University of BRISTOL

Bristol Composites Institute

Towards highly-tailorable, structural efficient and resilient composite designs

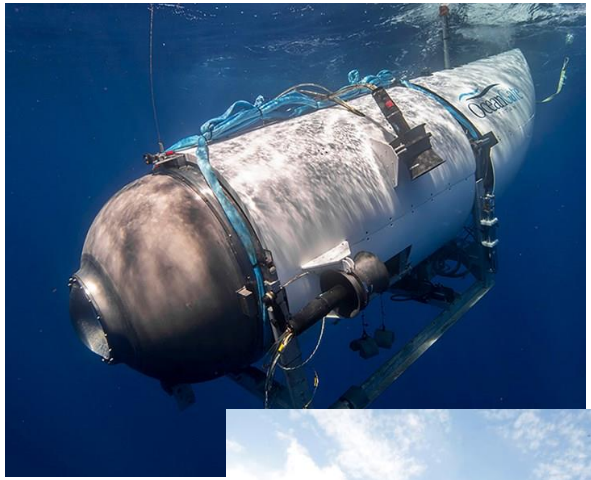
Dr. Xun Wu

Prof. Michael Wisnom

16th of November, 2023

Background

- Carbon fibre composites are widely used in many industries where high performance and light weight are required.
- Carbon fibre is brittle, low toughness, low elongation.
- Carbon fibre has shown weak performance in compression
- All of these significantly reduce the design margin and result in weight penalty.
- Or, may cause catastrophic failure



Aim

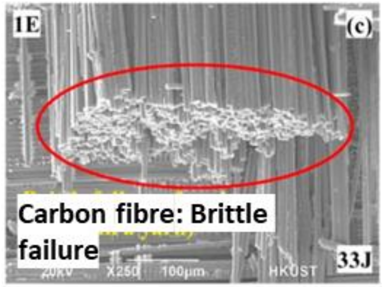
Develop highly-tailorable, structurally efficient and resilient composite designs under different loading conditions

(1) Re-configuring existing material systems,

(2) Introducing controllable failure mechanisms,

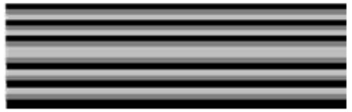
(3) Tailoring fit-for-purpose localised properties in each part of a single laminate, for example in an impact loading case.

Our approaches



Carbon fibre composites:

Brittle, low toughness, low deformation, Lack of energy absorption mechanisms



(M.E.Kazemi, 2021)

<u>Hybridising with</u>
high strain material:

Flexible, long elongation, large energy absorbed during deformation.

Various different grades of carbon fibre composites:

- HM fibres, IM fibres and HS fibres.
- Standard ply and thin ply prepregs.

High strain materials:

- Glass-fibres, UHMWPE fibre, Nylon, Kevlar etc
- Angle plies
- Thin metal materials

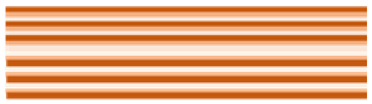
Our approaches

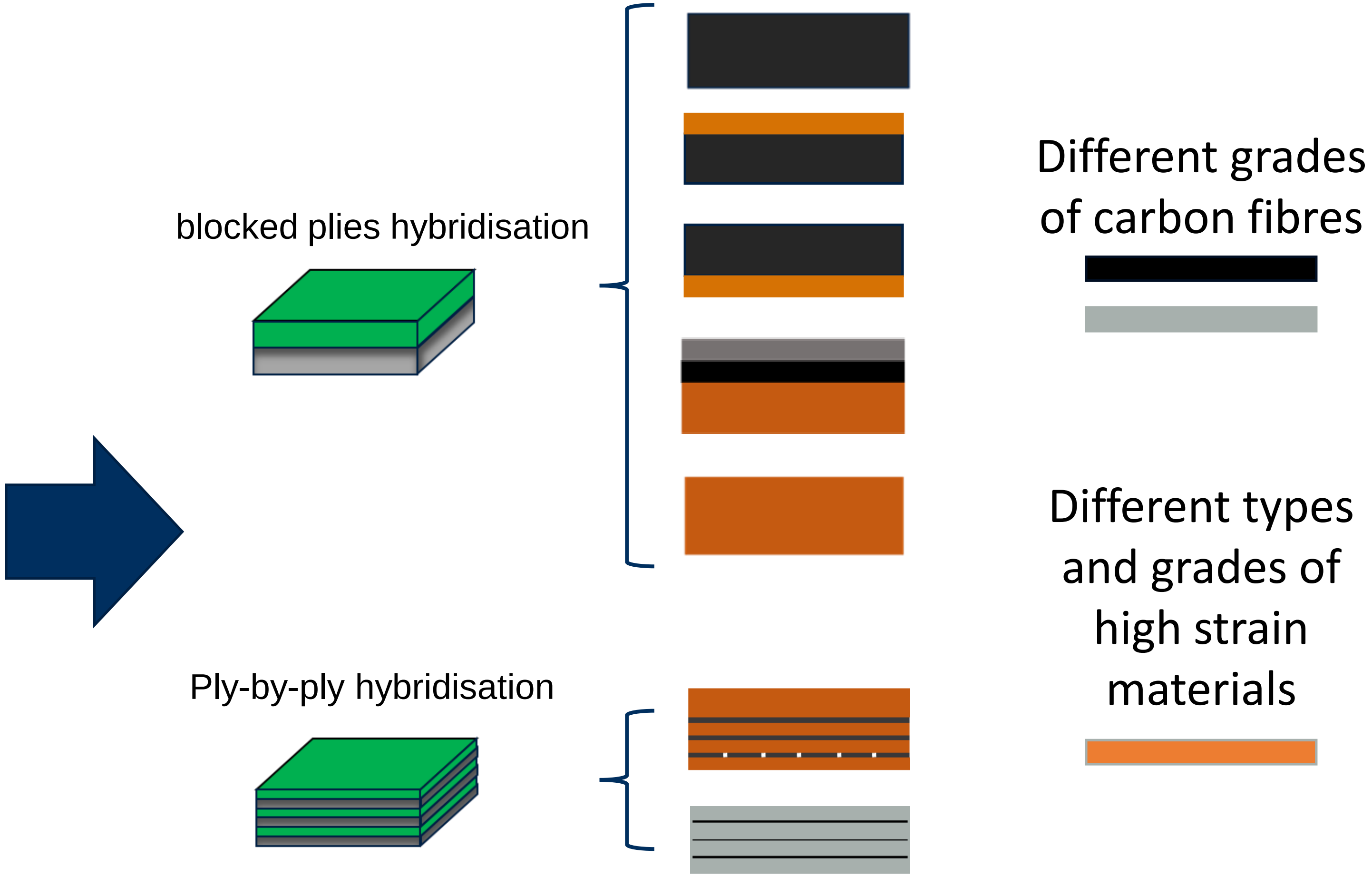
Re-configure the existing material systems, introducing controllable mechanisms

