Failure Mechanisms and Strain Distribution in Aramid-Reinforced Aluminium Laminates under Uniaxial Tension

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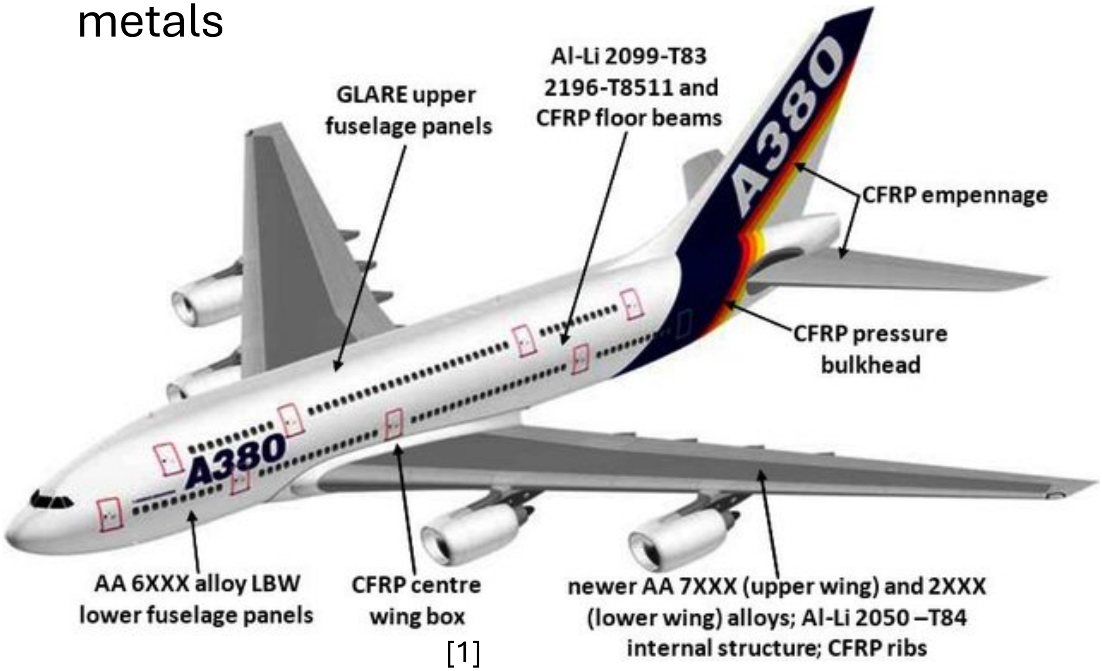
Introduction

- Fibre-Metal Laminates (FMLs) are laminate structures of fibre (yarn) reinforced-composites and metals
- Typical: Aramid-Aluminium laminates (ARALL), Glass Reinforced Laminates (GLARE) etc
- Combine the stiffness of composites and the damage tolerance (fatigue, impact) of metals



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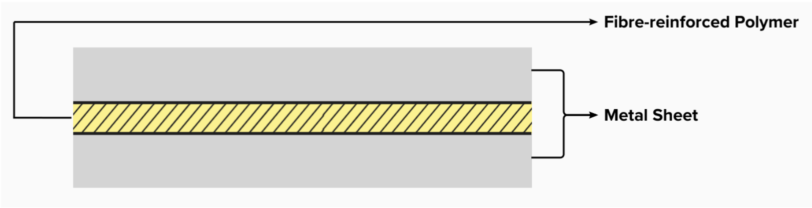
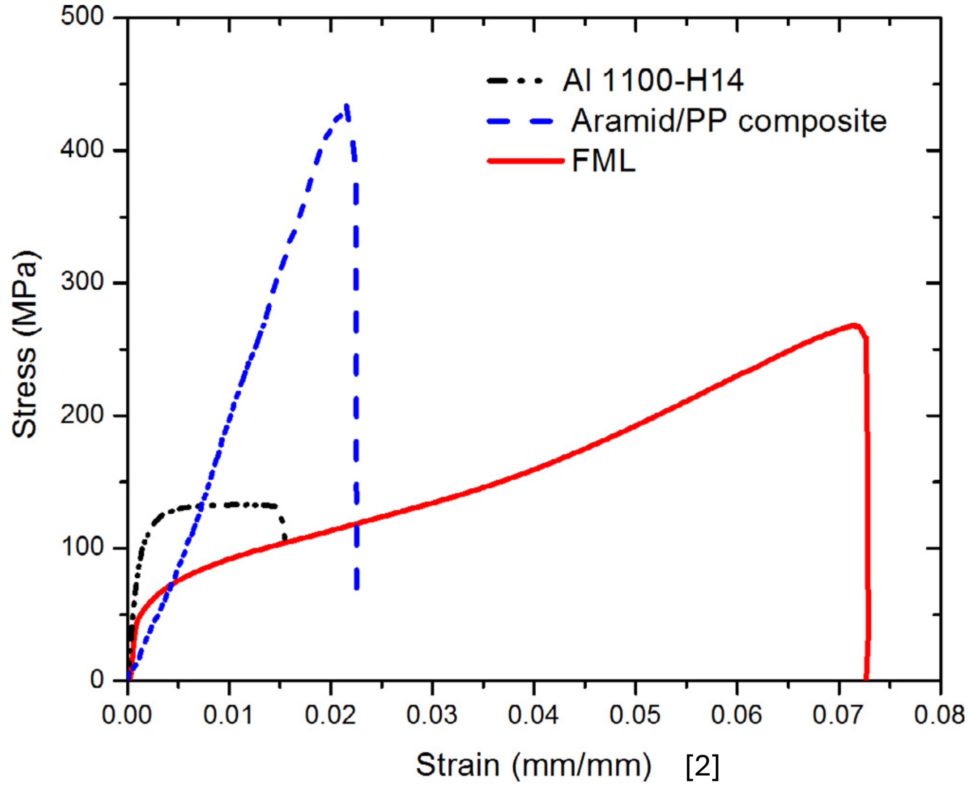


[1] Wanhill RJH. Carbon Fibre Polymer Matrix Structural Composites. Aerospace Materials and Material Technologies, 2016, 309–41

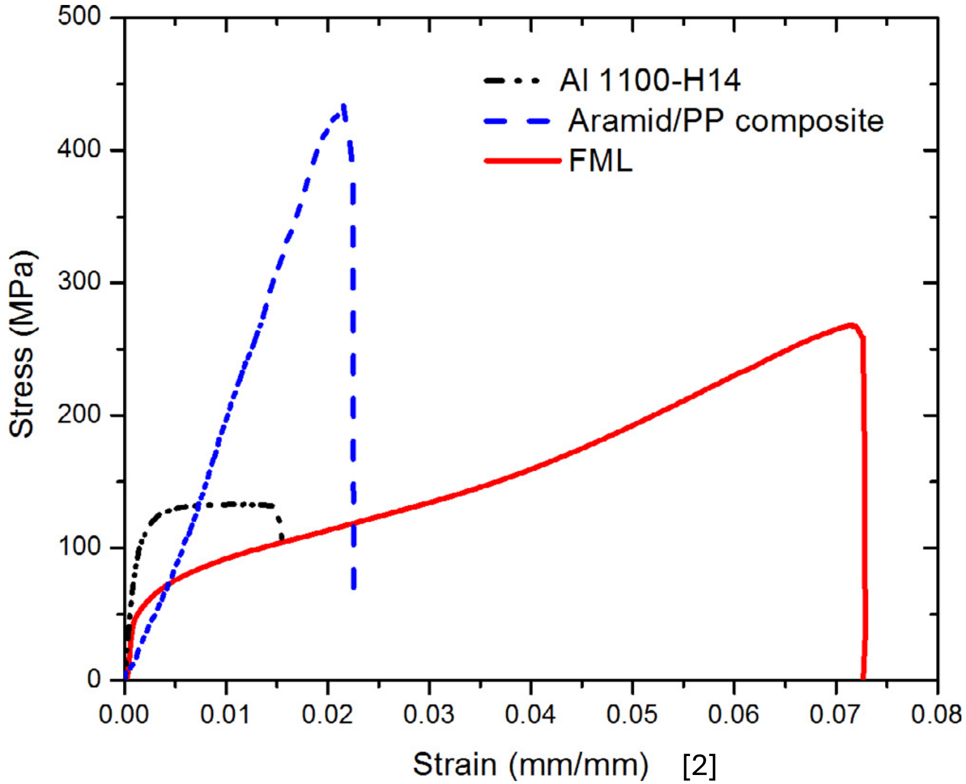
Introduction



- Previous research on ARALL systems has shown an increased ductility in uniaxial tension, well above that of the individual phases

