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Repair and joining of vitrimer carbon fibre reinforced polymers (vCFRPs)

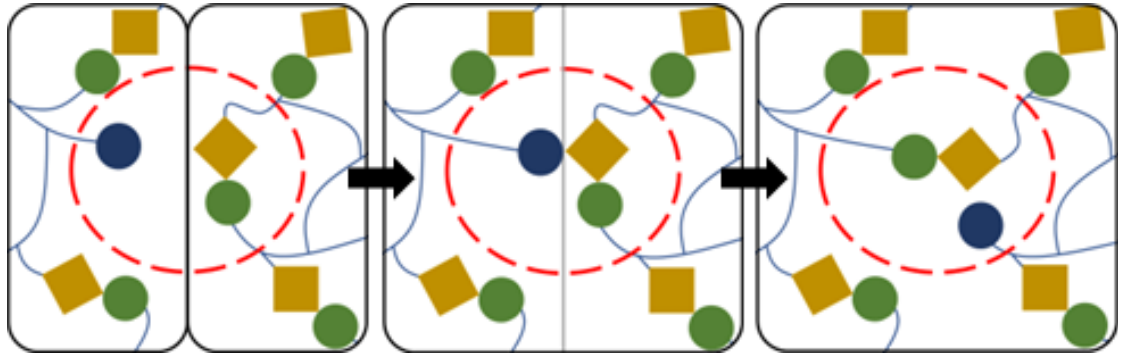
Oriol Gavalda-Diaz
oriol.gavaldadiaz@nottingham.ac.uk

Phoebe Rylatt, Gabriele Albertini, Davide de Focatiis, Nick Warrior and Oriol Gavalda-Diaz
Composites Research Group, Faculty of Engineering, University of Nottingham

Introduction

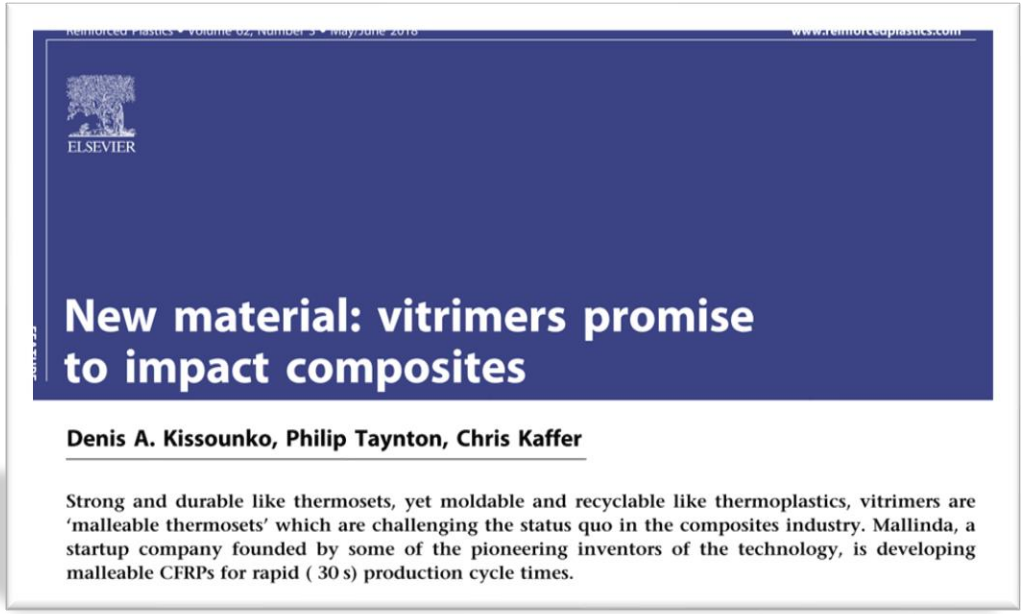
[1]Lieber et al., Science, 2011

Leibler and coworkers[1] developed the first epoxy vitrimer in 2011 which had a property unique among thermosets: dynamic covalent bonding.



Without depolymerising, a thermoset can flow, promoting reprocessing and repairability.

This has risen the interest of using vitrimers in the composites community.

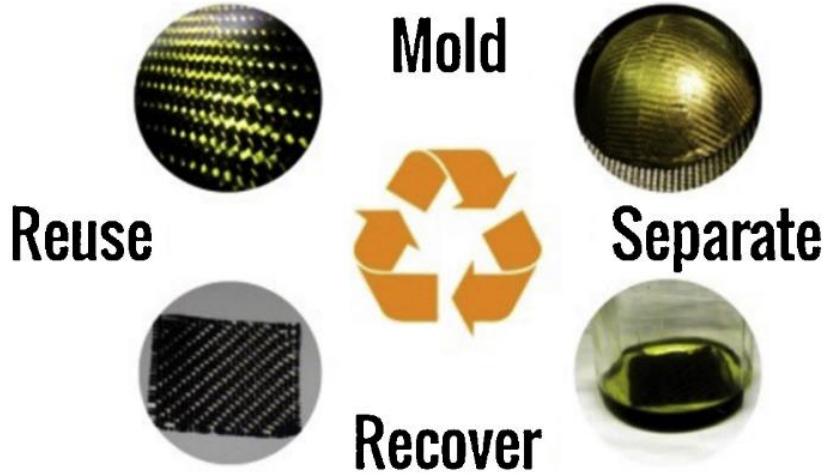


ELSEVIER

New material: vitrimers promise to impact composites

Denis A. Kissounko, Philip Taynton, Chris Kaffer

Strong and durable like thermosets, yet moldable and recyclable like thermoplastics, vitrimers are 'malleable thermosets' which are challenging the status quo in the composites industry. Mallinda, a startup company founded by some of the pioneering inventors of the technology, is developing malleable CFRPs for rapid (30 s) production cycle times.



Some examples of vCFRP

Materials Horizons

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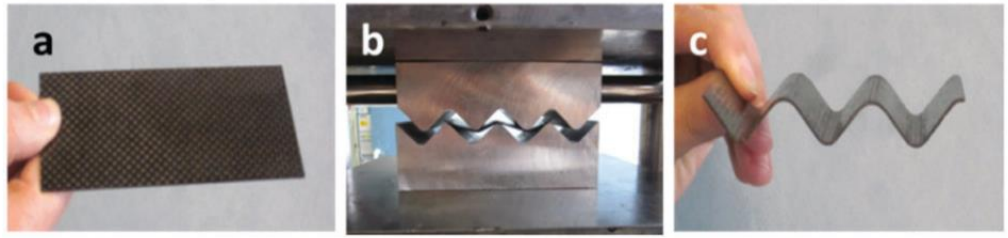
Epoxy resin with exchangeable disulfide crosslinks to obtain reprocessable, repairable and recyclable fiber-reinforced thermoset composites†

Alaitz Ruiz de Luzuriaga, Roberto Martin, Nerea Markaide, Alaitz Rekondo, Germán Cabañero, Javier Rodríguez and Ibon Odriozola*



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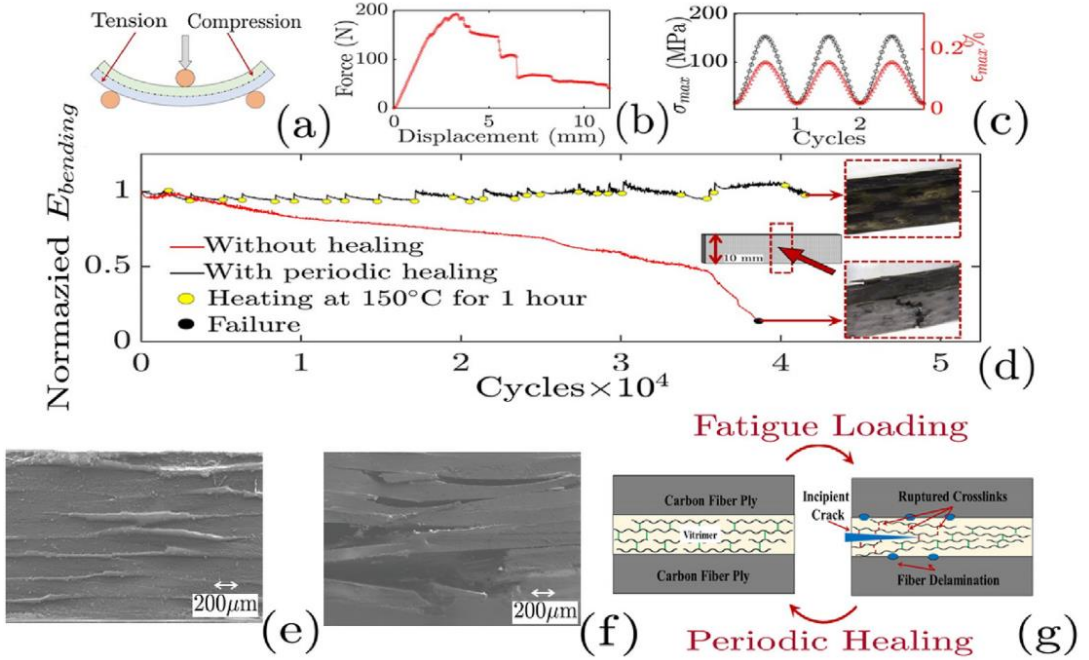
ELSEVIER

