the specimens labelled **C** were the most brittle.

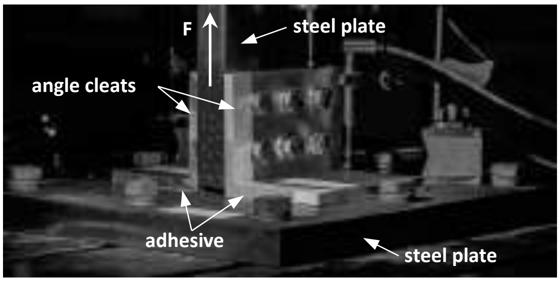

Figure 1: *Geometry of the setup*

Figure 2: *Applying the adhesive*

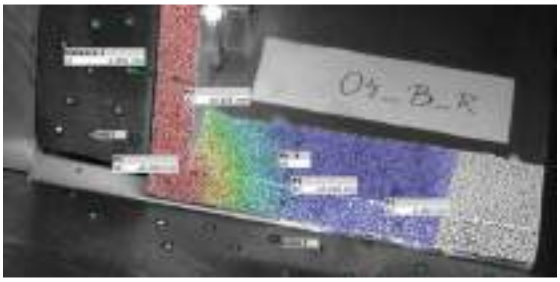

Figure 3: *DIC – Displacement monitoring*

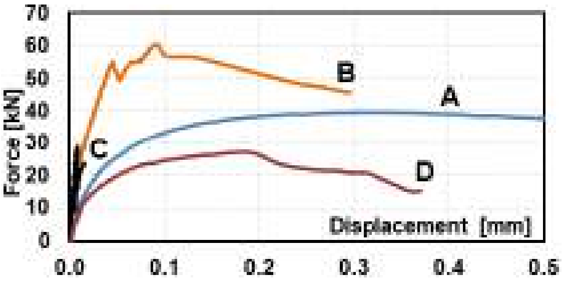

Figure 4: *Load-displacement curves*

Application of embedded laminated connections for glass structures

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Objectives / Description / Main outcomes

Ongoing research at the CTU in Prague is focused on characteristics of embedded laminated connection for glass structures and its applications. The connection combines mechanical and adhesive fixing systems and it is suitable for facades, banisters, roofs and insulating panels. Its advantage is that due to identical manufacturing process as for the common laminated glass, there is no additional action needed and the panels along with connections are immediately ready for the application on site. Moreover, the connection effectively excludes formation of thermal bridges. The connection does not pass through the whole glass layer, as typical for common mechanical point connections, and the outer laminated ply remains seamless (Figure 1). Therefore, it is an optimal solution for insulating panels requiring fixing to the rest of the structure without breaching its uniform surface. The panel stays sealed and fulfils aesthetical standards of modern architecture at the same time. However, the design procedure has not been clearly defined so far.

For the initial experiments, small-scale specimens with one connection were used. Different combinations of glass plies (TVG, ESG, float) and foils (various EVA) were tested in order to reveal the characteristics of this type of connection under different short-term loads. The small-scale tests showed the dominant mode of failure, as well as the load-bearing capacity. They were followed by experiments performed on real-scale glass panels suitable for facade, roof or banister applications. The short-term as well as the long-term loads were applied to verify the knowledge obtained from the small-scale tests. The simple laminated (Figure 2) and the insulating (Figure 3) glass panels with four connections were used for the short and the long-term experiments. The banister panels with two sets of connections in lower corners were tested under the short-term loads only (Figure 4).

The experiments confirmed the small-scale tests findings. The collapse is caused by reaching the tensile resistance limit of glass due to a bending moment. Panels do not collapse because of stresses arising around the connections. After the collapse of the connection, the steel element debondes from the foil without damaging the foil. Therefore, the results imply a clear potential of presented applications. Nevertheless, more tests should be performed to determine the exact collapse load and a mode of failure. The data obtained from the experiments are going to be used for the FEM analysis. The numerical model should specify the characteristics of the embedded laminated connection and its surroundings. Parametrical study should be included as well.

