

ARRESTING PROPAGATING KINKBANDS: FAILURE MECHANISMS UNDER LONGITUDINAL COMPRESSION OF CARBON-BORON FIBRE HYBRIDS

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<http://tinyurl/pinholab>



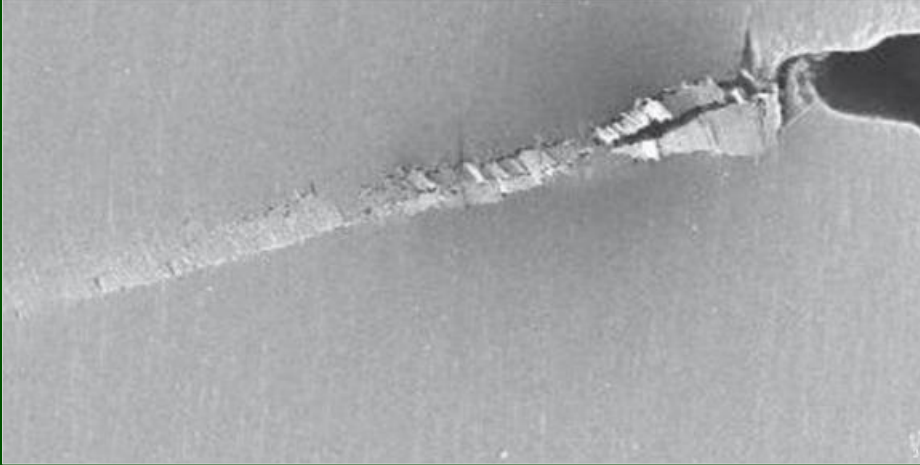
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The Composites Centre
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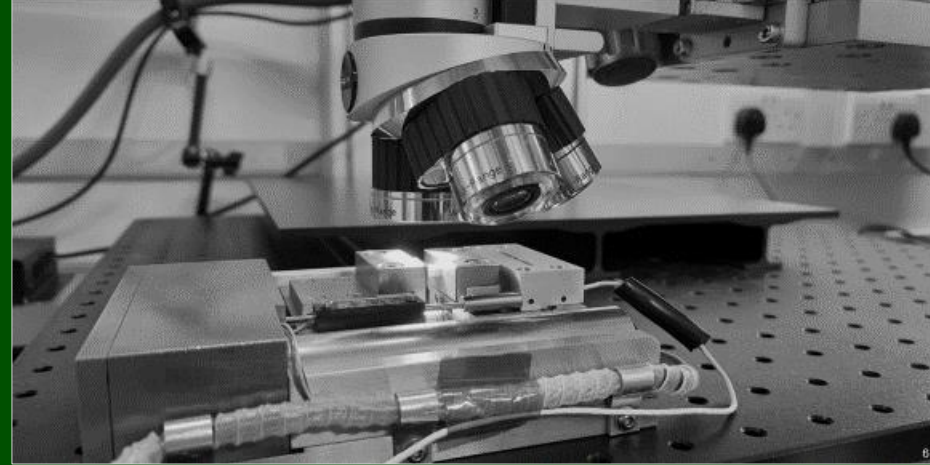


Outline

Background and motivation



Manufacturing and testing



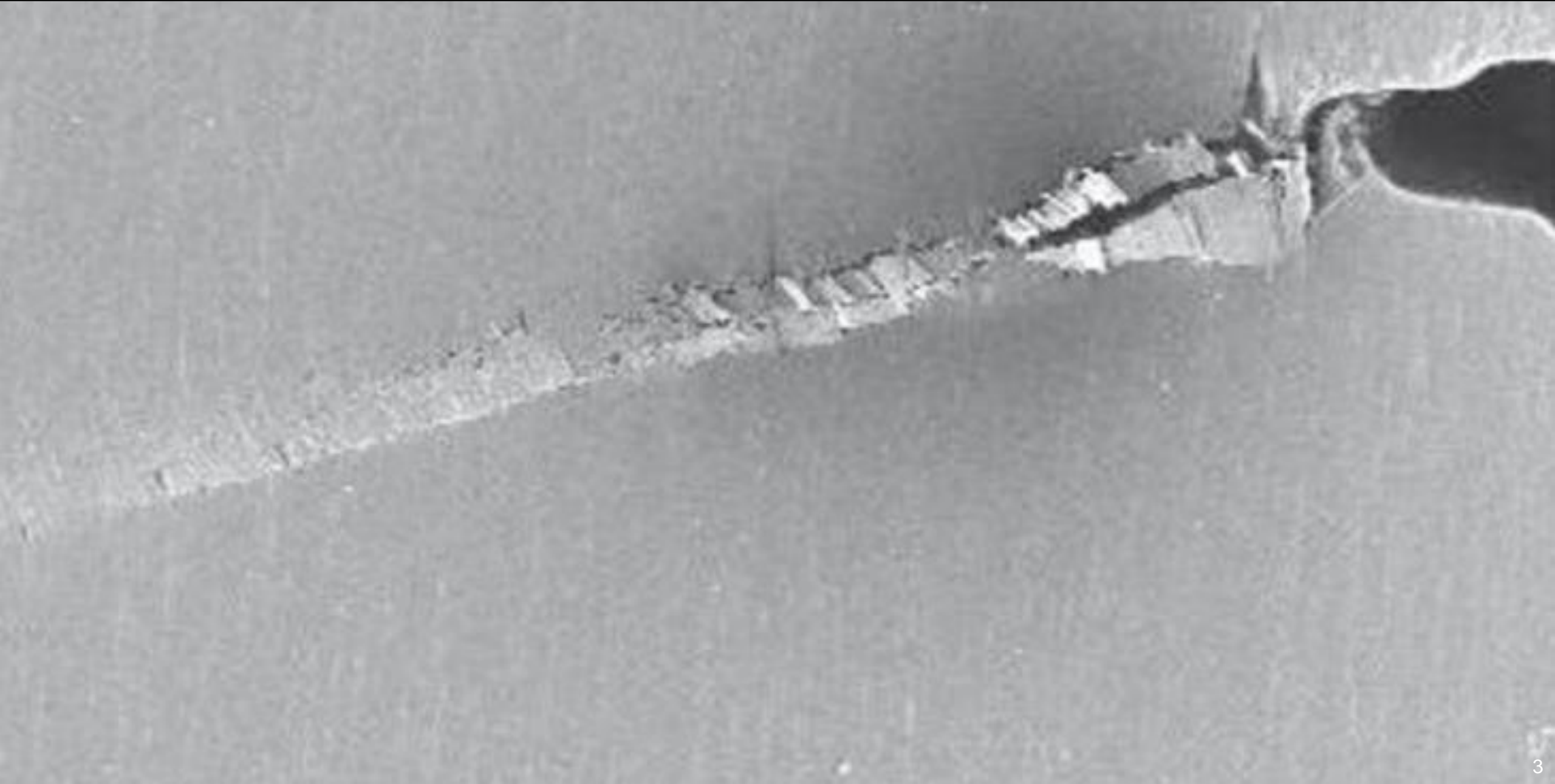
Results



Conclusions and prospects

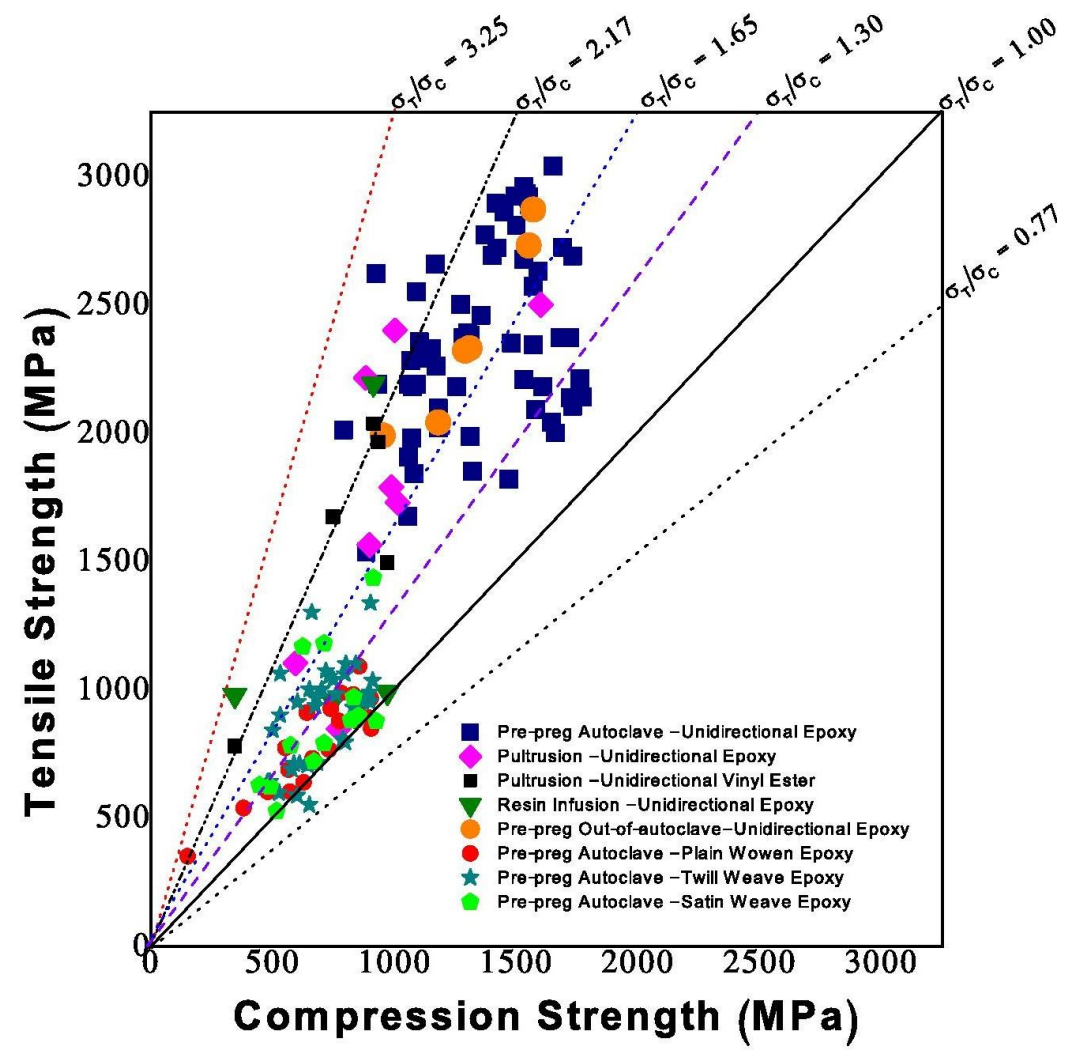


Background and motivation



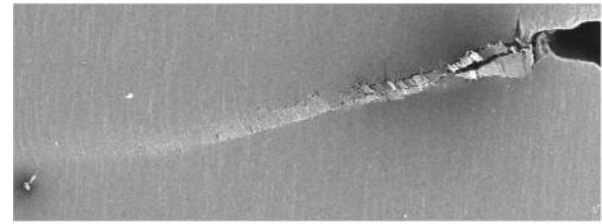
Why compression?