Reversing fatigue in carbon-fiber reinforced vitrimer composites

Mithil Kamble [a, 1], Aniruddh Vashisth [b, 1], Hongkun Yang [c, 1], Sikharin Pranompont [a], Catalin R. Picu [a, ***], Dong Wang [c, **], Nikhil Koratkar [a, d, *]

[a] Department of Mechanical, Aerospace and Nuclear Engineering, Rensselaer Polytechnic Institute, Troy, NY, 12180, United States
[b] Department of Mechanical Engineering, University of Washington, Seattle, WA, 98195, United States
[c] State Key Laboratory of Organic–Inorganic Composites, Beijing University of Chemical Technology, Beijing, 100029, China
[d] Department of Materials Science and Engineering, Rensselaer Polytechnic Institute, Troy, NY, 12180, United States

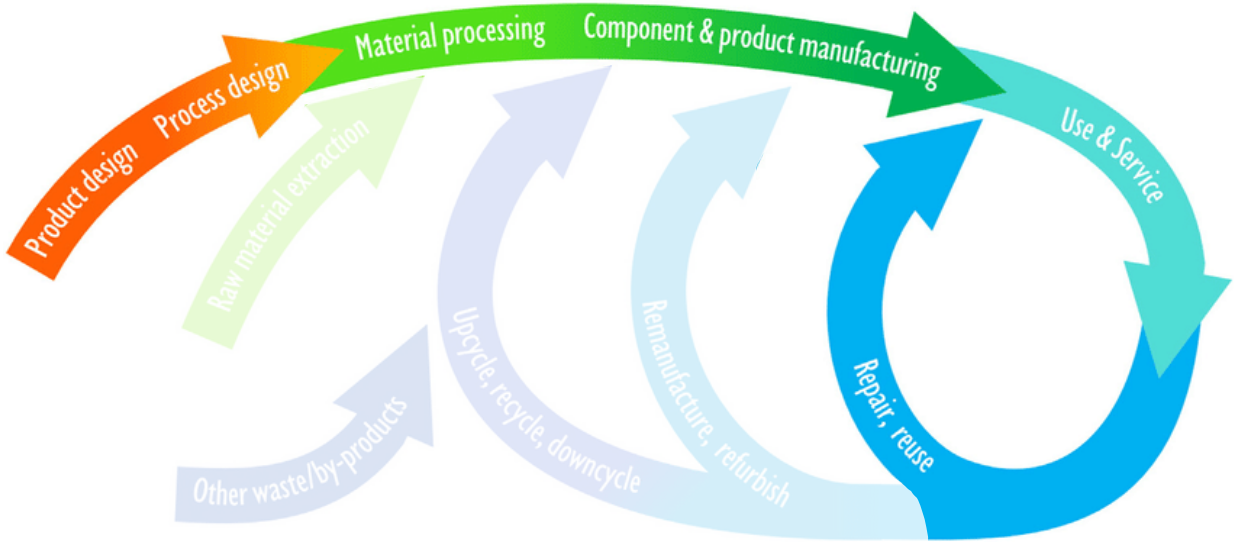


Our work

[2]Ruiz de Luzuriaga et al., Material Horizons, 2016
[3]Kamble et al., Carbon, 2022
[4]Mallinda Inc.

Evaluate the following aspects of vCFRP

I. Manufacturability
II. Reparability
III. Joinability

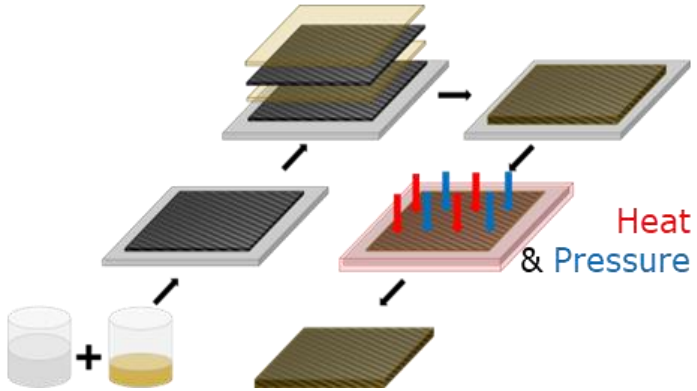


We have studied four different vitrimers with different of dynamic bonding nature and different vitrification temperatures

- Epoxy vitrimers with aromatic disulfides[2] - VAFD
- Epoxy vitrimer with transesterification[3] - VAA/TBD
- Polyimine-based[4]- V100 / V130

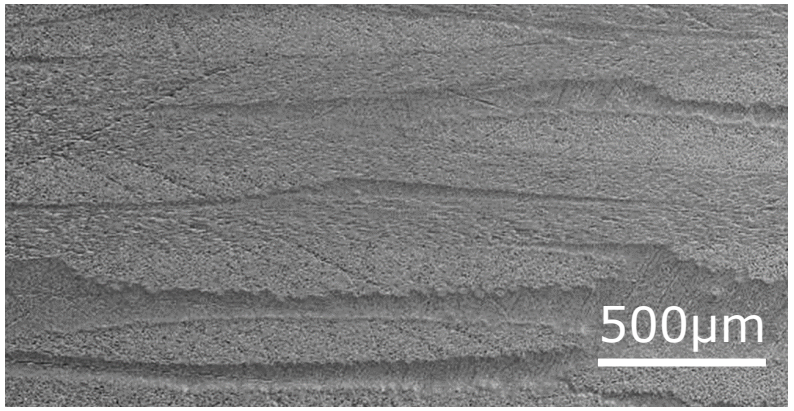
Evaluating manufacturability

Manual lay up + Autoclave

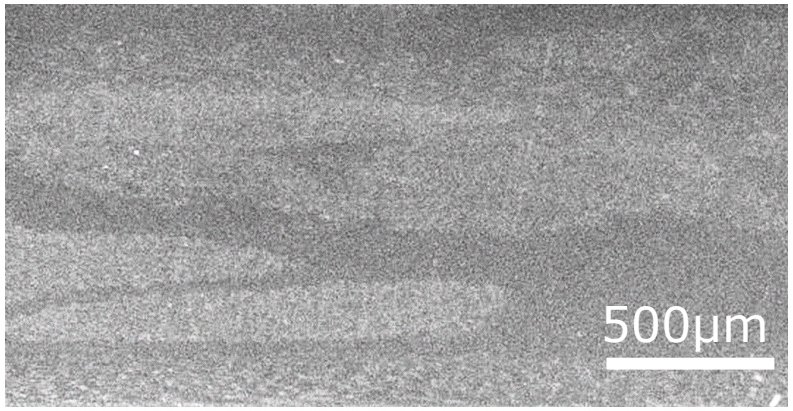


- 8 plies per sample
- Cured in the autoclave at 7 bar following the temperature cycle defined by supplier/scientific papers

