Multifunctional Composites with Easy-Repairing and Integrated Damage Sensing Capabilities

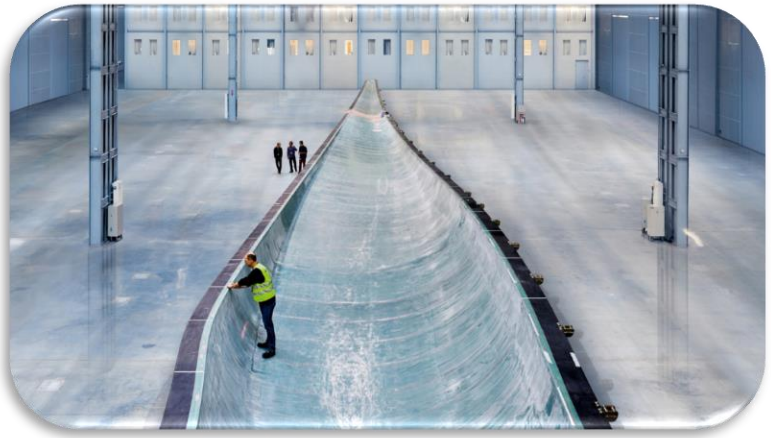
Thomas D.S. Thorn

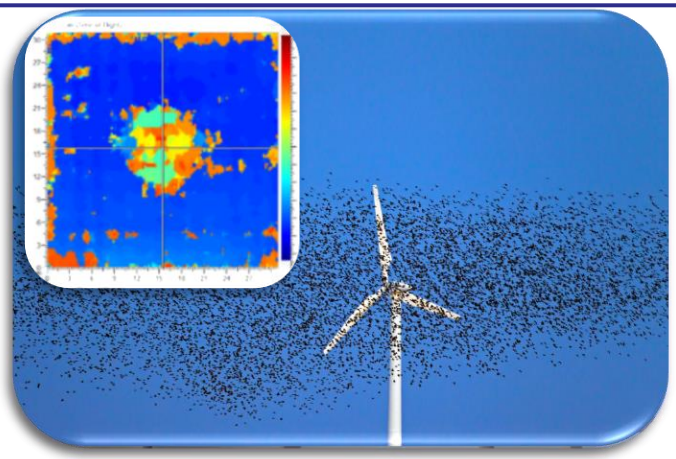
School of Engineering and Materials Science
Queen Mary University of London

t.d.s.thorn@qmul.ac.uk

The Thermoset Composite Lifecycle

Queen Mary University of London





Manufacture → **Service Life** → **End of Life**

The Thermoset Composite Lifecycle

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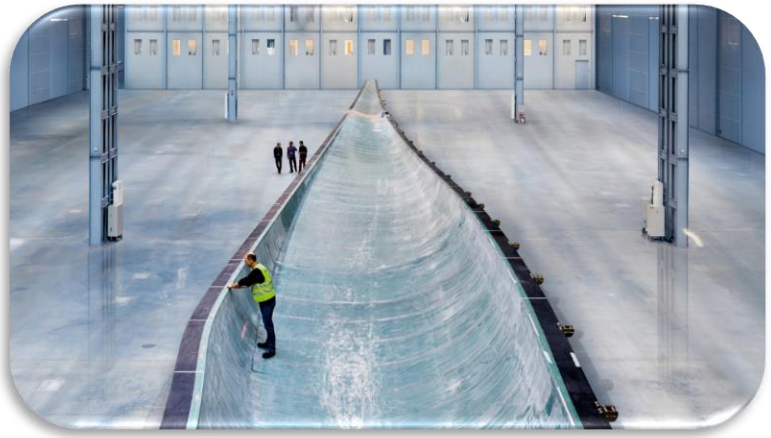
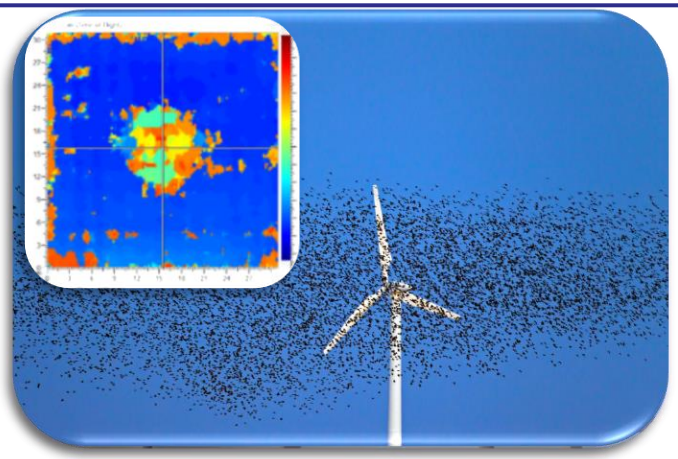
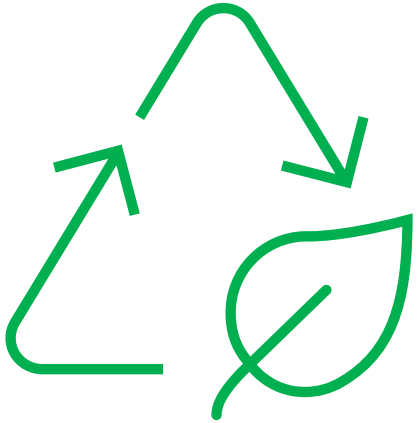




Manufacture

Increased Service Life

End of Life



Easy Repairing

£

Traditional Thermoset Repairing

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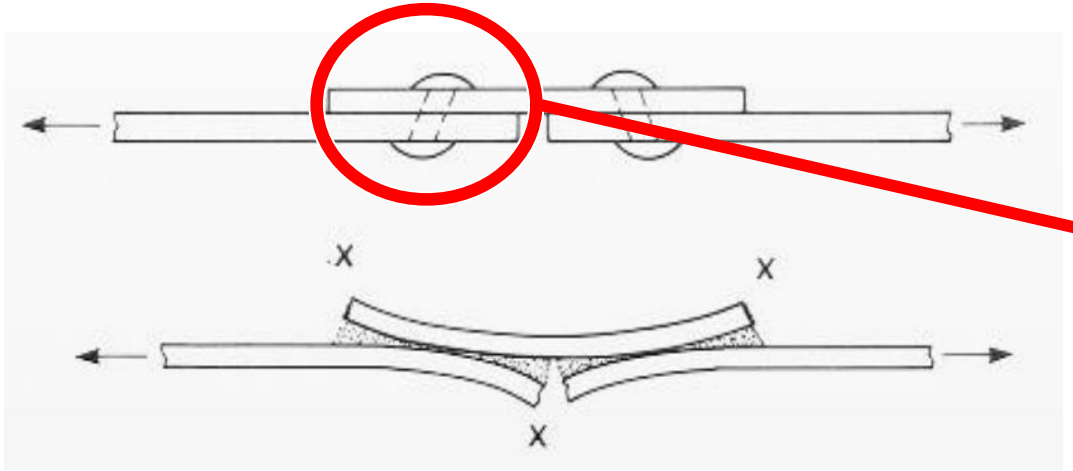
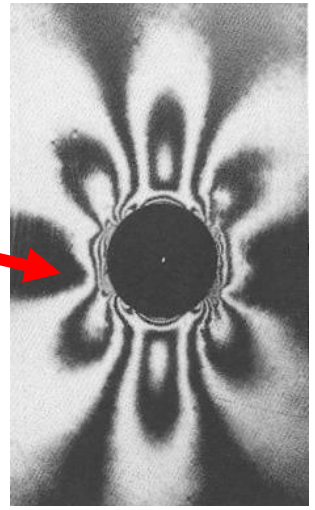
Patch it up!

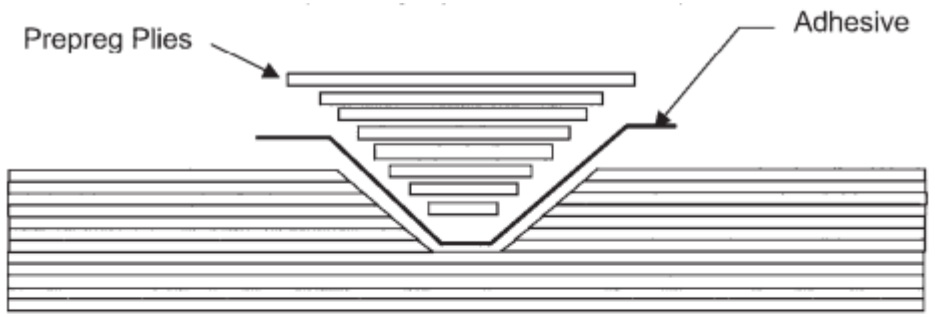
Bonded/Bolted Patch



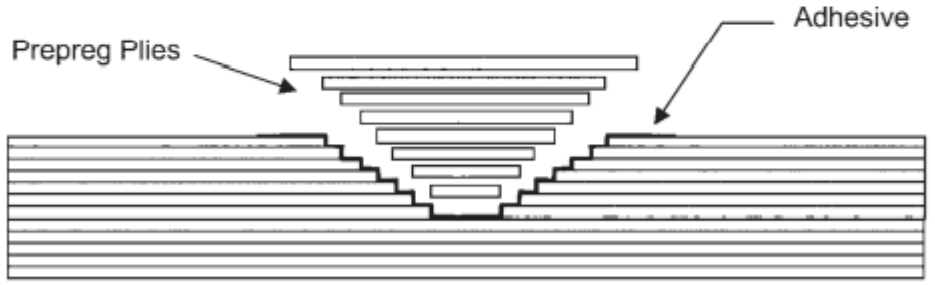


Replace it!

Scarf/Stepped Lap



Scarf



Stepped Lap

Traditional Thermoset Repairing

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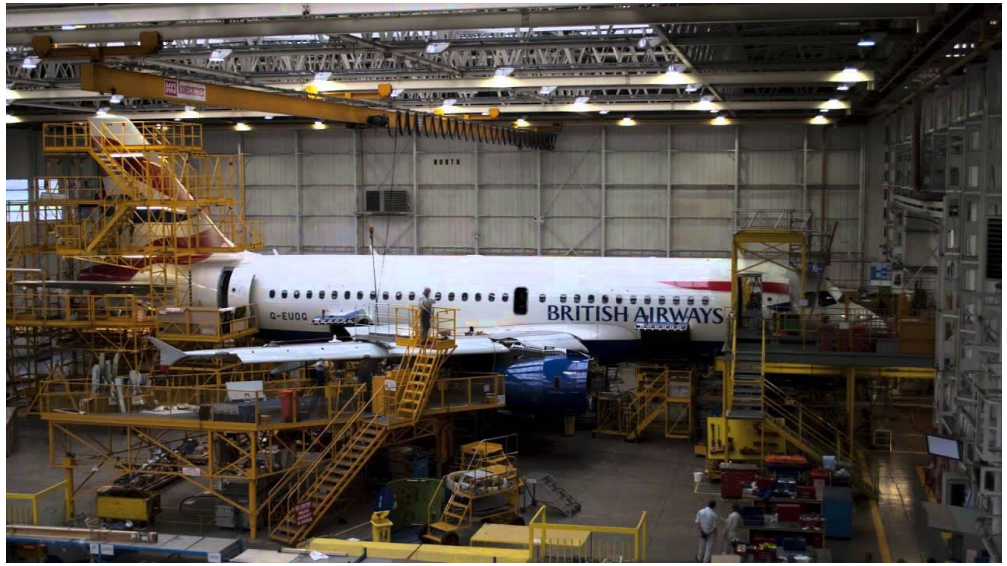
Patch it up!

Bonded/Bolted Patch

Replace it!