[2] N.G. Gonzalez-Canche , E.A. Flores-Johnson, J.G. Carrillo, Composite Structures, 172 (2017) 259–266

Introduction

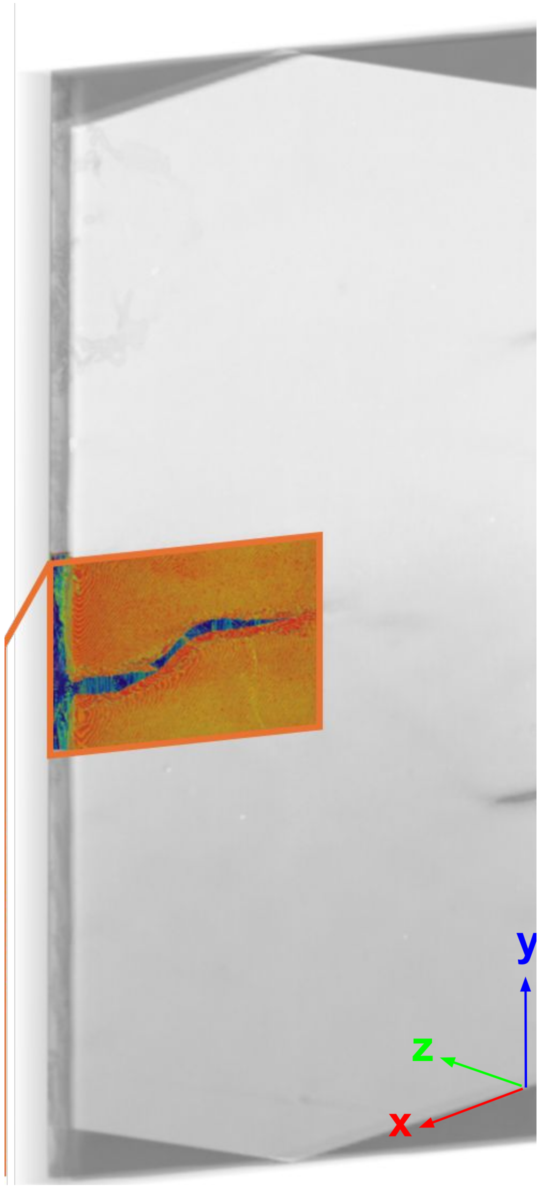


[2]

Research Questions

1. How does the strain distribution evolve with applied strain?
2. Role of strain localisation at the onset and evolution of failure
3. Role of microscopic deformation mechanisms during failure

[2] N.G. Gonzalez-Canche , E.A. Flores-Johnson, J.G. Carrillo, Composite Structures, 172 (2017) 259–266



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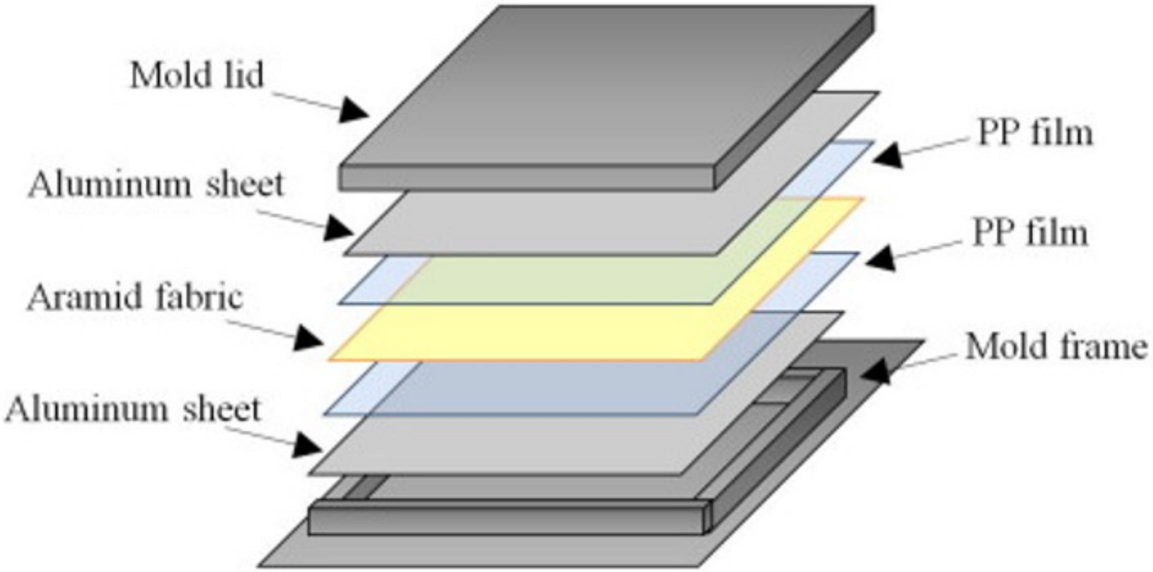
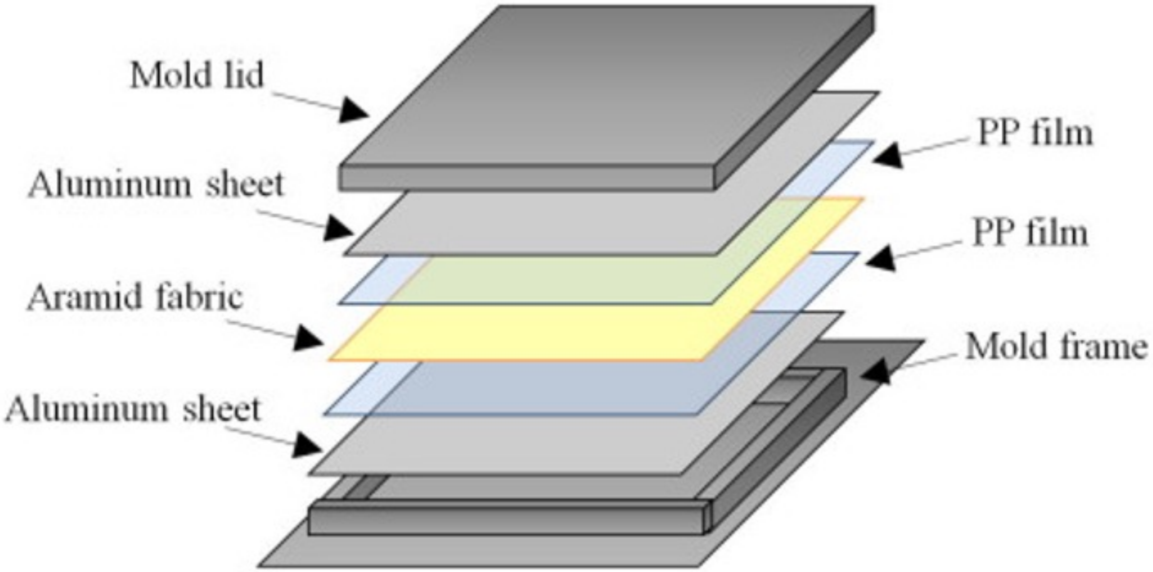
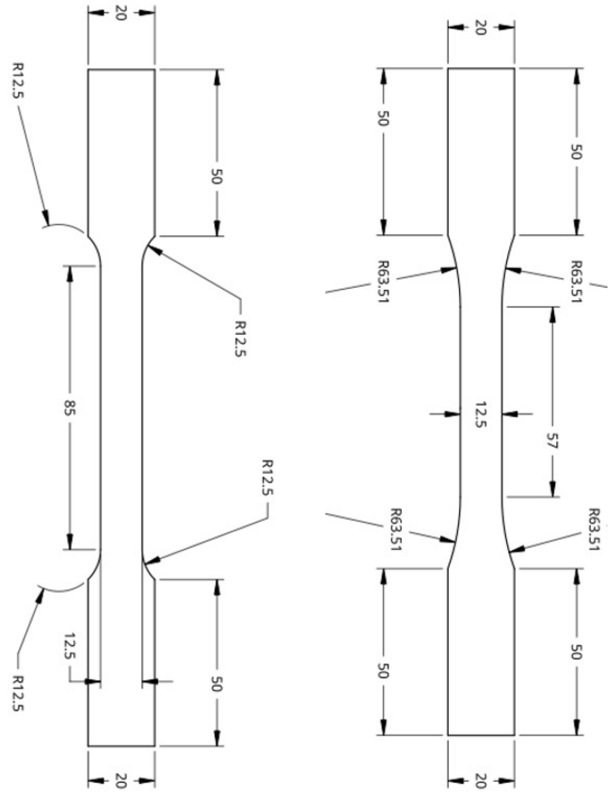
Specimen Manufacturing and Testing



