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Failure prediction of injection-moulded short-fibre composites: characterisation and prediction from coupons to components

Imperial College London

The Composites Centre
for research, modelling, testing and training in advanced composites

mecomposites

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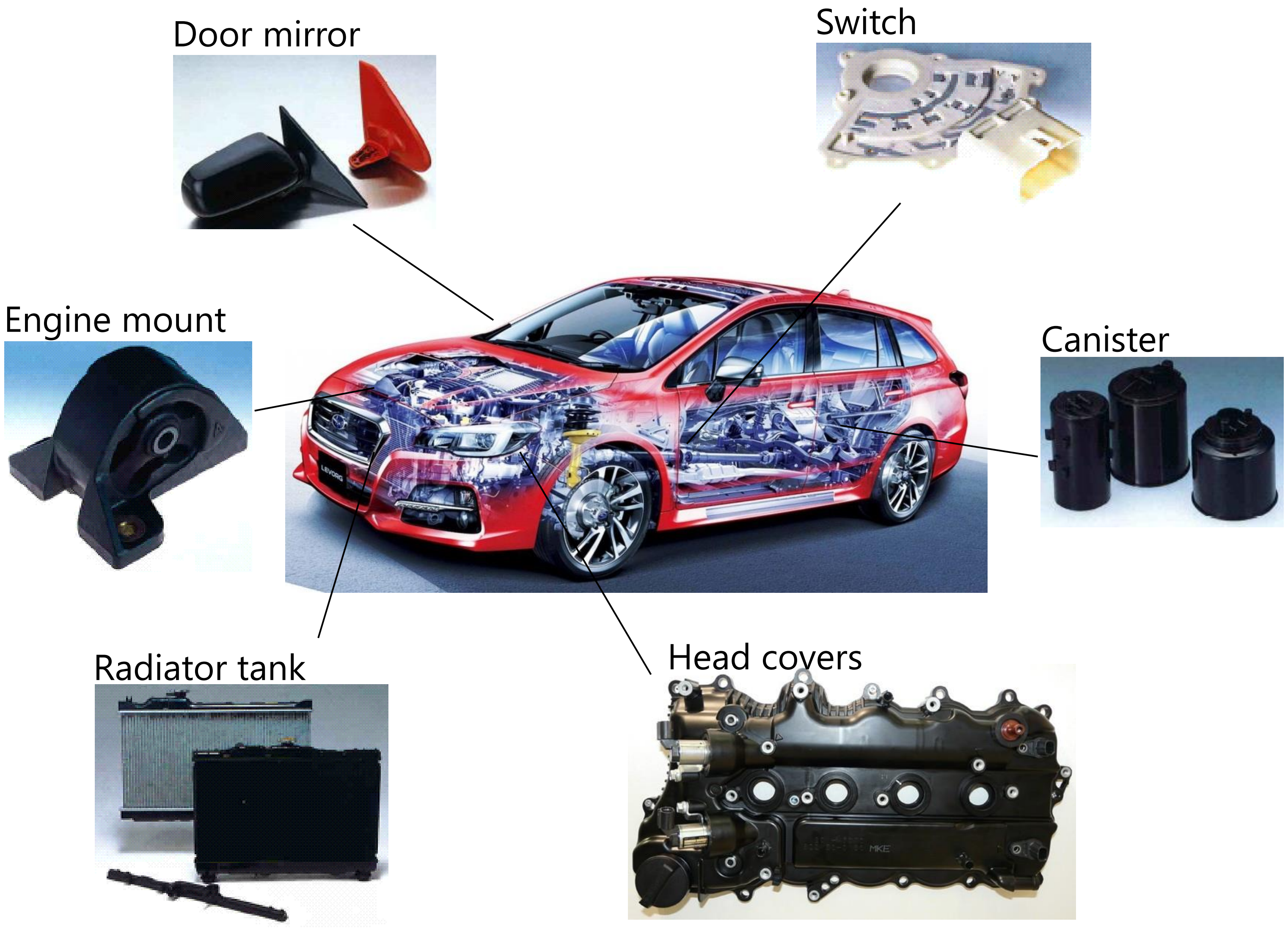
Injection-moulded short-fibre composites