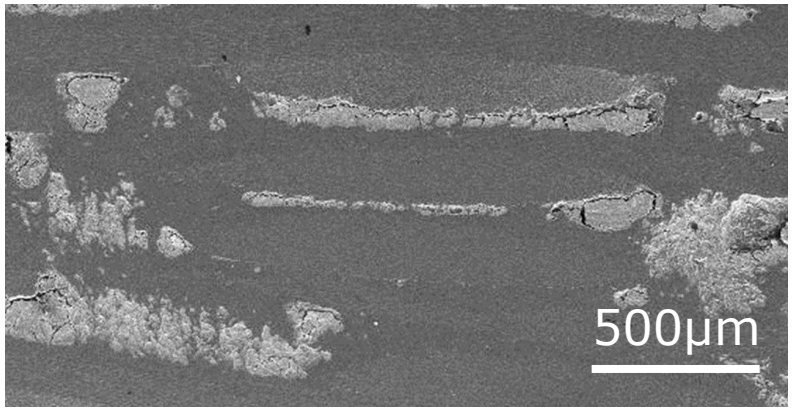
a) DGEBA, AA, TBD



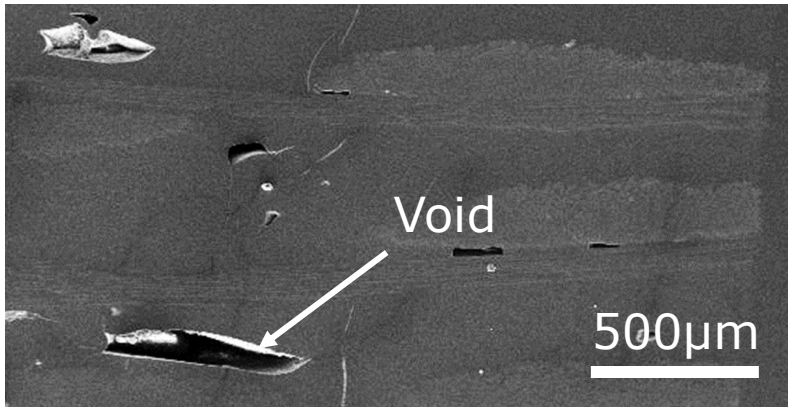
b) DGEBA, AFD



c) V100

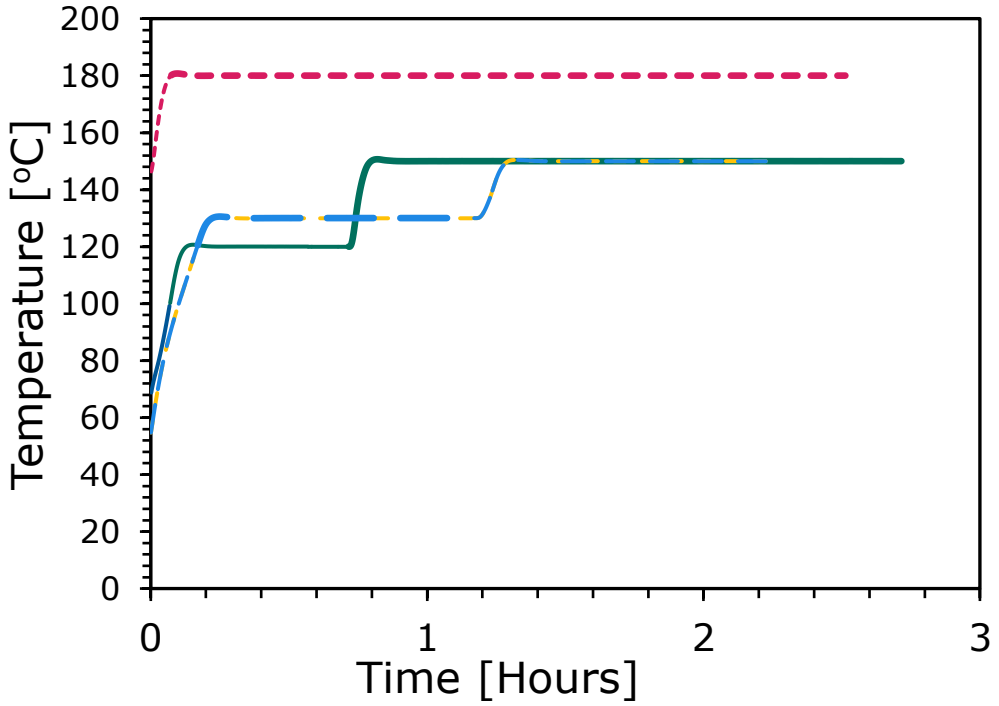


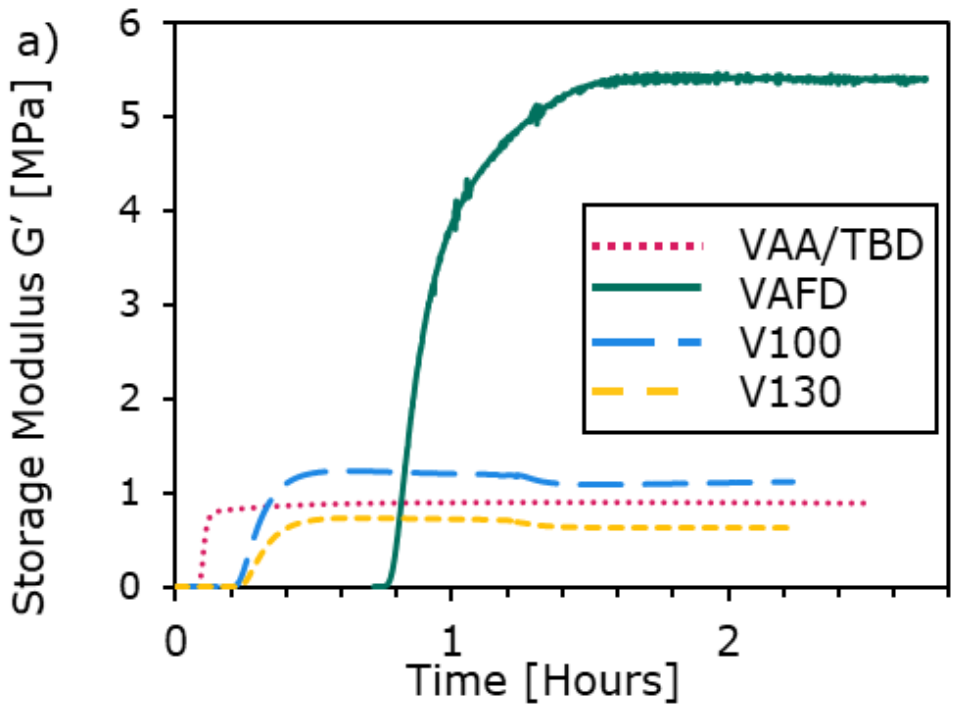
d) V130



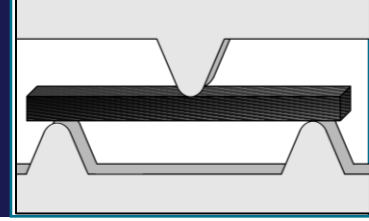
Viscoelastic experiment

We monitor the storage modulus of the resin over the curing cycle to ensure that the materials are fully cured. This is important when studying healing and repair.





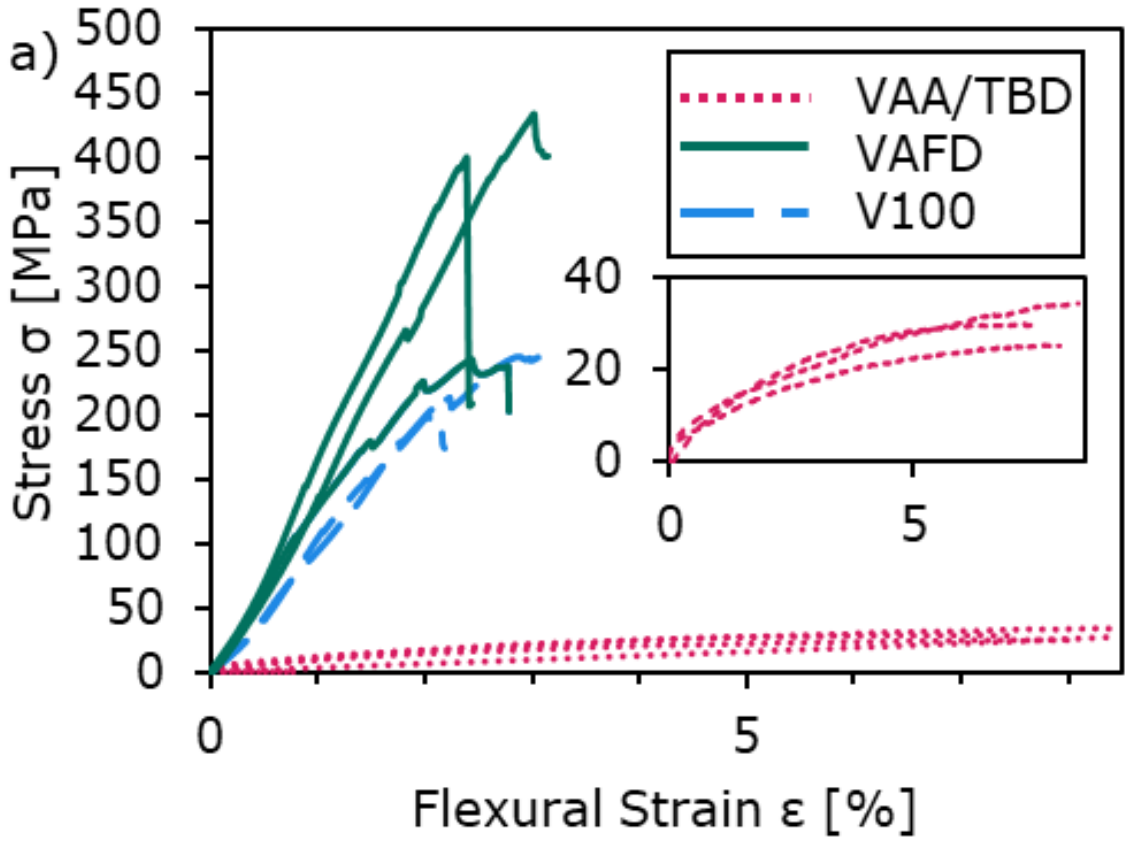
Comparison of mechanical properties



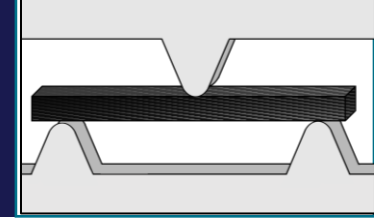
Mechanical properties of small specimens (30 x 3 x 3 mm) tested in 3-point bending.