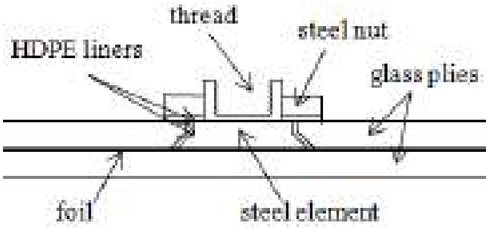

Figure 1: *Scheme of an Embedded Laminated Connection*

Figure 2: *Fractured Façade Panel*

Figure 3: *Insulating Panel during Testing*

Figure 4: *Banister Panel during Testing*

Adhesives for glass load-bearing structures

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Objectives / Description / Main outcomes

Glass structures are modern elements, especially in the last decades. Glass is used for facades, canopies, railings, and other load-bearing structures such as beams and columns. Glass is a very strong but brittle material. The appropriate design of the connection is very important. Commonly used are mechanical connections, which have several disadvantages (stress concentration near bolts, visual interruption of transparency, etc.). Another way to connect glass to glass or other materials is through adhesive connections. Adhesive connections eliminate the above-mentioned disadvantages and provide other reasons for their use, e.g. elimination of vibrations, sealing of the connection (water tightness), eliminating additional production processes such as drilling holes for bolted joints, etc. Lack of knowledge and standards about adhesives in load-bearing structures eliminate their wider use.

The research focuses on transparent adhesives in load-bearing structures, the effect of elevated temperature and environmental effects on their mechanical properties. The first experimental part of the research is focused on the small-scale test of double-lap adhesive glass-glass joints loaded in shear mode. Three glass panes with dimensions of 50x50mm and nominal thickness of 19mm were bonded as double-lap joints; see Figure . The glass panes were bonded with 1 mm adhesives. In total, 8 adhesives were tested. Here are presented 2 of them. One rigid adhesive and one semi-rigid adhesive. Each adhesive was tested in 3 sets: (i) reference set, (ii) set at elevated temperature, (iii) set of specimens affected by artificial ageing. The shear stress in the adhesive was induced by the compression load on the middle glass pane; see Figure . The test was controlled by continuously applying displacement until the specimen's collapse. The speed of the crosshead was 0.05 mm/min. Most of the specimens failed during artificial ageing; see Figure . The colour of the adhesive was yellow or orange. Only one specimen with semi-rigid adhesive withstands artificial ageing. The specimen achieved a shear strength of 0.33 MPa during shear loading. The same adhesive in the reference set achieved average shear strength of 9.21 MPa which is app. three times higher compared to rigid adhesive (3.04 MPa); see Figure . Both sets at elevated temperature achieved an average shear strength of 0.13 MPa; see Figure . Both adhesives withstand elevated temperatures even if the reduction in shear strength was significant. Any of the adhesives could not be recommended as suitable adhesives for bonding in an external environment but have potential for indoor applications.

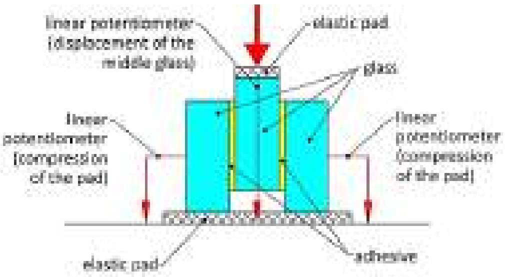

Figure 1: *Schema of the experiment*

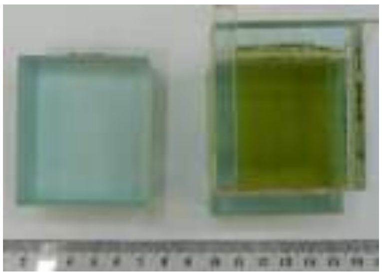

Figure 2: *Specimen after artificial ageing*

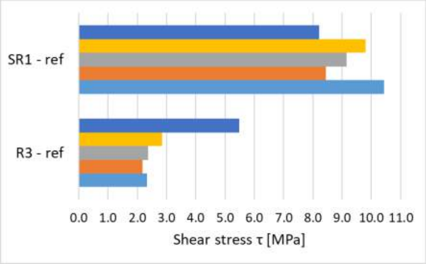

Figure 3: *Shear strength - reference set*

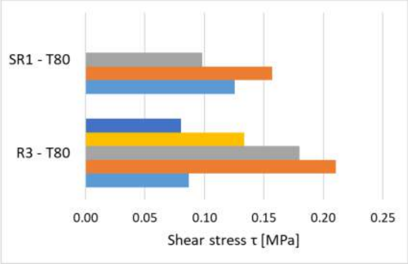

Figure 4: *Shear strength – temperature 80°C*

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