- FML Construction: Plain-woven aramid fabric (style 724, Kevlar 129 fiber, 1000 denier) + PP film (0.2 mm) + AA1100-H14 aluminium alloy sheet (0.3 mm)
- Fabric orientation: 0°/90° and ±45°
- Thermo-molded at 175 °C and 2 MPa for 20 min

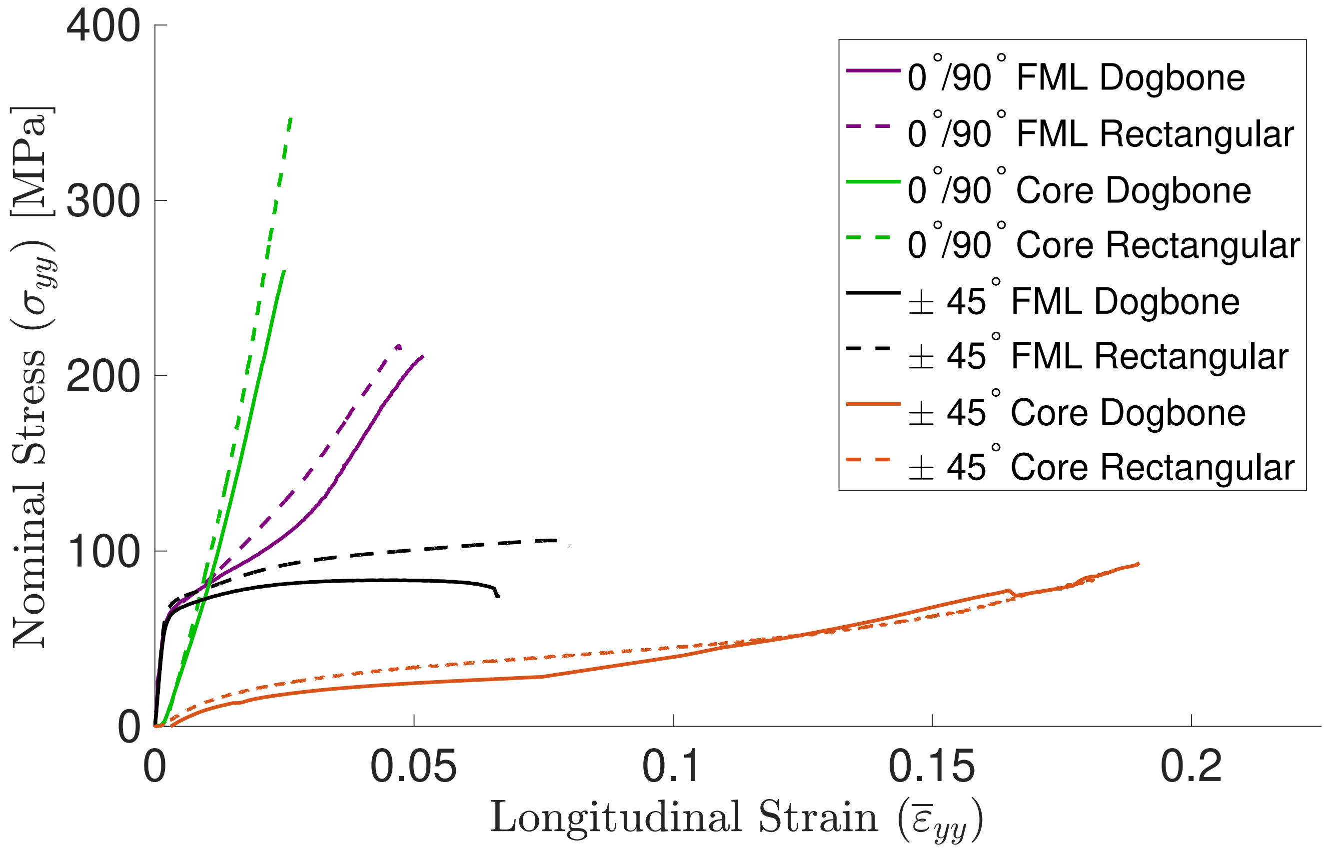
Specimen Manufacturing and Testing



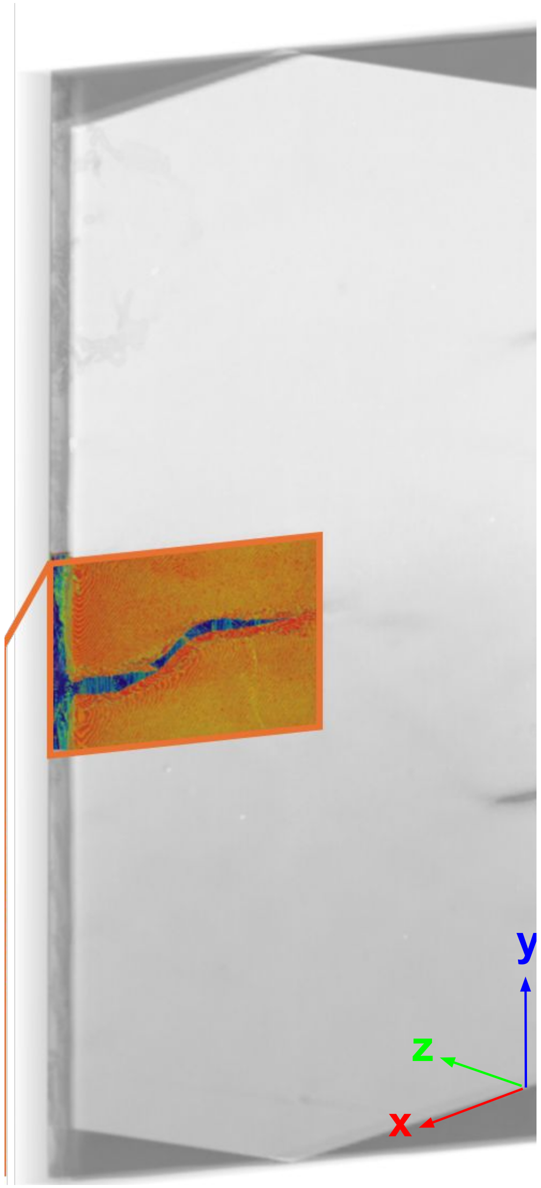


- Tensile testing: ASTM D3039 (FRPs; rectangular specimens); ASTM E8 (metals; dumbbell specimens)
- Strain field measured with DIC technique (Correlated Solutions VIC-3D)

Benchmarking of Mechanical Response



- Rectangular specimens fail at grip interface – challenging to measure localised strain distribution
- Modified dumbbell geometry provides equivalent response and was used here