Scarf/Stepped Lap



Traditional Thermoset Repairing

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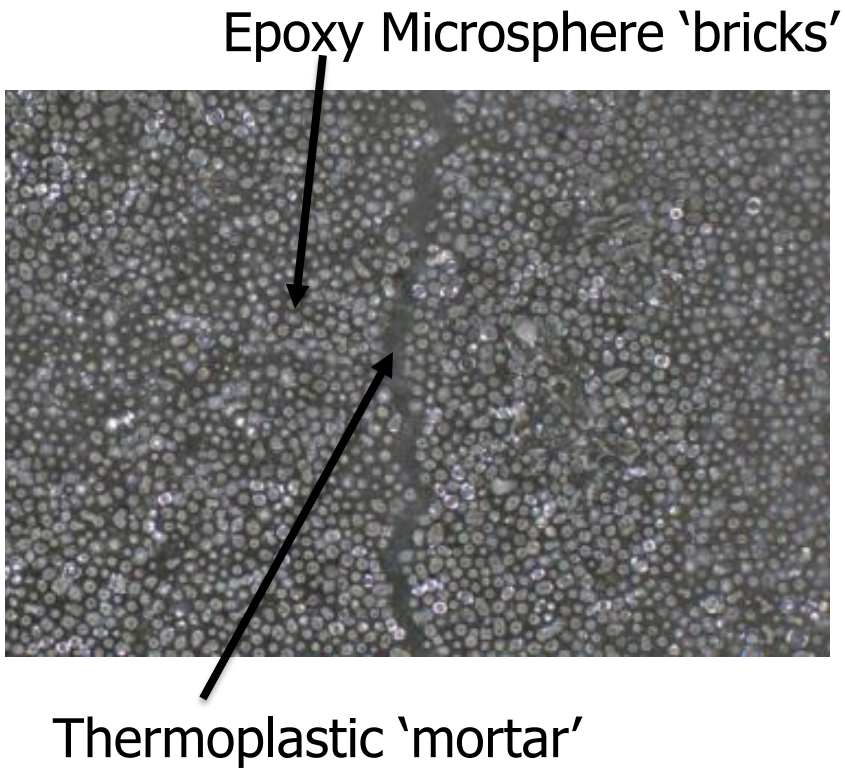
What if the structure isn't easy to move?

Make the Matrix Intrinsically Repairable?

Thermoplastic blending

(repair with heat)

Pioneering science, but what are the engineering challenges?



Cohades A, Manfredi E, Plummer CJ, Michaud V. Thermal mending in immiscible poly (ε-caprolactone)/epoxy blends. European Polymer Journal. 2016 Aug 1;81:114-28.

Make the Matrix Intrinsically Repairable?

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Thermoplastic blending

Pioneering science, but what are the engineering challenges?

Thermal Properties

Environmental Barrier

High Viscosity Processing

Cohades A, Manfredi E, Plummer CJ, Michaud V. Thermal mending in immiscible poly (ε-caprolactone)/epoxy blends. European Polymer Journal. 2016 Aug 1;81:114-28.

The Interleaving Approach

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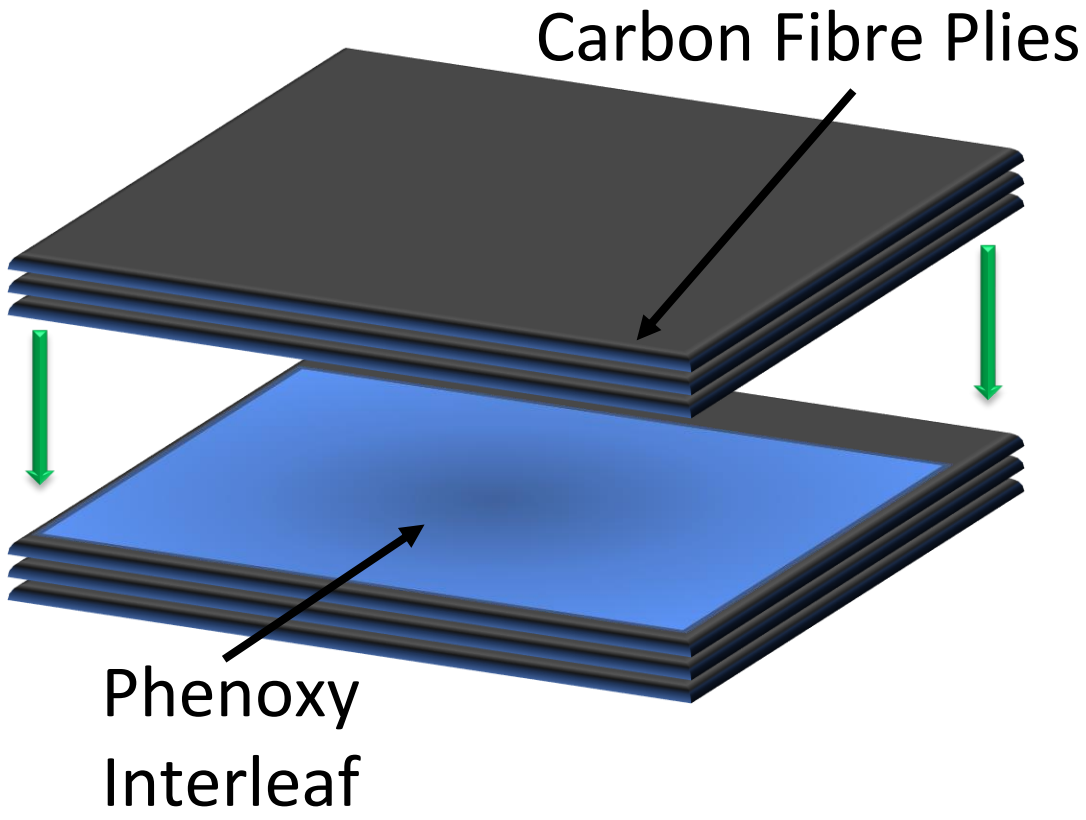
Thermoplastic Phenoxy

- High T_g (90°C)
- A known toughening agent

Interleaving

- Scalable
- Localized
- Liquid Resin Compatible



The Interleaving Approach

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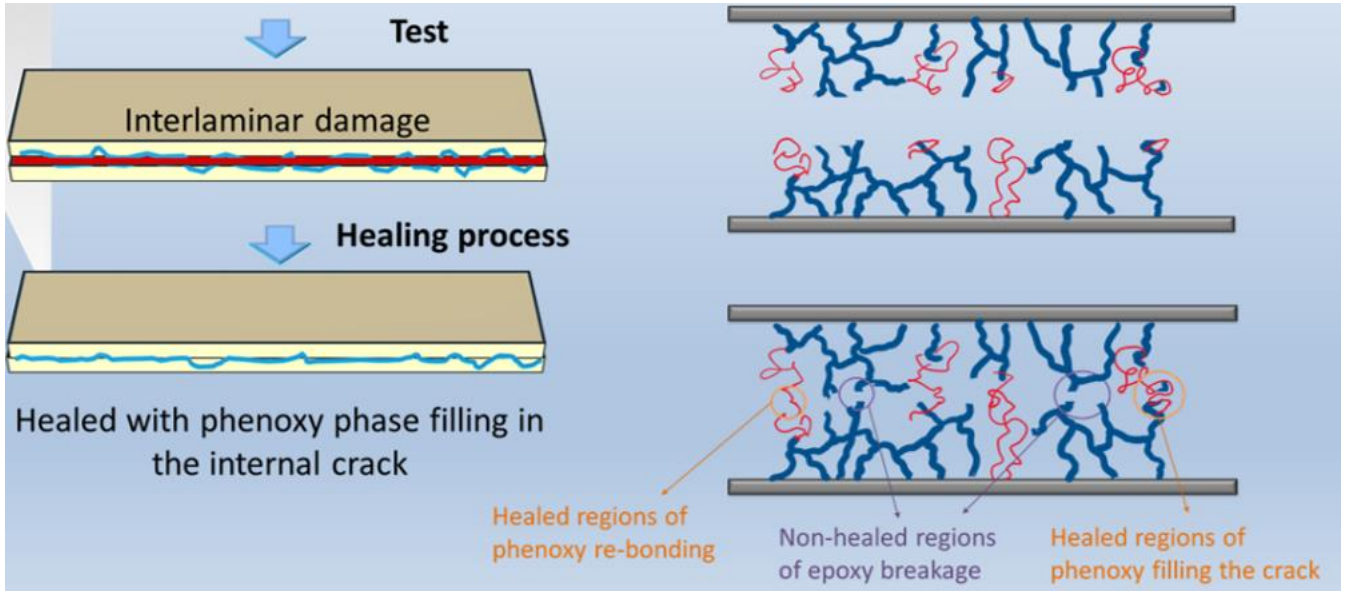

Interleaving

- Scalable
- Localized
- Liquid Resin Compatible

Toughening & Repair

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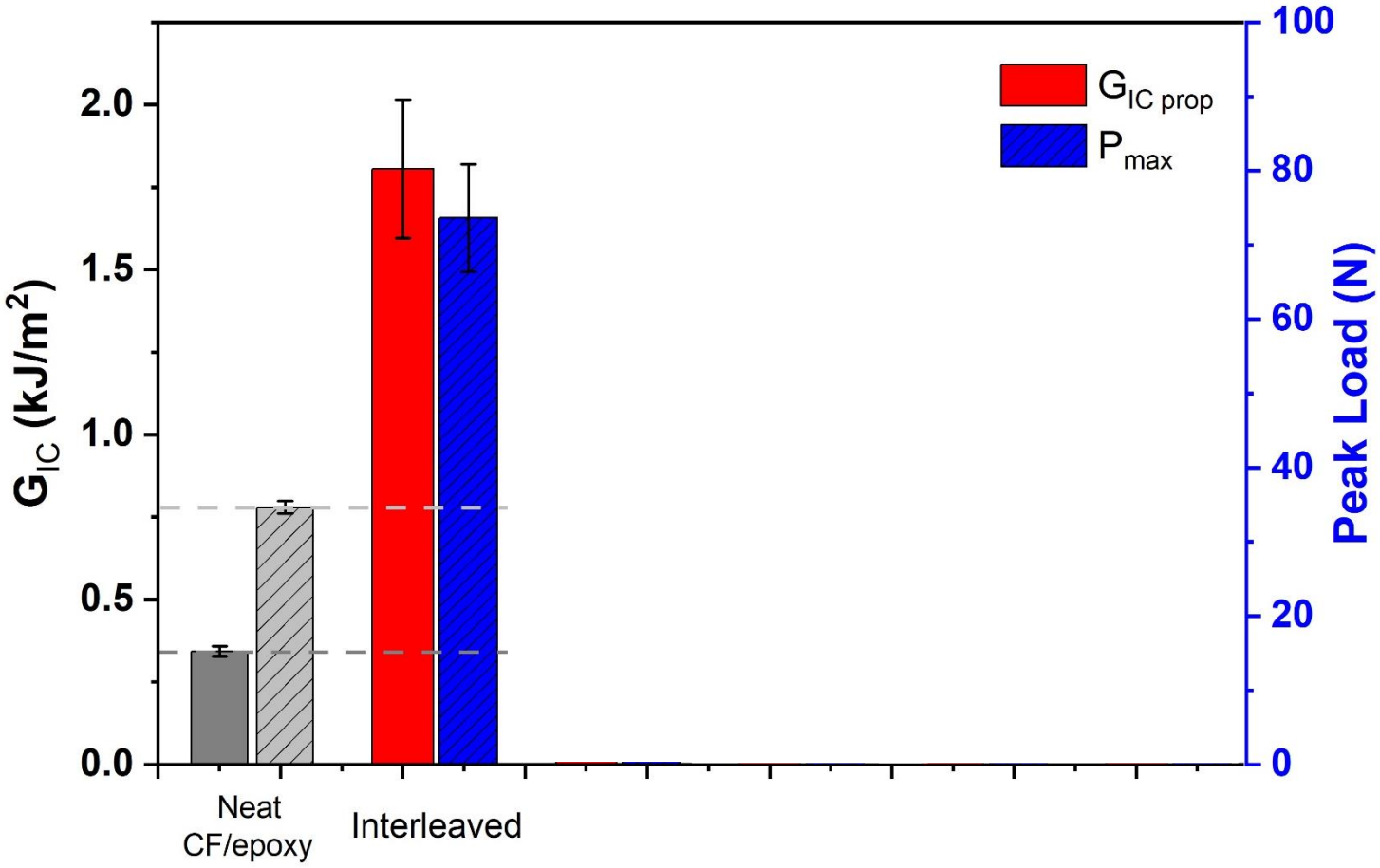
Initial Fracture Toughness