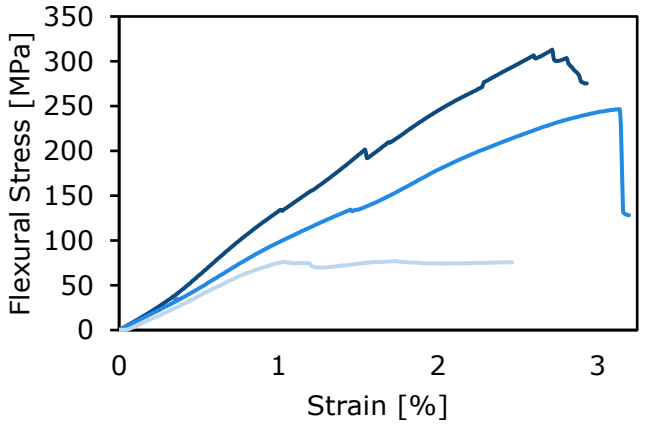
The three vCFRP show a wide difference in properties going from a more brittle-type failure to a pseudo-ductile type failure

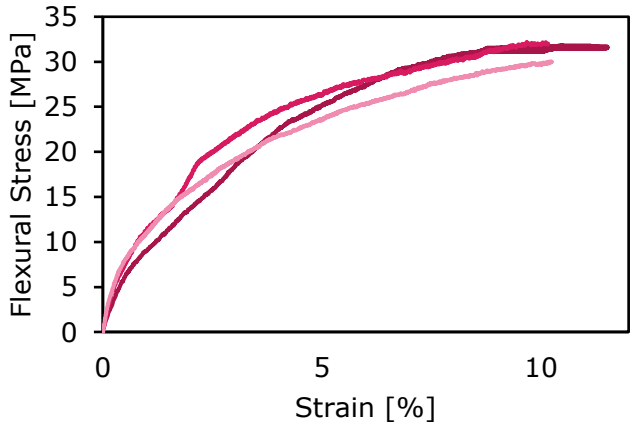
These samples are then used to evaluate repairability and healing properties.