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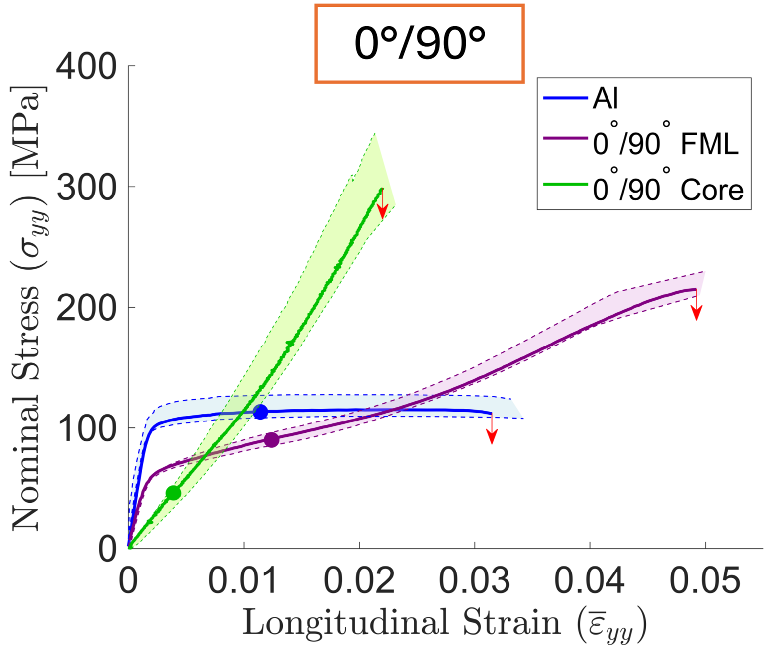
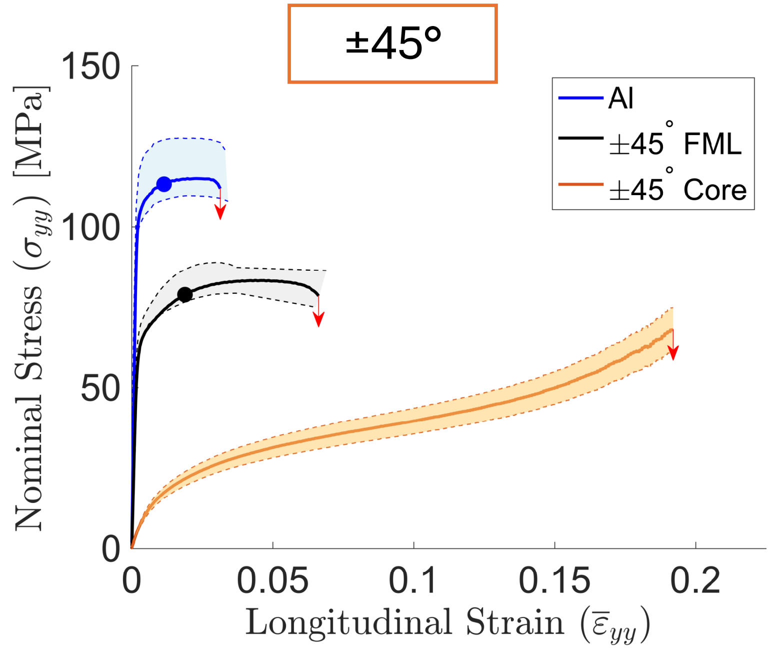
Tensile Response of ARALL Composites

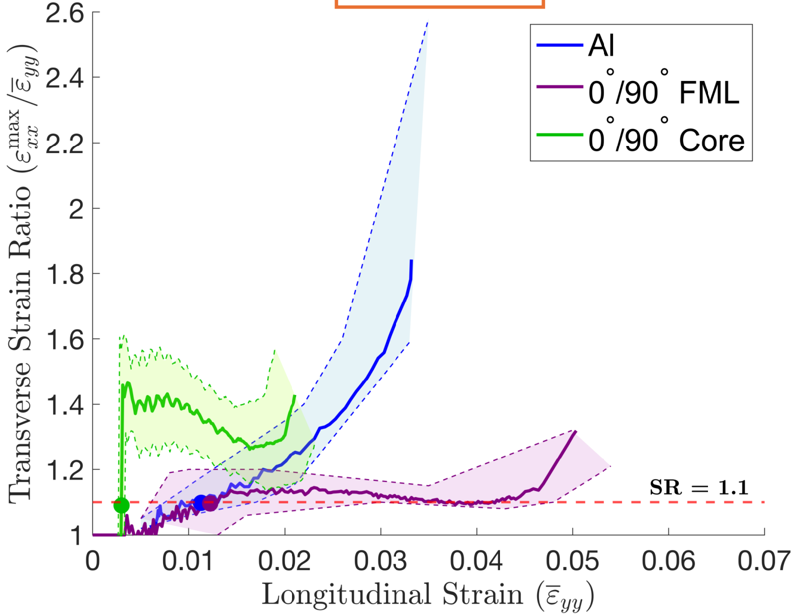




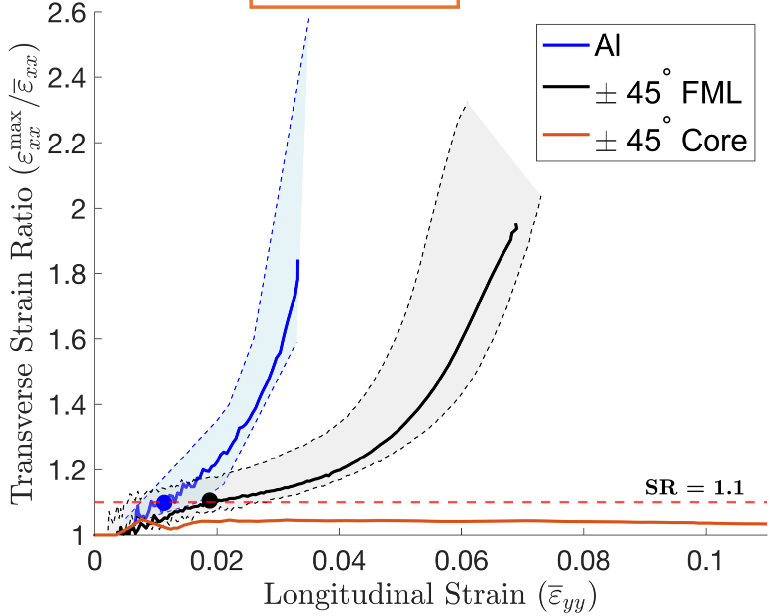
- 0° /90° system: Failure strains: 0.030 (AA1100); 0.025 (Aramid/PP core); 0.050 (FML)
- ±45° system: Failure strains: 0.030 (AA1100); 0.20 (Aramid/PP core); 0.080 (FML). Initial elastoplastic response corresponds to rule of mixtures (isostrain) predictions