430% ↑ Toughness

(0.34 kJ/m² → 1.81 kJ/m²)

110% ↑ Maximum Load

(34.7 N → 72.9 N)



Toughening & Repair

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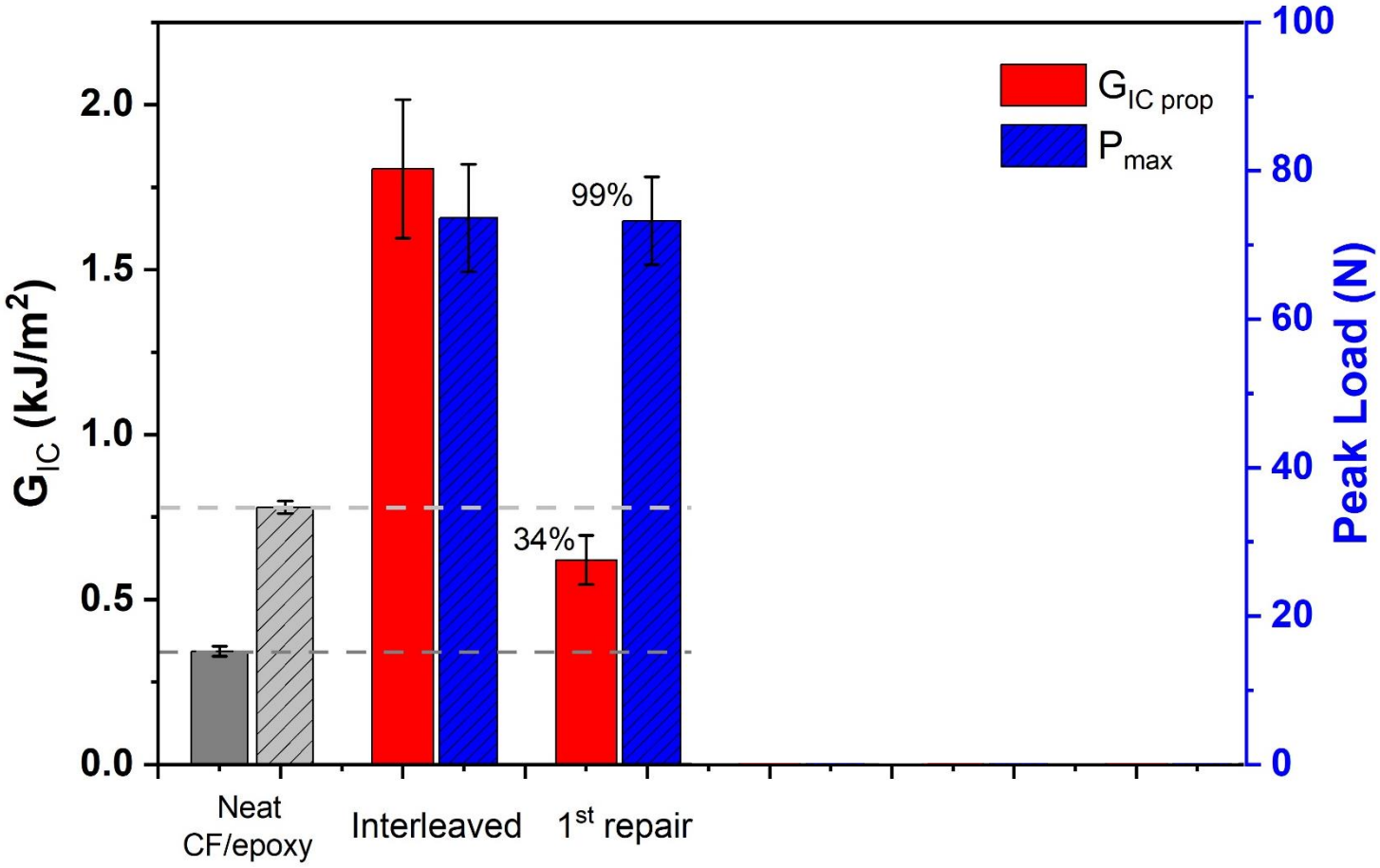
After 1st Repair

Repaired but with Reduced Toughness

No Change to Maximum Load

Outperforming Reference



Toughening & Repair

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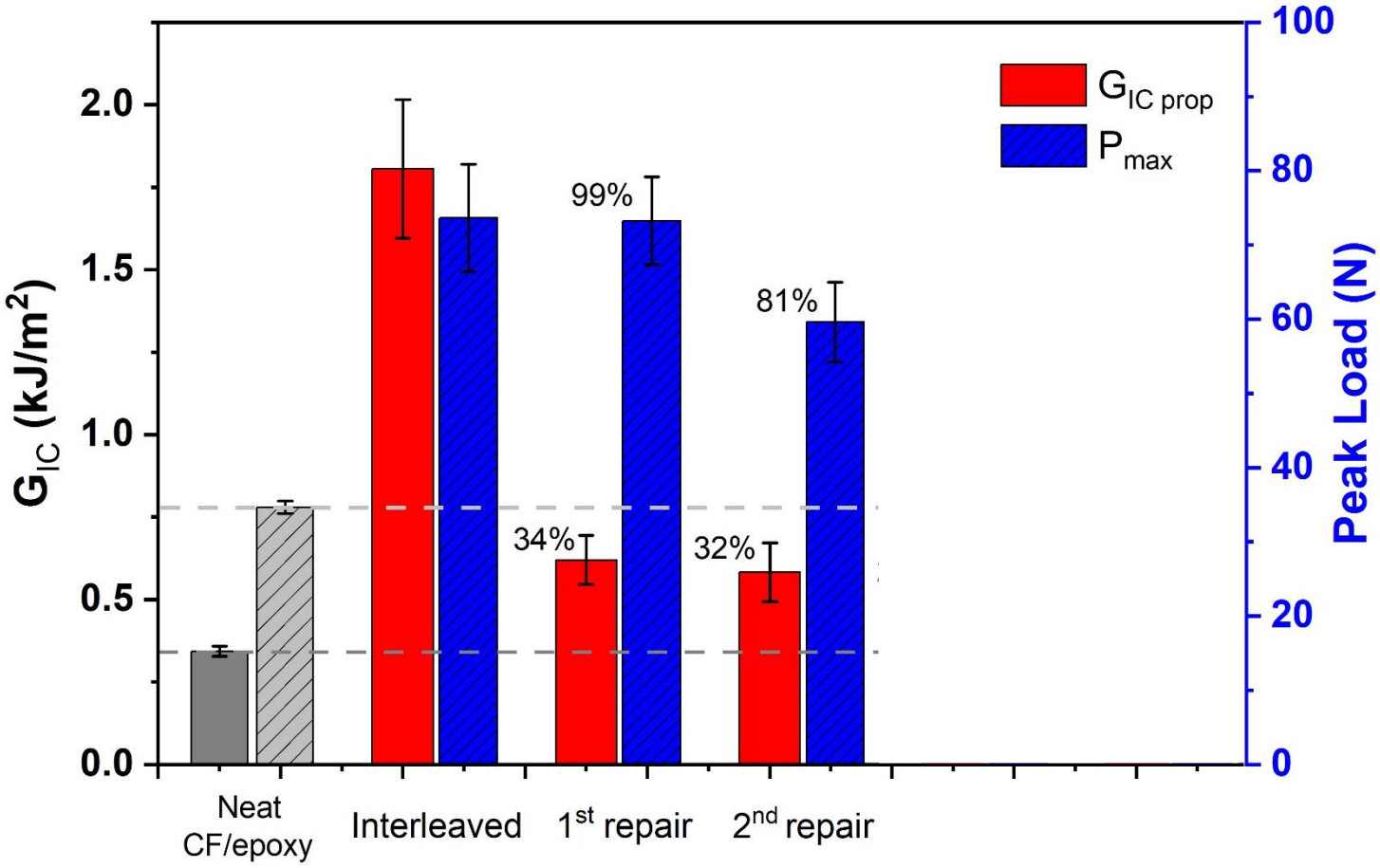
After 2nd Repair