Advantages

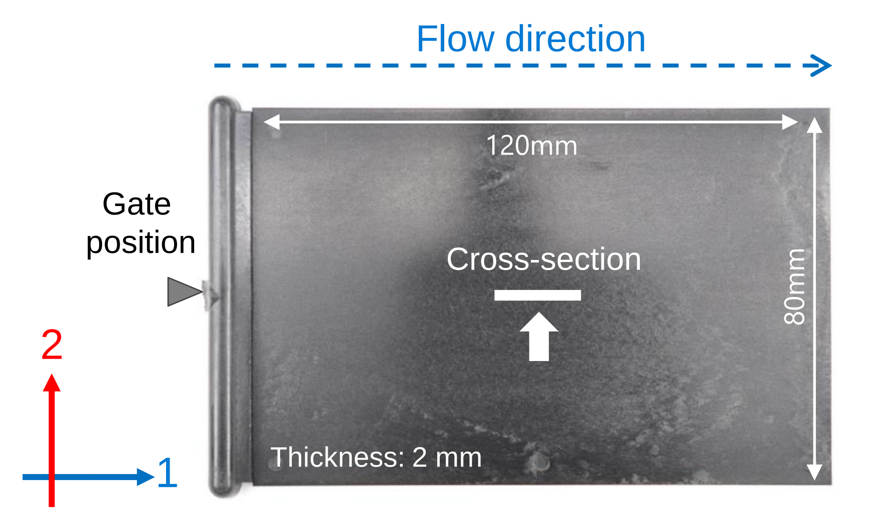
- Lightweight
- Complex 3D geometries
- Short manufacturing cycles
- Automatic processing

Applications in automotive

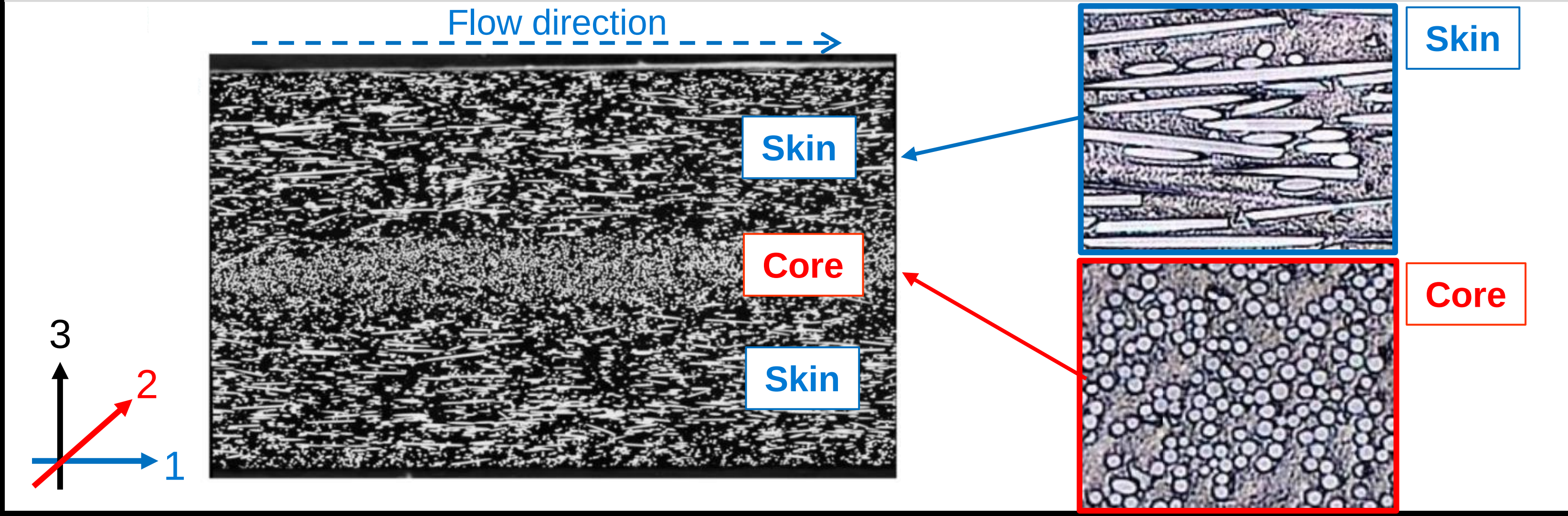


Challenge: complex skin-core microstructure

Injection moulding



Cross-section



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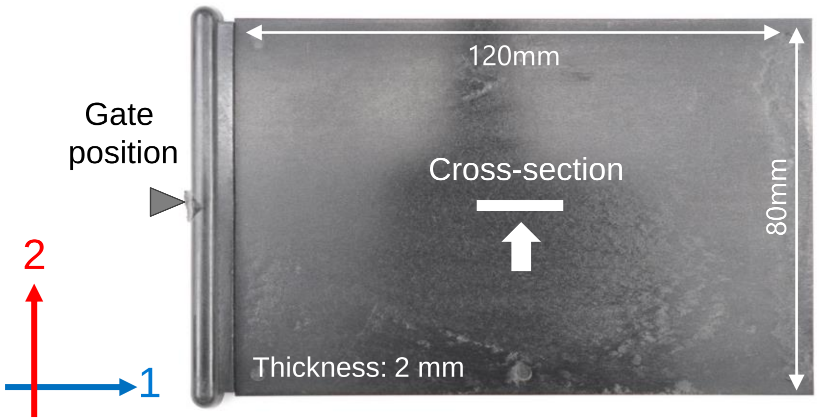

