University of BRISTOL

Bristol Composites Institute

MEASURING COMPRESSIVE BEHAVIOR OF COMPOSITES BY FLEXURAL TESTS

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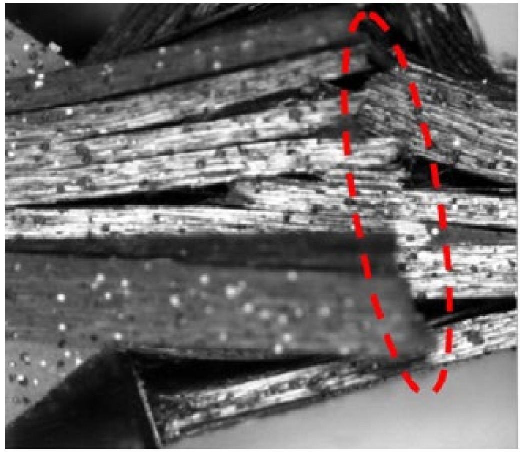
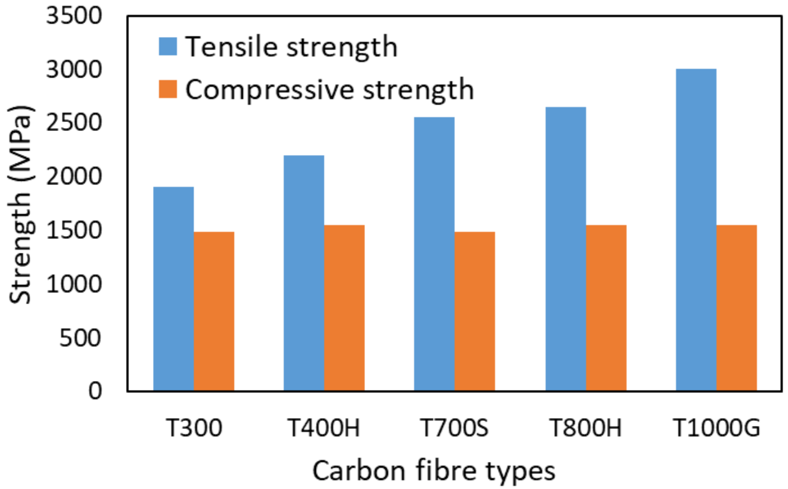
Background

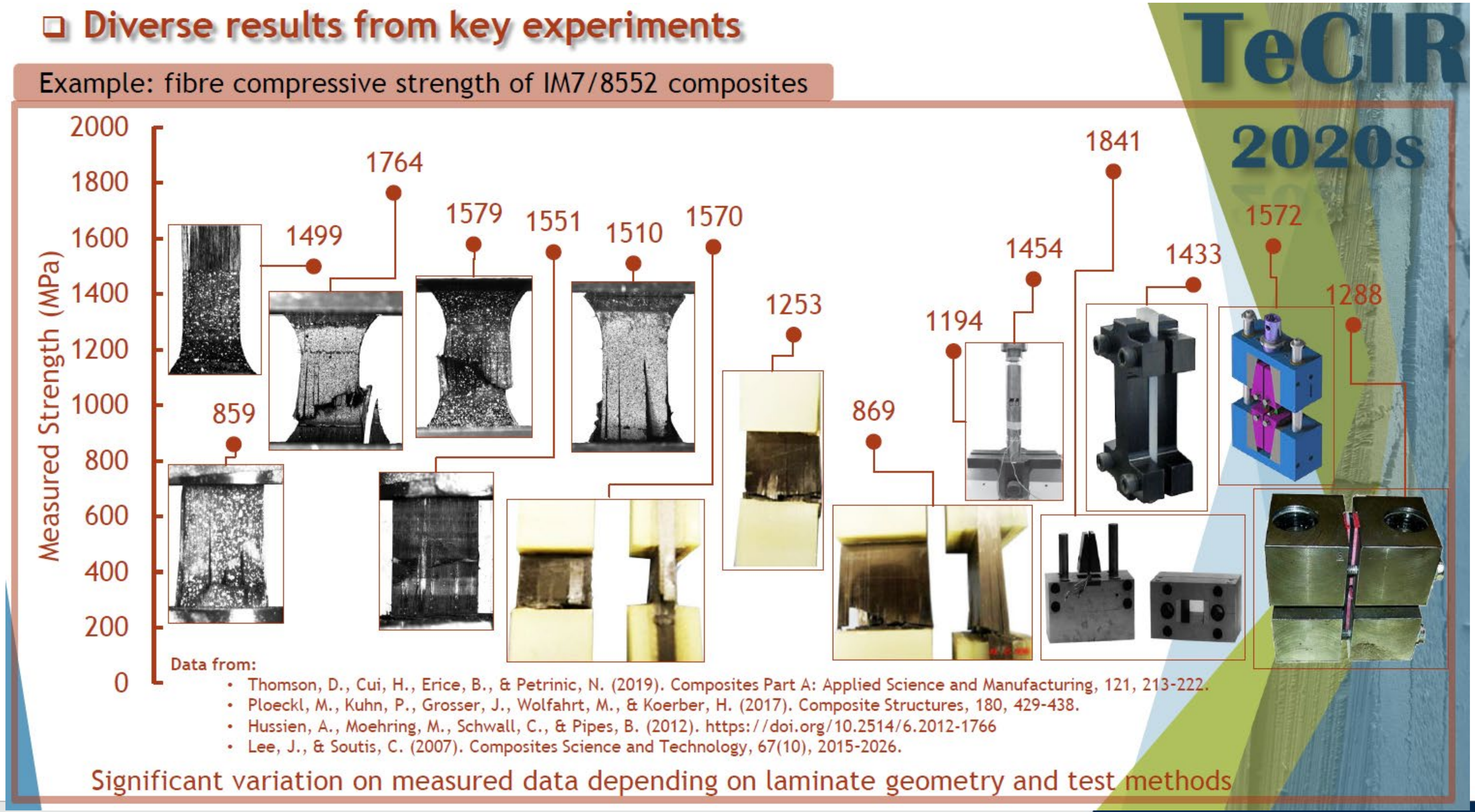
- Compressive strength is a key limitation for composite structures
- Typically significantly lower than tensile strength
- Open hole compressive strength and Compression After Impact (CAI) are design drivers
- Very difficult to measure compressive strength accurately
- Low values and high variability in many tests