Carbon fibre composites:

Brittle, low toughness, low deformation,
Lack of energy absorption mechanisms

<u>Hybridising with</u>
high strain material:
Flexible, long elongation, large energy absorbed during deformation.

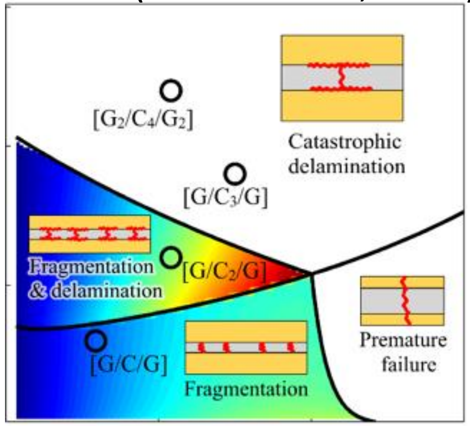




Tensile loading:

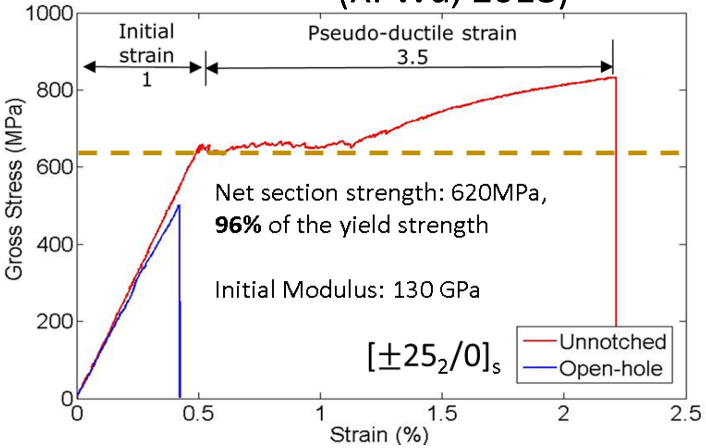
- Pseudo-ductile materials with a large damage tolerance capability were developed in previous EPSRC HiPerDuCT programme grant.
- Pseudo-ductile responses were achieved in **thin ply angle plies**, **glass/carbon** and **carbon/carbon** hybrid specimens in tension.

(M. Jalalvand, 2015)



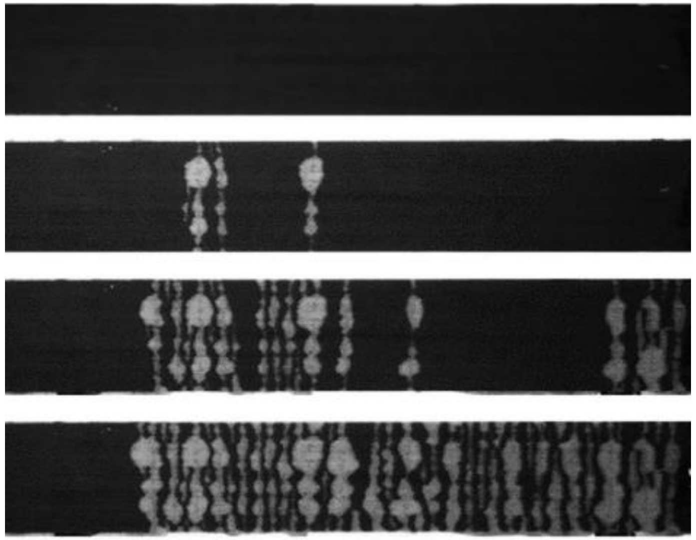
damage mode map for pseudo-ductile design

(X. Wu, 2018)



Pseudo-ductile thin ply angle plies + reduced notch sensitivity

(M.Fotouhi, 2016)



Fibre fragmentation in thin carbon layer of glass/carbon hybrid

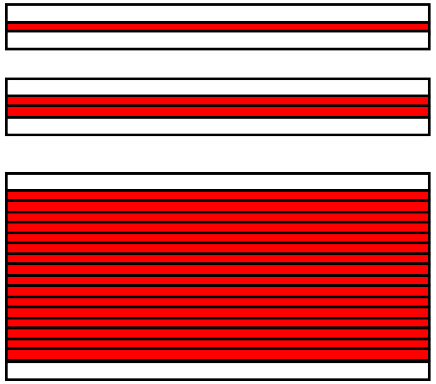
Compression: Glass/thin carbon

(Aree Tongloet, 2023)