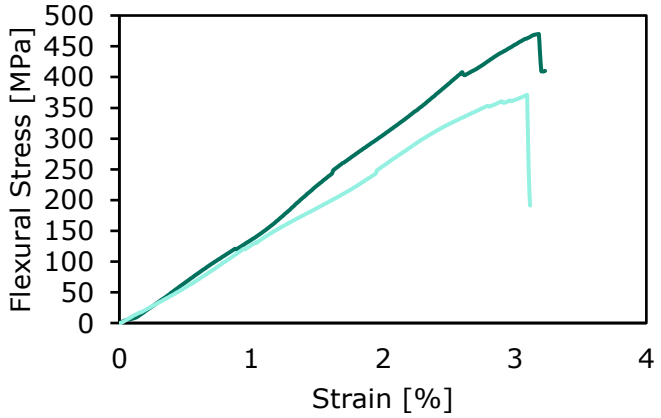


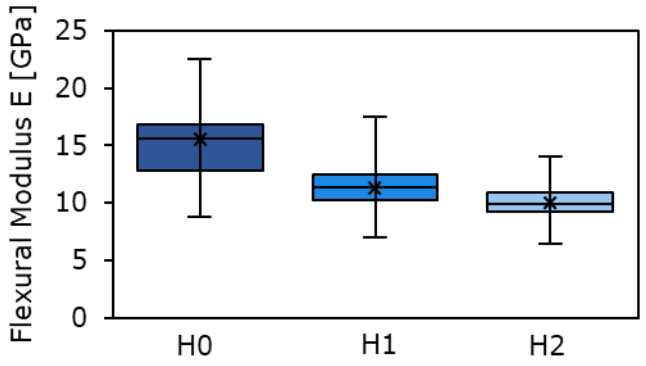
Repair – non localised damage - 3PB

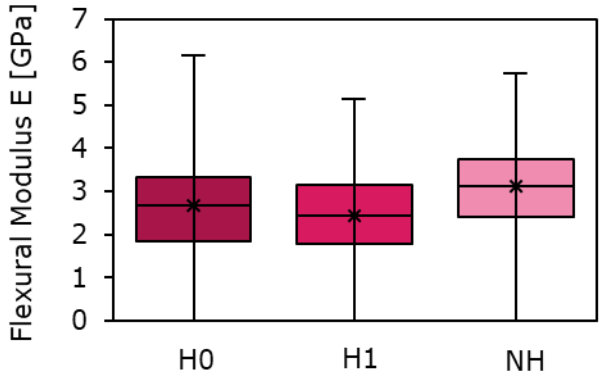


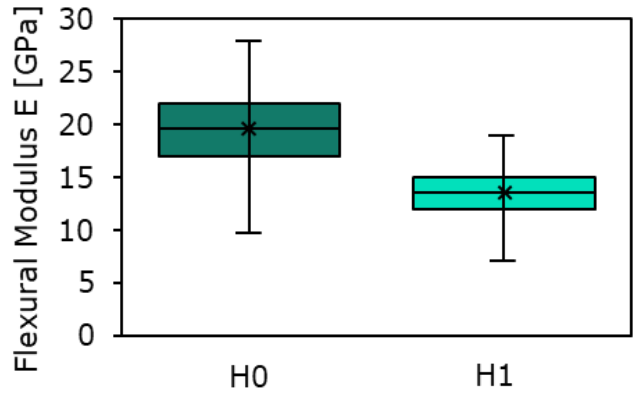


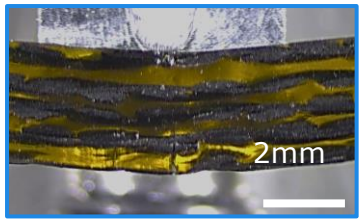


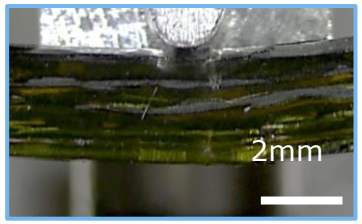


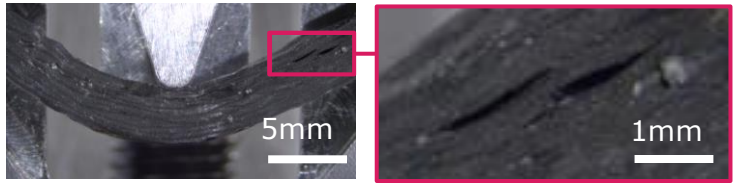


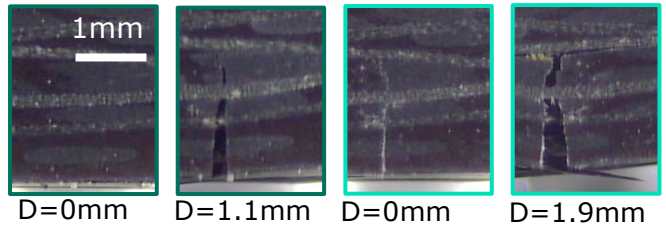




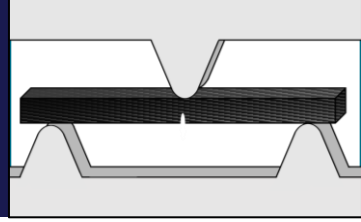




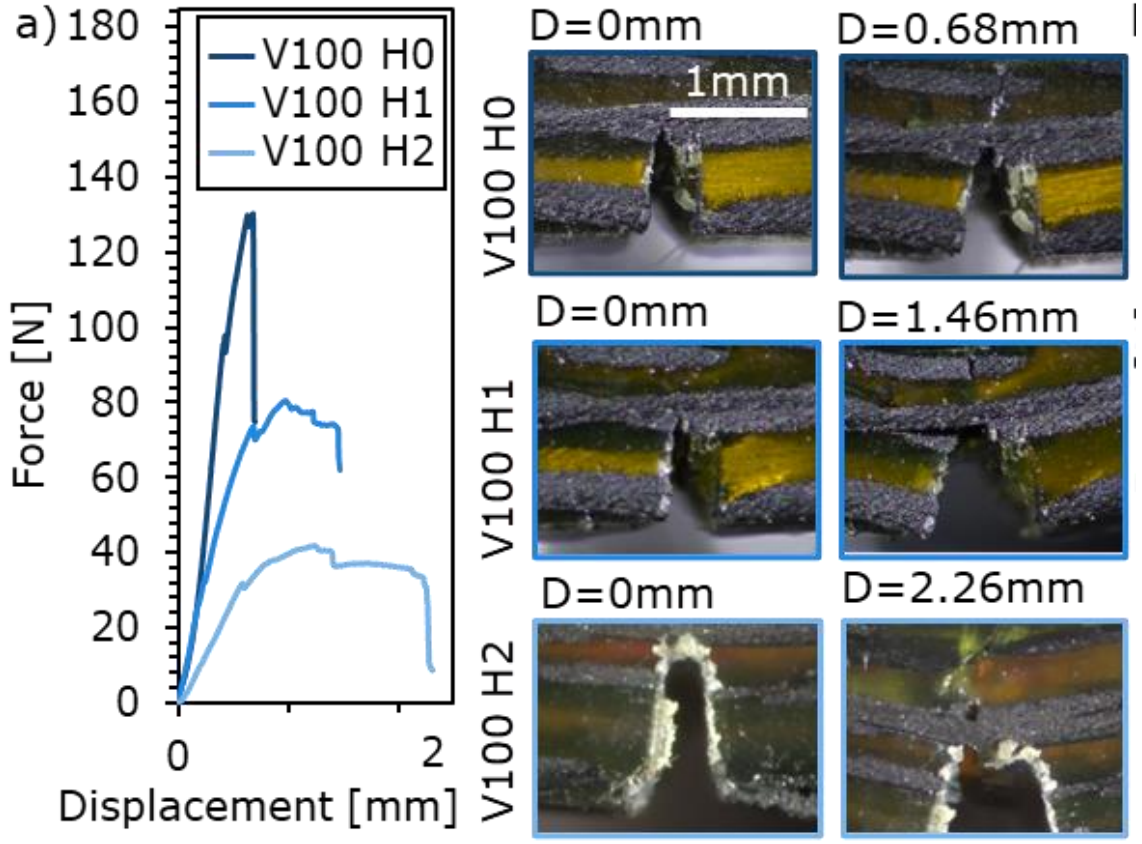


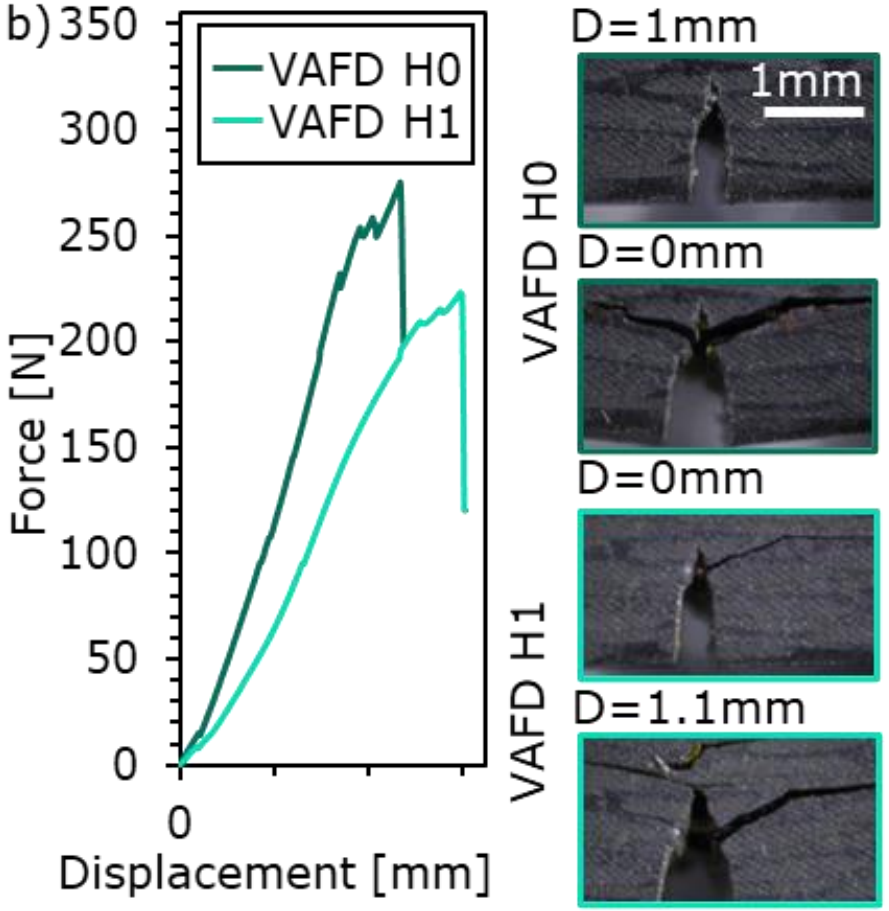


Repair – localised damage - SENB

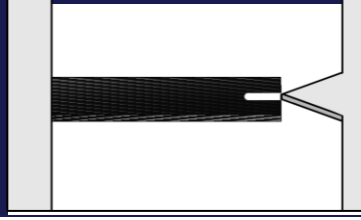


We use Single Edge Notch Beam (SENB) to measure healing capabilities during translaminar fracture. Crack healing is observed during temperature/pressure is applied. However, the initiation toughness after healing is not fully recovered.





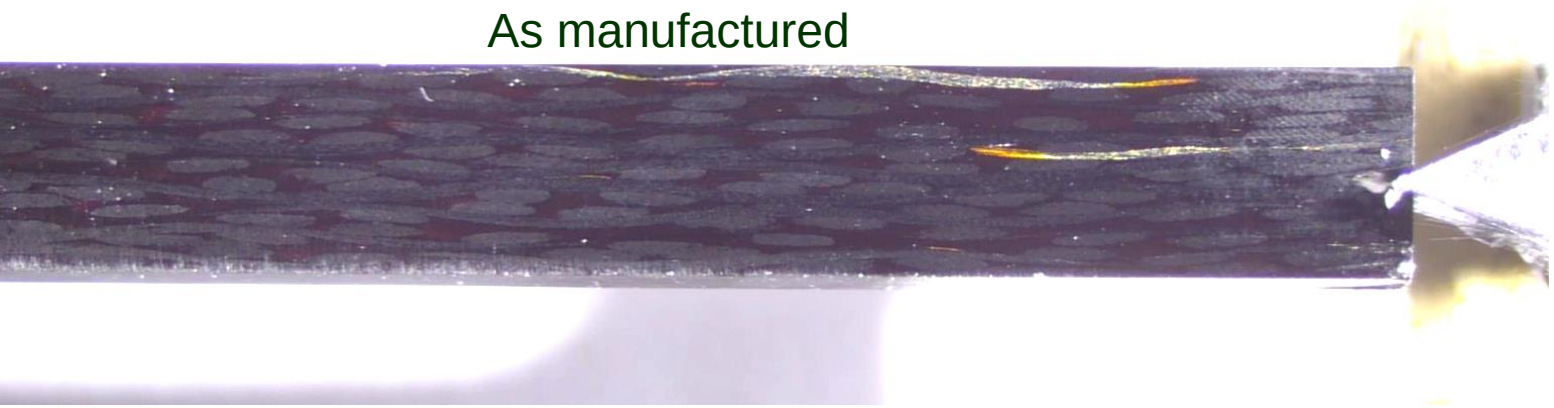
Repair – localised damage - DCB



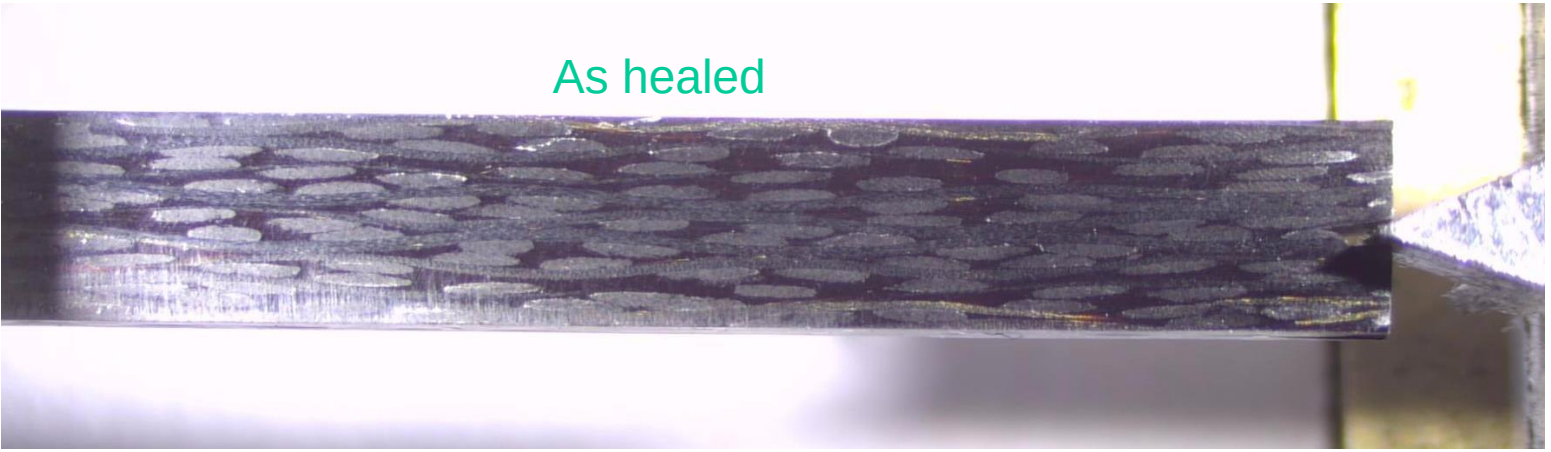
We use Double Cantilever Beam Test (DCB) to measure healing capabilities in interlaminar fracture.

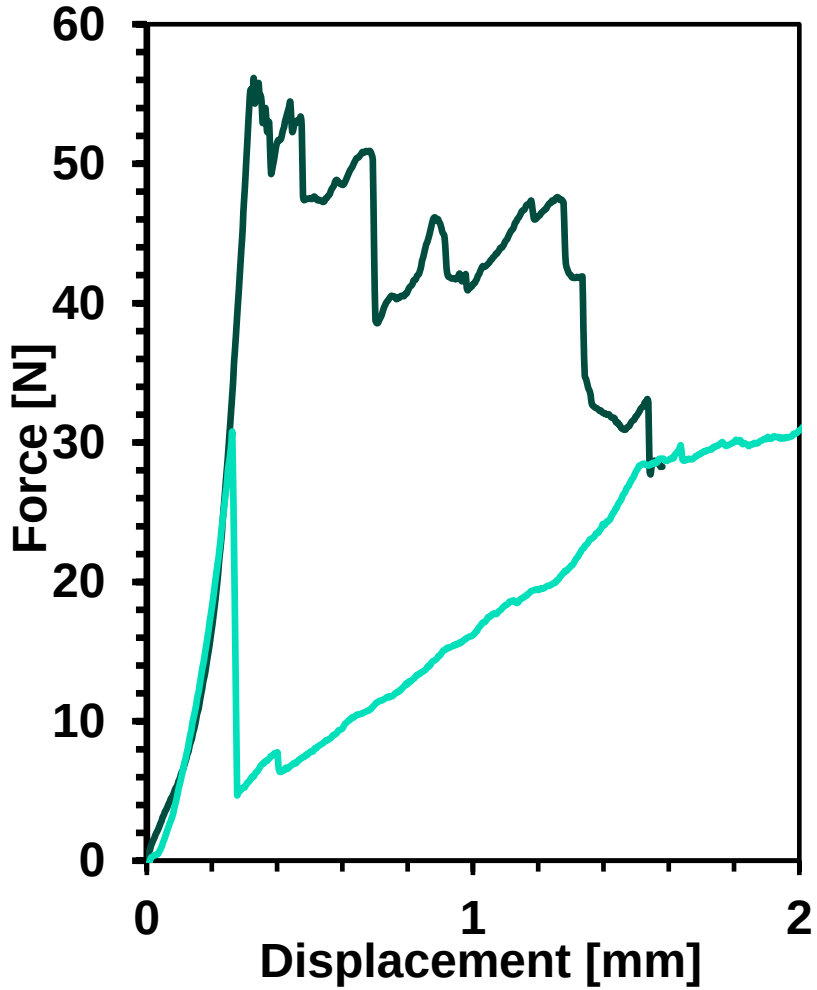
Example of poor healing (DCB 1):