Ueda, 2023

Variations in reported strength of UD IM7/8552

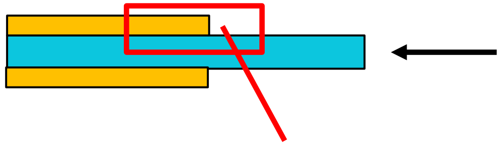


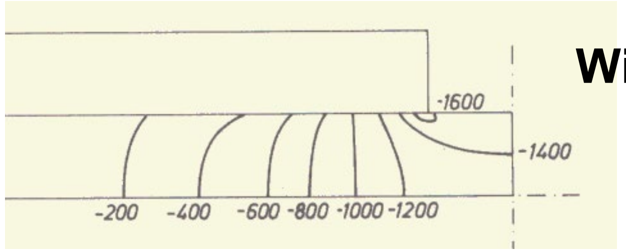
More than factor of 2 difference!

Hao Cui, Cranfield, NWPU Suzhou

Compression testing

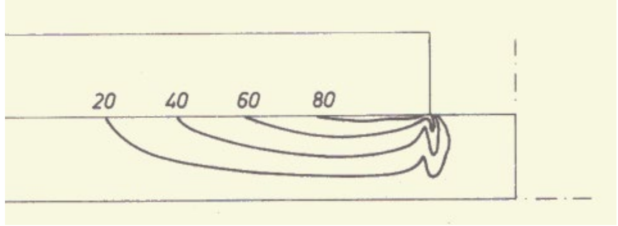
- Load introduction causes stress concentrations
- Shear stresses present, which reduce strength
- Normally get premature failure at grips
- Gauge section failures usually associated with buckling or defects





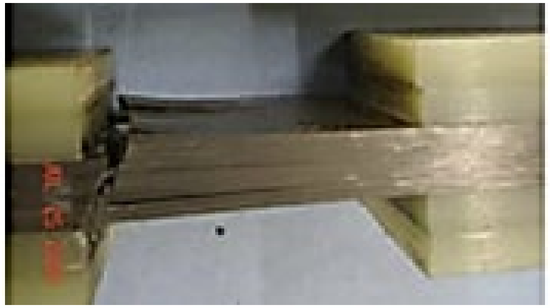
Wisnom, 1991

Compressive stress



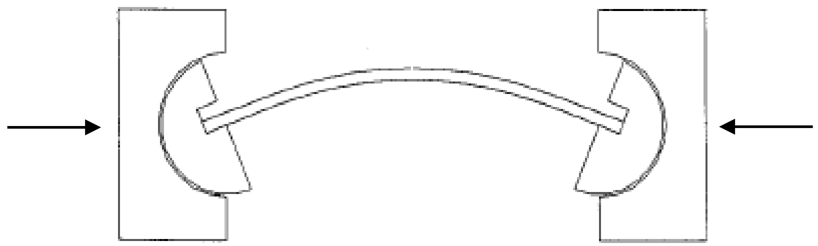
Interlaminar shear stress

Lee & Soutis, 2007



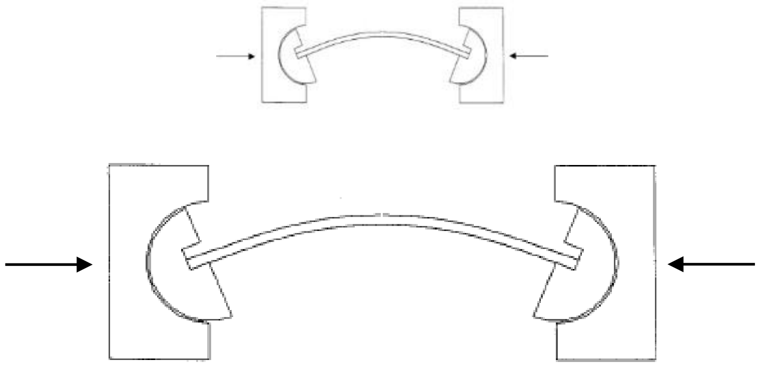
Flexural testing

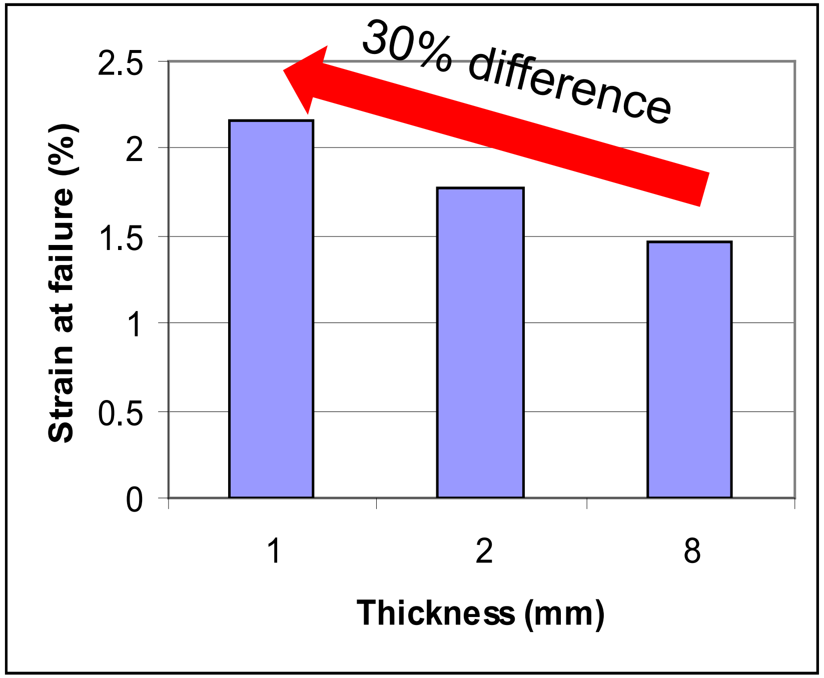
- Simple test and specimen preparation
- Four-point bending can produce compressive failure away from stress concentrations
- Pin-ended buckling tests completely eliminate stress concentrations and can give much higher failure strains
- BUT may overestimate the failure strain due to the effect of the strain gradient