Longitudinal compressive strength is a weakness

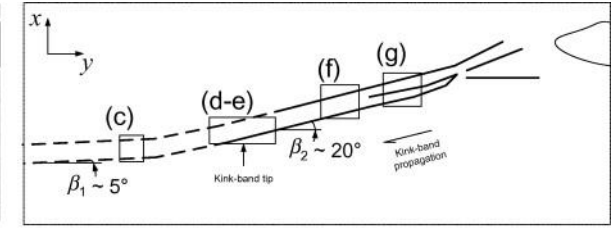


[📖 S. Nunna et al. 2022]

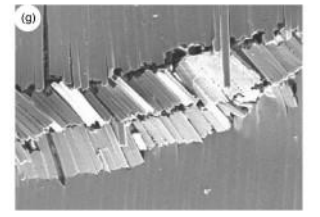
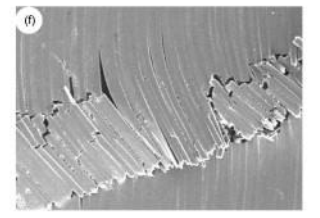
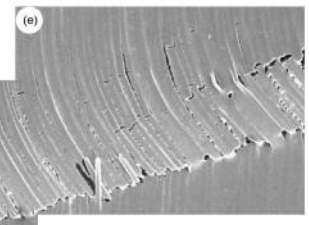
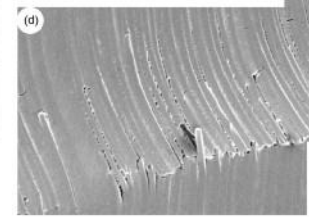
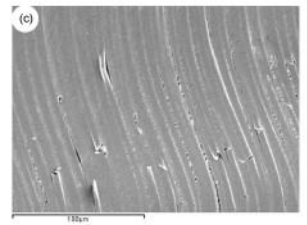
Most CFRPs fail by kinkband formation



(a) Overall view of damage close to the notch



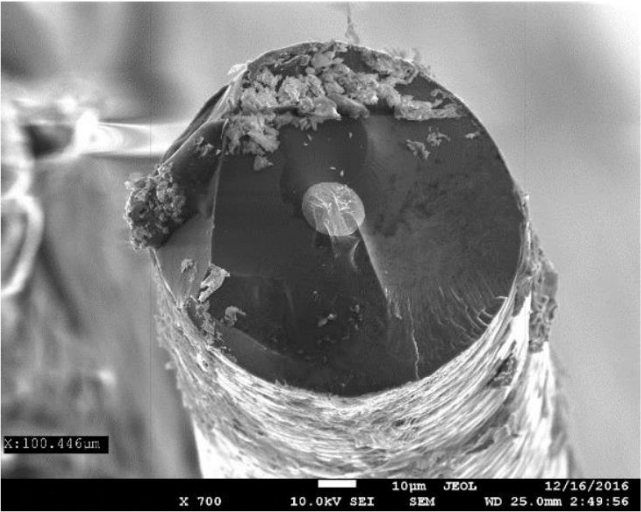
(b) Key to location for micrographs (c) to (g)



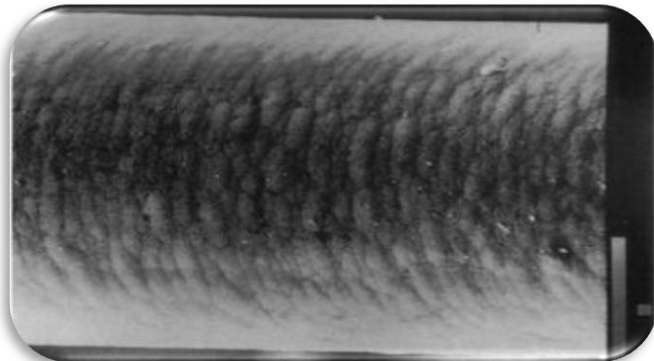
[📖 Gutkin et al. 2010]

Why boron fibre?

What is boron fibre?



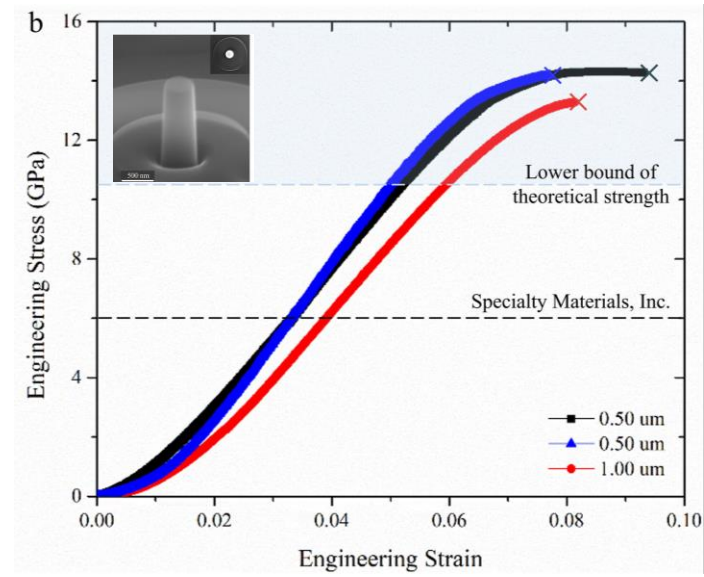
[Heredia & Banerjee, 2016]



[Courtesy of Specialty Materials Inc.]

Performance

- Unmatched performance:
 - Boron/epoxy $X_c = 2930$ MPa
 - Boron micropillar compression:

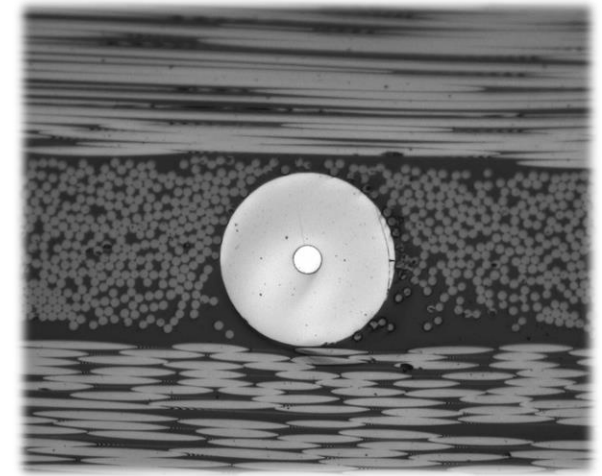


[Maita et al. 2020]

- Lack of studies on compressive failure mechanisms

Hybridization

- Opportunity for:
 - Higher performance than CFRP
 - Lower cost than boron alone



- UD boron/carbon fibre hybrids are commercially available
- Lack of studies on compressive failure mechanisms

Manufacturing and testing



Materials and manufacturing

Materials used

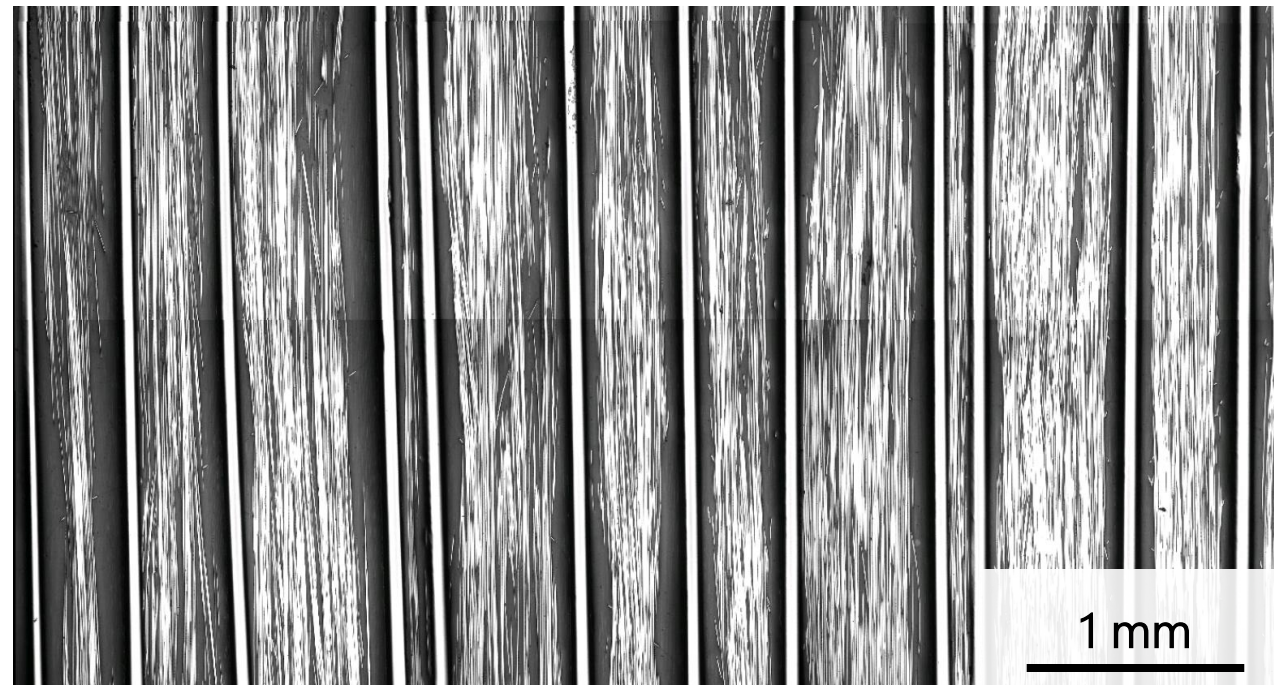
- HyBor (52 FPI)
 - Boron fibre ~102 μm , 43 gsm
 - T1100G carbon fibre, 75 gsm
 - TC275-1E epoxy, 61 gsm
- IM7/8552

Plate layup:

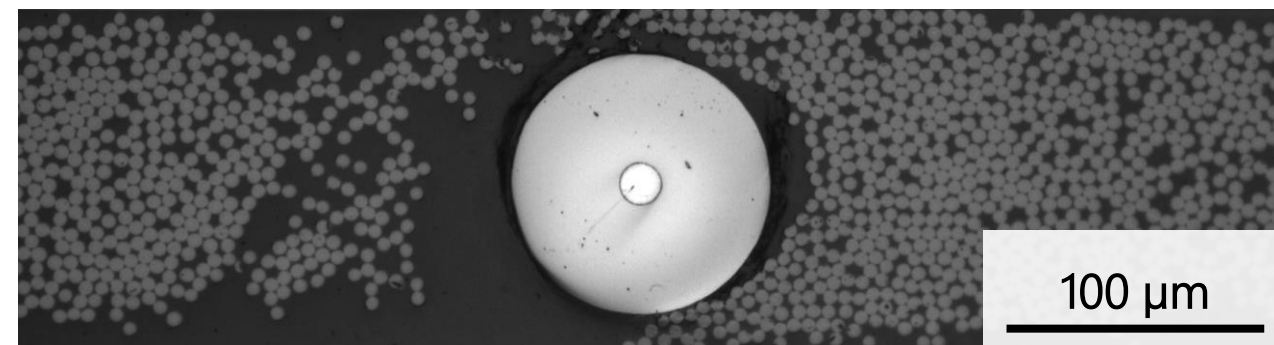
$[90^{\text{IM7/8552}} / 0^{\text{HyBor}} / 90^{\text{IM7/8552}}]_S$

- Failure in HyBor first
- Low failure load
- Possibility to test HyBor:
 - Embedded
 - Exposed (polishing outer 90° ply)

HyBor 52 FPI longitudinal section micrograph

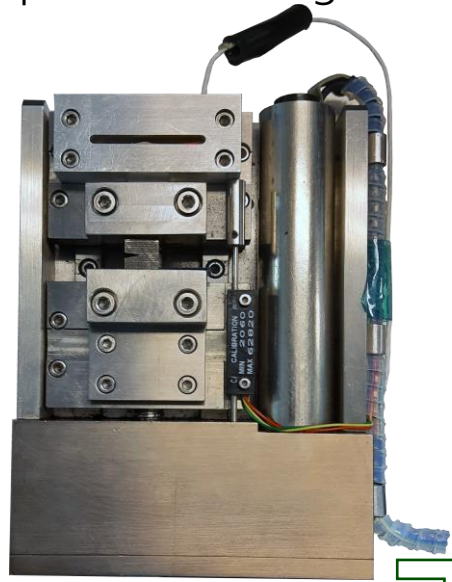


HyBor 52 FPI cross-section micrograph

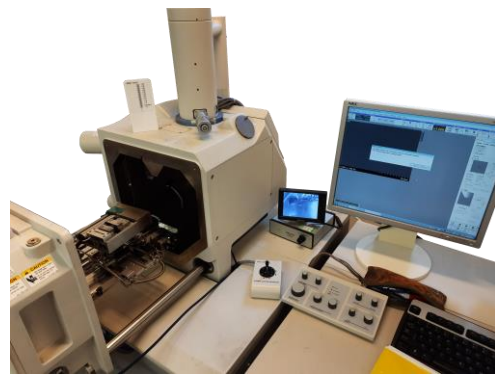


Testing

Tests on small specimens using 5 kN Deben device

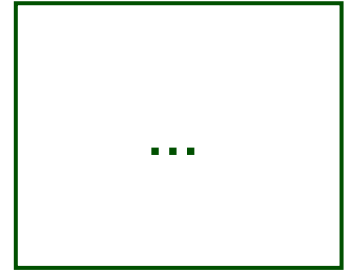
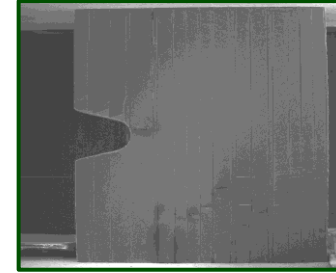
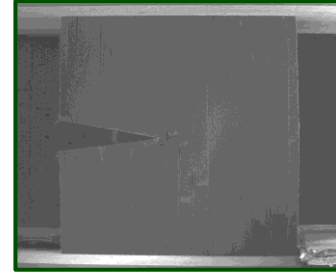