Transverse Strain Ratio Evolution

0° /90°

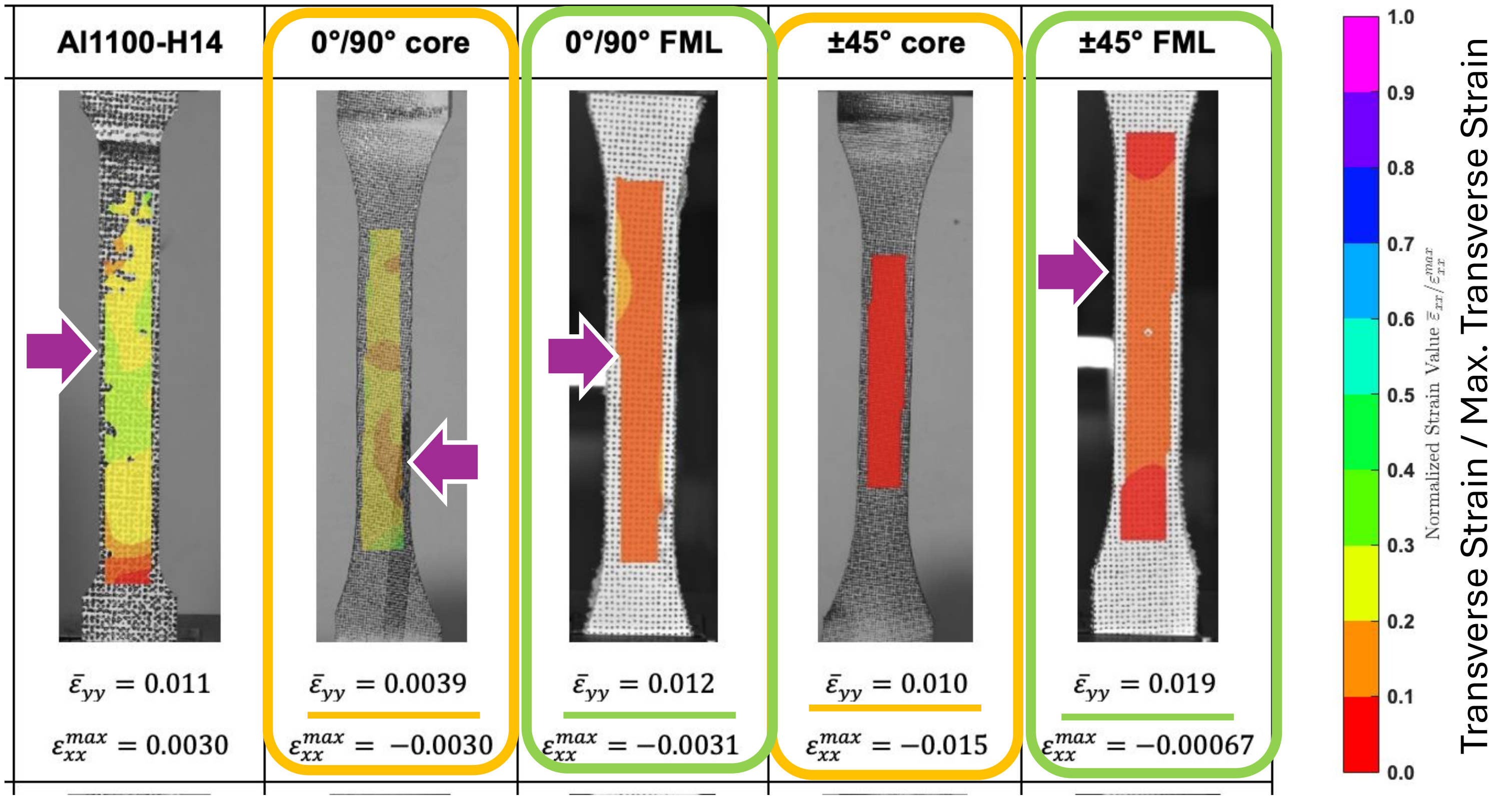


±45°



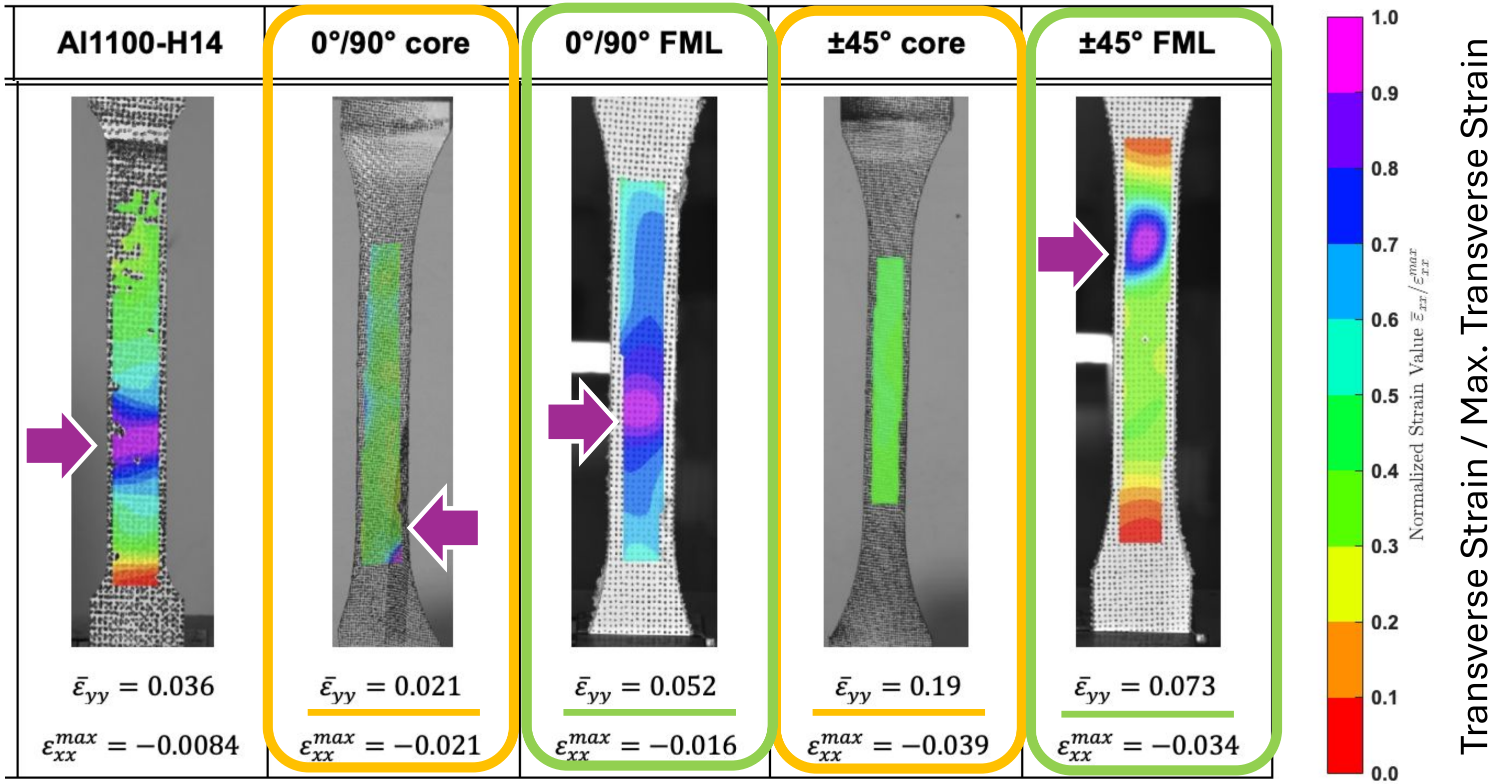
- Transverse strain ratio (SR) = max transverse strain / mean transverse strain in gauge area. Indicates instance of strain localisation.
- SR = 1.1 corresponds to max stress (initiation of diffuse necking) in AA1100
- Core response: very early localisation in 0°/90°, no localisation in ±45°
- FML response: delayed strain localisation – minor in 0°/90° but no growth

Transverse Strain Distribution at Onset of Localisation (SR = 1.1)