Effect of strain gradient

- Scaled tests on T800/924 carbon-epoxy showed a strong effect of thickness
- Failure is due to shear instability at the micromechanical level
- With strain gradient, less stressed fibres support others, increasing failure strain





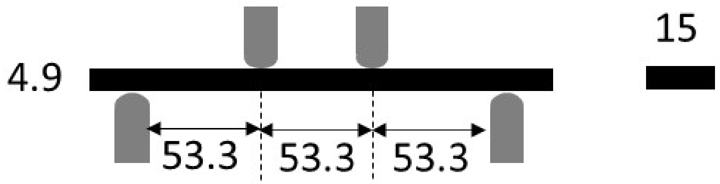
Wisnom, Atkinson and Jones, 1997

Overview

- Avoiding roller failure in bending tests
- Sandwich beam tests
- Evaluating the effect of strain gradient
- Measuring pseudo-ductile stress-strain response in compression using a bending test

Four-point bending

- ASTM D6272, span-to-thickness ratio 32:1
- Rubber pads under loading noses
- Standard loading nose diameter D=10 mm
  - Failed in compression, significant variability
  - 4 / 5 specimens failed at loading point
- Repeated with loading nose D=25 mm
  - 10 specimens all failed in gauge section
  - 18% higher strain at failure



D=10mm: Failure at loading noses

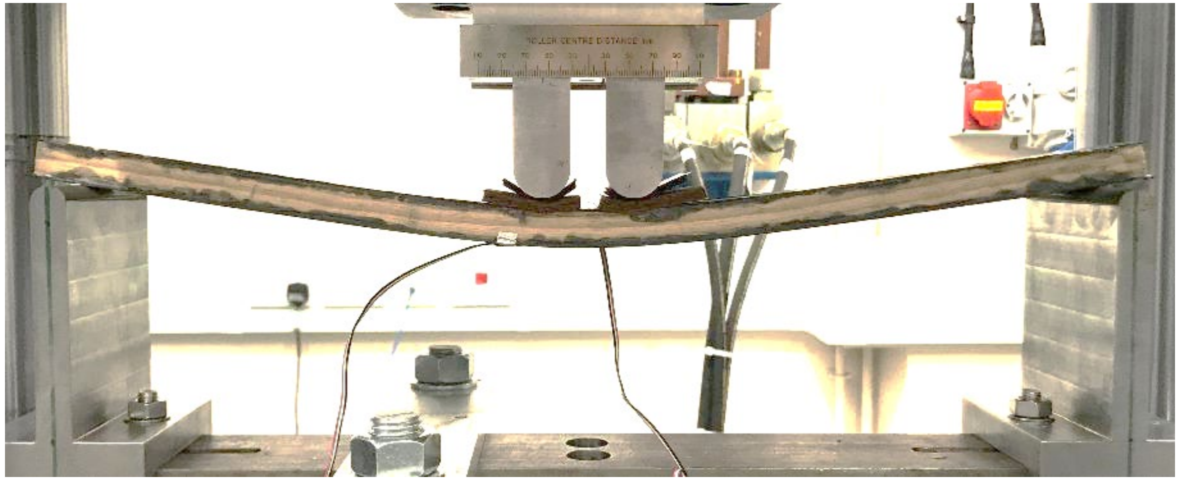
D=25mm: Failure in the gauge section

Loading nose D (mm)	Strain at failure(%) (CV)	No of samples
10	**-1.19 (13.2%)**	5
25	**-1.41 (7.5%)**	10