Hirox optical microscope for DIC

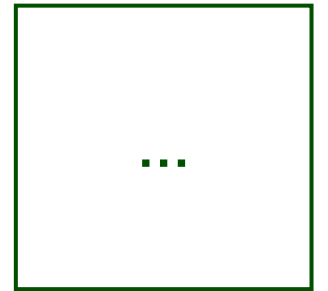
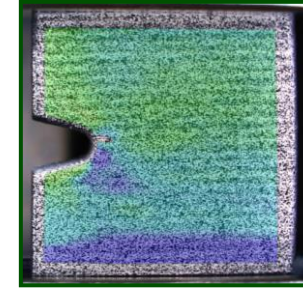
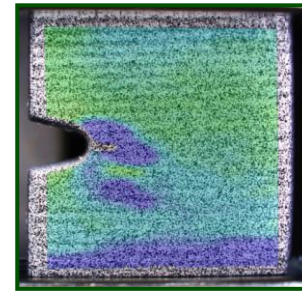


Hitachi SEM for in-situ testing

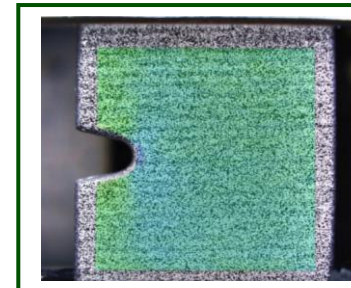
Tested with 90° ply polished away, in-situ SEM