S-Glass/M55 hybrid with three different thicknesses of carbon plies tested in compression using a novel four-point bend configuration:

Specimen configuration	Knee-point strain (%)	Failure strain (%)
SG/M55$_1$/SG	0.48 (3)	0.78 (3)
SG/M55$_2$/SG	-	0.43 (2)
SG/M55$_{16}$/SG	-	0.31 (3)

Hybrid configurations

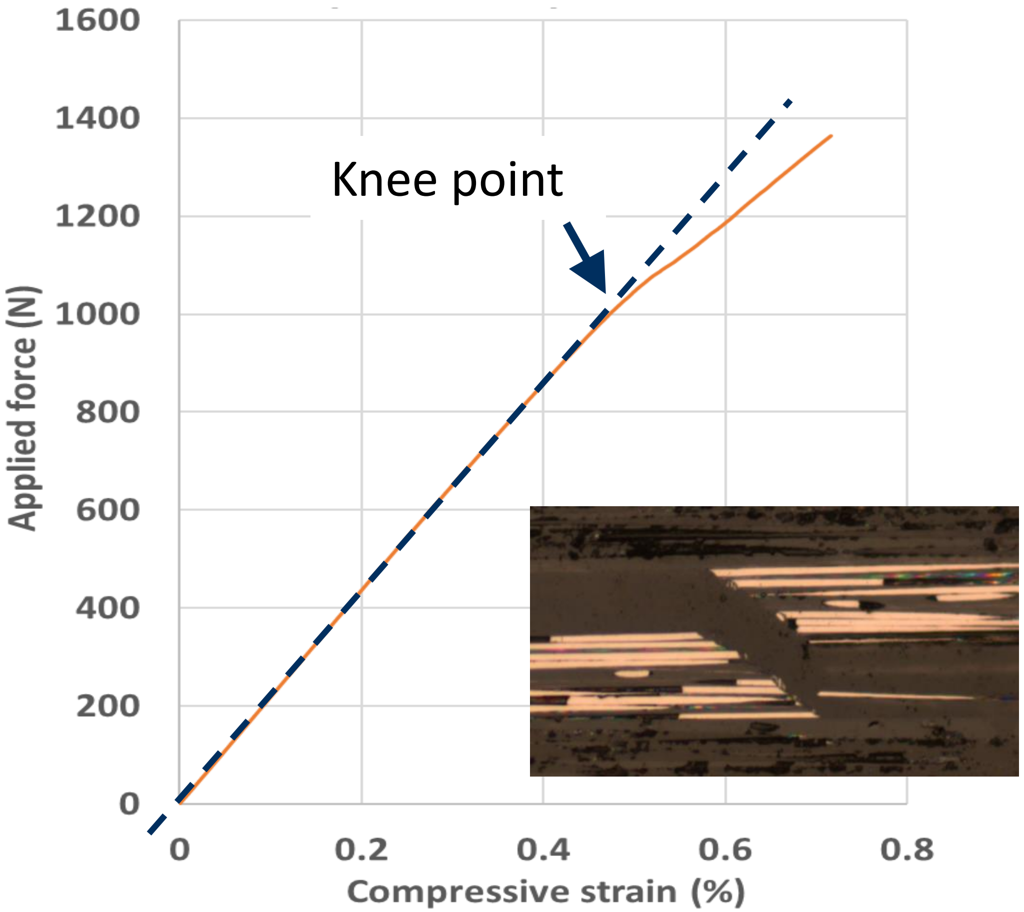


SG$_1$/M55$_1$/SG$_1$

SG$_1$/M55$_2$/SG$_1$

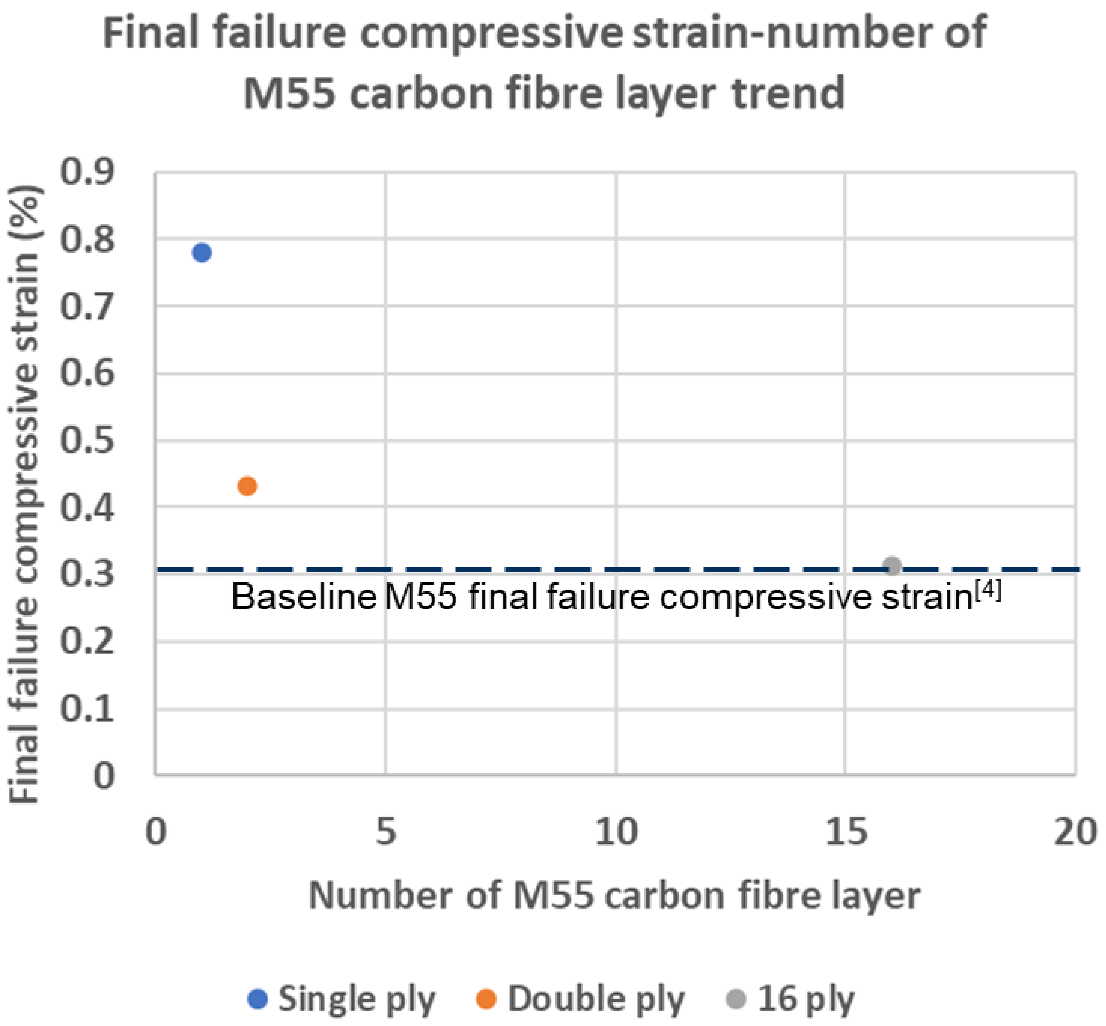
SG$_1$/M55$_{16}$/SG$_1$

Applied load-Compressive strain of SG1/M551/SG1