Wu & Wisnom, 2023

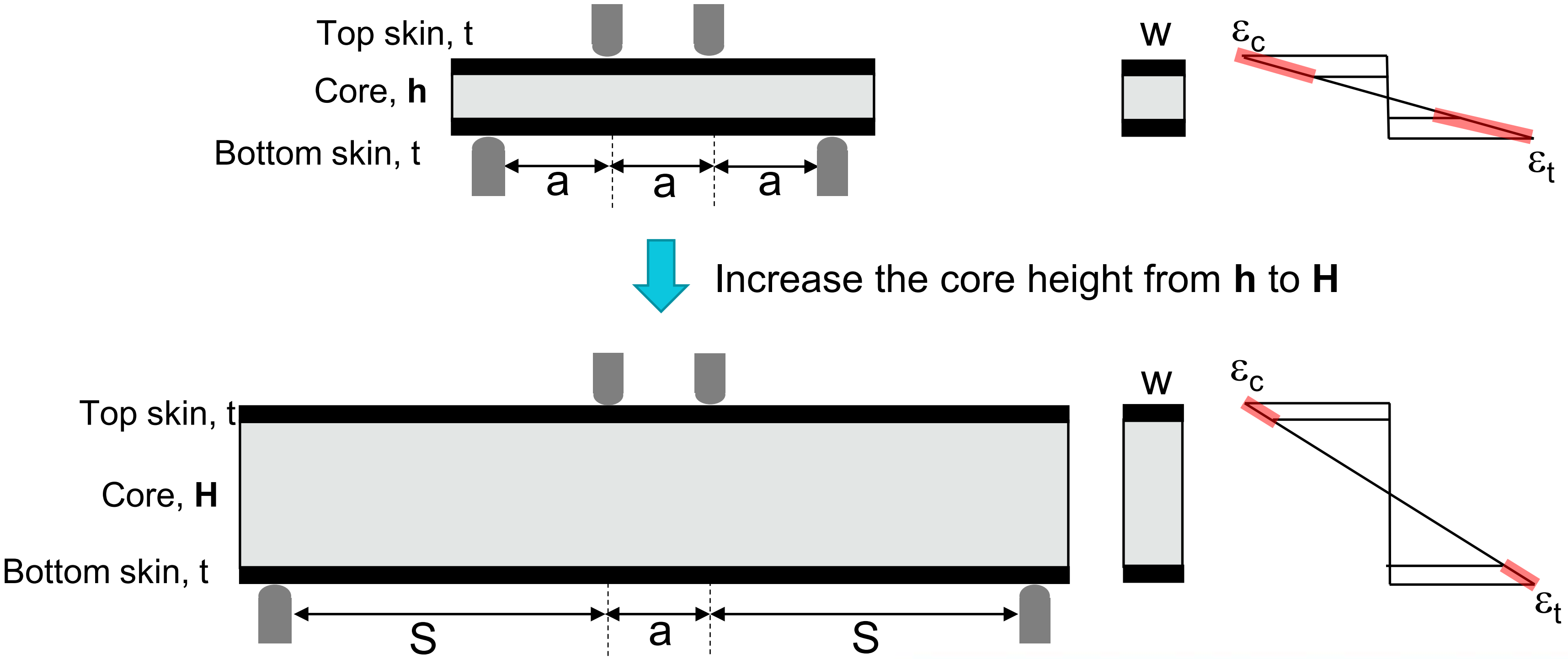
Avoiding strain gradient

- Sandwich beam with deep core
- Honeycomb can be used
- Relatively low shear strength
- Wood much stronger, easier to machine
- PMMA is alternative
- Skins bonded with epoxy



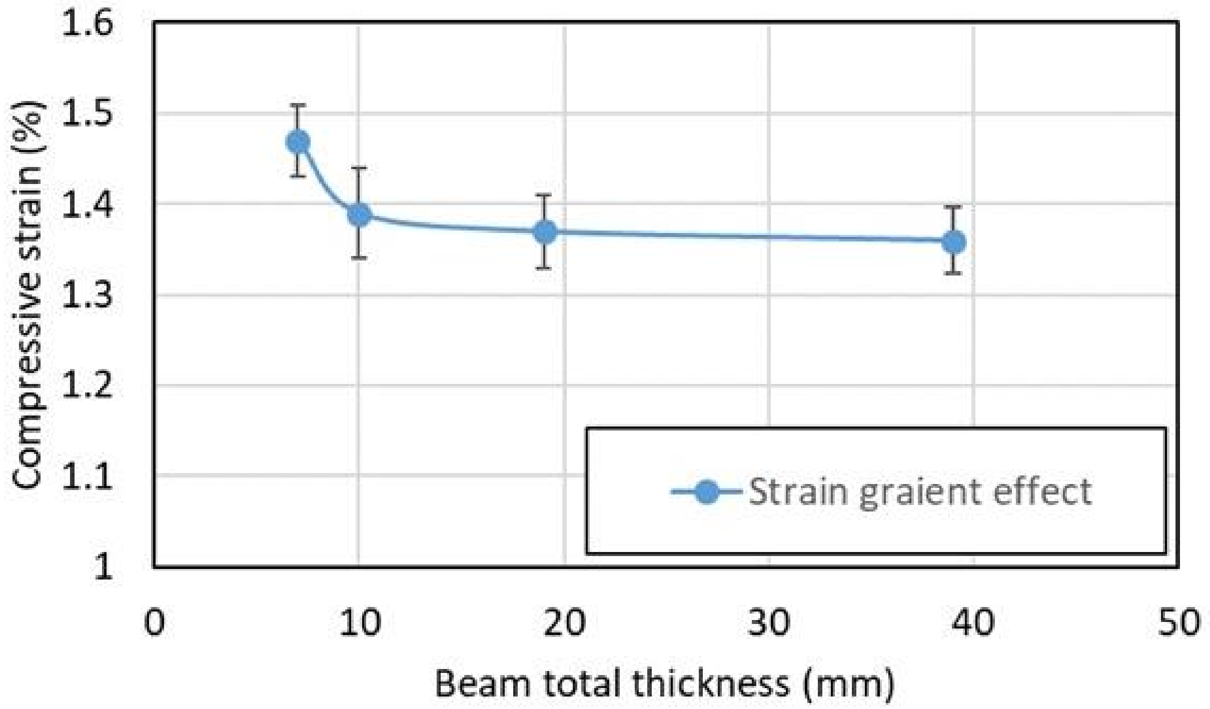
Sandwich beams – effect of strain gradient

- Vary depth of the beam to change strain gradient
- Keep gauge section dimensions the same
- Increase span to limit loading forces



Results - effect of strain gradient

- IM7/8552 carbon/epoxy skins, t = 0.5 mm
- Core t from 6 mm to 38 mm
- Little effect of strain gradient above 10 mm thickness
- 1.36% strain for 38 mm core
- 14% greater than 1.19%, highest reported in direct compression **(Thomson et al, 2019)**