Stabilised Toughness

Slight Loss of Peak Load



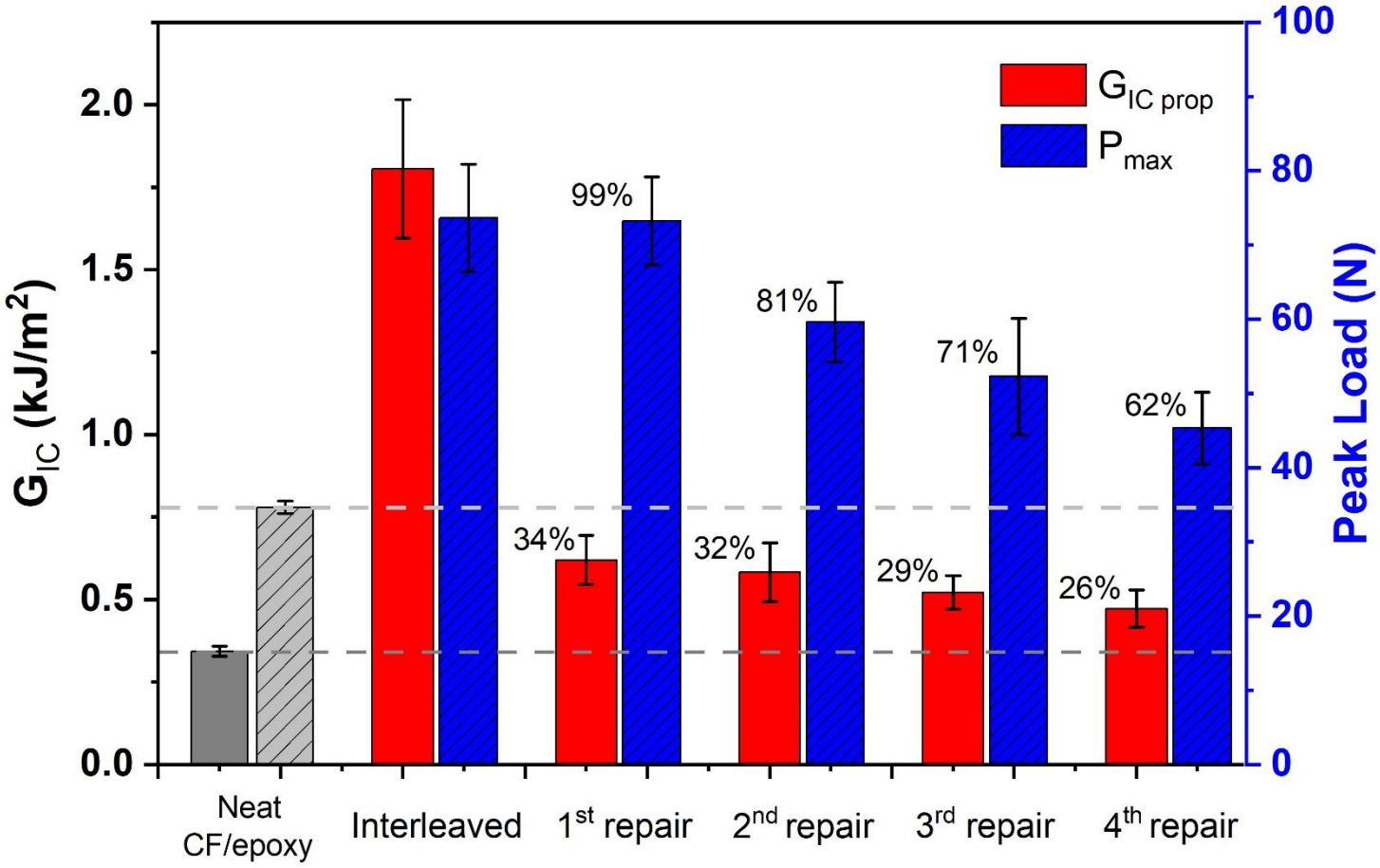
Toughening & Repair

Queen Mary University of London

3rd & 4th Repairing…

Small Declines in Toughness

Steady Decline in P_{max}



Characterization

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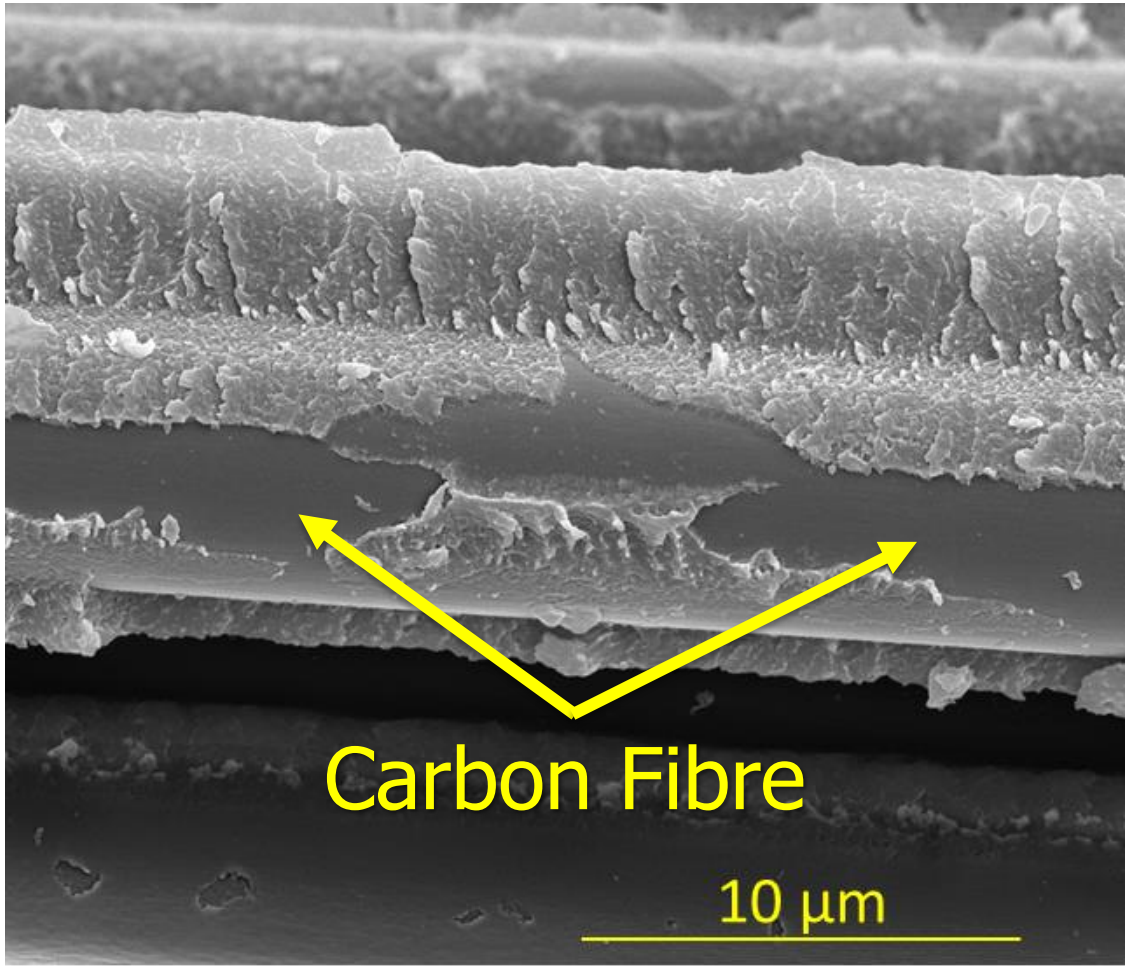
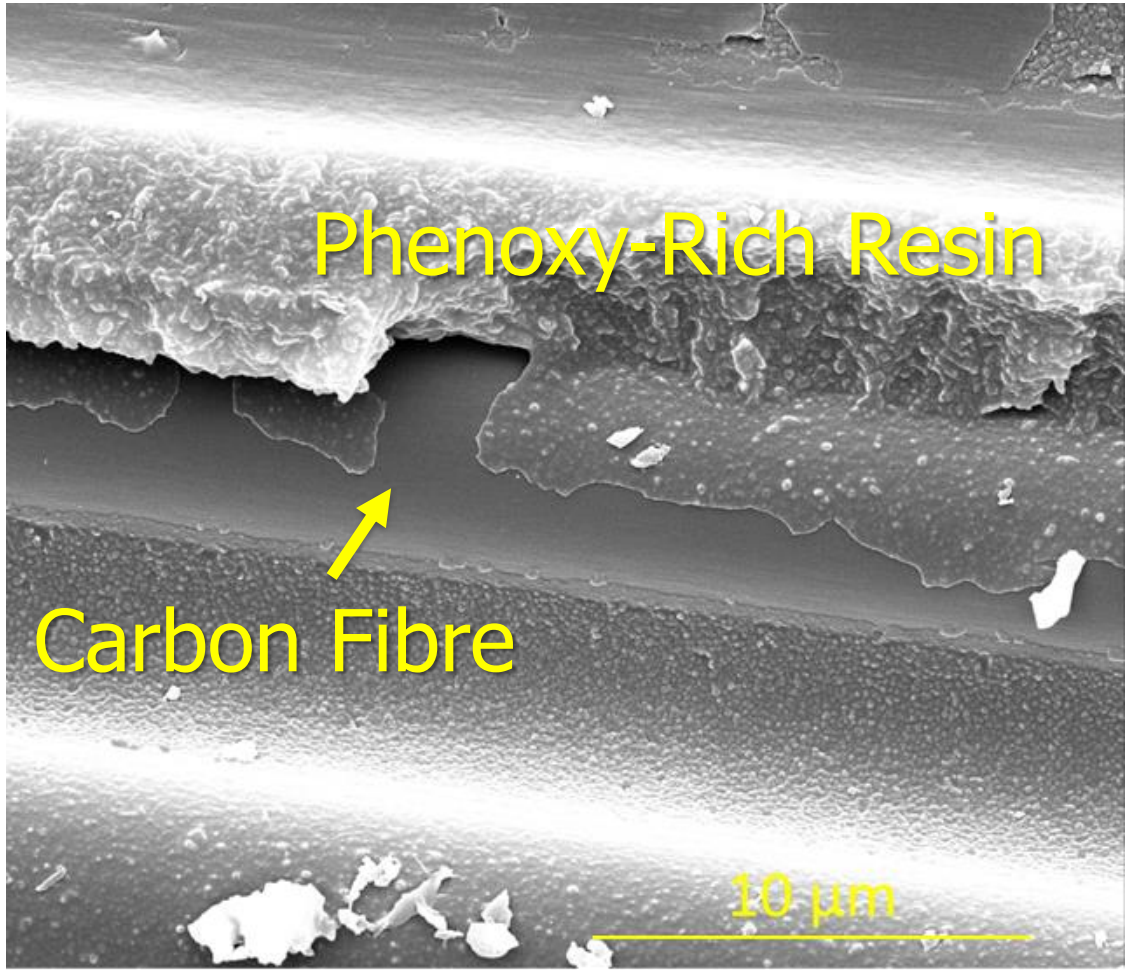
After 1st Fracture



After 5th Fracture



Characterization

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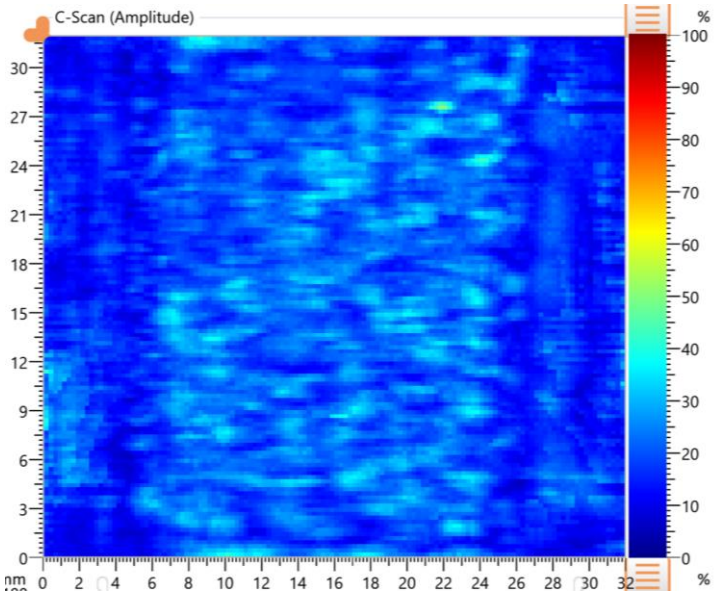
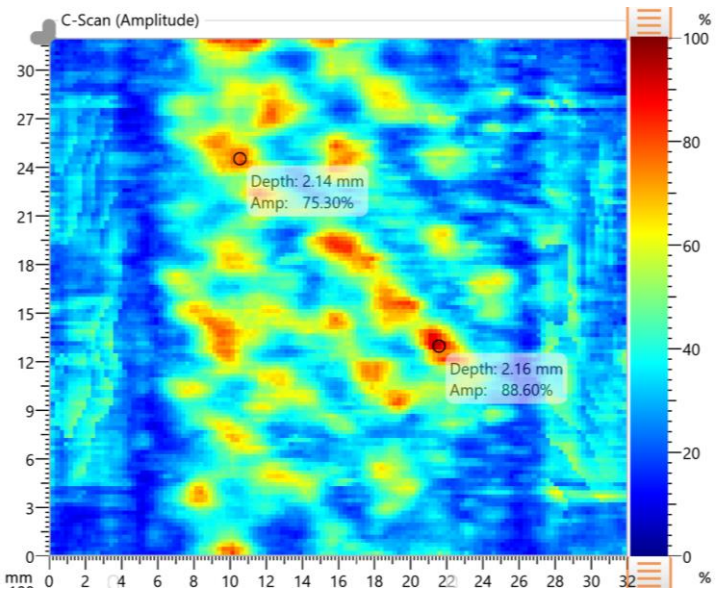
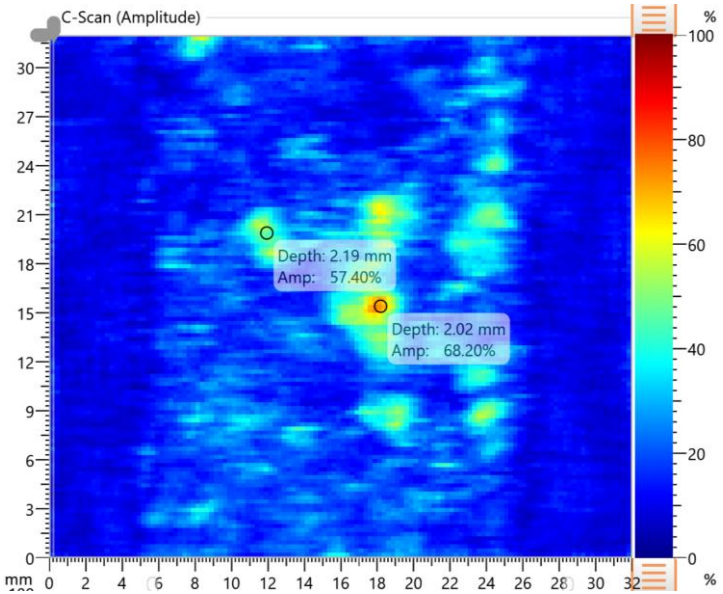
Pristine Laminate