Compression: Glass/thin carbon

(Aree Tongloet, 2023)



Fibre fragmentation

0.78%

Gradual failure

Fragmentation + kink-band

0.43%

Kink-band + delamination

0.31%

Catastrophic failure

Increase of carbon plies

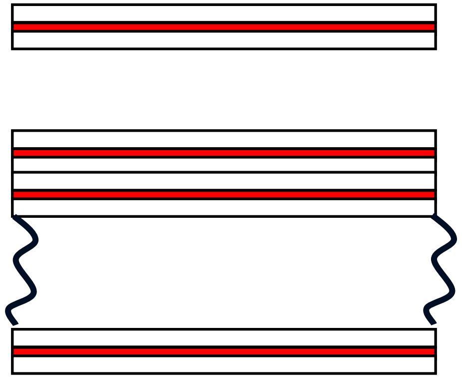
Compression: Glass/thin carbon

(Putu Suwarta)

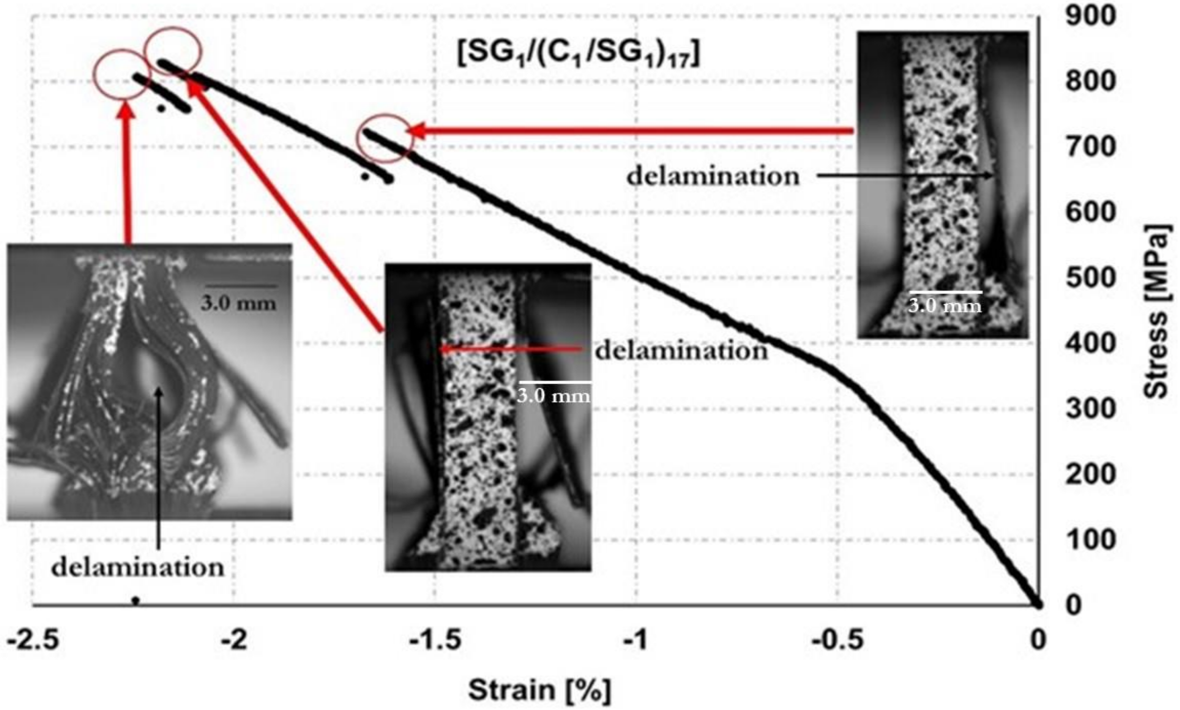
Specimen configuration	Knee-point strain (%)	Failure strain (%)
SG1/M55$_1$/SG	0.48 (3)	0.78 (3)
[SG/M55$_1$/SG]$_{17}$	0.55 (3)	2.15 (8)