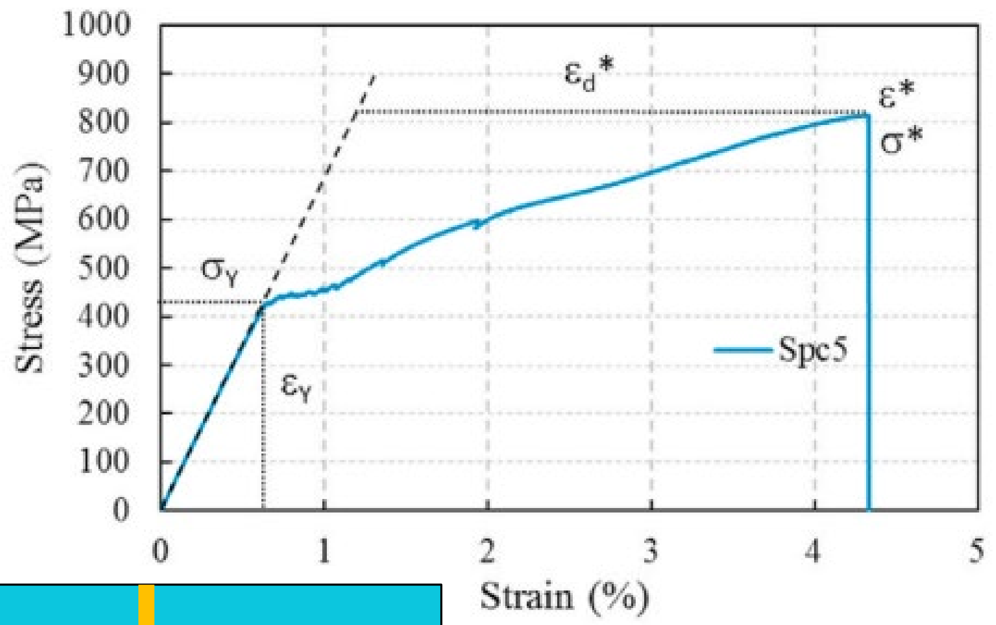


Pseudo-ductile composites

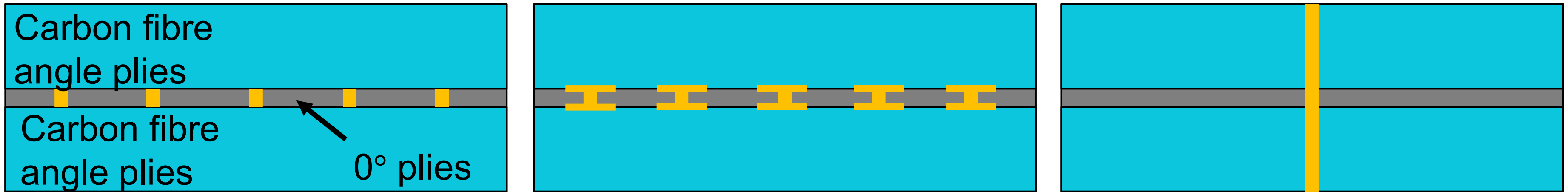
- Thin-ply carbon/epoxy angle-plies with central 0s

$[\pm 27_7/0]_s$

Standard modulus | High modulus



- Pseudo-ductile response in tension:



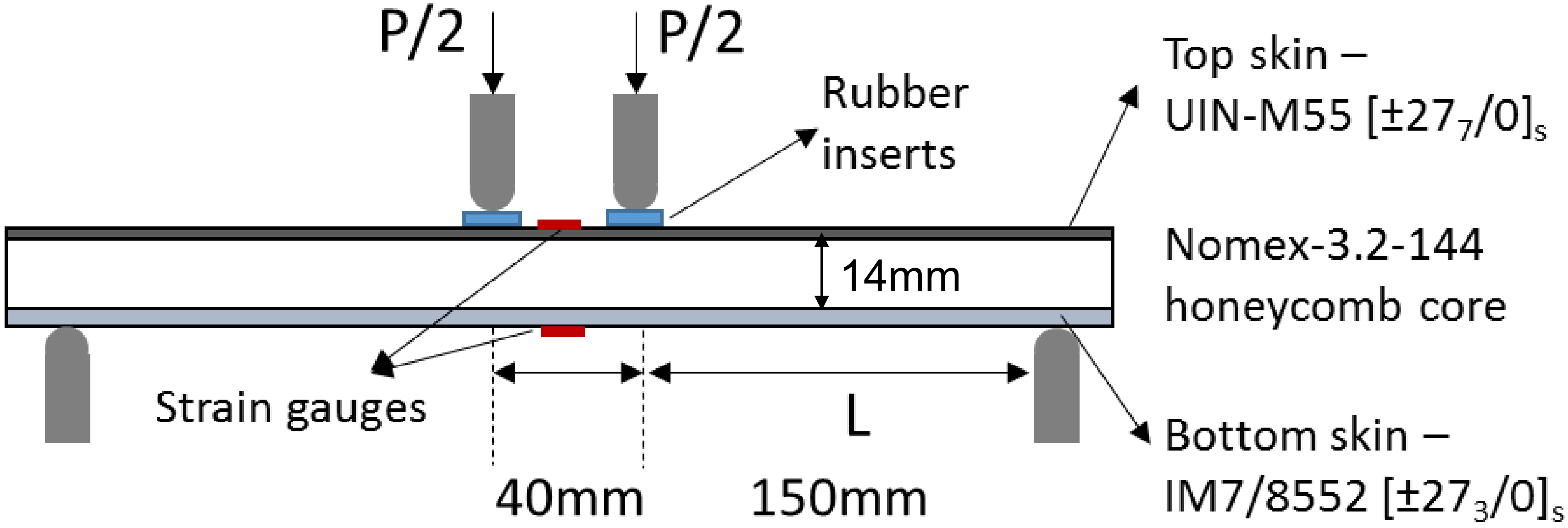
Fragmentation of UD plies | Dispersed delamination | Angle plies failure