As manufactured

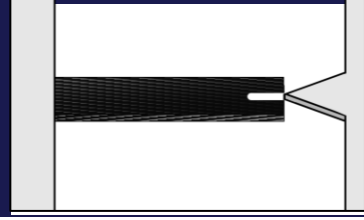


As healed



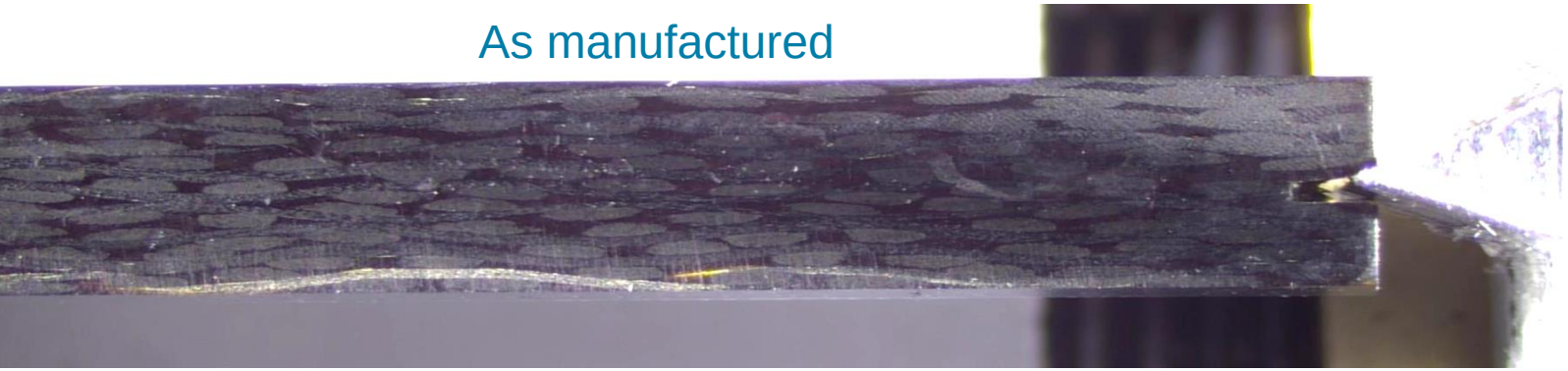


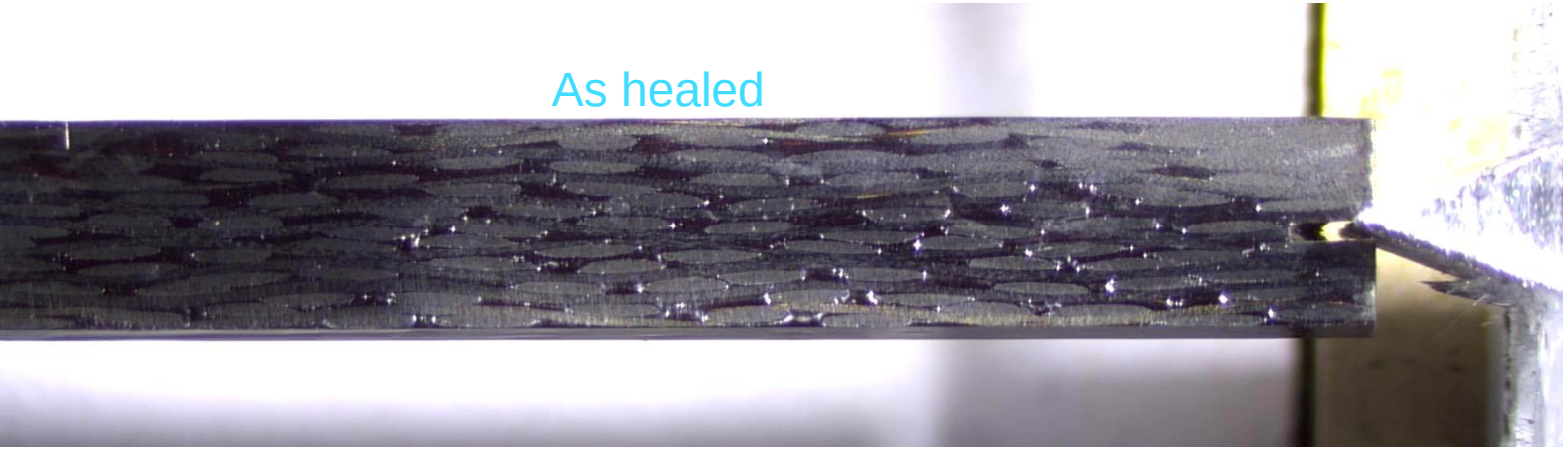
Repair – localised damage - DCB

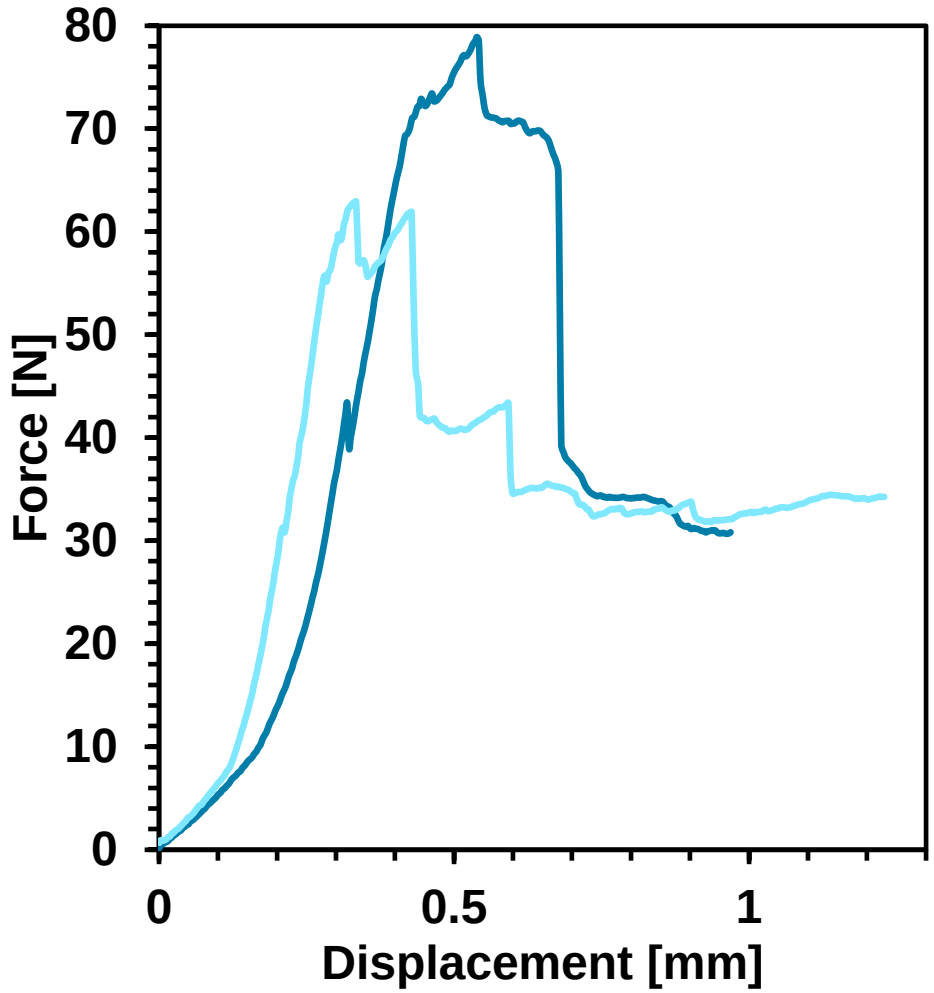


We use Double Cantilever Beam Test (DCB) to measure healing capabilities in interlaminar fracture.