Single Sublaminate — [SG/M55$_1$/SG]

Repeated Sublaminates — [SG/M55$_1$/SG]$_{17}$

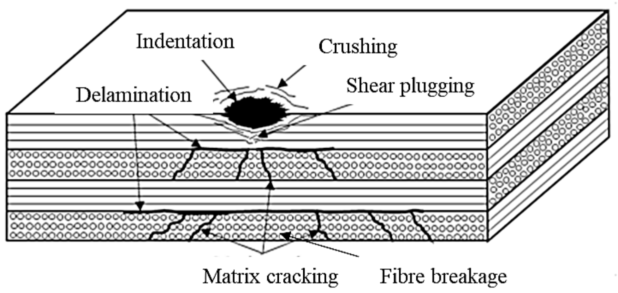


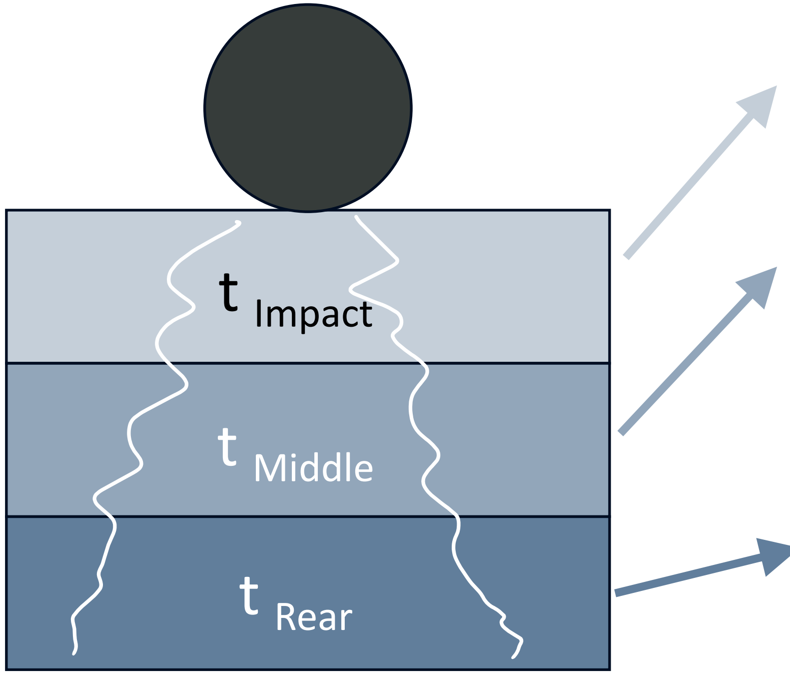
Compressive stress-strain of [SG/M55$_1$/SG]$_{17}$



Impact

- In impact, energy absorption mechanisms include - crush and contact failure, shear plugging, matrix cracking, delamination and fibre fracture.
- Designing fit-for-purpose localised properties for each part of an impact sample.





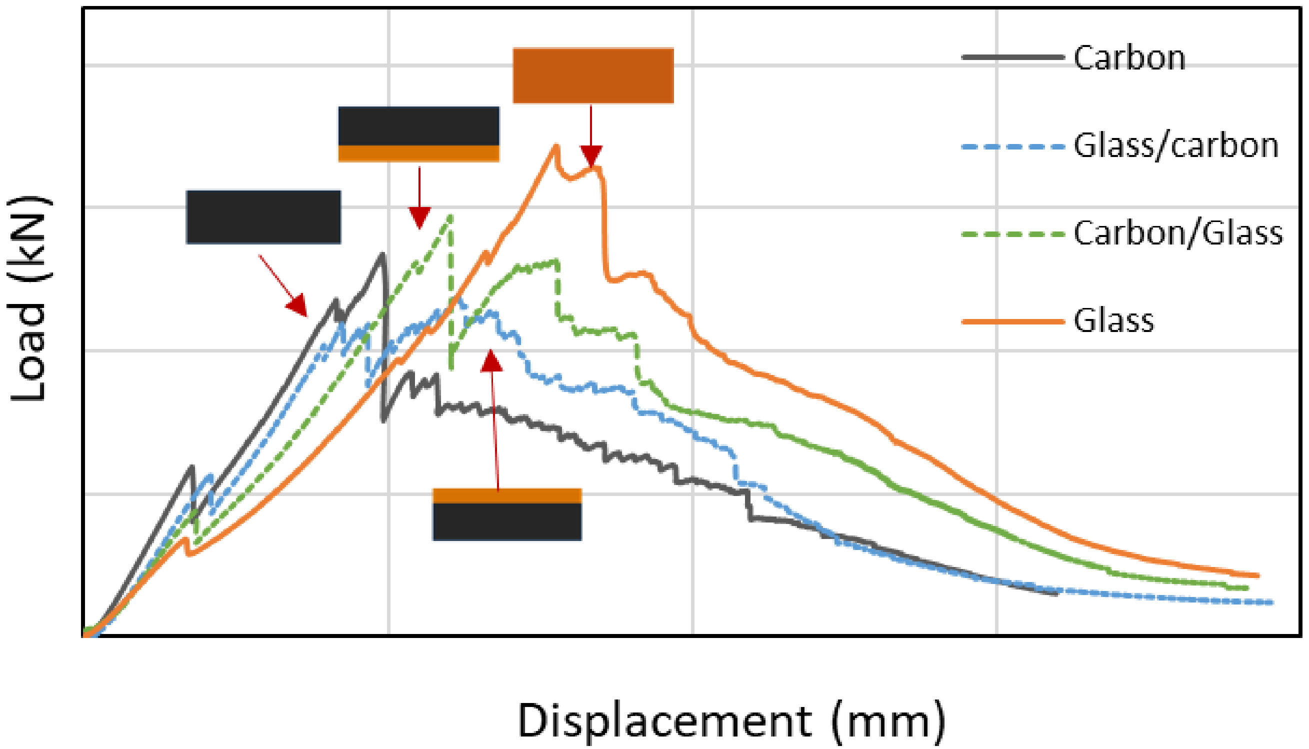
Major load carrying part, Load redistribution