Tested with 90° ply on



Tested initially with 90° ply, then polished + in-situ SEM

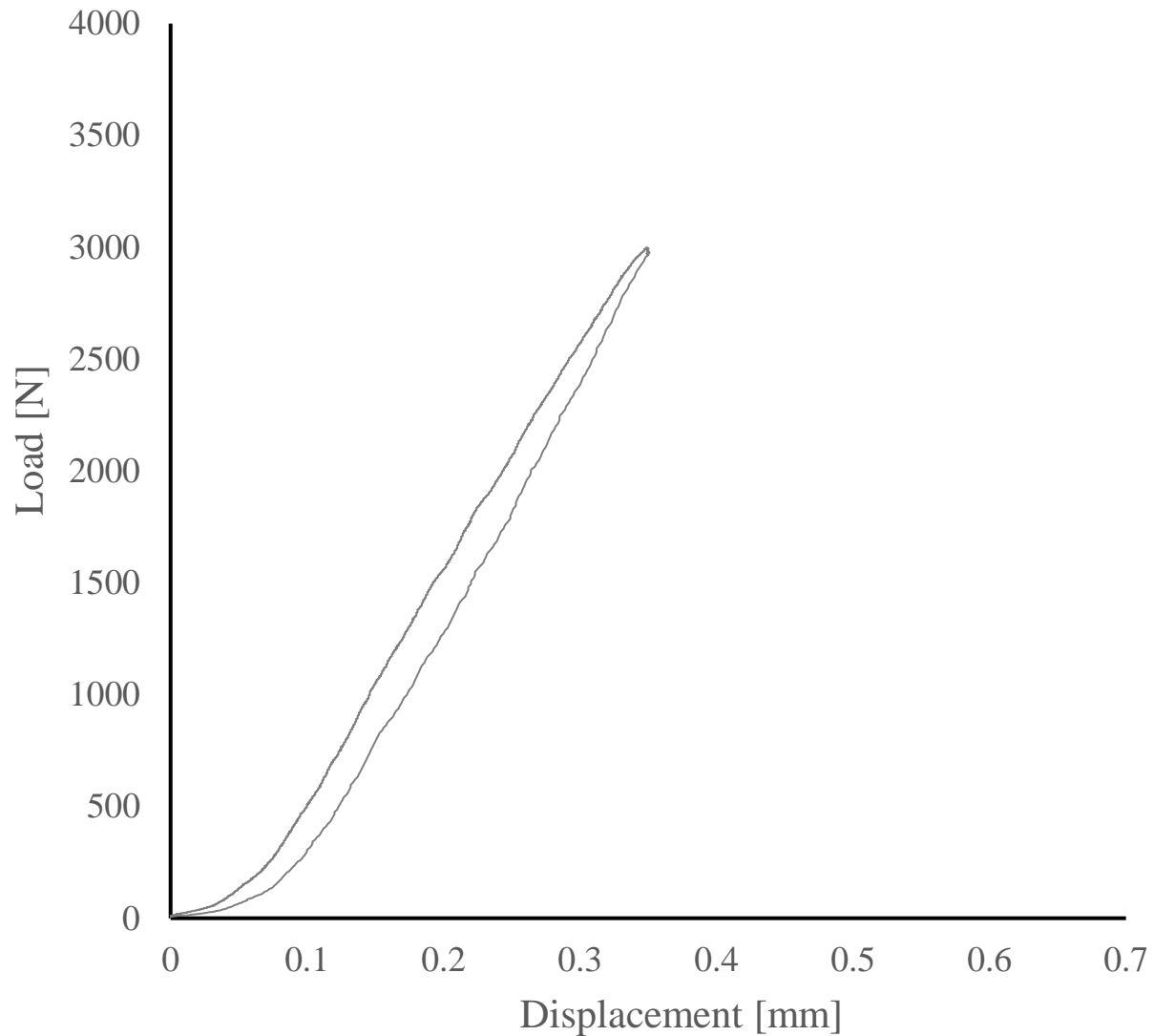


Results

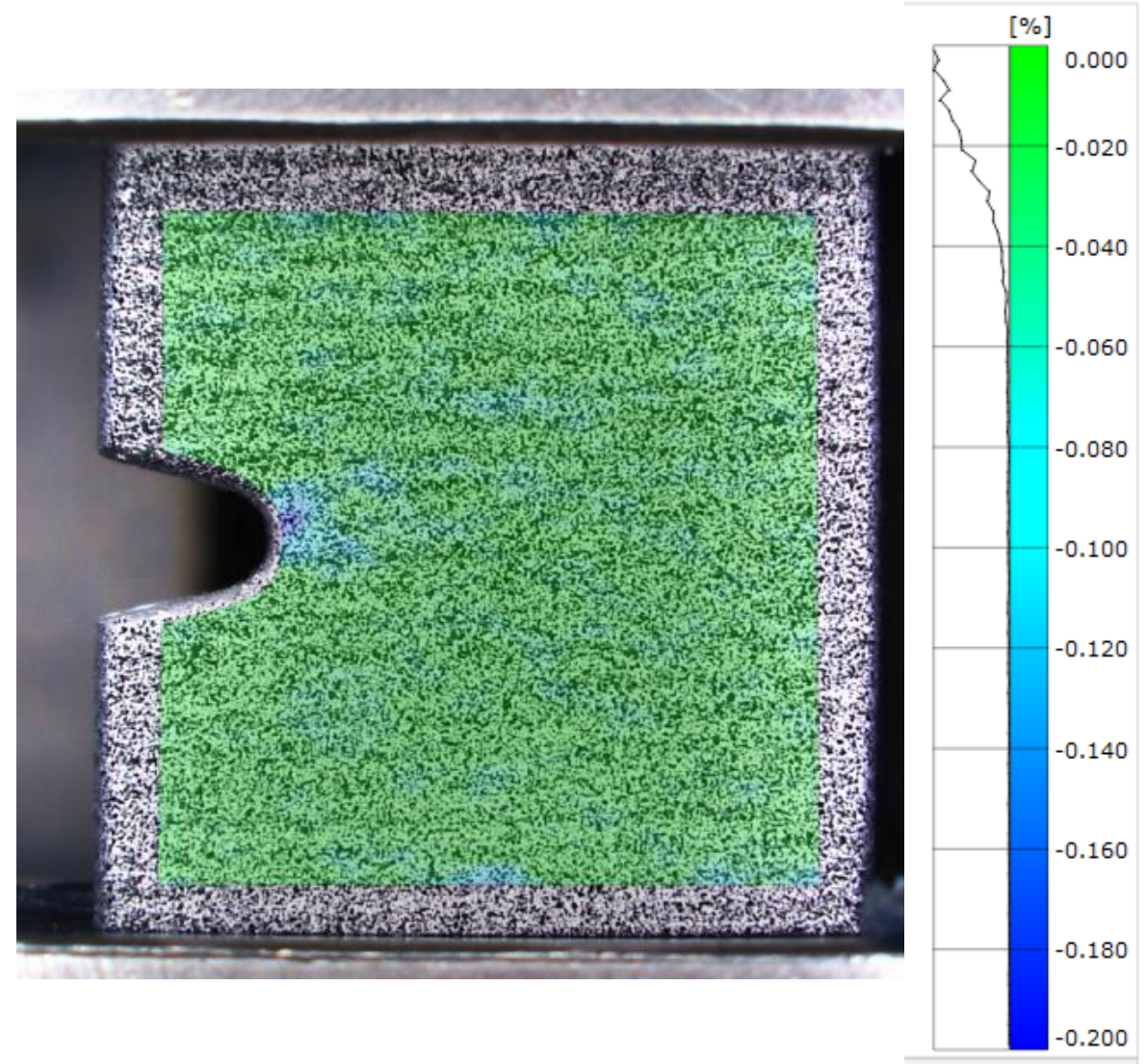


Phase 1: loading with external 90° ply

Load displacement

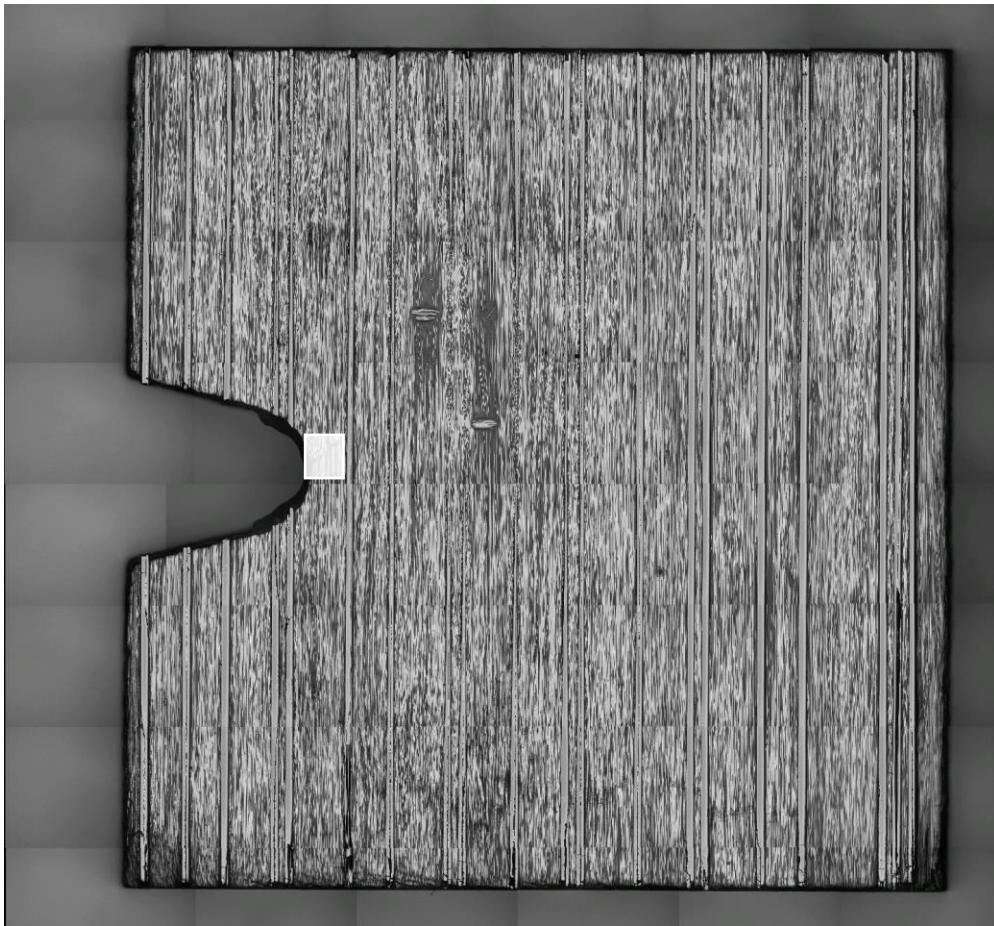


Residual longitudinal strain after unloading

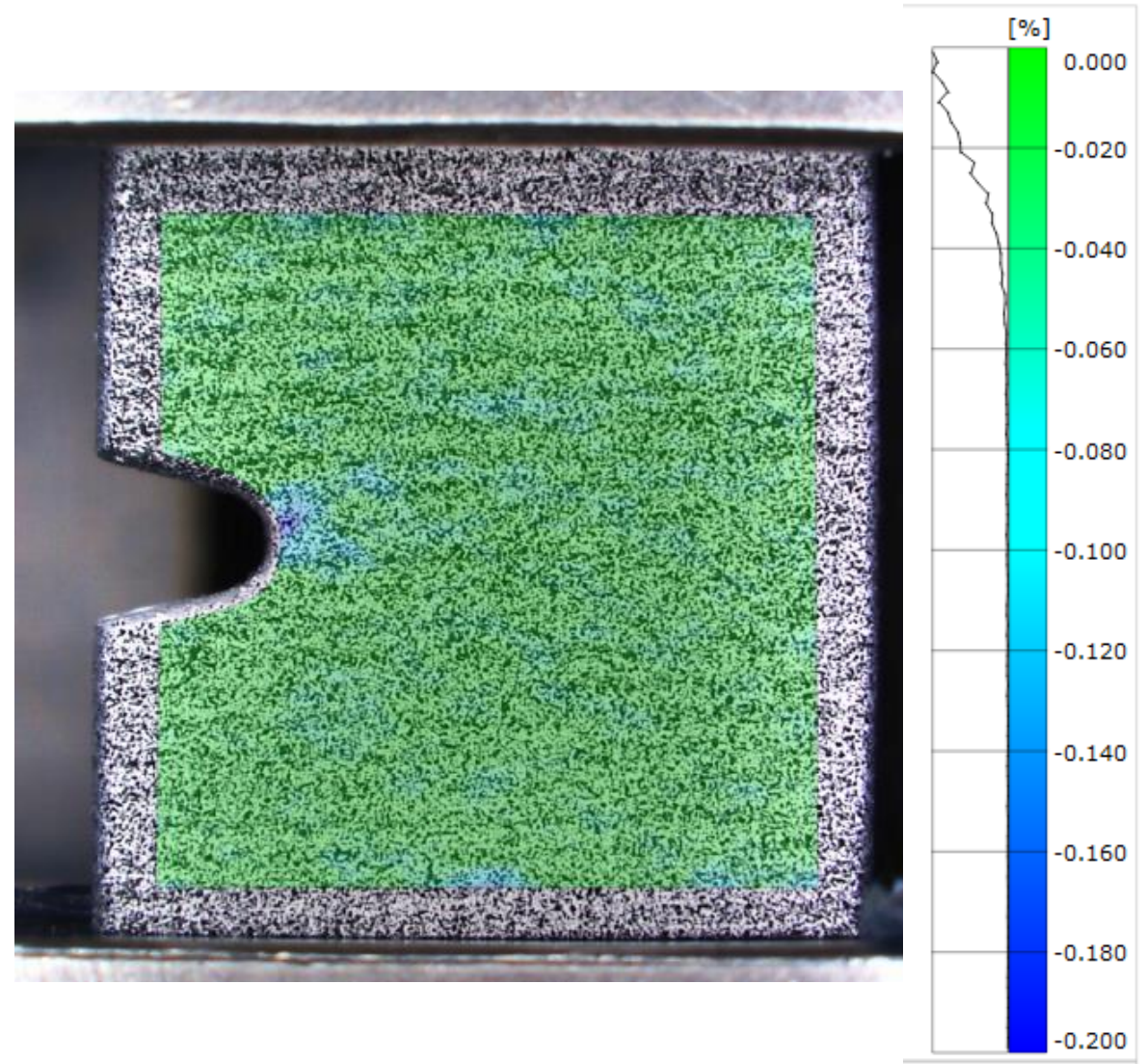


Phase 1: loading with external 90° ply

Initial damage produced

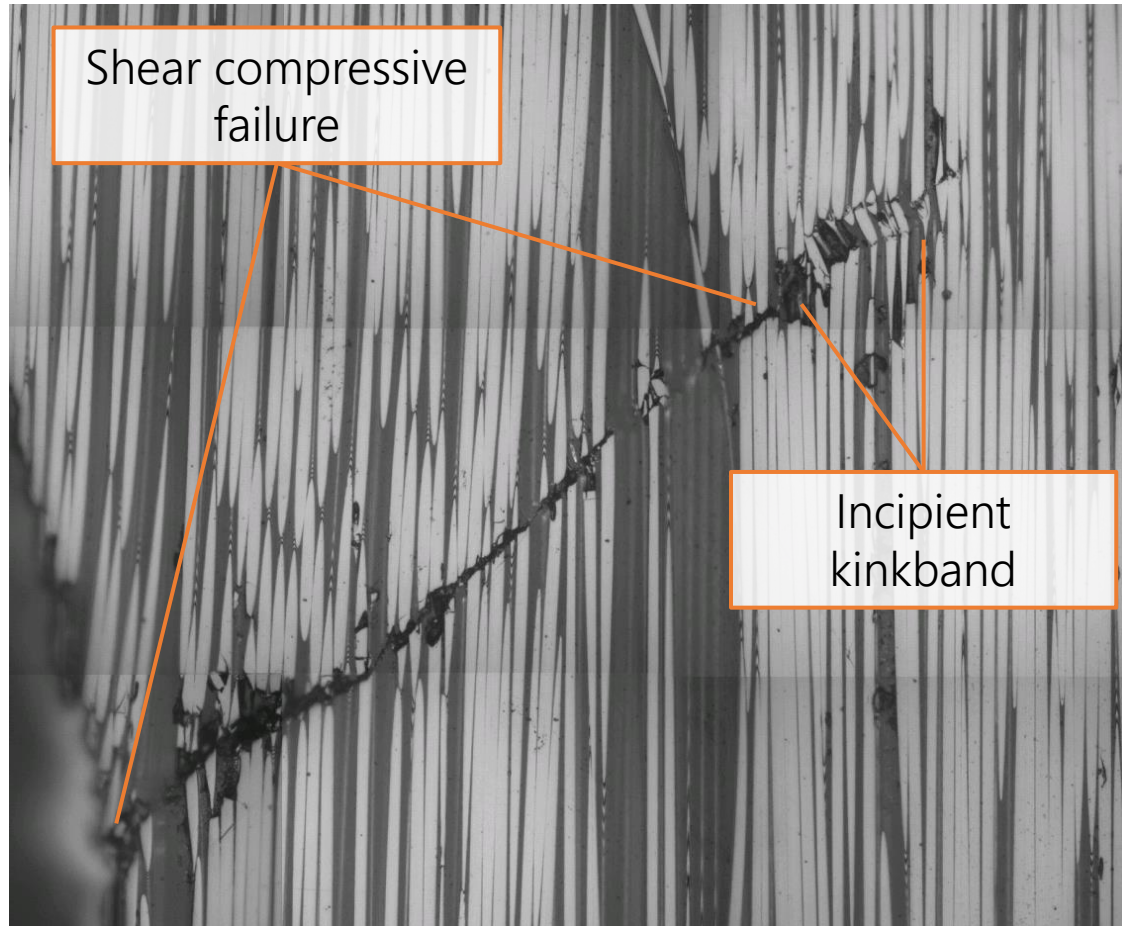


Residual longitudinal strain after unloading

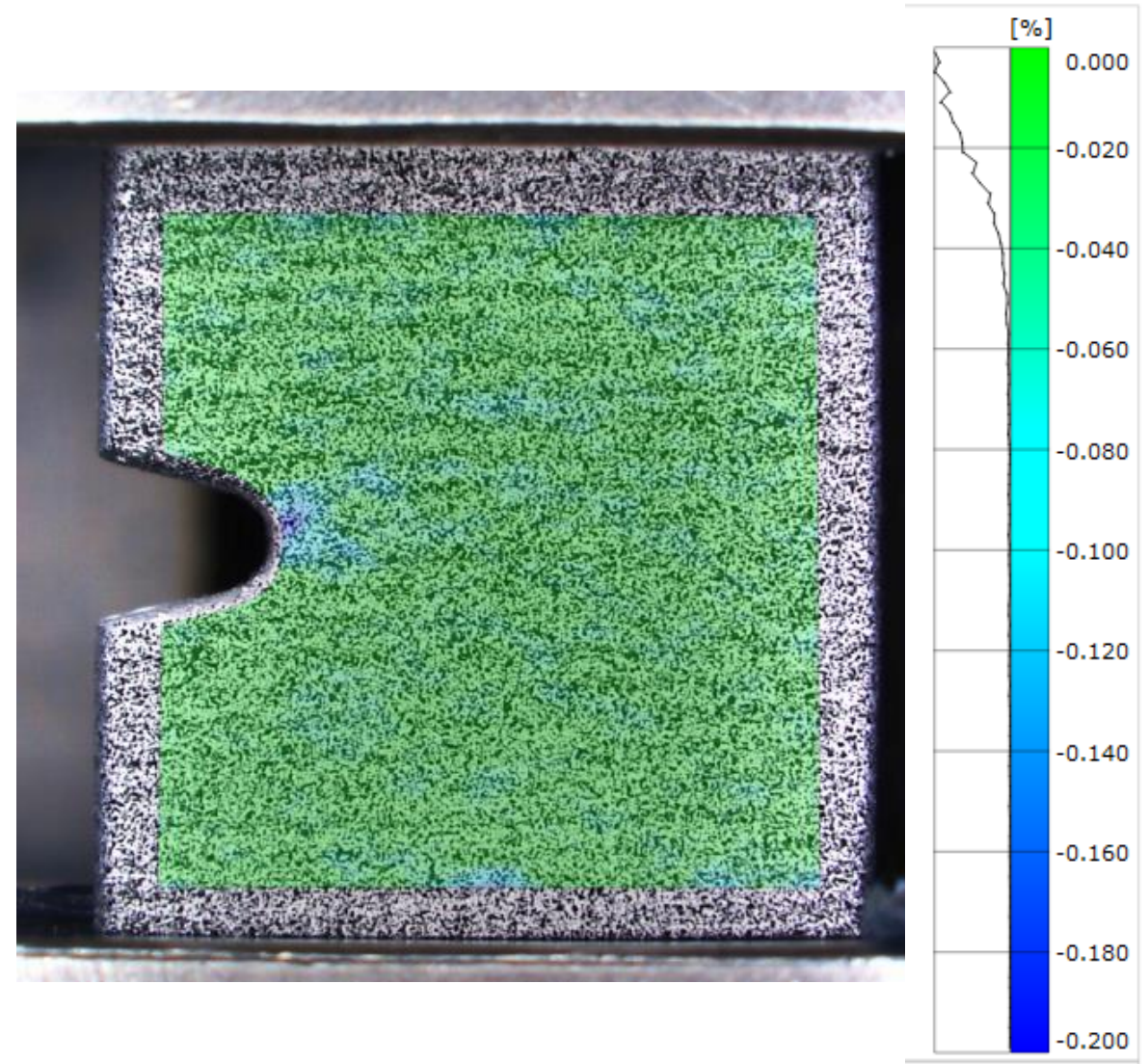


Phase 1: loading with external 90° ply

Initial damage produced

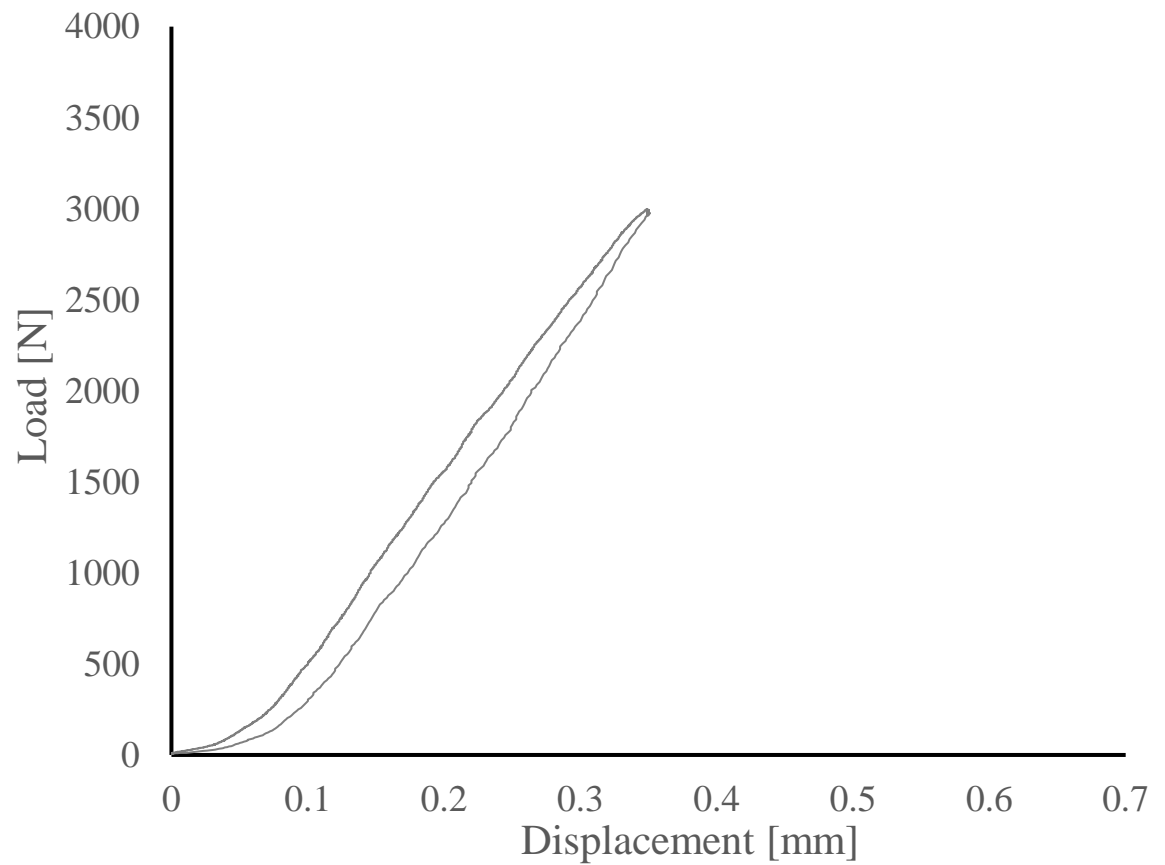
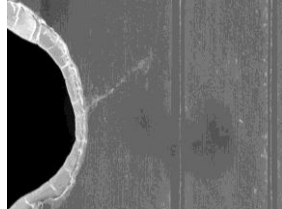