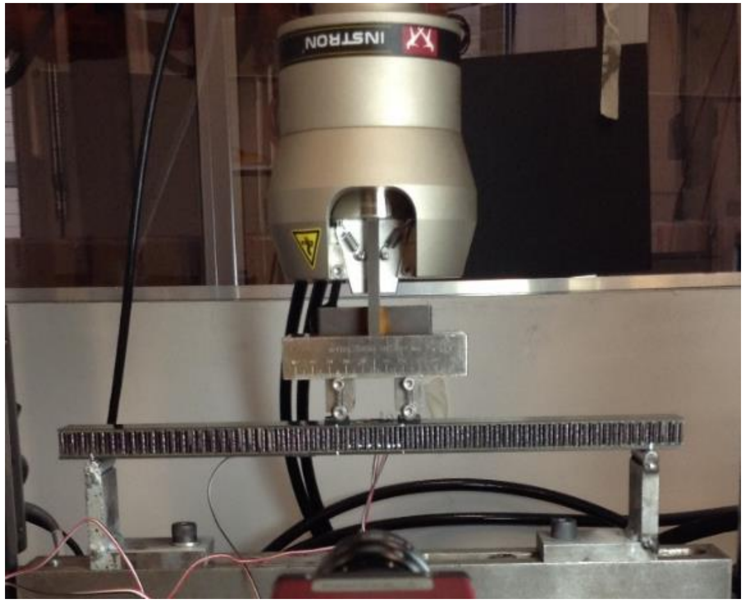
Edge view

Wu, Fuller, Wisnom, 2020

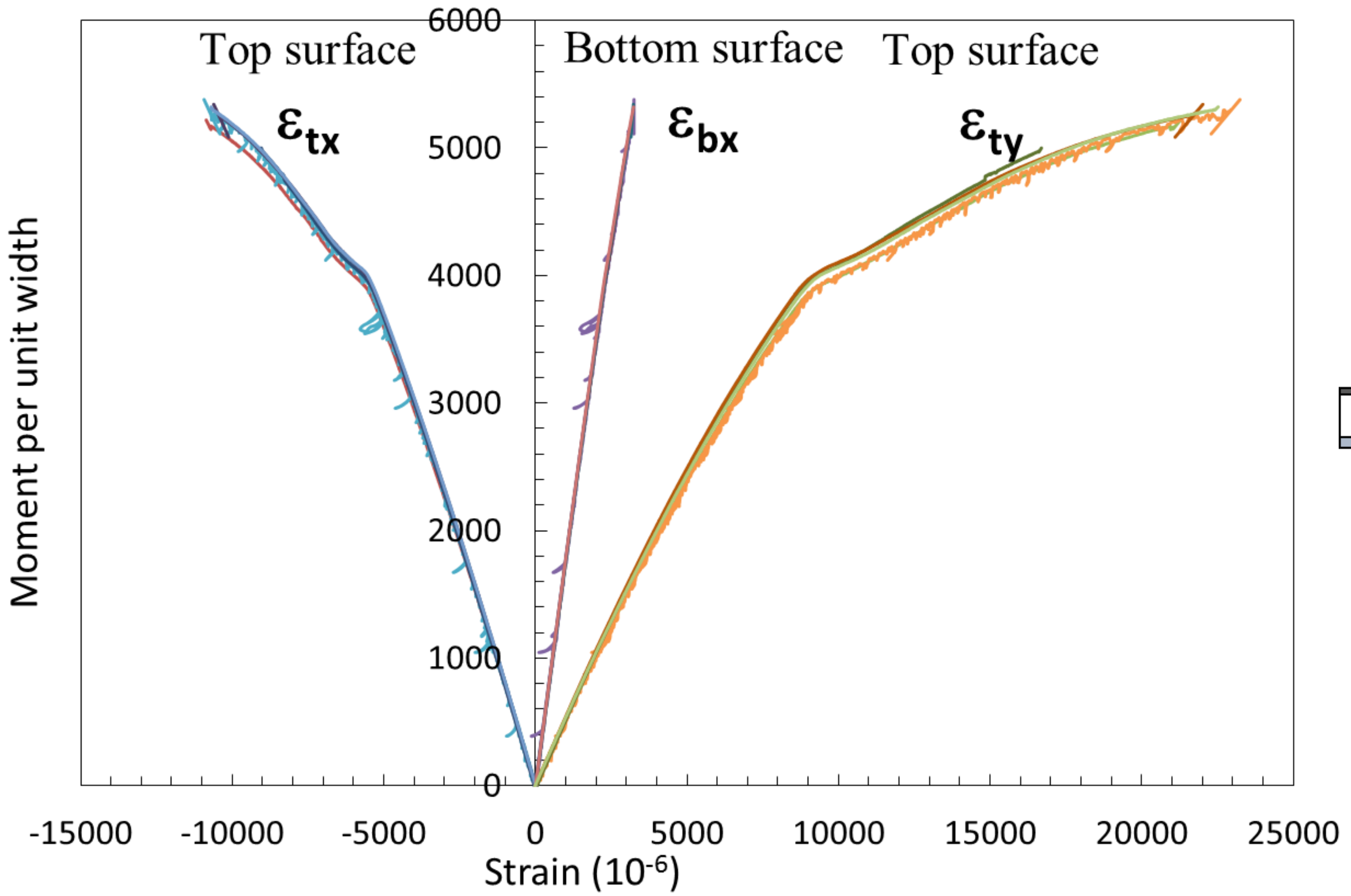
- What happens in compression?