Low ILSS, allow more delamination and shear deformation

Major load carrying part
Large deformation and high strain material.
Additional mechanisms: Delamination, matrix cracking, localised fibre fragmentation

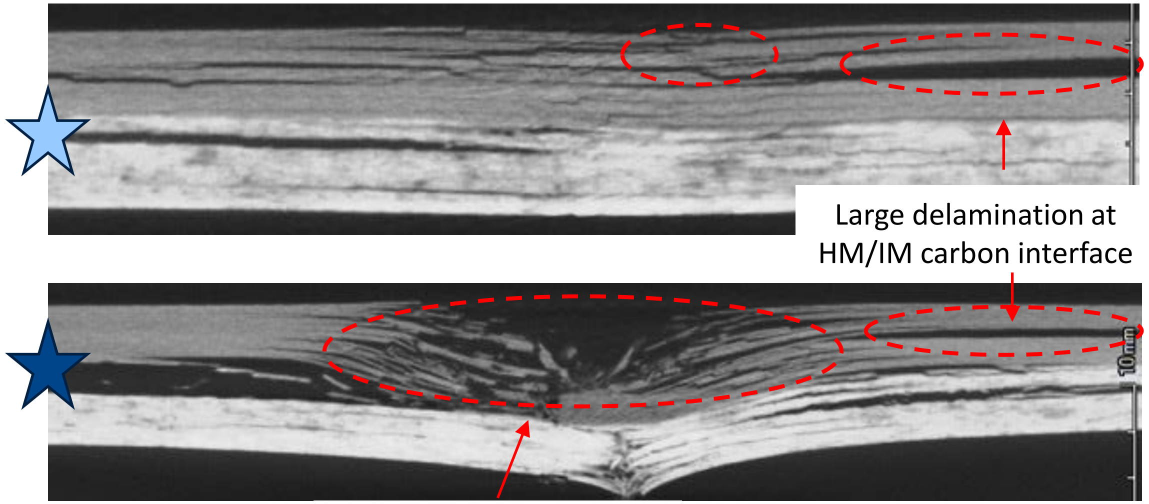
Impact: block-by-block hybrid

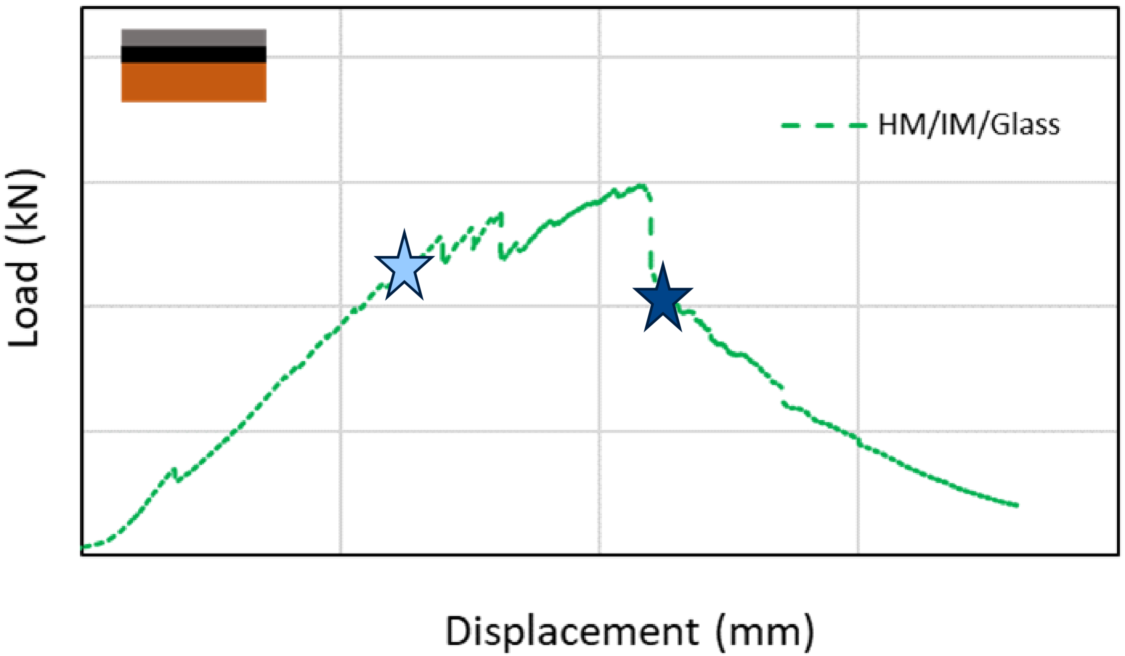
- Monolithic **carbon**, **glass** and **block-by-block hybrids**
- Adding high strain S-glass fibre layers to the carbon fibre plies, impact resistance, energy at penetration initiation and full penetration have been improved.
- Pure glass laminate on its own produces the best peak load and energy absorption.