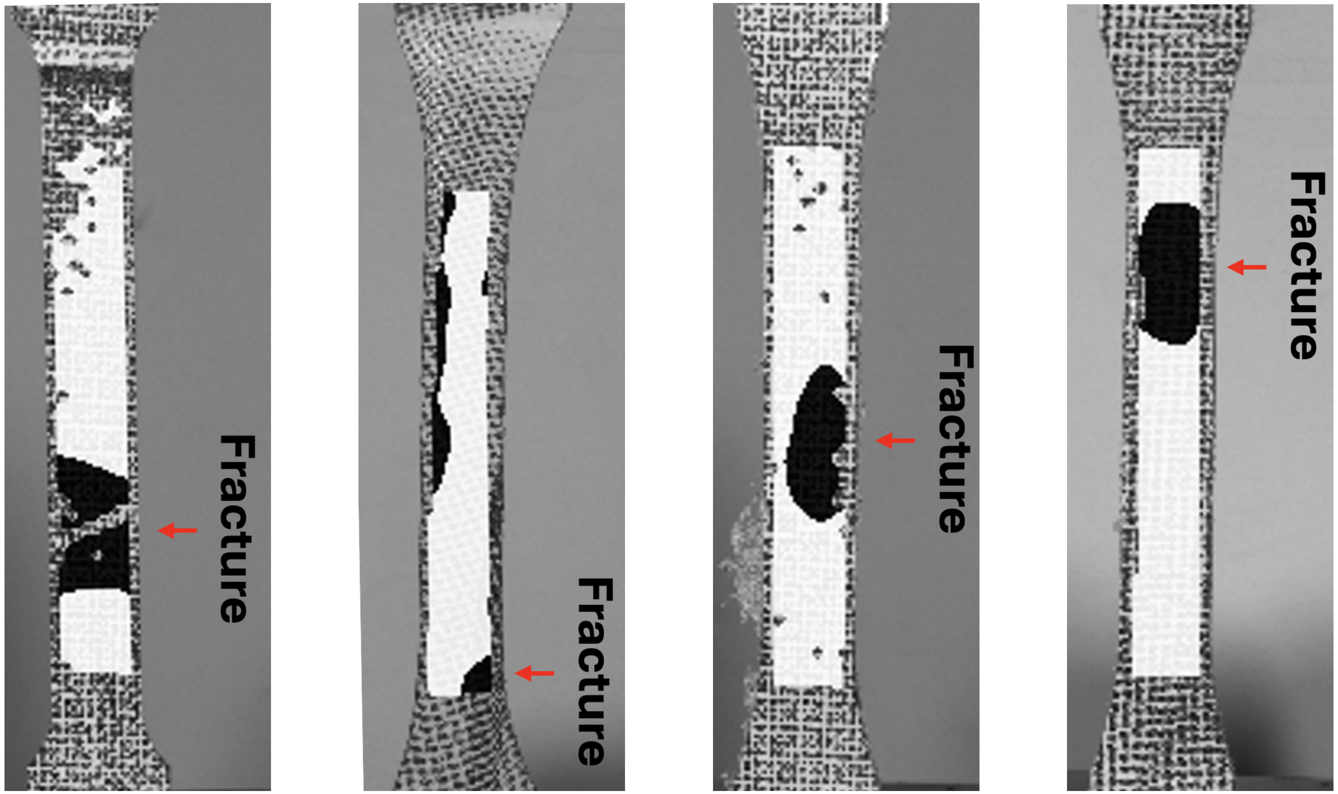
- Core behaviour: very early localisation in 0°/90°, no localisation in ±45°
- FML behaviour: delayed localisation in facesheet (minor in 0°/90°) -> core induces uniform deformation

Transverse Strain Distribution at Fracture



- Core behaviour: Very localised propagation in 0°/90°, no localisation in ±45°
- FML behaviour: Propagation via localised necking in Al facesheets in both orientations
- Extent (area fraction) of strain localisation?

Localised Deformation Area Fraction

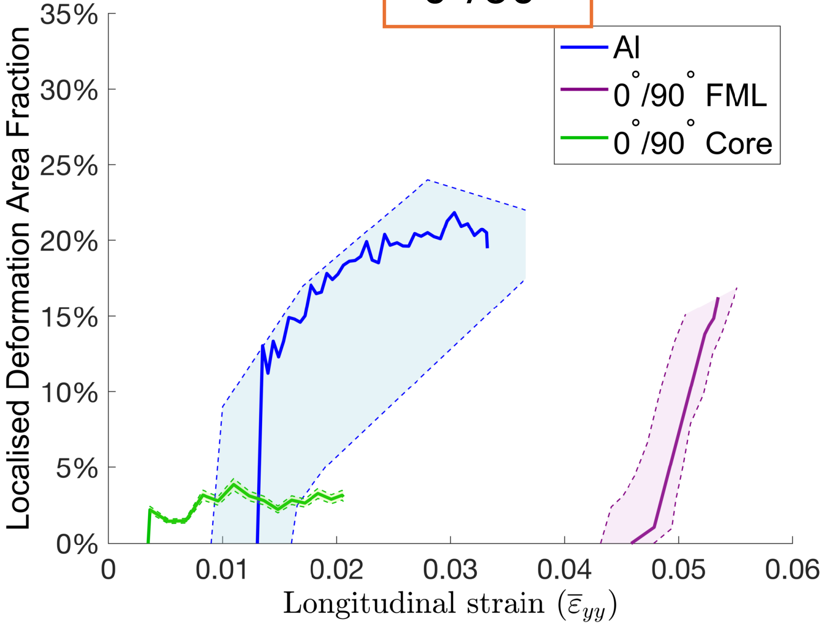


AA1100 | 0°/90° core | 0°/90° FML | ±45° FML

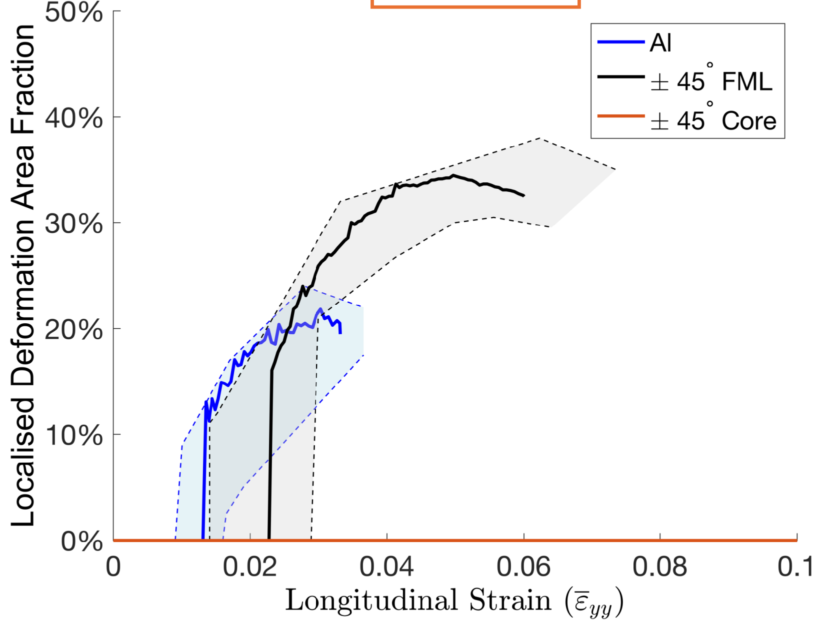
- Area Fraction = Area of localised deformation (strain ratio >1.1) / Gauge Area
- Evolution can give insight on redistribution of strain with axial deformation

Evolution of Localised Deformation A.F.

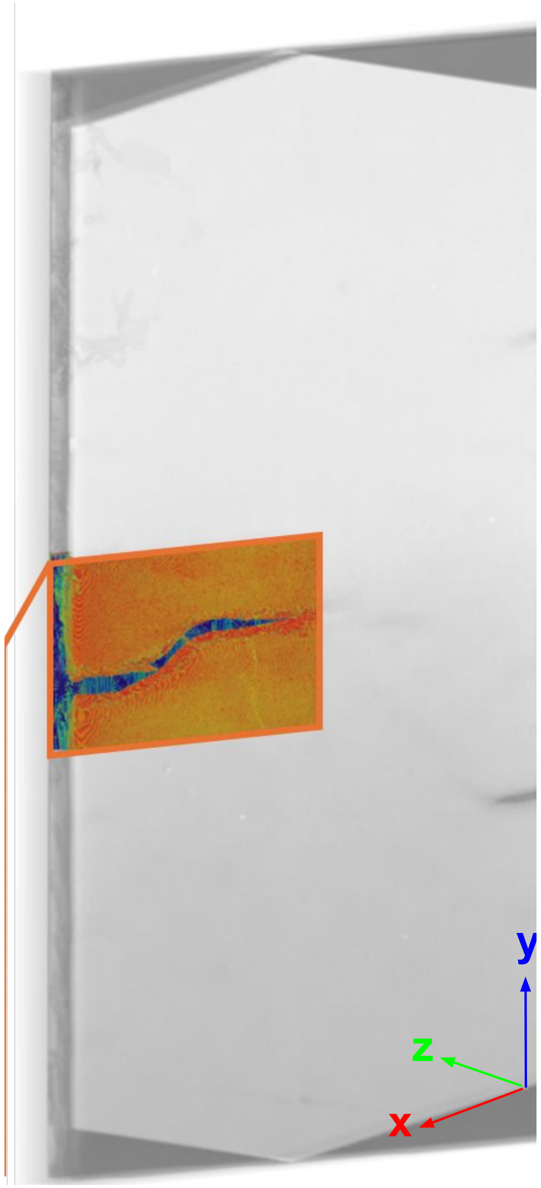
0°/90°



±45°



- Diffuse and localised necking + fracture in A1100
- Localised deformation only in 0°/90° core - no growth
- Delay of growth in 0°/90° FML due to strain redistribution – followed by localised necking
- Uniform deformation only in ±45° core
- Delay of localisation in ±45° FML, diffuse and localised necking