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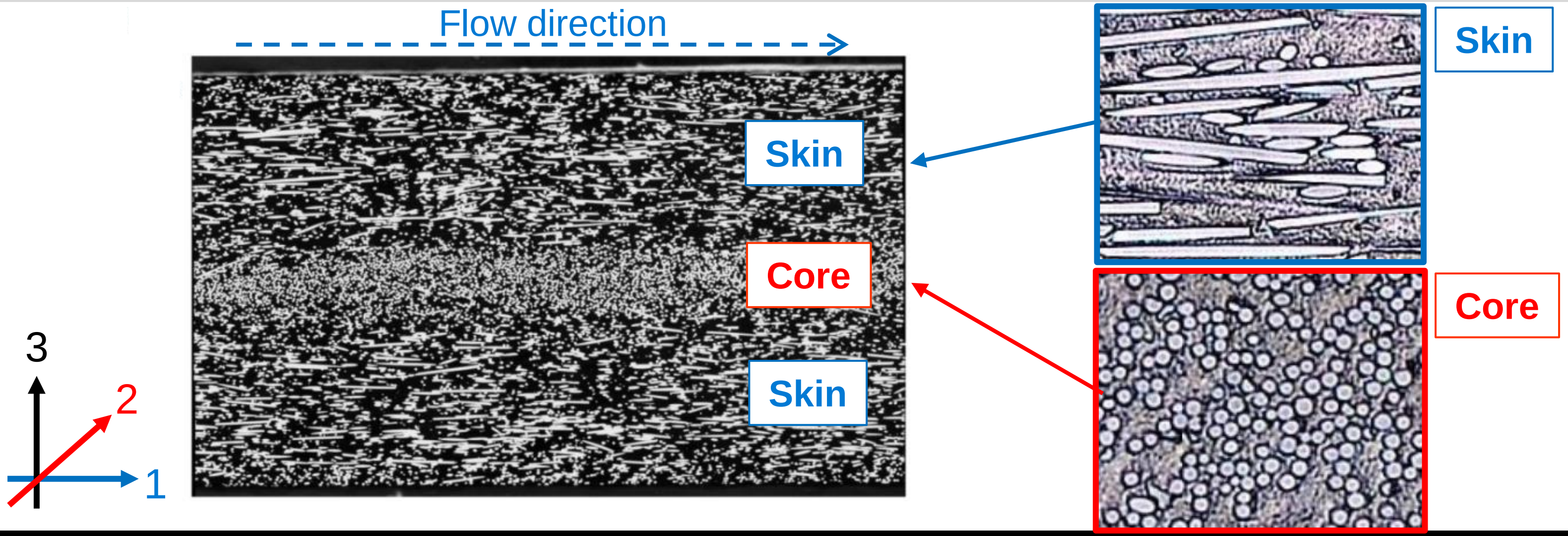
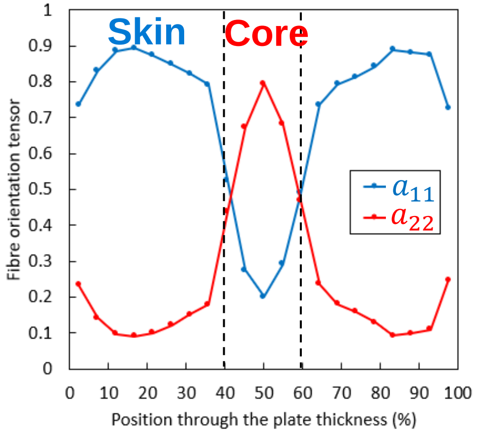


Fibre orientation tensor

$$A = \begin{bmatrix} \boldsymbol{a_{11}} & a_{12} & a_{13} \\ a_{21} & \boldsymbol{a_{22}} & a_{23} \\ a_{31} & a_{32} & \boldsymbol{a_{33}} \end{bmatrix}$$



a_{11}: flow direction (high in skin)

a_{22}: transverse direction (high in core)