Impact: HM/IM/glass hybrid

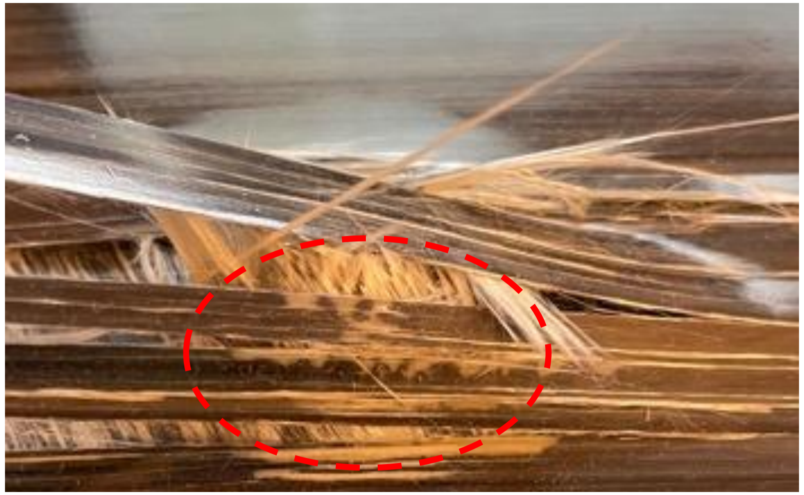
- Monolithic **carbon**, **glass** and **HM/IM/glass**
- Early damage initiated from HM carbon layers and then damage spread widely to IM carbon layers. This led to gradual reduction in stiffness and additional energy absorption.



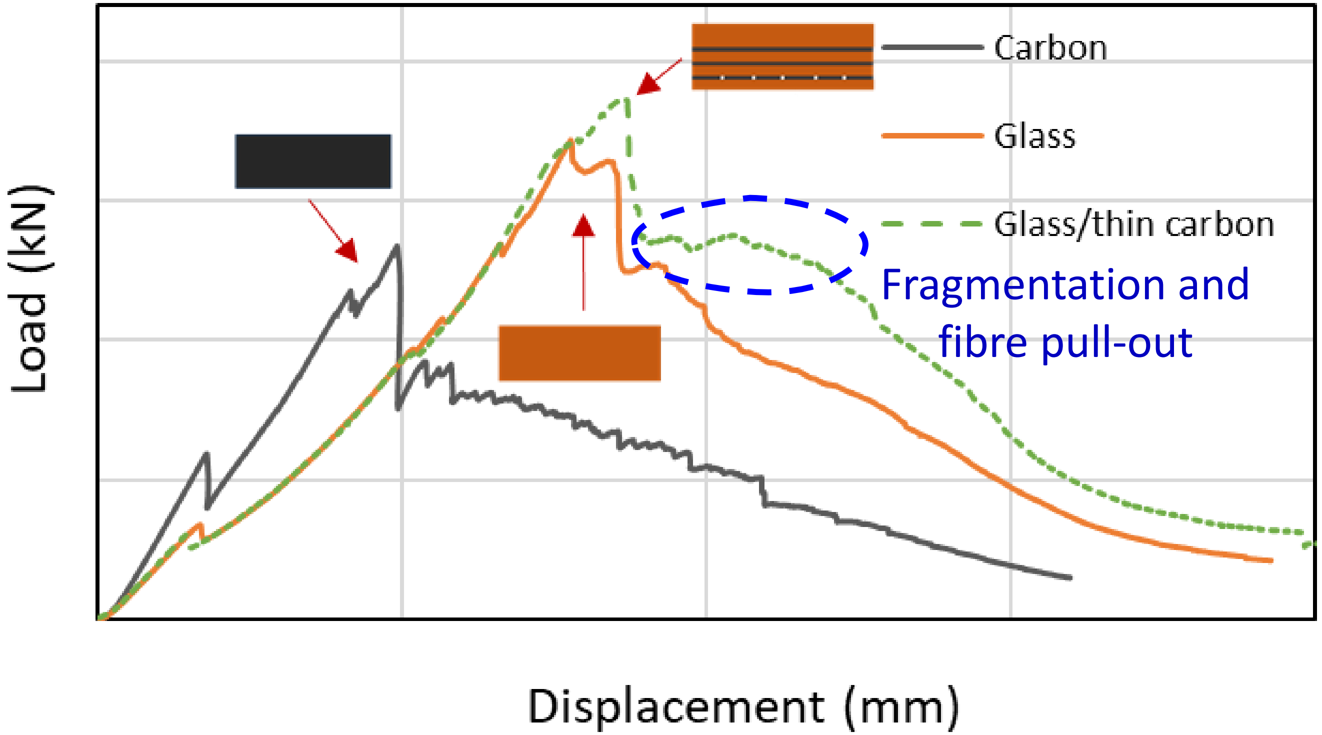


Impact: glass/thin carbon interlayer

- Monolithic **carbon**, **glass** and **interlayered glass/thin carbon hybrid**
- Fibre fragmentation in the thin carbon, stable fibre pull-out and localised delamination were promoted.