After Fracture / Before Repair



After Repair



Optimizing Service Life

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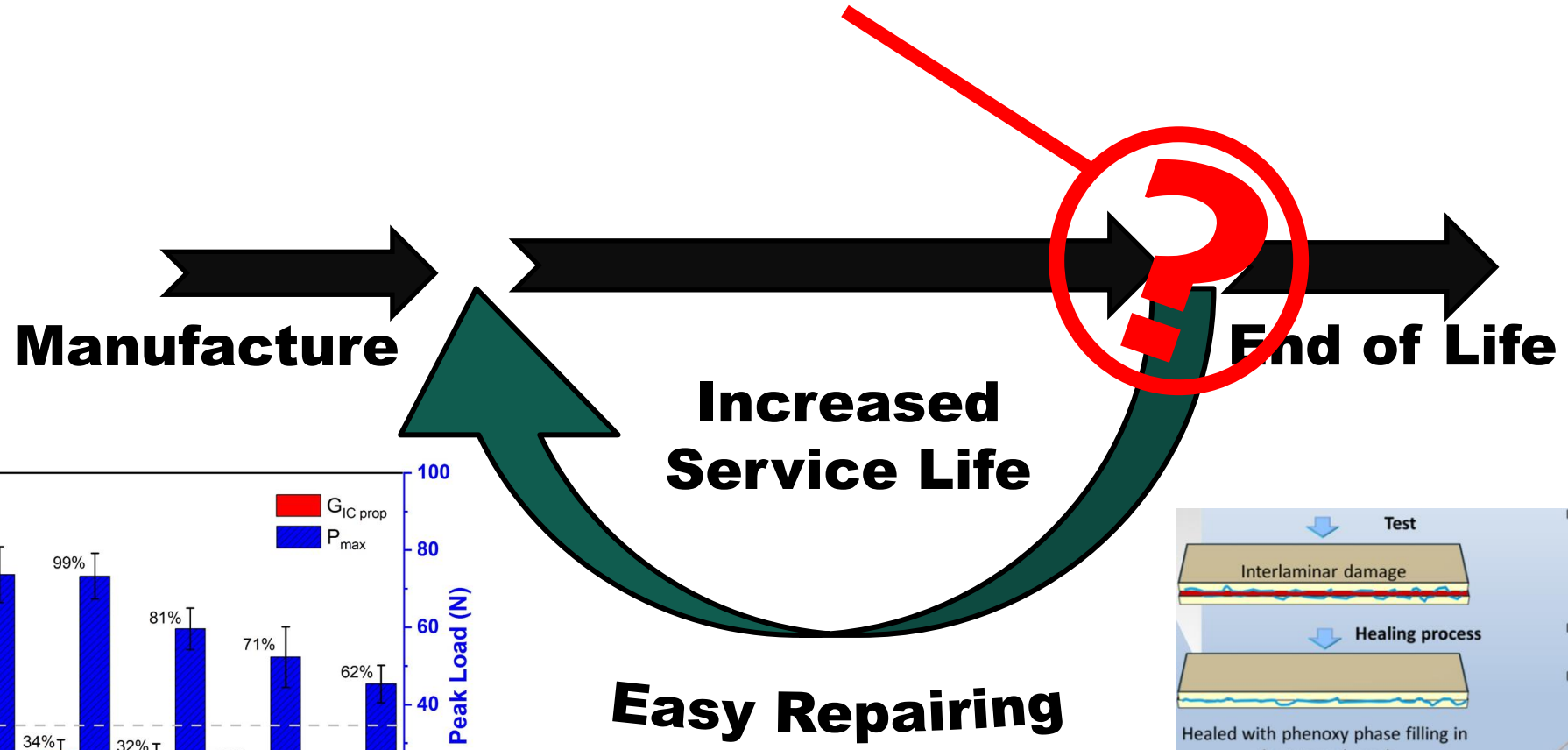
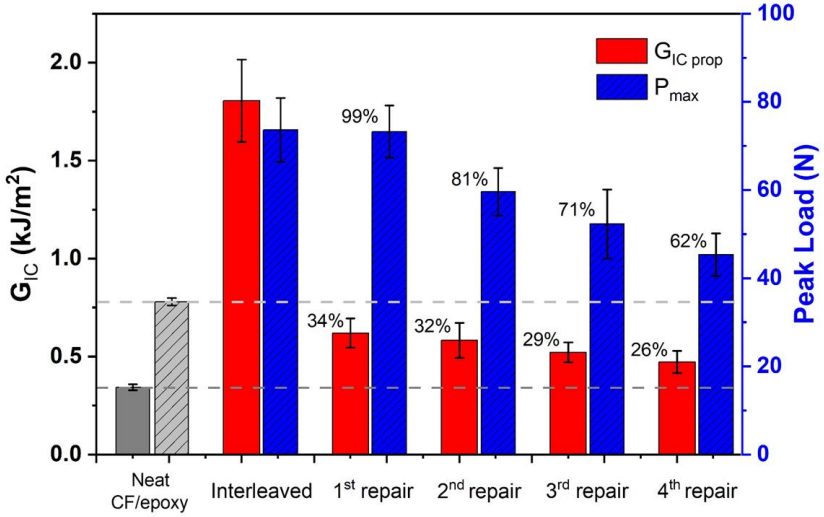
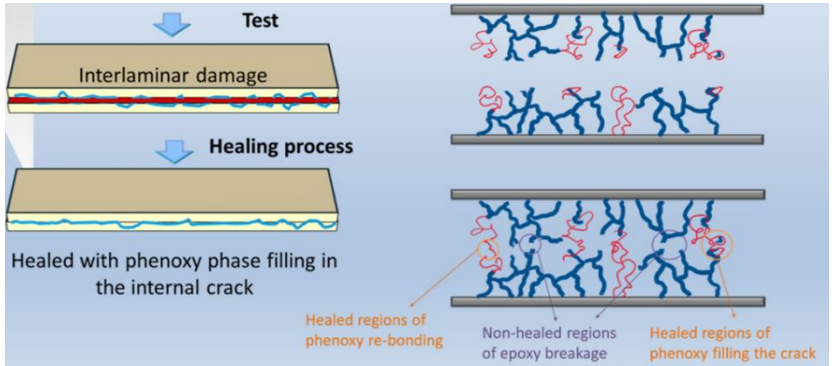
When to Repair?

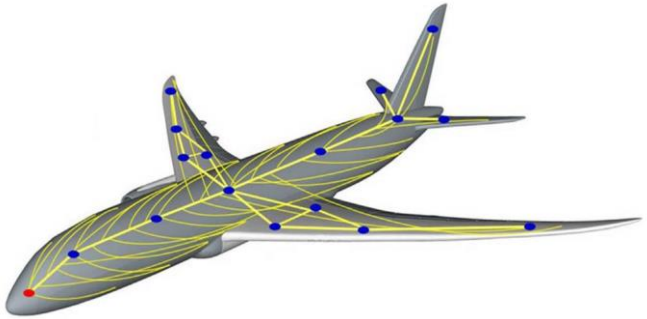


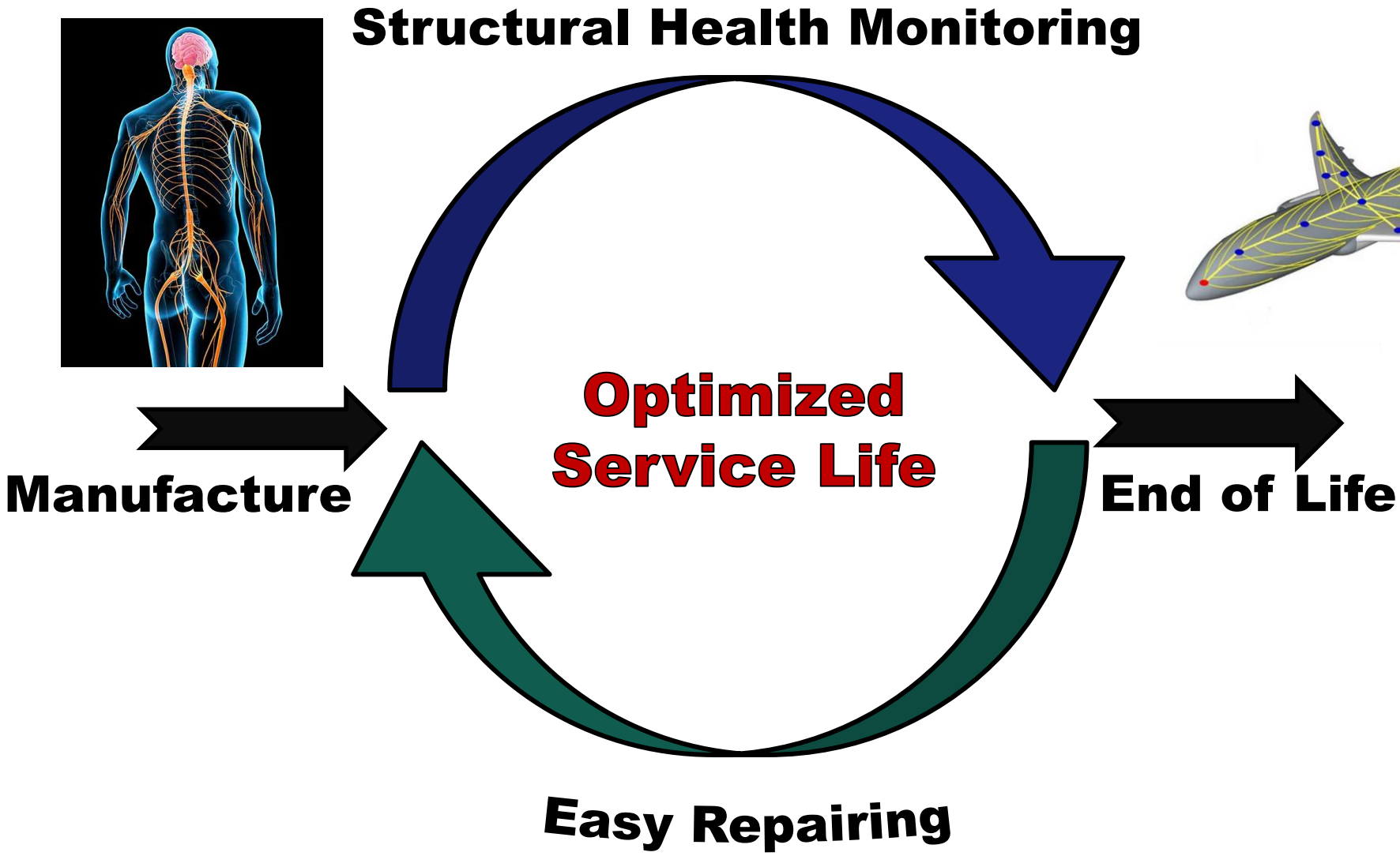




Zhang H, Bilotti E, Peijs T. The use of carbon nanotubes for damage sensing and structural health monitoring in laminated composites: a review. Nanocomposites. 2015 Oct 2;1(4):167-84.