Residual longitudinal strain after unloading



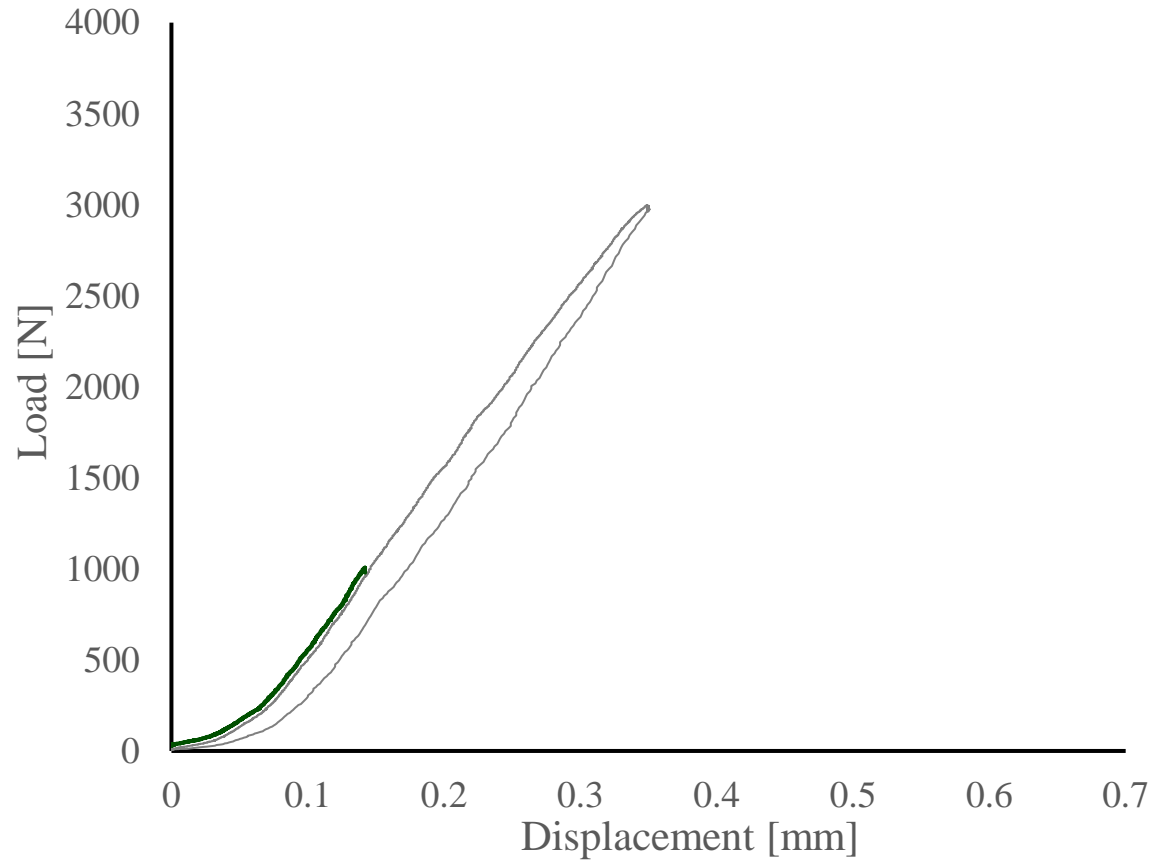
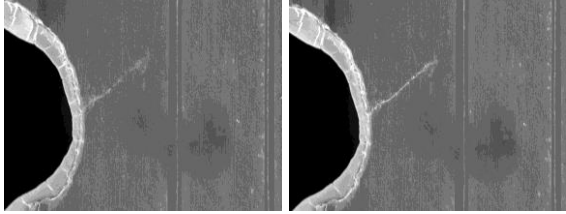
Phase 2: in-situ SEM test, polished specimen

0 N



Phase 2: in-situ SEM test, polished specimen

0 N 1000 N

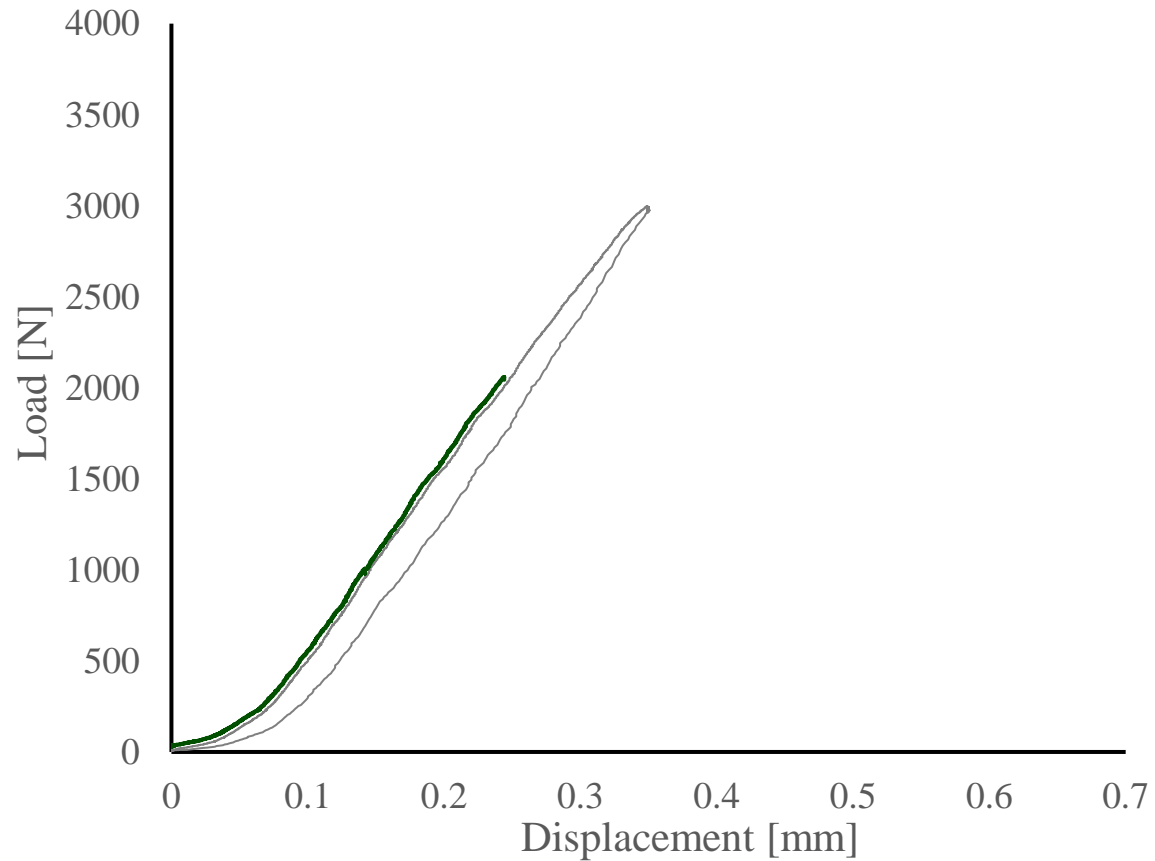
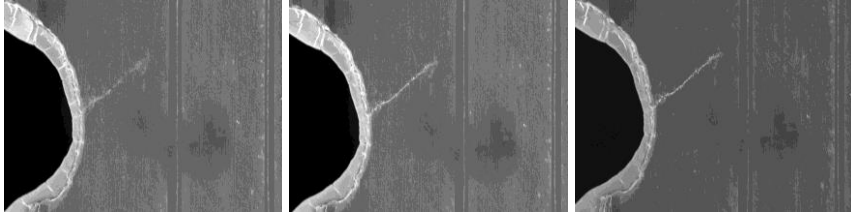