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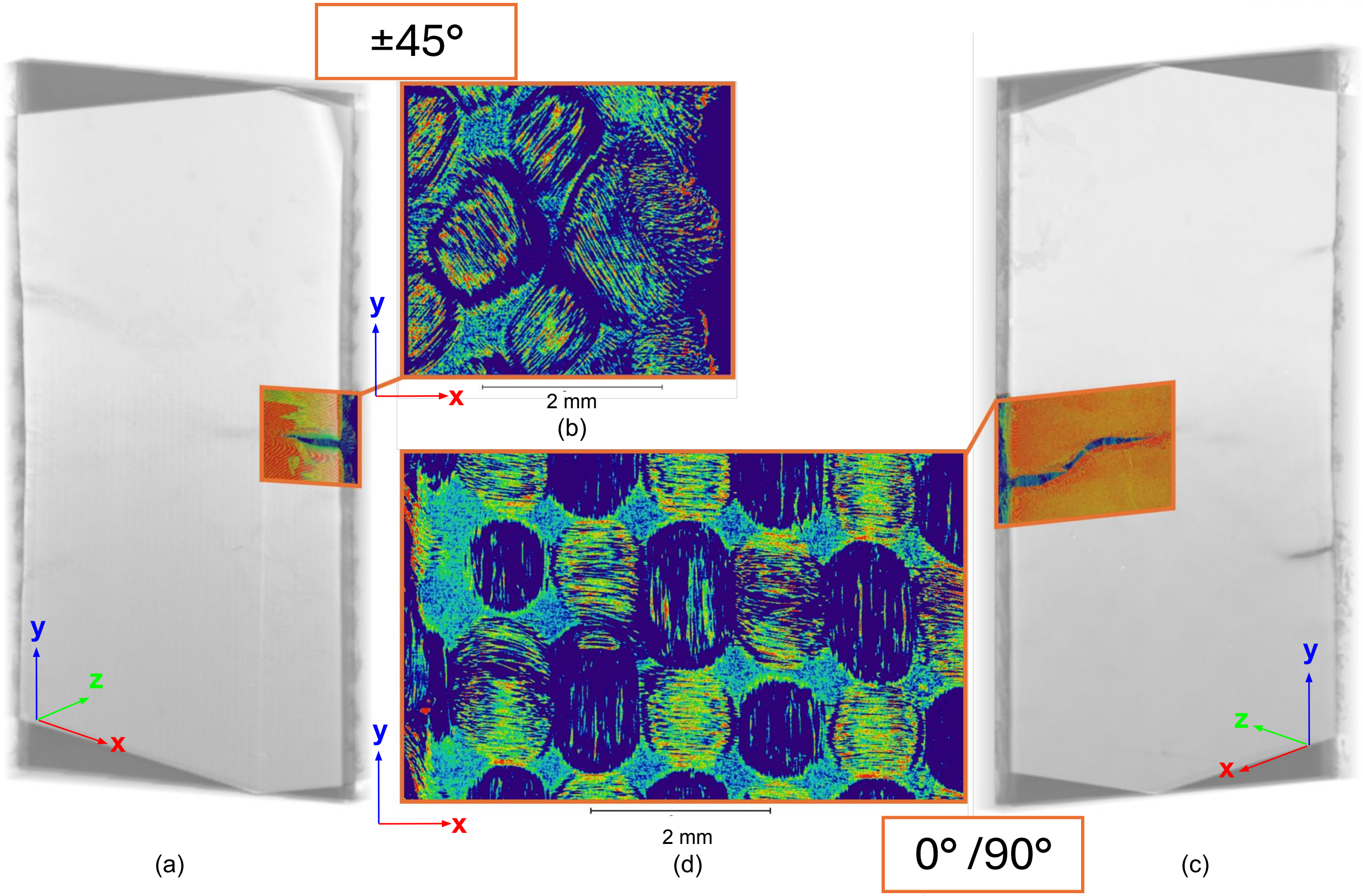
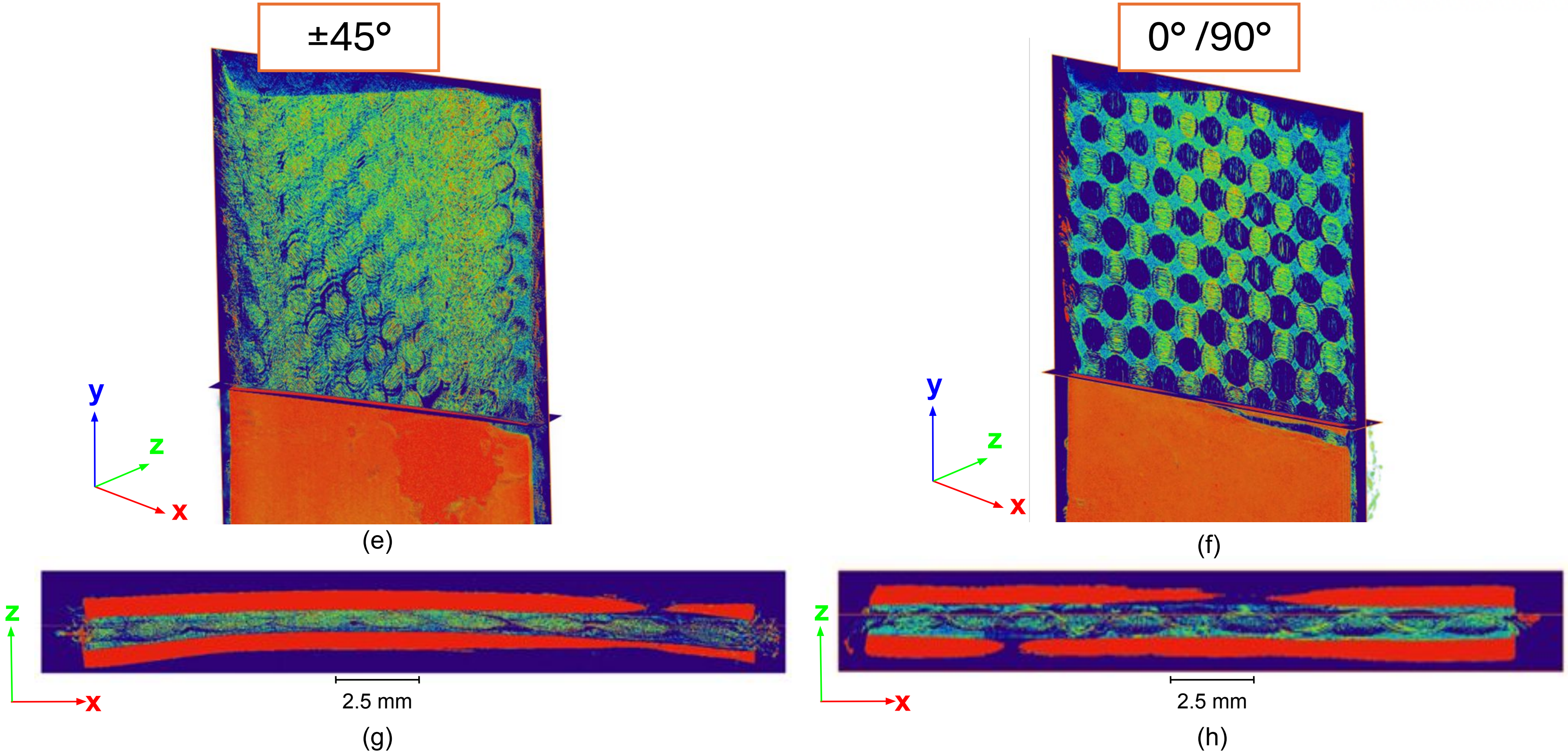
XCT: In-Plane Core Deformation