Optimizing Service Life





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Structural Health Monitoring

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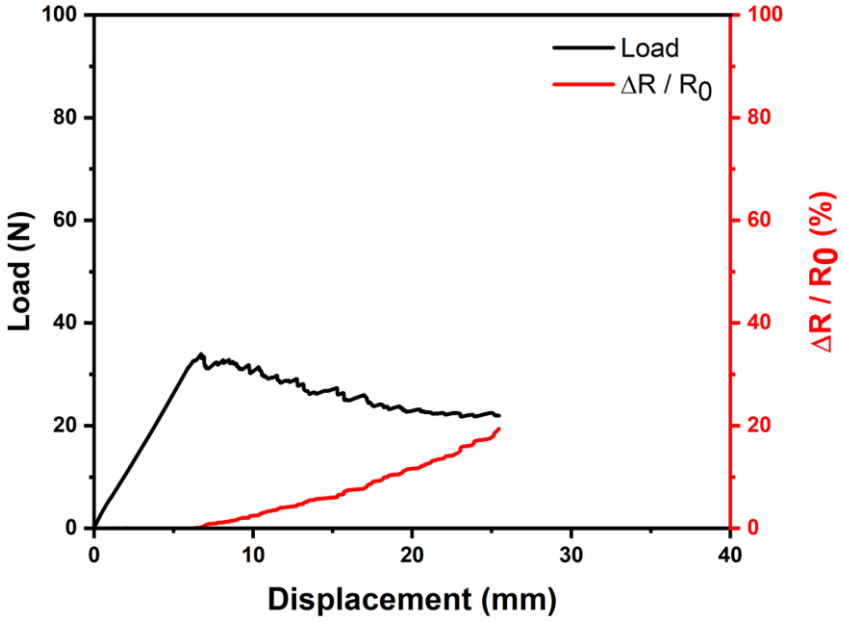
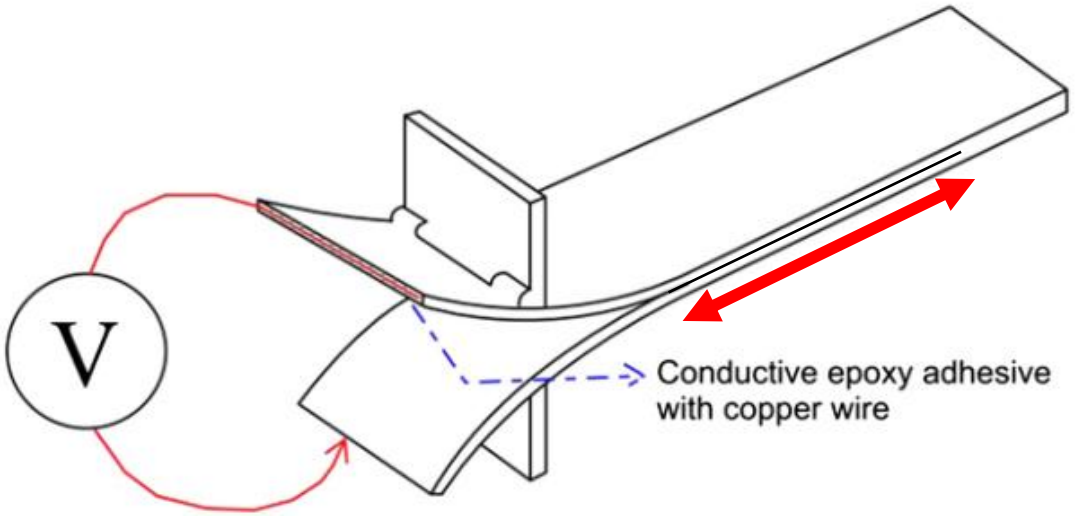
Measure through-thickness Resistance during Fracture



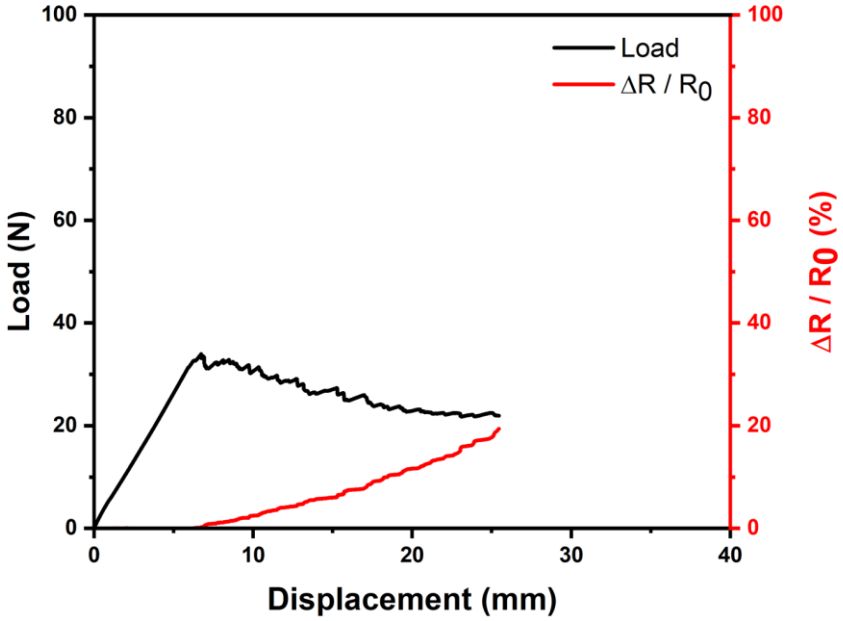


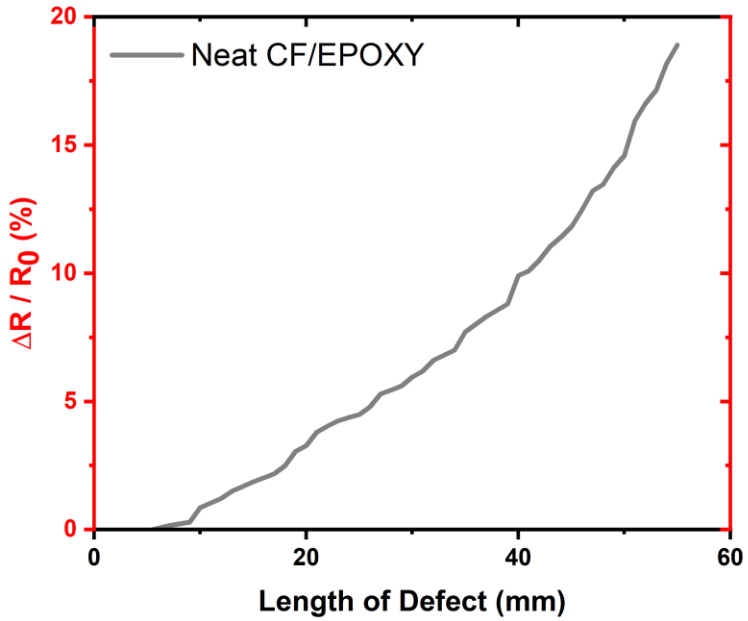
Carbon/Epoxy

Structural Health Monitoring

Queen Mary University of London

Measure through-thickness Resistance during Fracture





Carbon/Epoxy

Structural Health Monitoring

Queen Mary University of London

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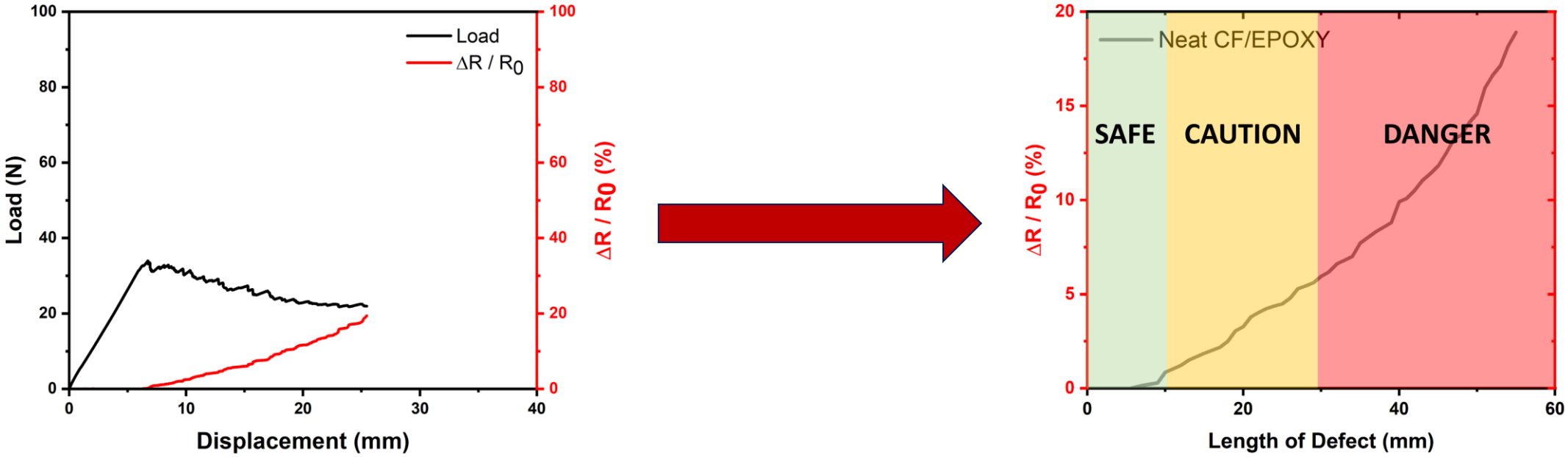

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Structural Health Monitoring