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0 N

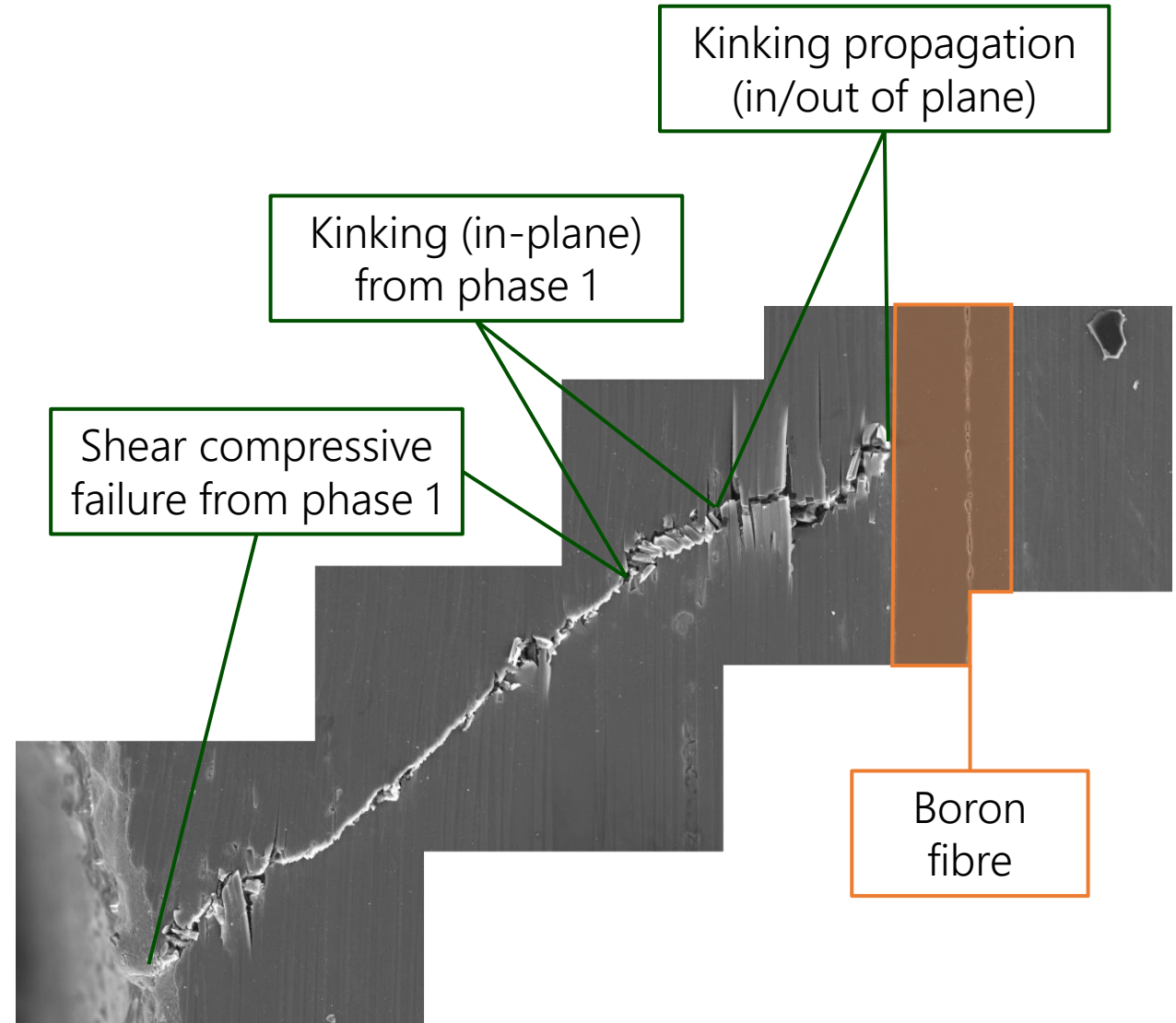
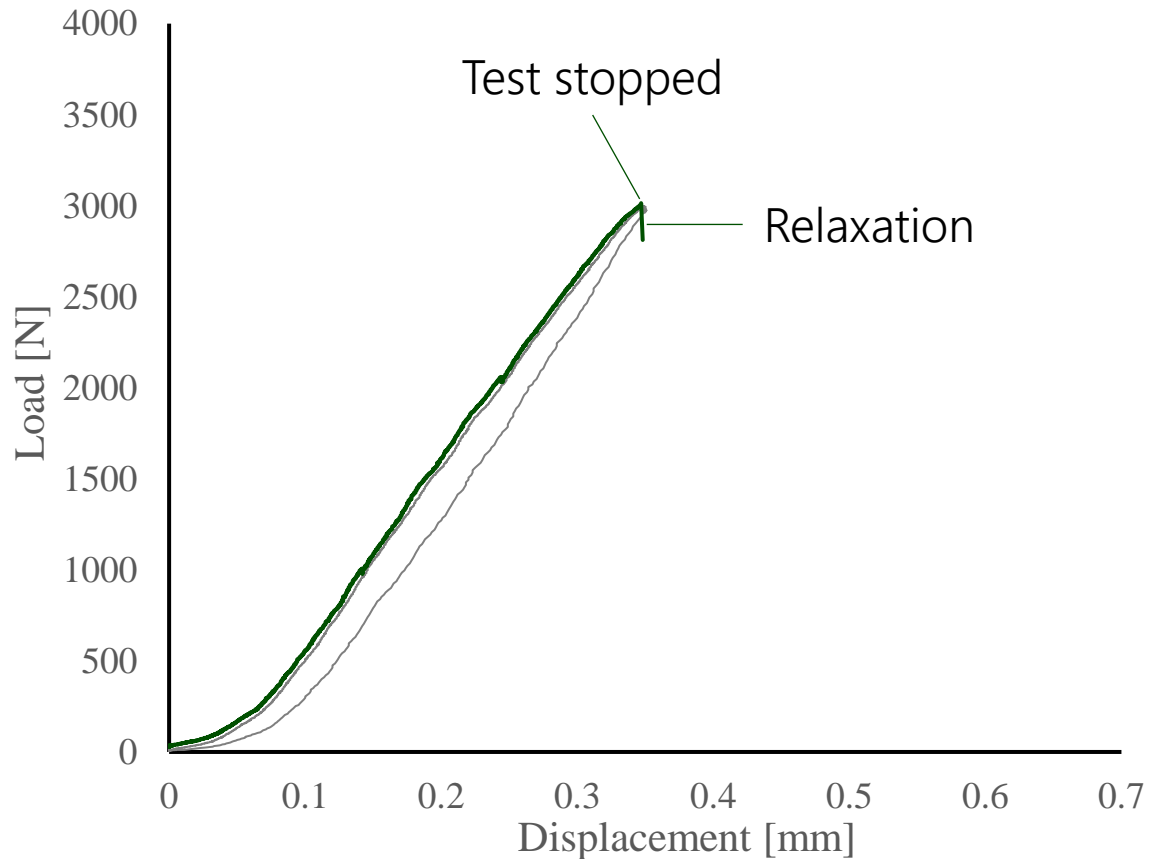
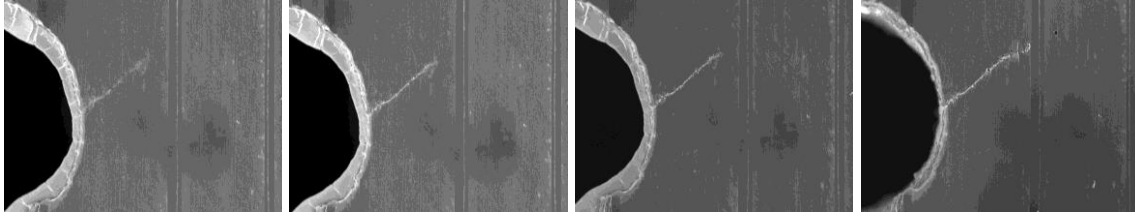
1000 N

2000 N



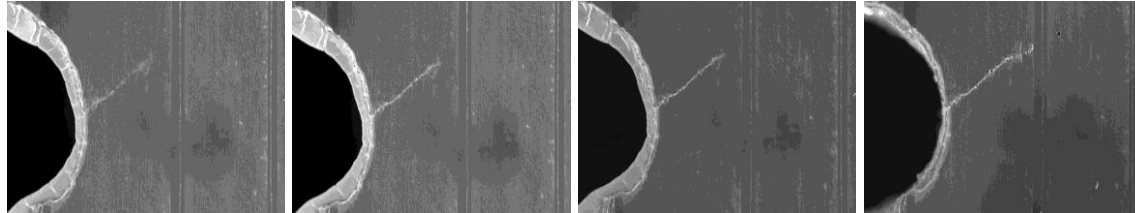
Phase 2: in-situ SEM test, polished specimen

0 N 1000 N 2000 N 3000 N

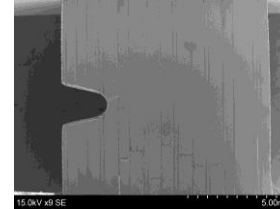


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0 N 1000 N 2000 N 3000 N

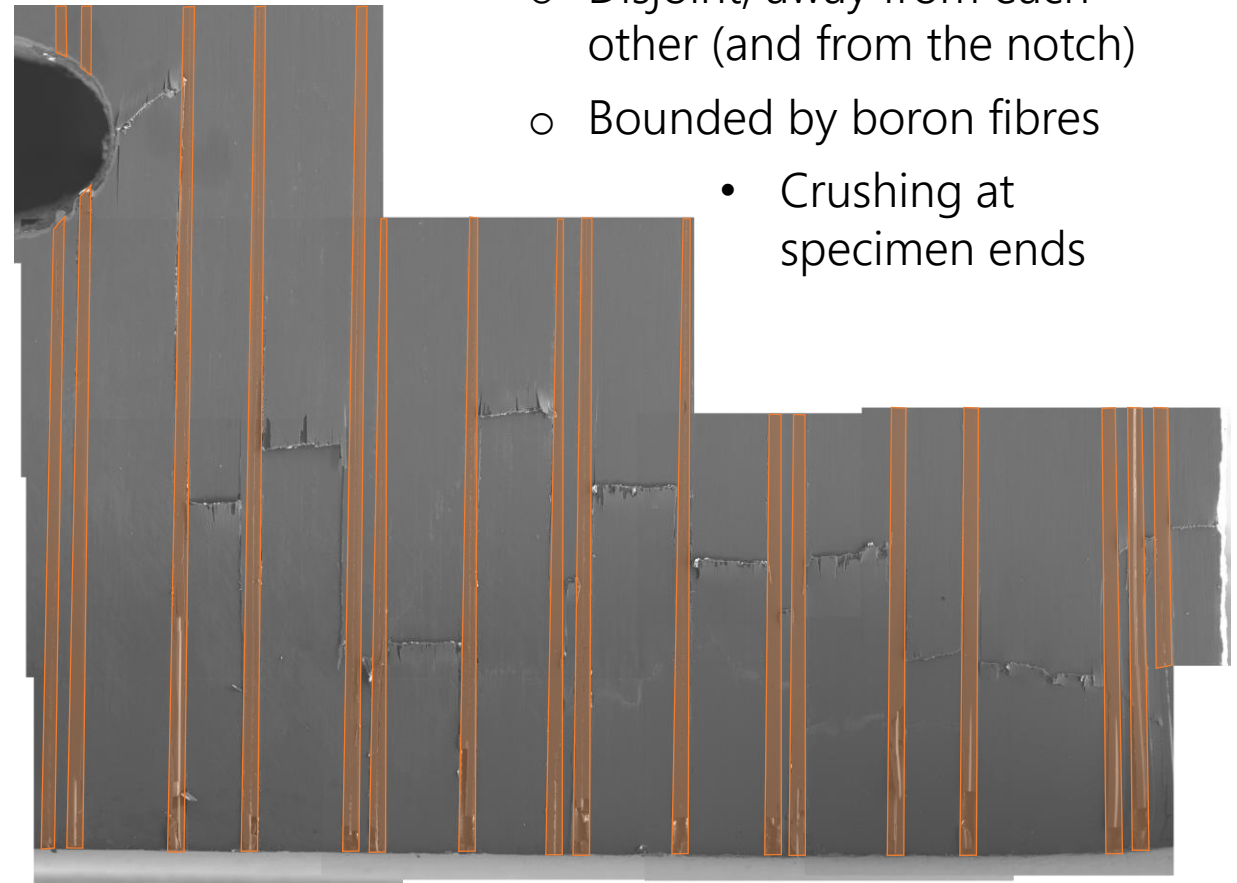
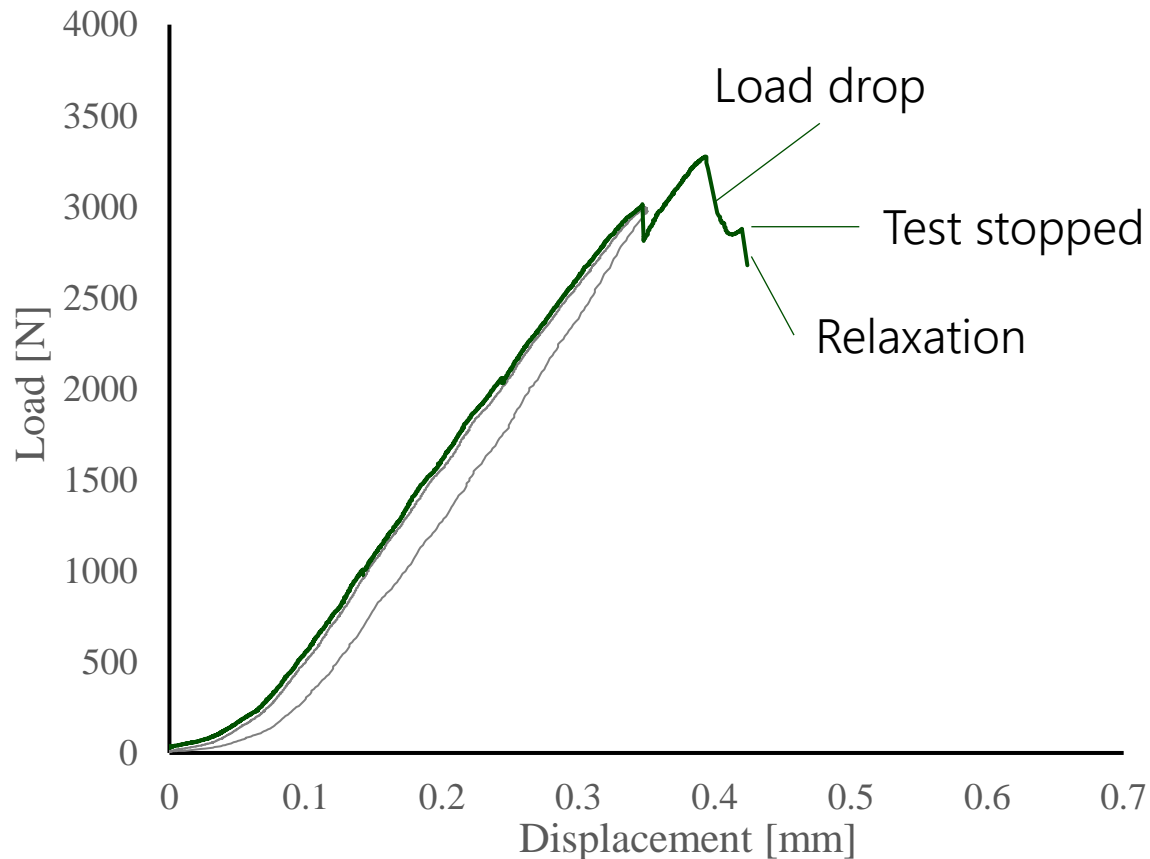


After drop

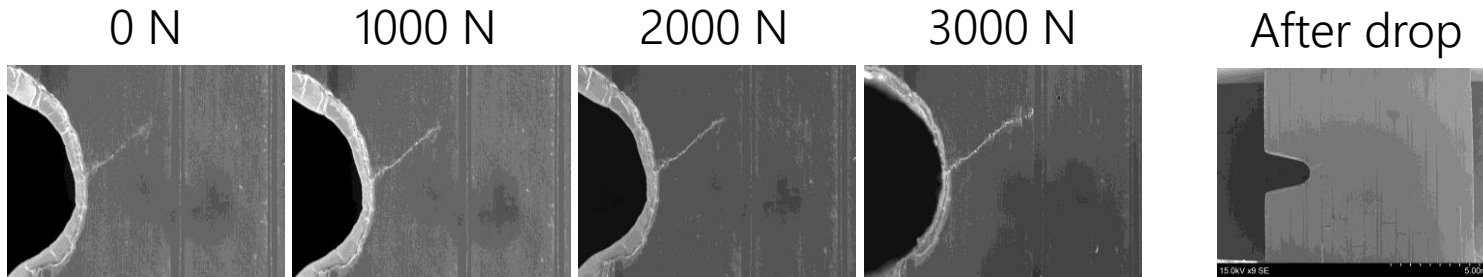


Remarks:

- Initially increasing load
 - No kinkband propagation
- At drop, kinkbands forming:
 - Disjoint, away from each other (and from the notch)
 - Bounded by boron fibres
- Crushing at specimen ends

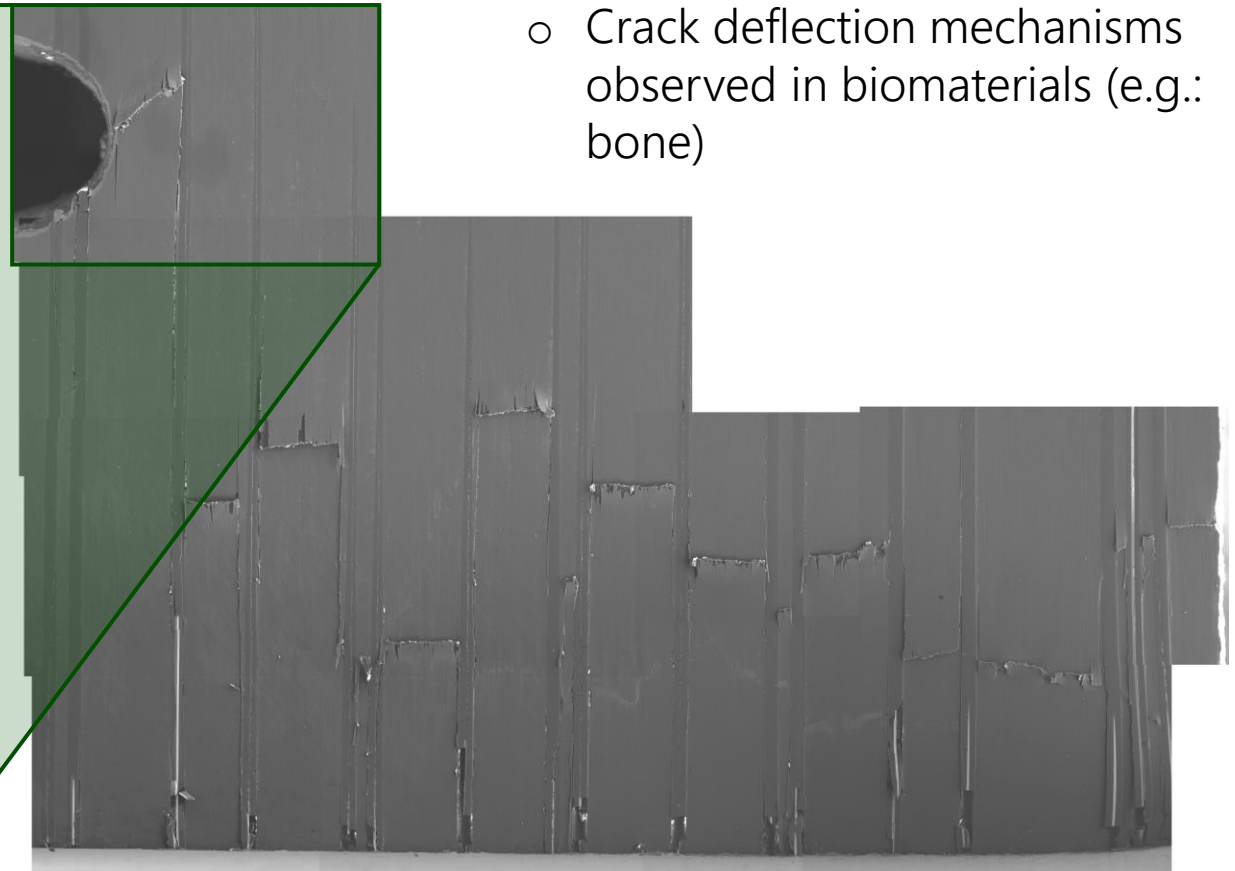
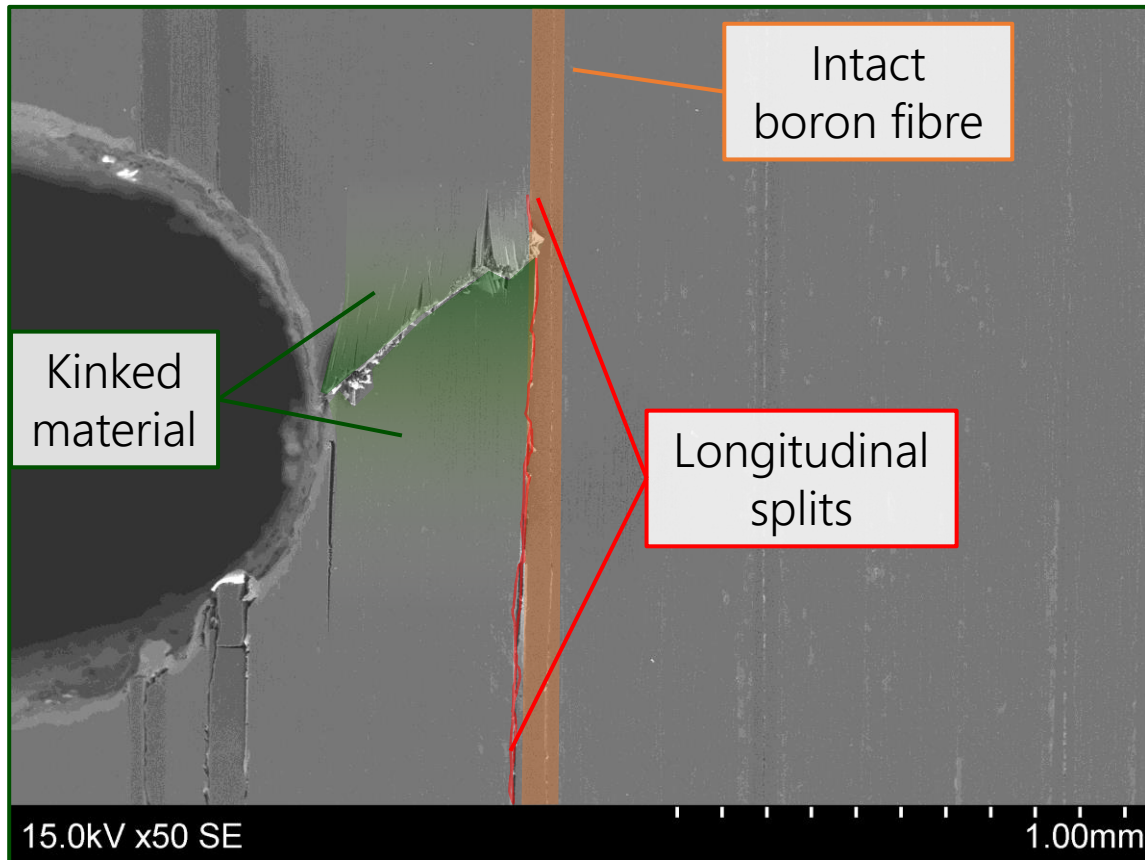


Phase 2: in-situ SEM test, polished specimen



Remarks:

- Boron fibre remains intact (despite being polished and exposed)
- Longitudinal splits develop separating the CFRP from boron
 - Crack deflection mechanisms observed in biomaterials (e.g.: bone)



Phase 2: in-situ SEM test, polished specimen

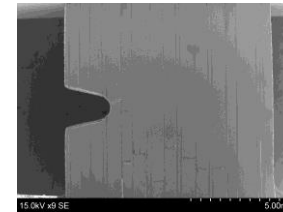
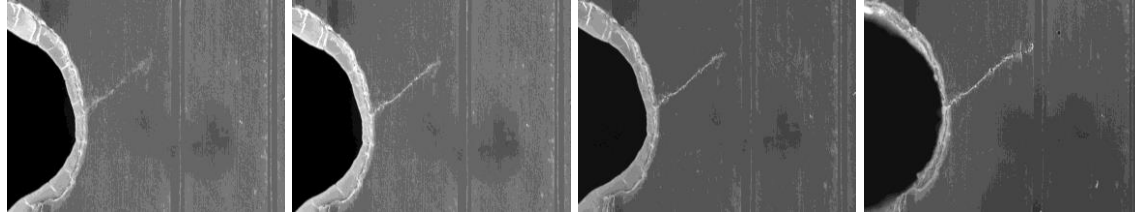
0 N

1000 N

2000 N

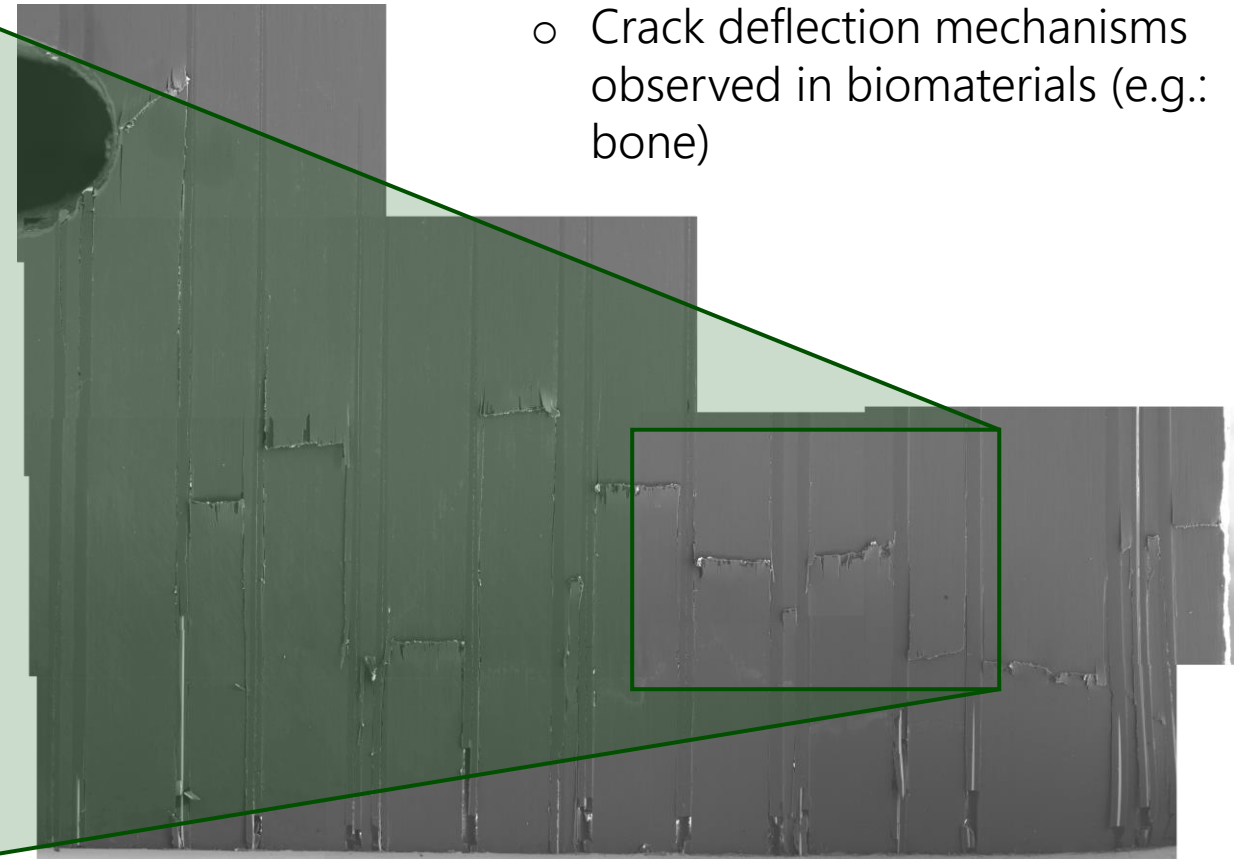
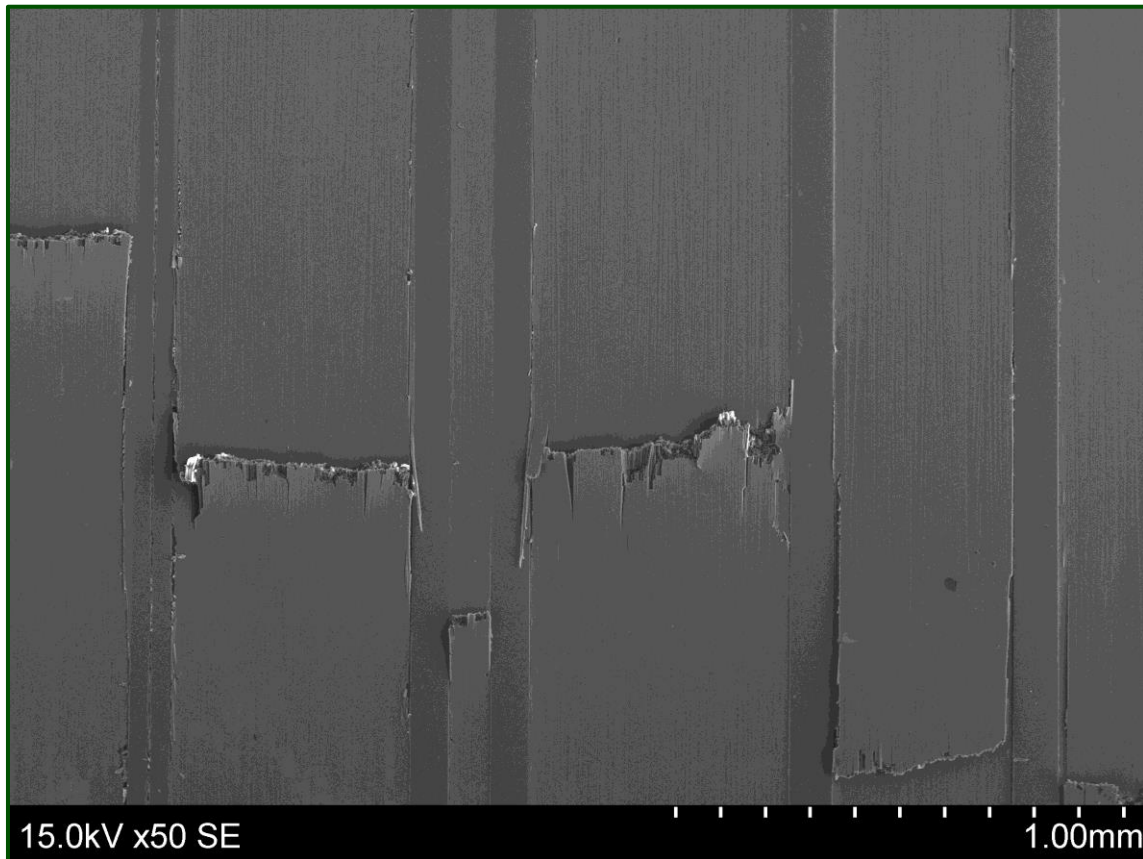
3000 N