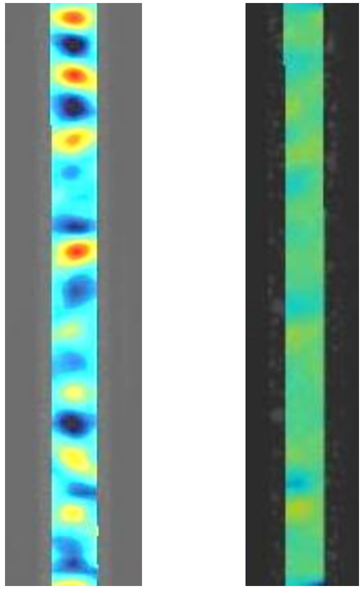
Fragmentation in carbon layers



Future work:

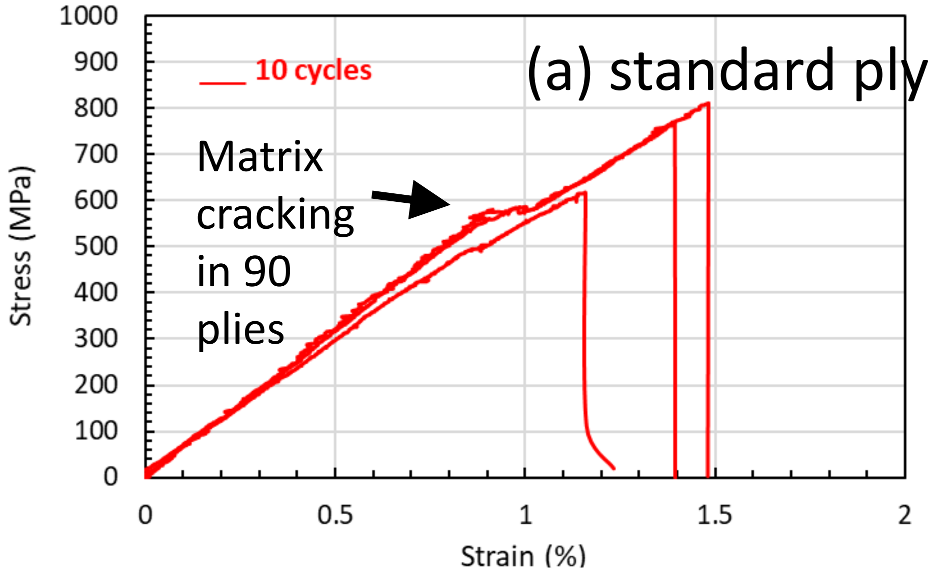
Cryogenic application:

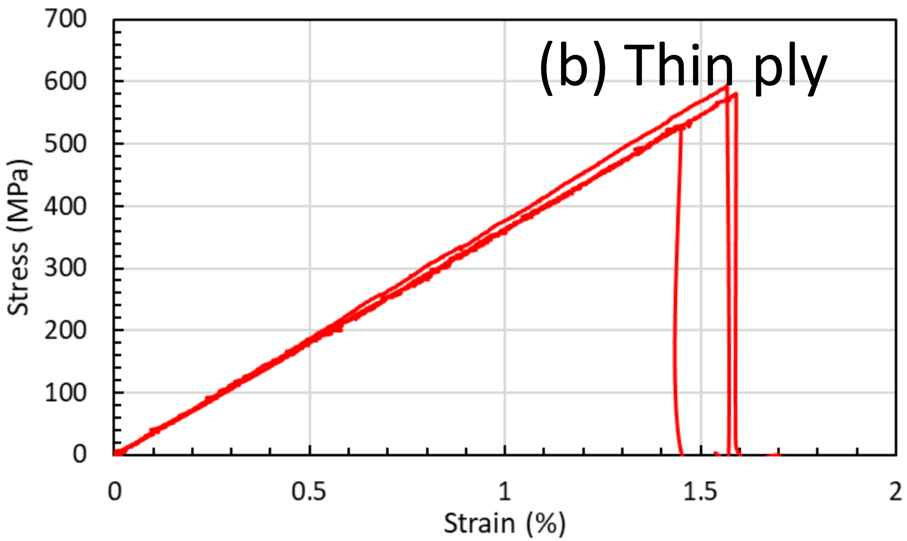
Thin ply materials and thin ply hybrid configurations have shown excellent resistance to matrix cracking.



(a) (b)

Tensile testing after 10 cryogenic cycles





Conclusions

- Hybridisation has been applied to improve the mechanical performance and damage tolerance capability of CFRP under different various loading conditions.
- All of these have been achieved by re-configuring the existing material systems and introducing controllable damage mechanisms.
  - Tension: pseudo-ductile responses were achieved in thin ply angle plies, glass/carbon and carbon/carbon hybrid specimens.
  - Compression: failure strain has been significantly improved and progressive compressive damage promoted – a shift of mechanisms towards fragmentation
  - Impact: energy absorption and resistance to penetration have been improved significantly, with point-to-point design of material.
- Future work: Cryogenic applications, Improve mechanical properties of bio-sourced material through hybridisation

Acknowledgements

- This work was partly funded under the UK Aerospace Research and Technology (ATI) FANDANGO Programme and the EPSRC Programme Grant EP/I02946X/1 on High Performance Ductile Composite Technology in collaboration with Imperial College, London.
- The authors also would like to acknowledge Rolls-Royce plc. For the support of this research through the Composites University Technology Centre (UTC) at the University of Bristol, UK.

University of BRISTOL
Bristol Composites Institute

Thank you!

Xunxun.Wu@Bristol.ac.uk

M.Wisnom@Bristol.ac.uk