Queen Mary University of London

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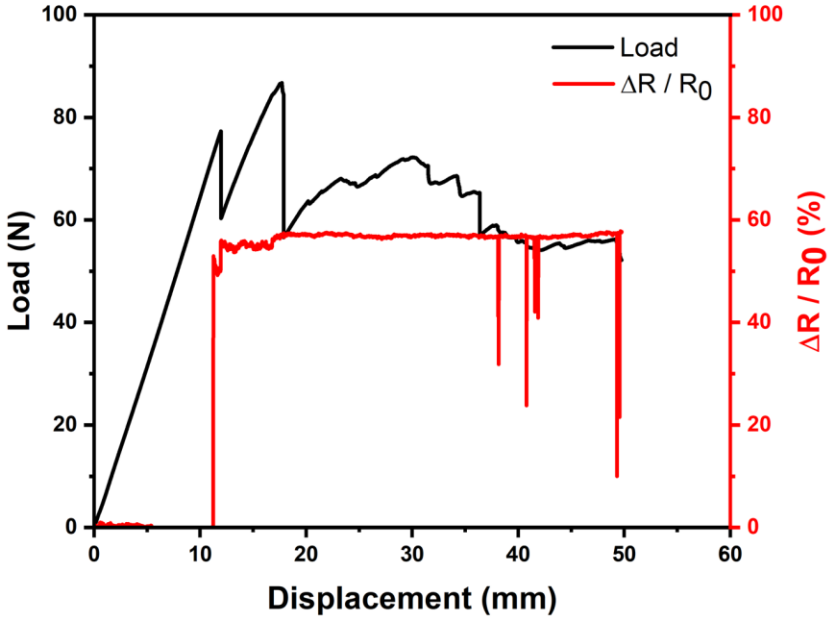
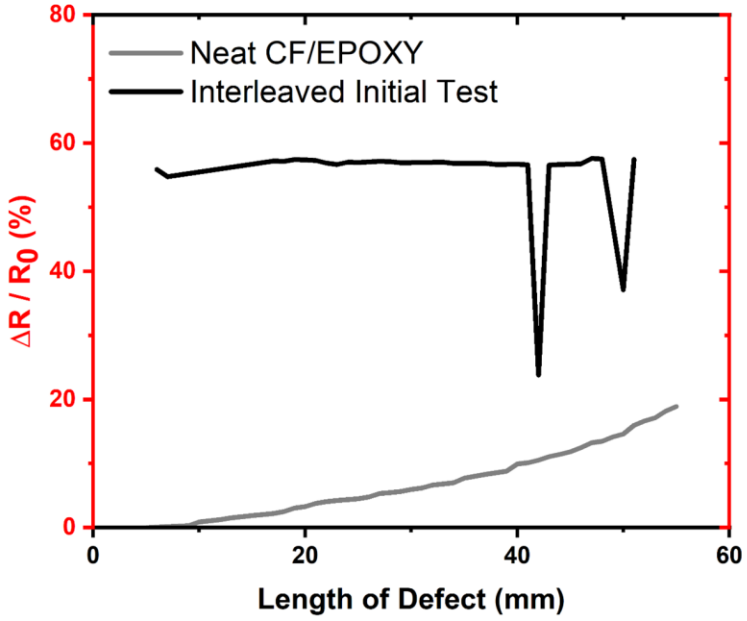