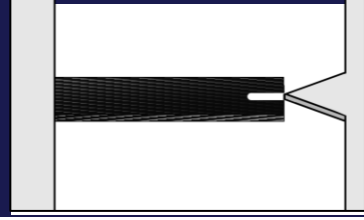
Example of a successful healing (DCB 2):







Repair – localised damage - DCB



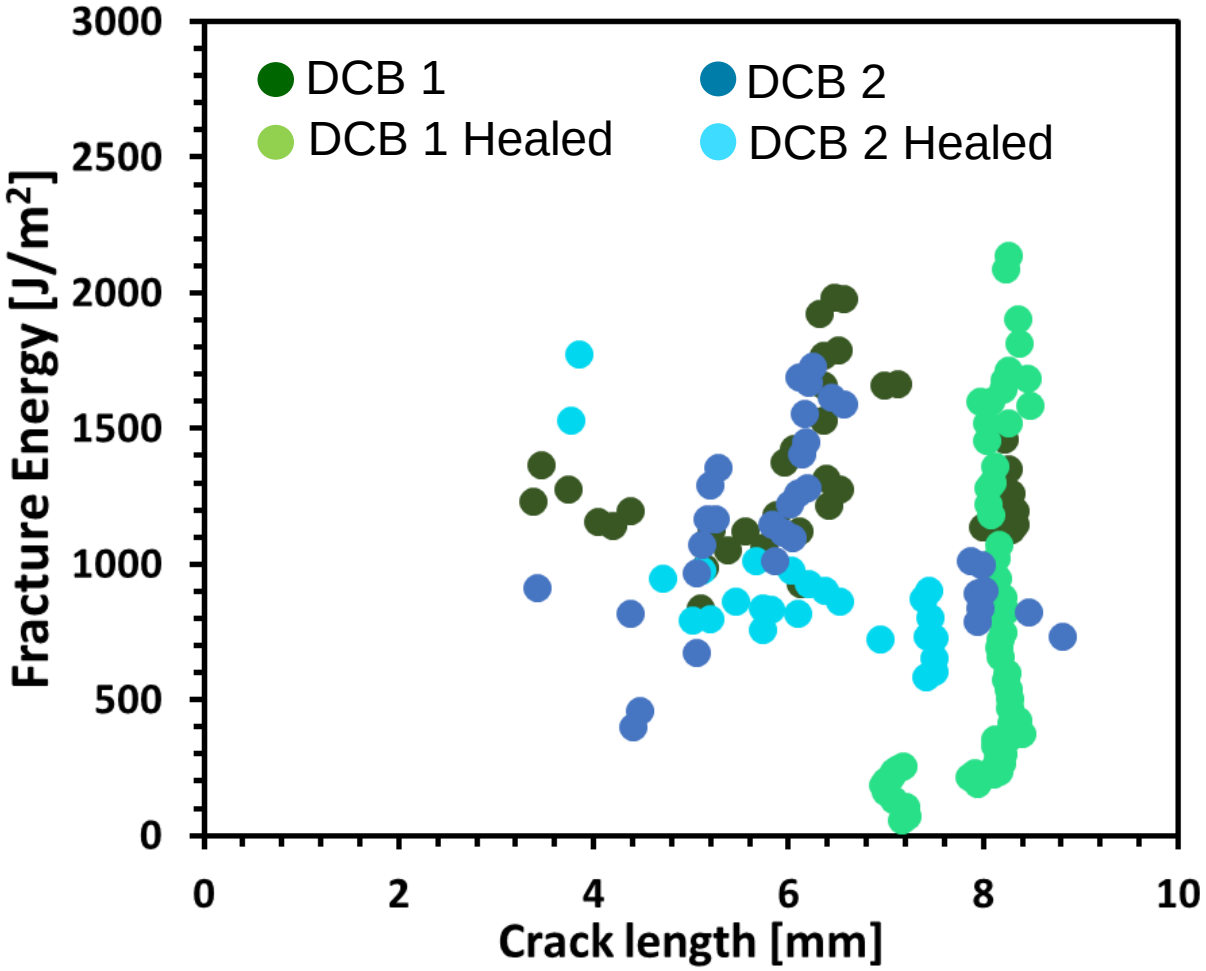
During the DCB test, we track the crack opening displacement (*δ*) and the crack length (*a*) to measure interlaminar fracture toughness/fracture energy (G_{ic}):

$$G_{Ic} = \frac{3E_{11}w_r^3\delta_r^2}{8a^4} + \frac{3E_{11}w_l^3\delta_l^2}{8a^4}$$

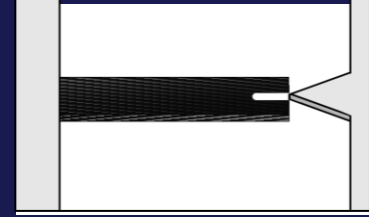
where w is the width of the arms and E_{11} the Young's Modulus in the bending direction

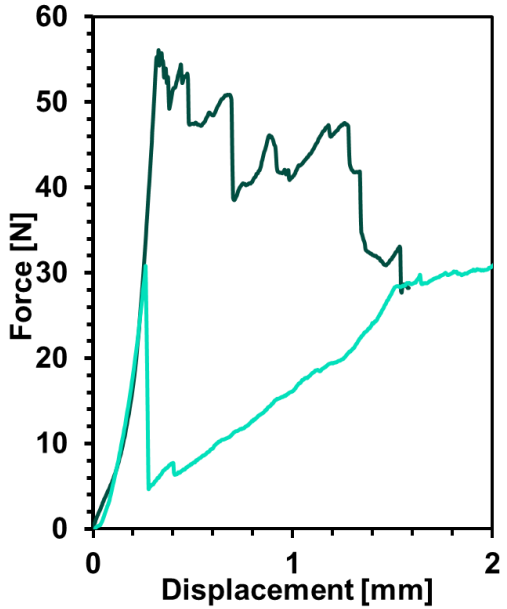
DCB 1 does not recover the properties until we reach the pristine region.

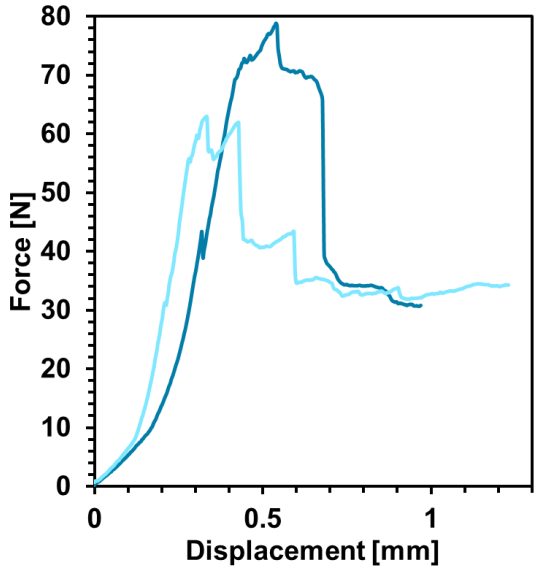
DCB 2 recovers almost the pristine interlaminar fracture energy from early on.