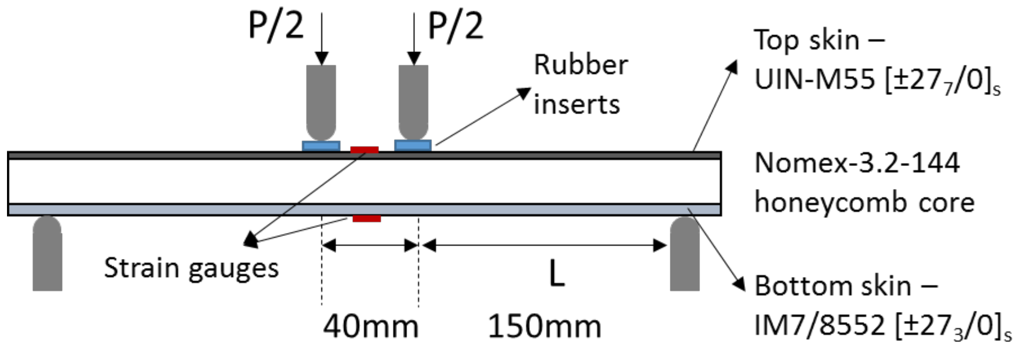
Sandwich beam - test setup





Results – surface strains against moment



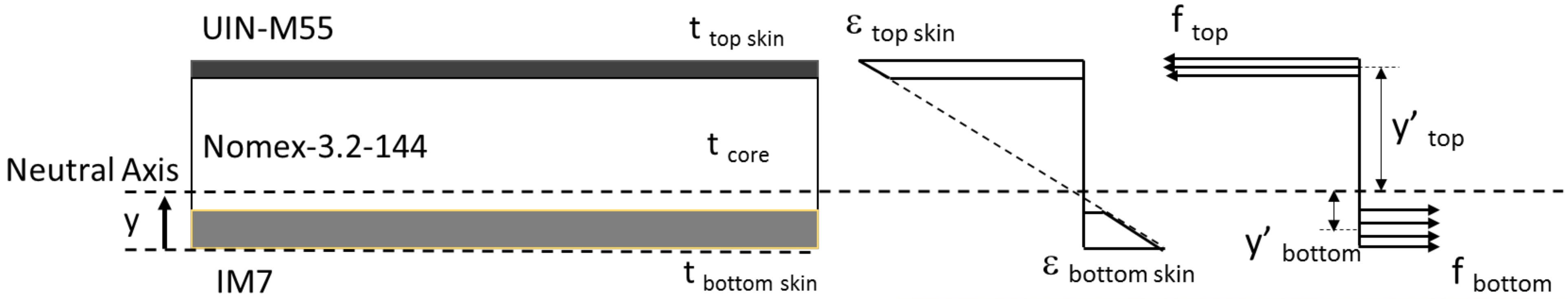


Sandwich beam set up

Results – stress evaluation

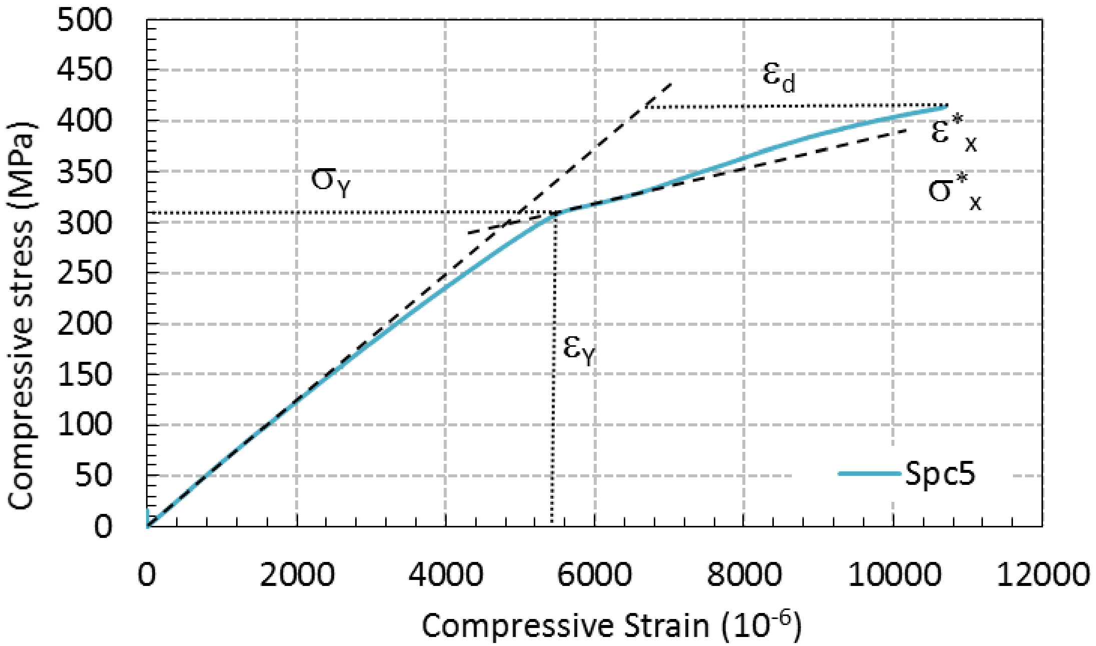
- Know moment from load and geometry
- Work out neutral axis position from strains based on linear strain variation
- Neglect contribution of core
- Load in tensile skin from strain and modulus
- Hence can calculate stress in compression skin

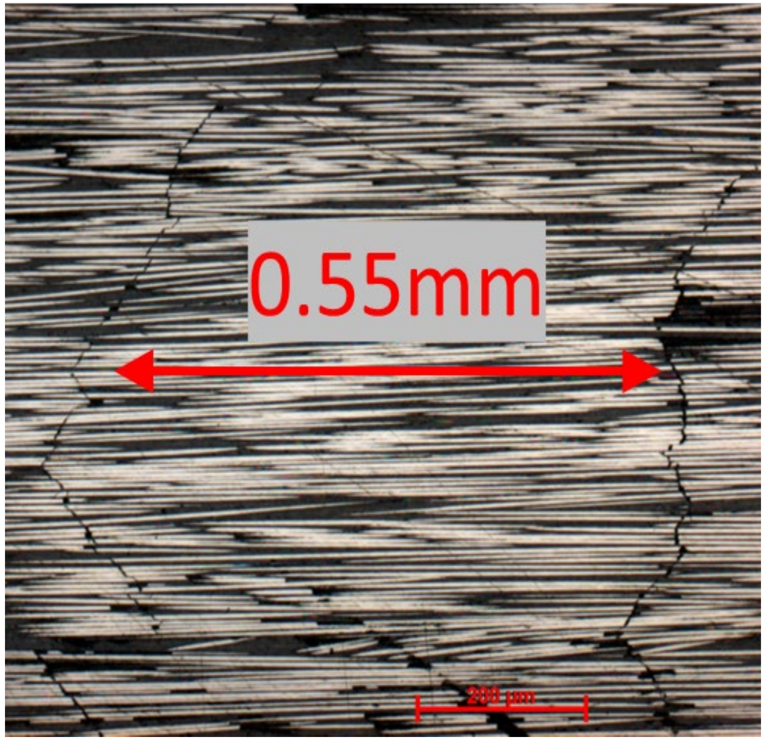
Neutral axis shifts relative to lower surface of the bottom skin



Stress-strain behaviour

- Pseudo-ductility in compression
- Nonlinear response with knee point
- Pseudo-ductile strain ε_d of 0.41%
- Fragmentation in 0º plies