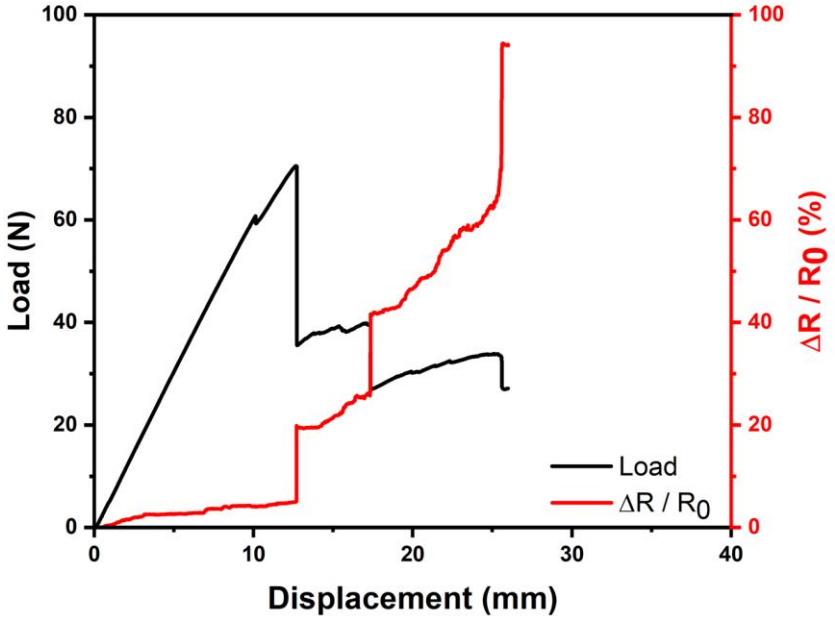
Phenoxy Interleaved

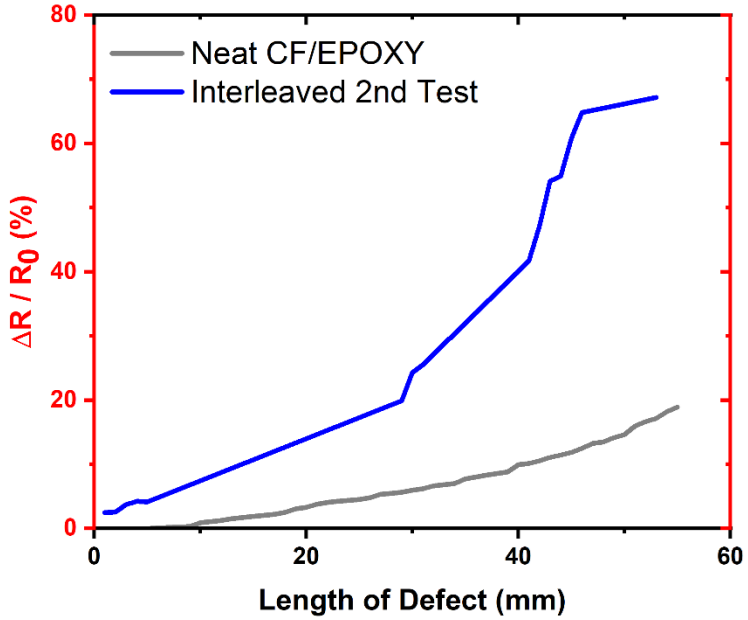
1st fracture

Structural Health Monitoring

Queen Mary University of London

Measure through-thickness Resistance during Fracture





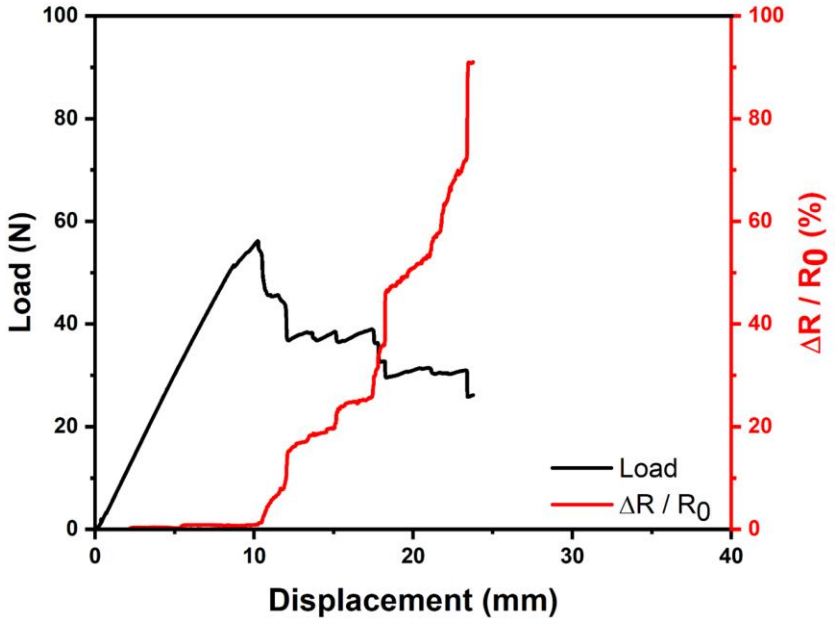
Phenoxy Interleaved

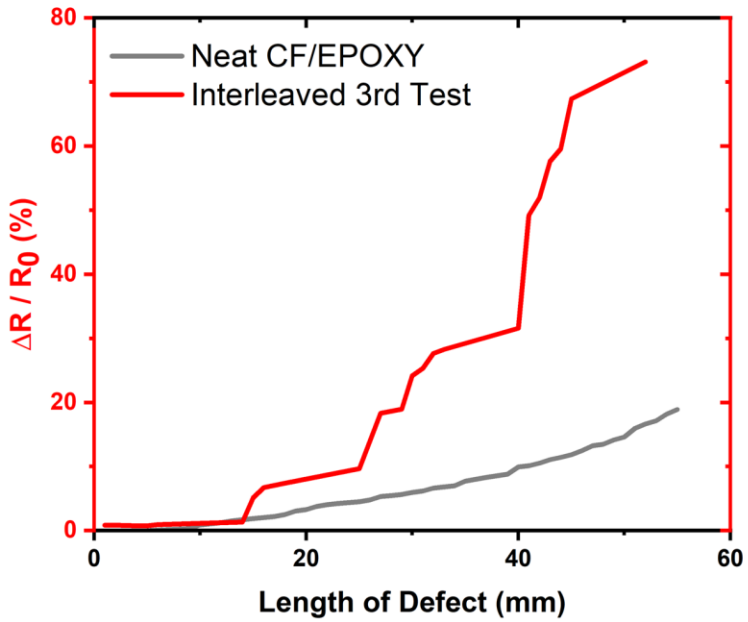
2nd fracture

Structural Health Monitoring

Queen Mary University of London

Measure through-thickness Resistance during Fracture





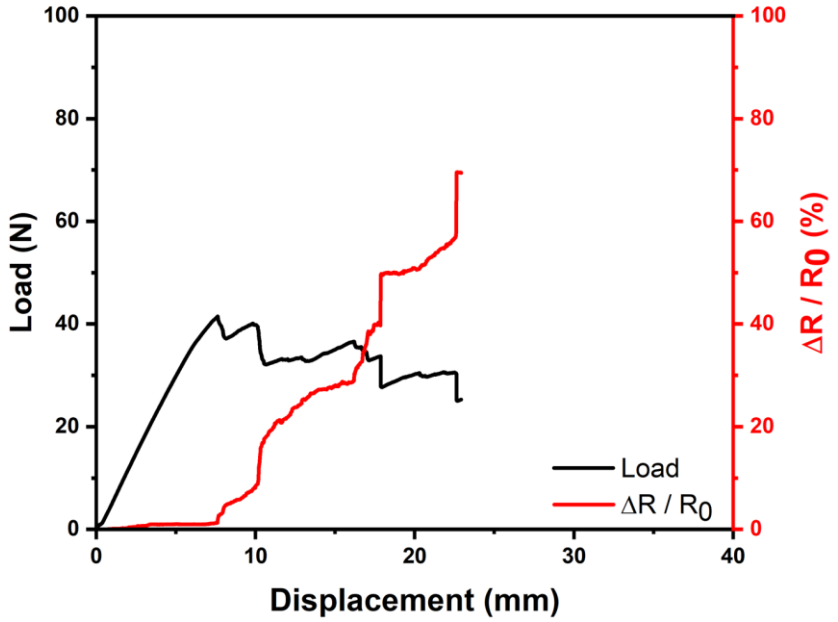
Phenoxy Interleaved

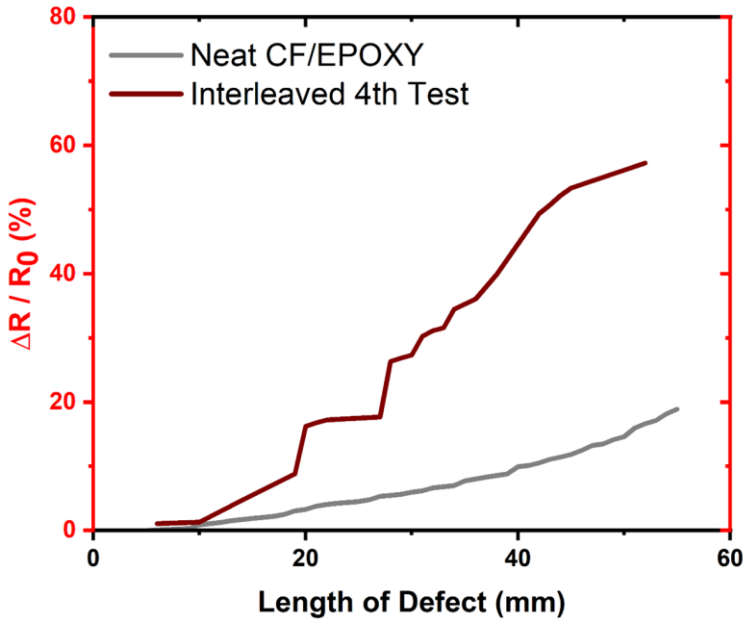
3rd fracture

Structural Health Monitoring

Queen Mary University of London

Measure through-thickness Resistance during Fracture





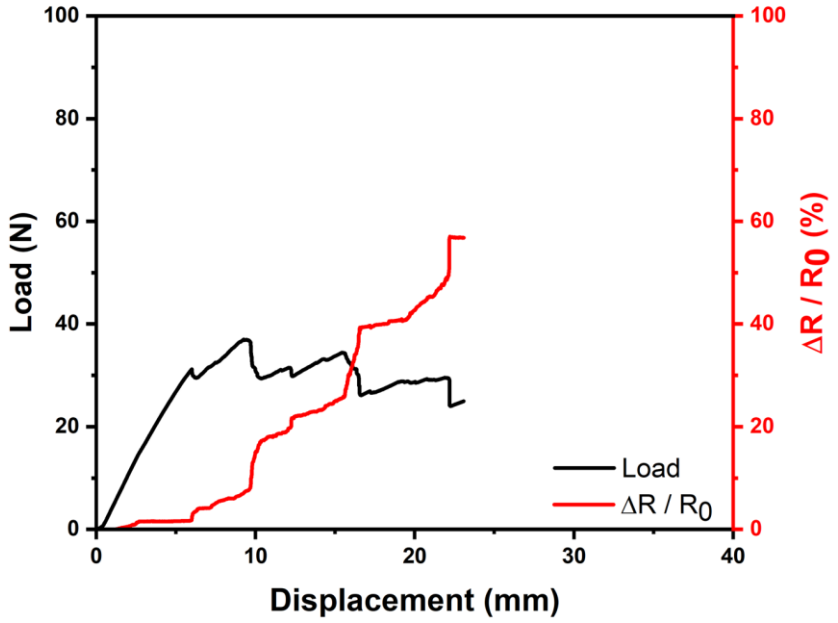
Phenoxy Interleaved

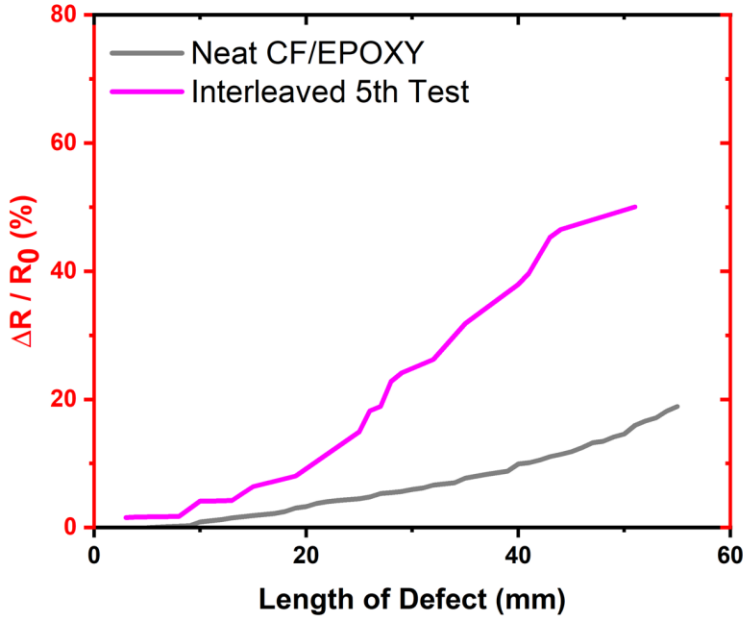
4th fracture

Structural Health Monitoring

Queen Mary University of London

Measure through-thickness Resistance during Fracture





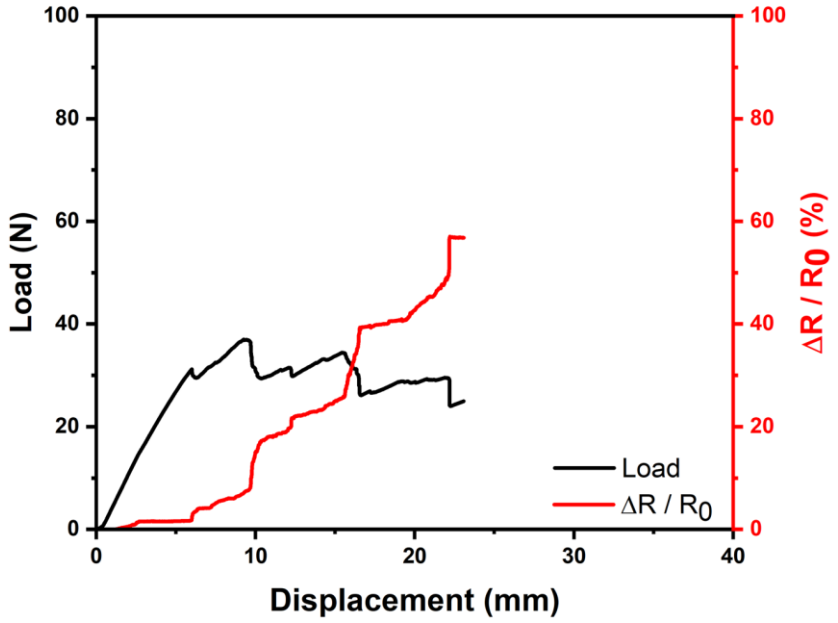
Phenoxy Interleaved

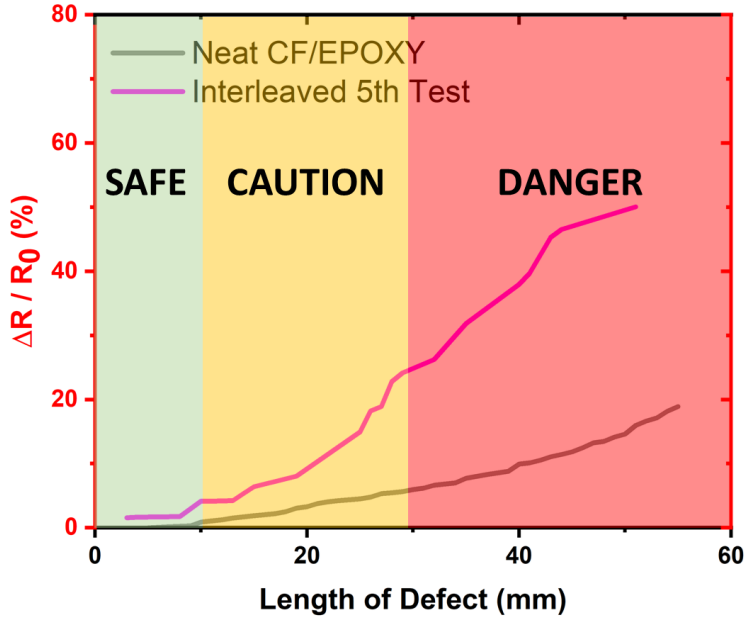
5th fracture

Structural Health Monitoring

Queen Mary University of London

Measure through-thickness Resistance during Fracture



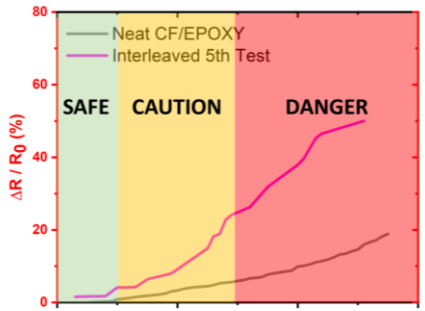


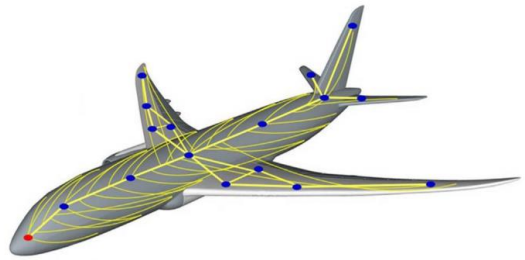
Phenoxy Interleaved

5th fracture

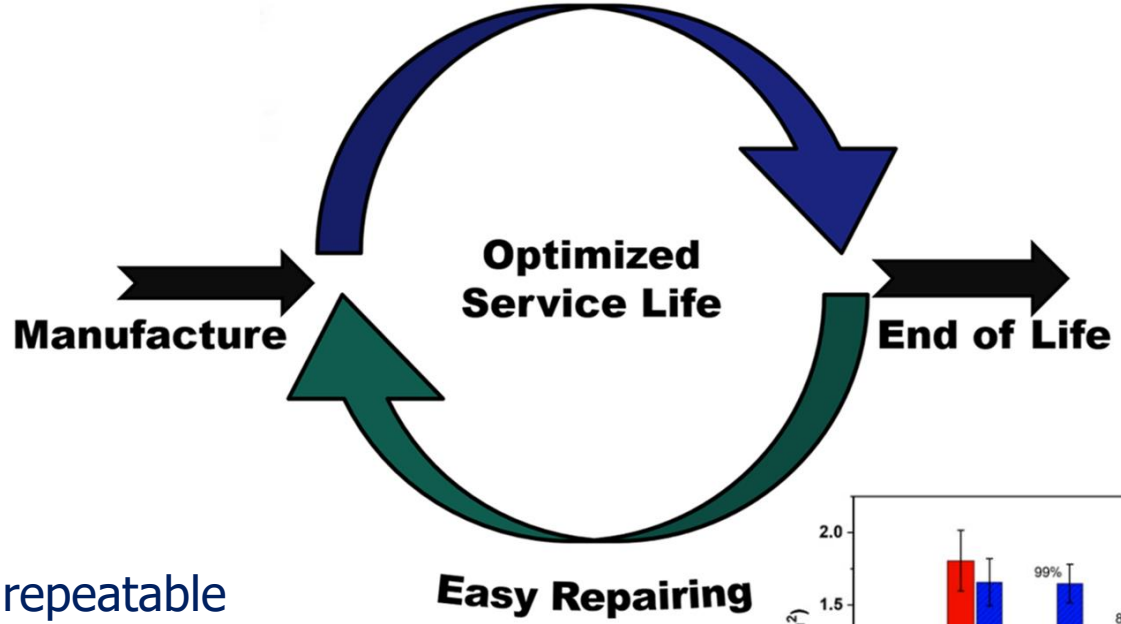
Summary

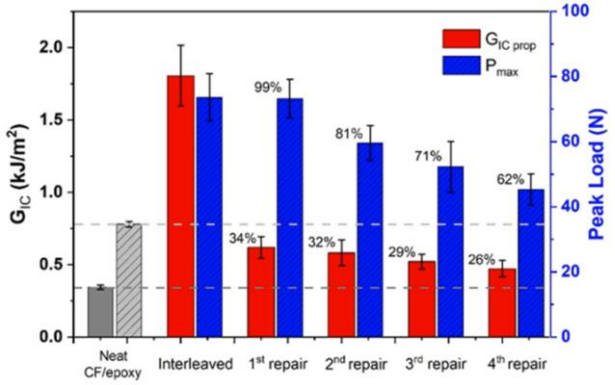
- Repeatably repairable composite demonstrated
- Potential to detect damage after repairing
- Optimizing service life in toughened components





Structural Health Monitoring





Read our open access paper: "Smart and repeatable easy-repairing and self-sensing composites with enhanced mechanical performance for extended components life" **Composites Part A**
https://doi.org/10.1016/j.compositesa.2022.107337

Acknowledgements

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Dr Dimitrios Papageorgiou

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Loughborough University

Professor Ton Peijs

WMG
THE UNIVERSITY OF WARWICK