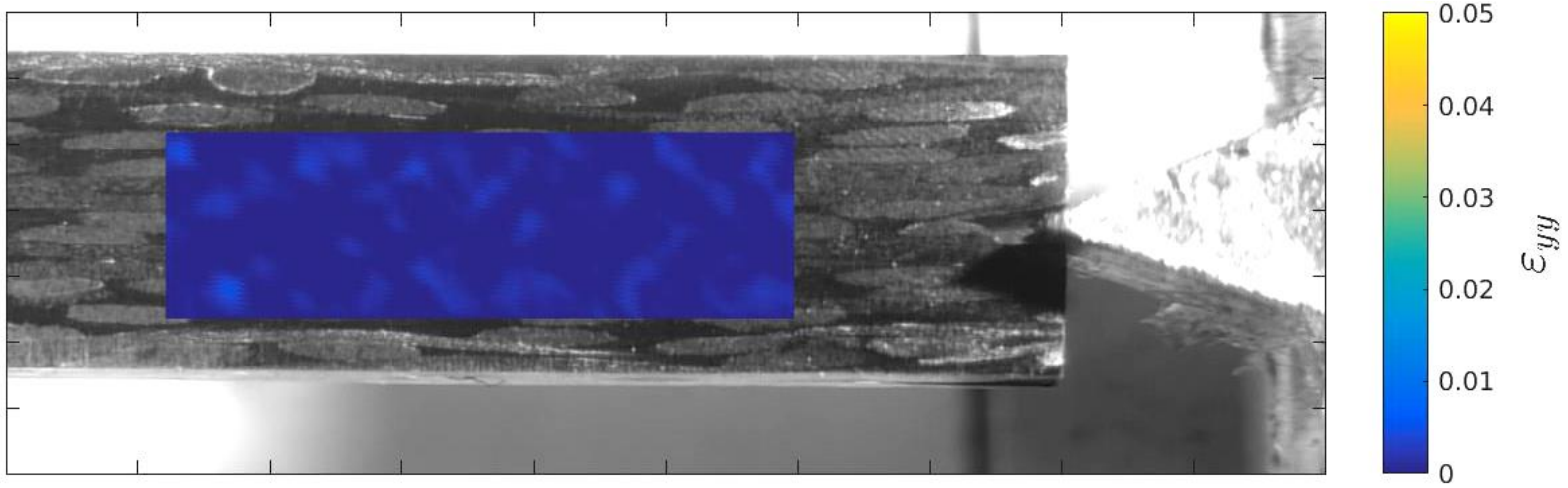
Repair – localised damage - DCB

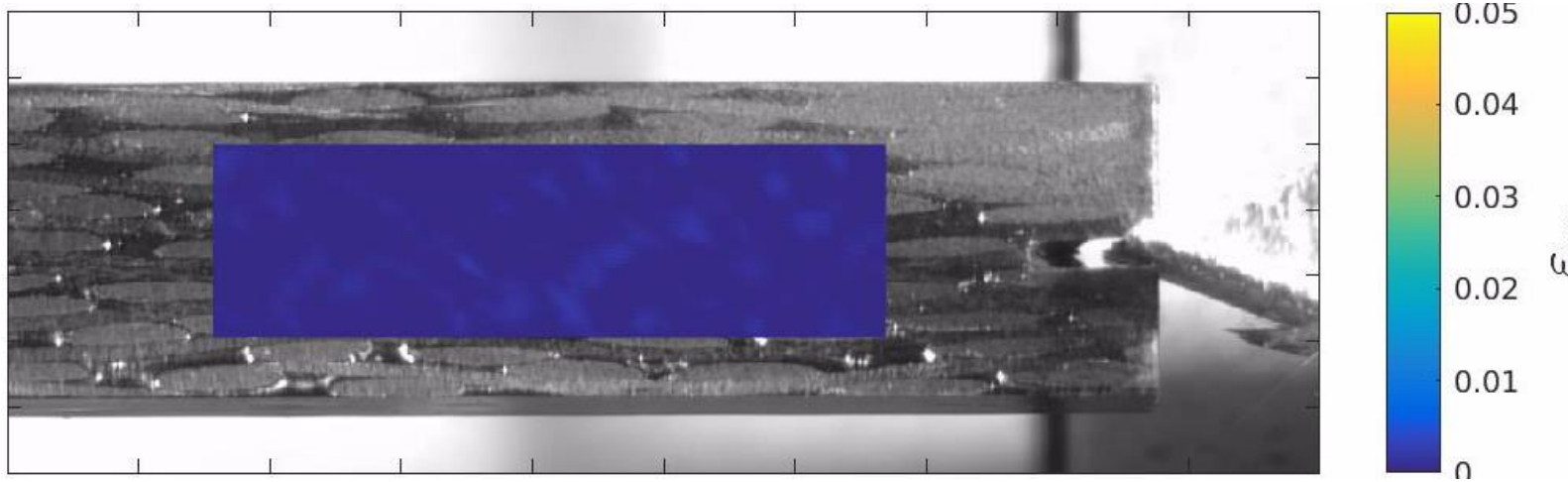




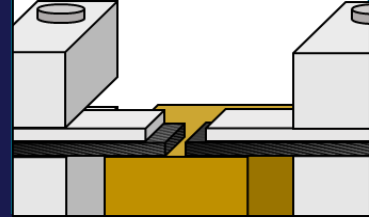


Preliminary work using DIC to study localised crack healing

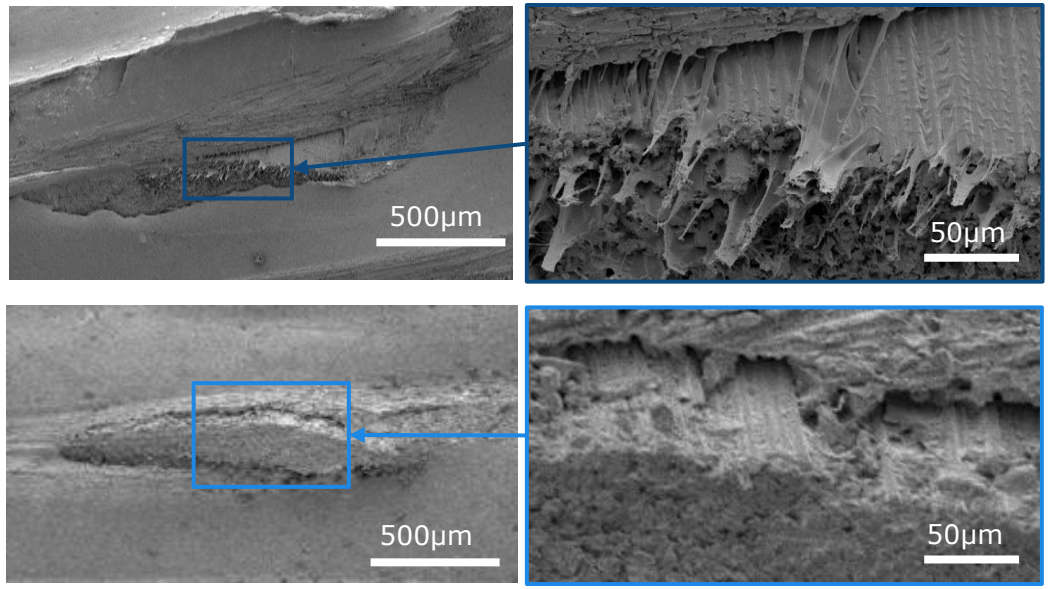


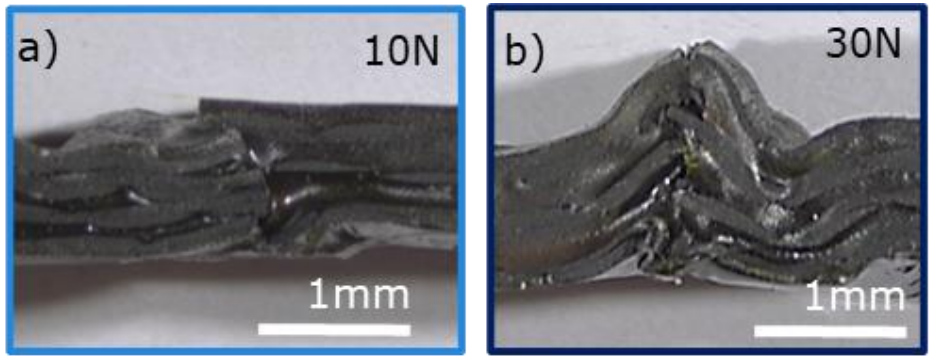


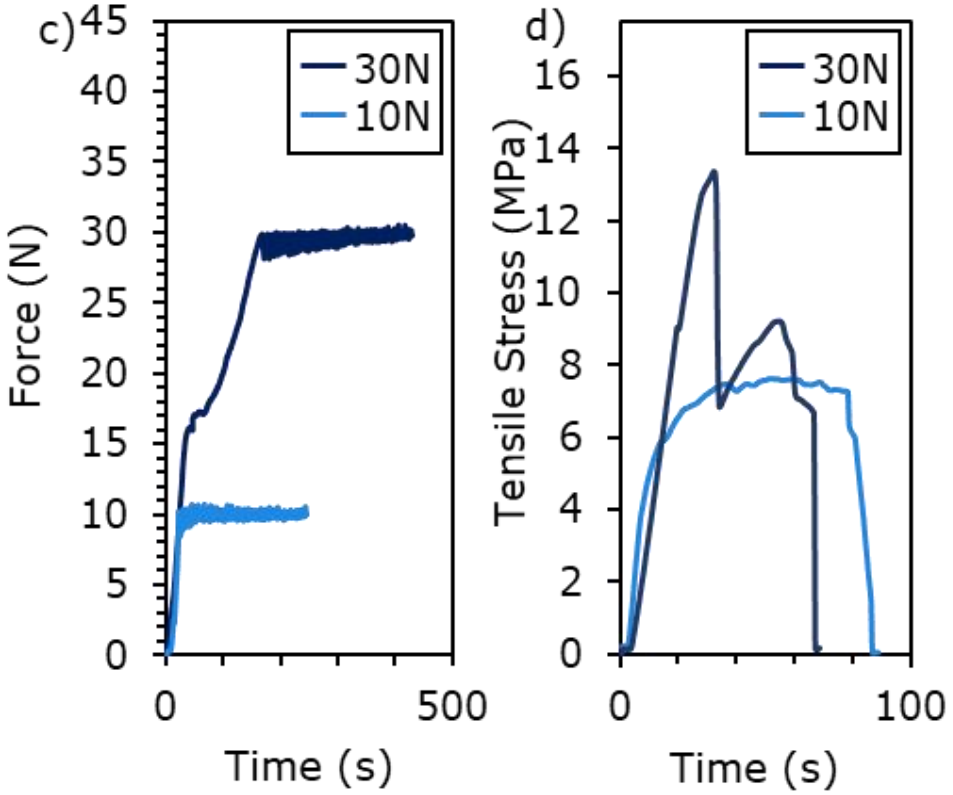
Joining



We join two samples by applying heat and pressure:
1 MPa (10 N) and 3 MPa (30 N).
The vitrimer flows and allows for the fibre to intertwin together.
Joined samples are then tested in tension.







Conclusions

- Different vitrimers very different microstructure and mechanical properties. We can reach similar properties to conventional CFRPs
- Repair has been studied by looking at localised and non localised damages.
- We observe some healing in after translaminar and interlaminar fracture.
- Joining can be investigated in the future

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Thanks for your attention

Oriol Gavalda-Diaz
oriol.gavaldadiaz@nottingham.ac.uk

Phoebe Rylatt, Gabrielle Albertini, Davide de Focatiis, Nick Warrior and Oriol Gavalda-Diaz
Composites Research Group, Faculty of Engineering, University of Nottingham