After drop



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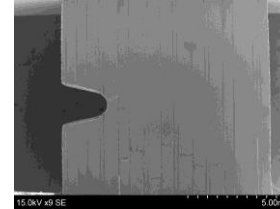
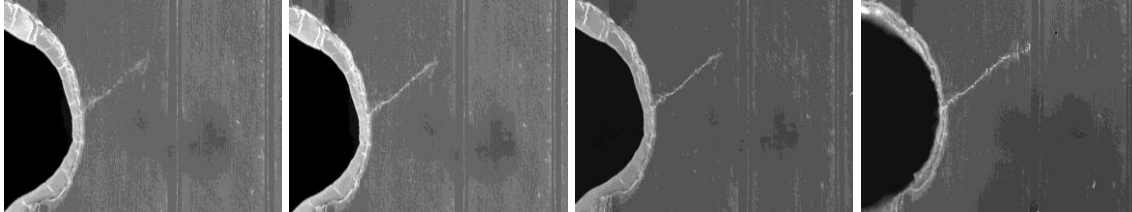
0 N

1000 N

2000 N

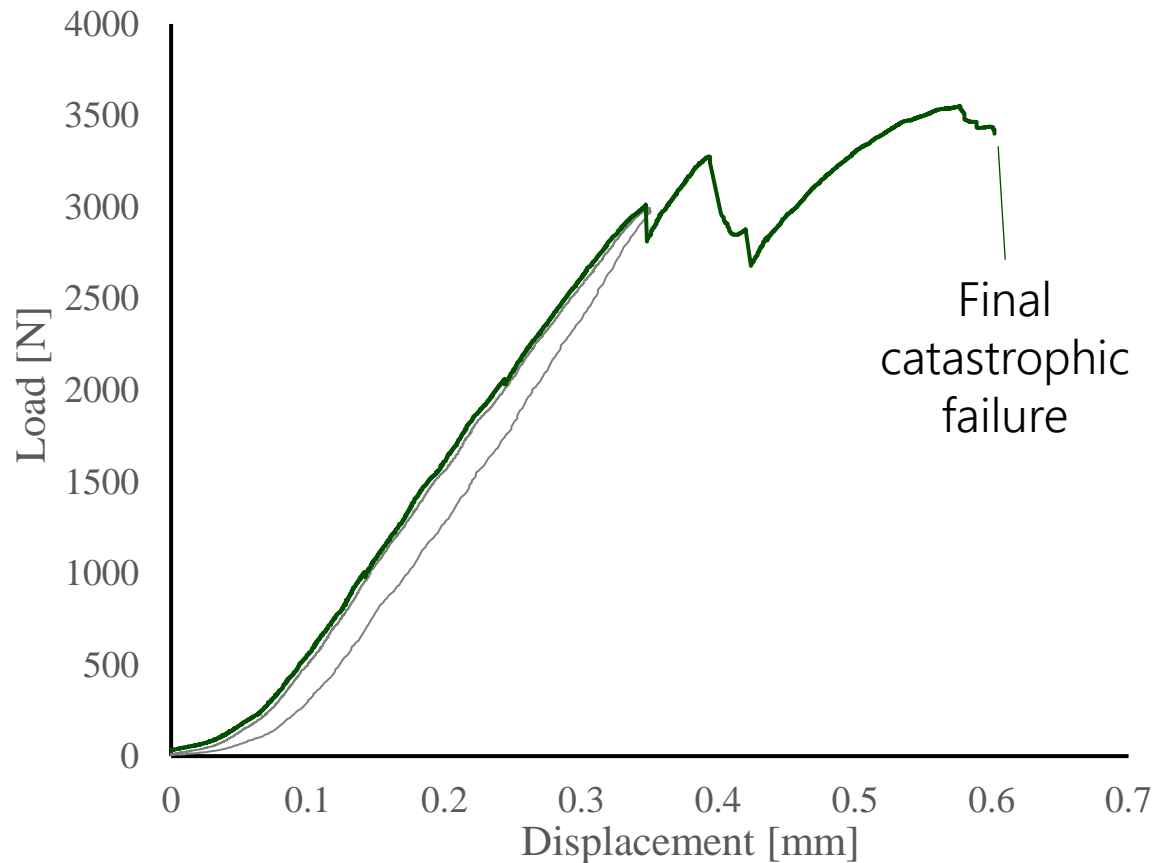
3000 N

After drop



Remarks:

- HyBor tolerated presence of kinkbands in all carbon regions
- New maximum load was achieved



Conclusions and prospects

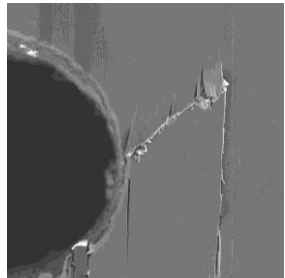
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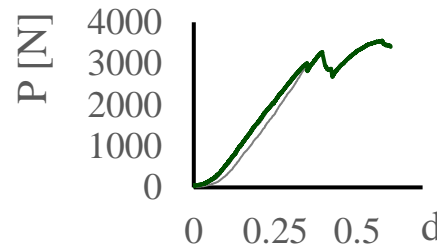


Conclusions

Boron fibre in the hybrid:



- Arrested kinkbands
- Promoted deflection into longitudinal splits
 - Observed in biomaterials
 - Known to improve fracture properties
- Remained intact after carbon failure
 - The hybrid tolerated initial damage
 - It could be loaded further



Prospects

Future research should:

- Investigate analytical/numerical models
- Investigate the effect of:
 - Geometrical variables
 - Material variables
- Consider coupon level test
- Investigate other approaches to reproduce the mechanisms observed



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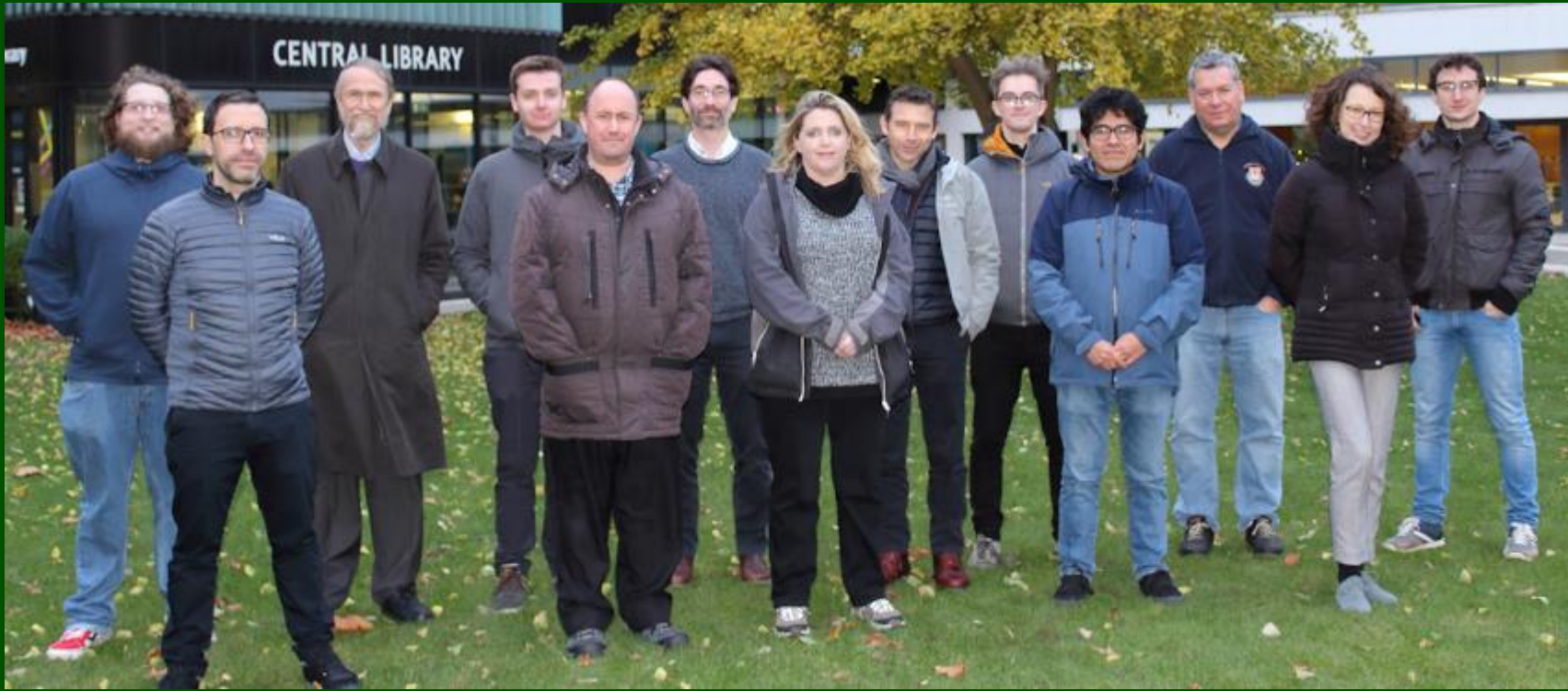
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<http://tinyurl/pinholab>



**Imperial College
London**



**Next
COMP**

Next Generation
Fibre-Reinforced Composites

<https://nextcomp.ac.uk>



I would like to acknowledge funding which supported this work from the UK Research and Innovation - EPSRC Programme Grant; Next Generation Fibre-Reinforced Composites: A Full Scale Redesign for Compression (EP/T011653/1)

A collaboration between Imperial College London and University of Bristol

**Imperial College
London**



Bristol Composites Institute

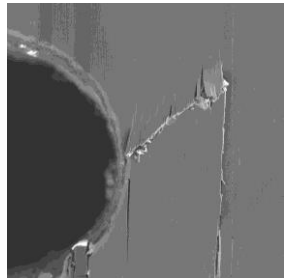
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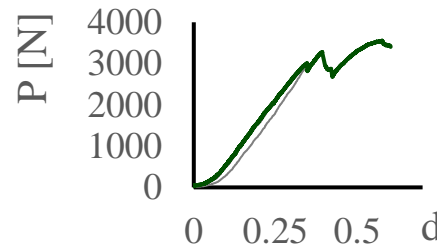


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