- ±45° FML: Yarn realignment at initiation of Al failure, but no core failure
- 0°/90° FML: No yarn realignment at initiation of Al failure, no core failure

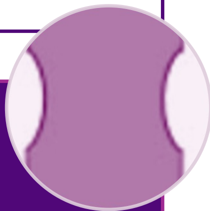
XCT: Out of Plane Failure



- ➢ No core/facesheet delamination at failure
- ➢ FML failure initiation -> Dictated by facesheet strain localisation and fracture

Concluding Remarks

- Onset of tensile failure at tensile strain of 0.015
- Progresses by diffuse necking, localised necking, fracture



AA1100 facesheet

- Core: Onset of tensile failure at strain 0.005
- Core: Progresses by localised failure
- FML: strain redistribution - delay of growth of localised def. to strain of 0.045
- Progresses by localised necking in Al facesheet

0°/90° layup system

- Core: Onset of tensile failure at strain 0.20
- Core: Progresses by uniform deformation
- FML: onset of failure at intermediate strain
- Progresses by diffuse and localised necking in Al facesheet

±45° layup system

1) Effect of residual thermal stresses
2) Exploitation of FML ductility in secondary forming operations

Thank you!

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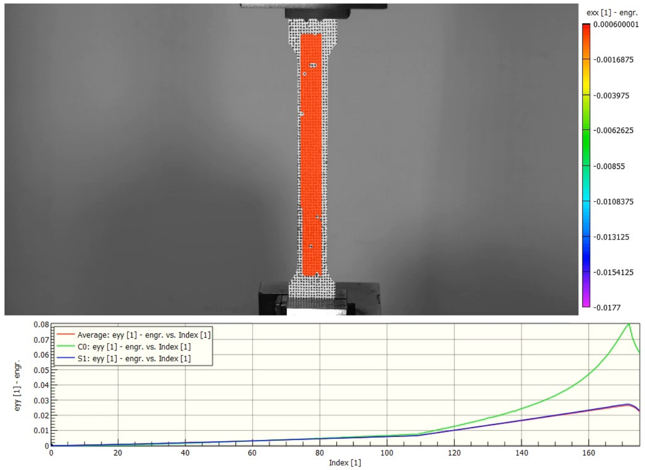
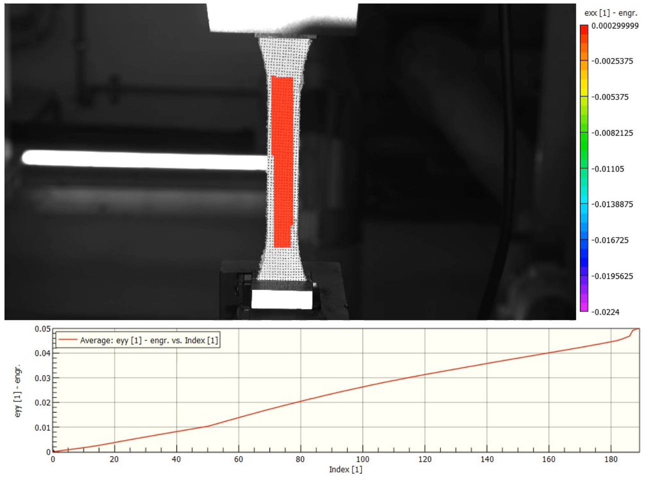
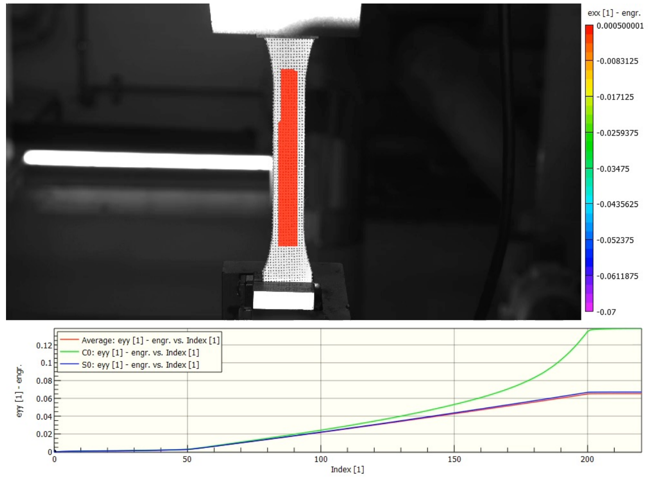
Lateral Strain (ε_{xx}) Evolution



AA1100

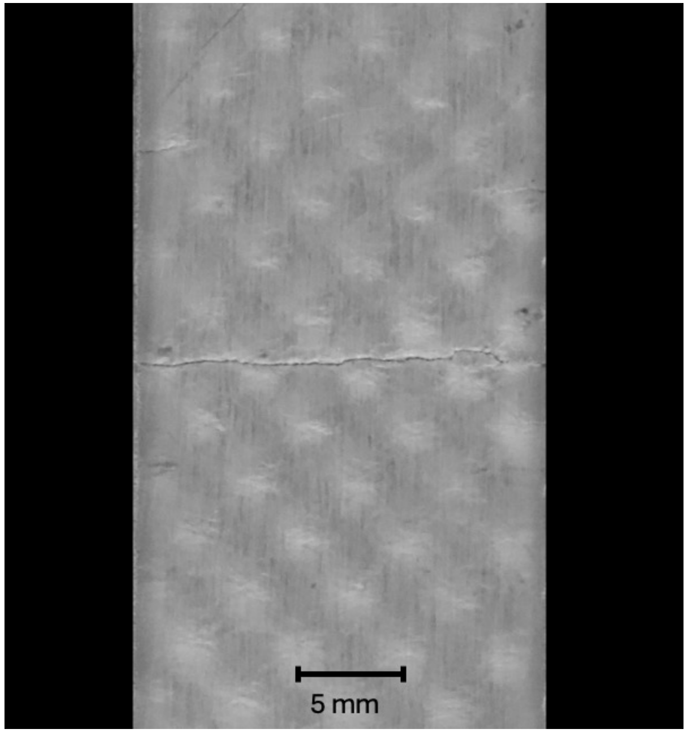


0° /90° FML

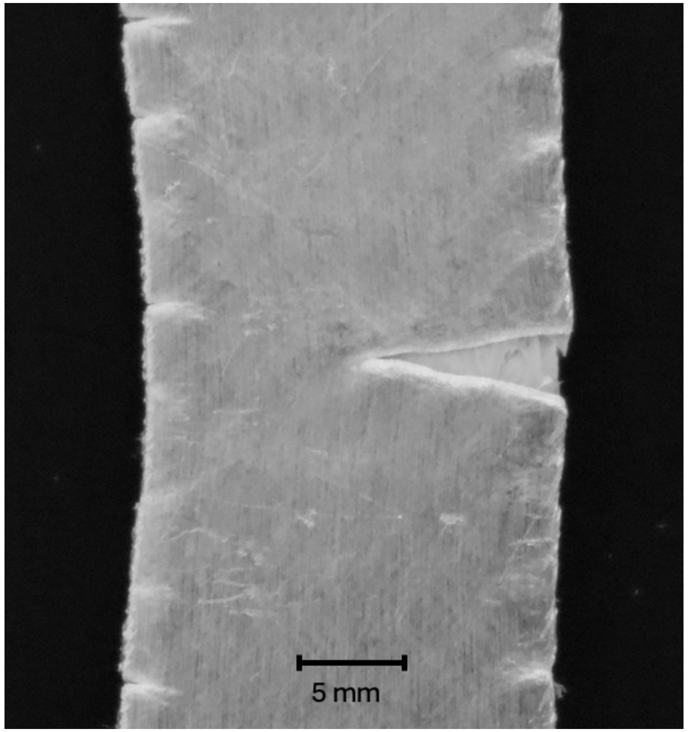


±45° FML

Macroscopic Failure Modes



0° /90° FML



±45° FML