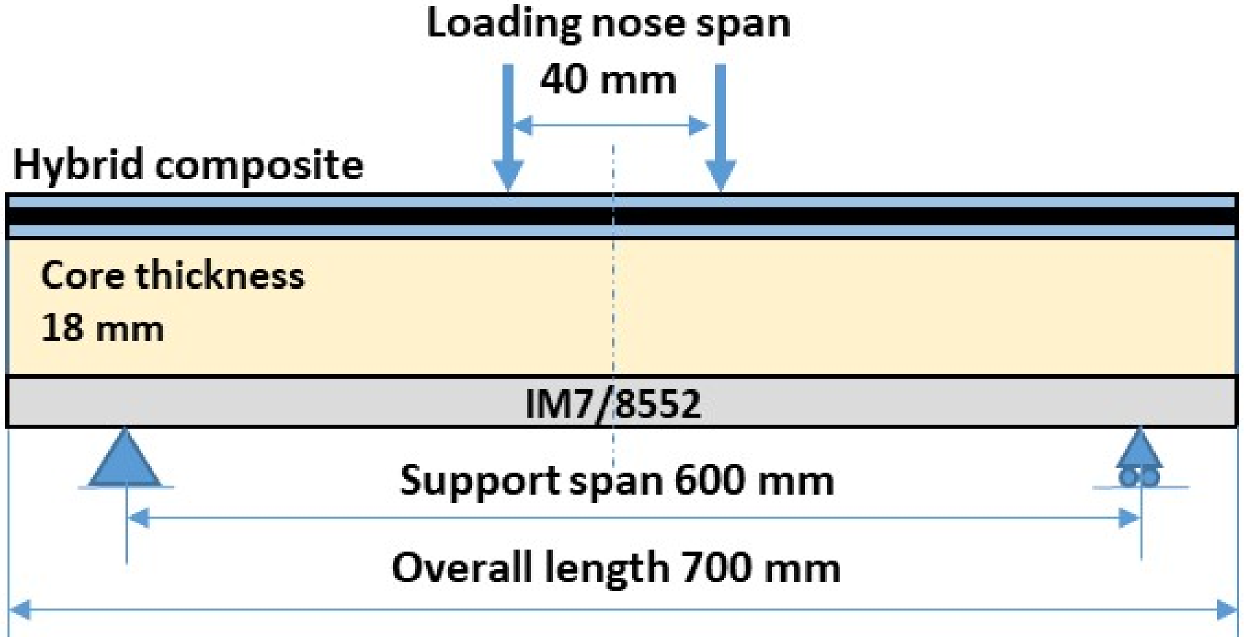
Ply fragmentation

Investigation of Compressive Behavior of Glass/Carbon Fibre Hybrid Composite with 4-point Flexural Test

Aree Tongloet

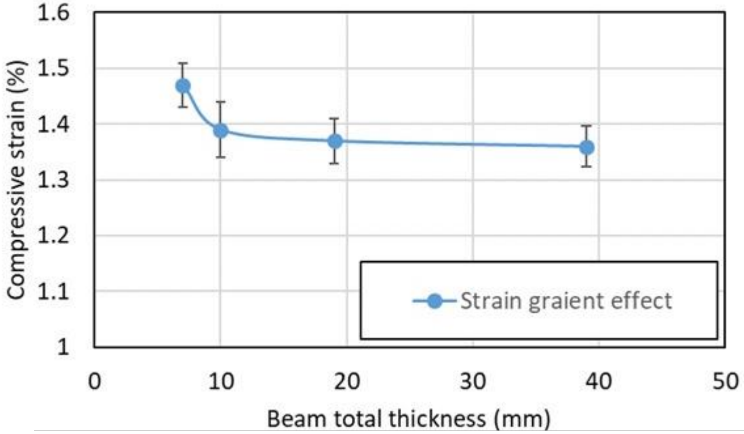
10.40 on Thursday, 3 August 2023

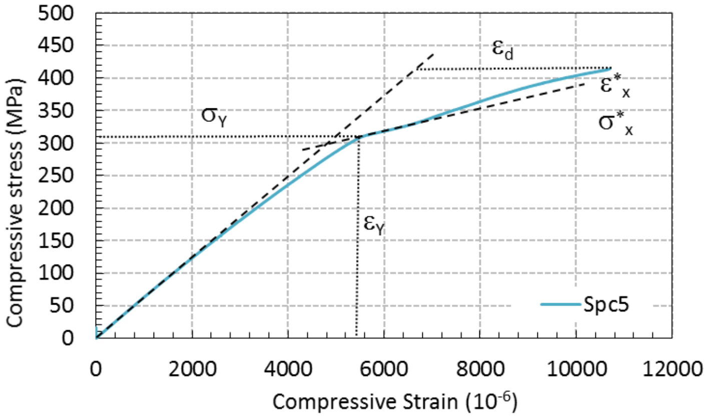
Hall 2A, Understanding & Improving Longitudinal Compressive Strength – Session 8



Conclusions

- Flexural tests can be used effectively to measure compressive response
- Need large rollers to avoid local failure
- Strain gradient effects have been quantitively measured - no strain gradient effect with deep sandwich beam
- Compressive pseudo-ductile stress-strain behaviour was demonstrated in thin-ply $[\pm 27_7/0]_s$ laminates from flexural tests





References

- D. Thomson, H. Cui, B. Erice and N. Petrinic "*A study on the longitudinal compression strength of fibre reinforced composites under uniaxial and off-axis loads using cross-ply laminate specimens*". Compos Part A Appl Sci Manuf, Vol. 121, pp 213–22, 2019. https://doi.org/10.1016/j.compositesa.2019.03.034
- M. R. Wisnom, J. A. Atkinson, and M. I. Jones *"Reduction in compressive strain to failure with increasing specimen size in pin-ended buckling tests*". Compos Science Techn, Vol. 57, pp 1303-1308, 1997. https://doi.org/10.1016/S0266-3538(97)00057-2
- X. Wu and M. R. Wisnom, "*Compressive failure strain of unidirectional carbon fibre composites from bending tests*". Composite Structures, Vol. 304, 116467, 2023. https://doi.org/10.1016/j.compstruct.2022.116467
- X. Wu, J. D. Fuller and M. R. Wisnom "*Role of fibre fragmentation on pseudo-ductility of thin-ply* $[\pm 27_7/0]_s$ *carbon fibre laminates with high modulus 0◦ plies under compressive and flexural loading*". Composites Science and Technology Vol. 199, 108377, 2020. https://doi.org/10.1016/j.compscitech.2020.108377
- M. R. Wisnom, "*Effect of Shear Stresses in Indirect Compression Tests on Unidirectional Carbon Fibre-Epoxy »*, AIAA Journal, Vol. 29, pp 1692-7, 1991. https://doi.org/10.2514/3.10792
- J. Lee, C. Soutis *"A study on the compressive strength of thick carbon fibre–epoxy laminates"* Compos Science Techn, Vol. 67, 2015-2026, 2007. https://doi.org/10.1016/j.compscitech.2006.12.001

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Thank you

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