a_{33}: thickness direction

Challenge: complex skin-core microstructure

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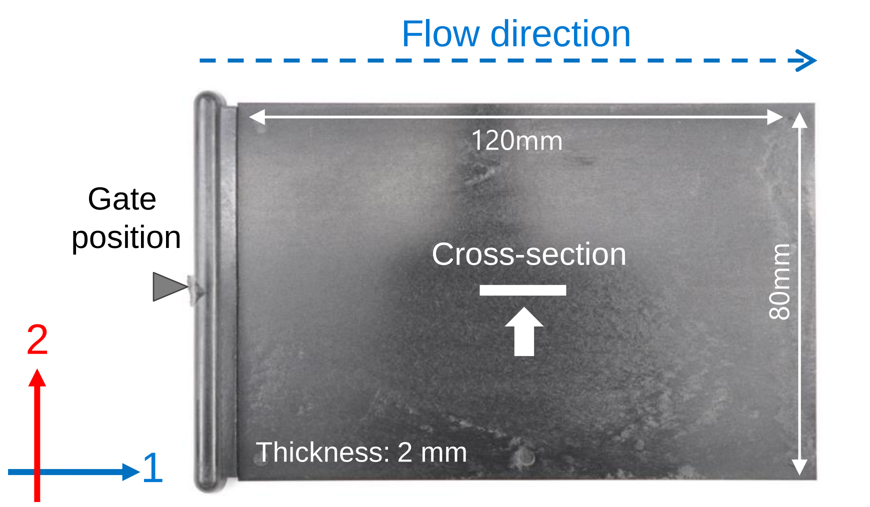

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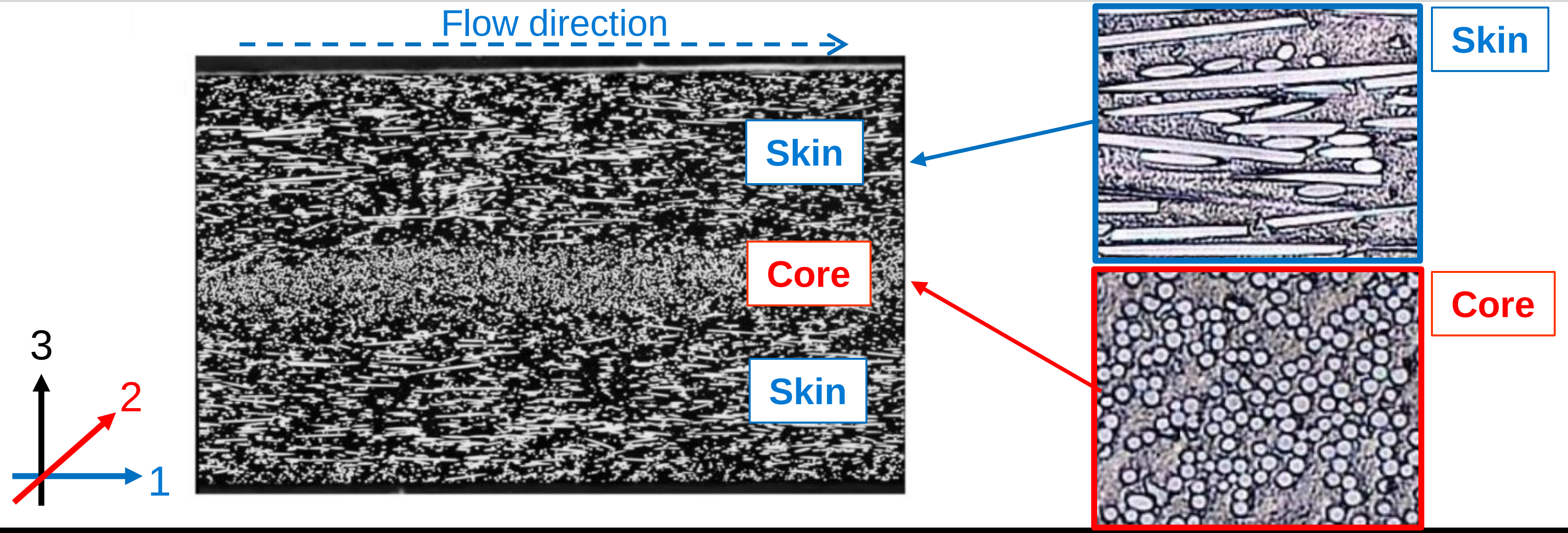

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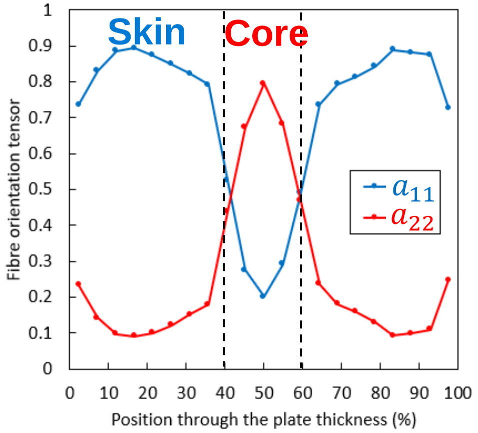

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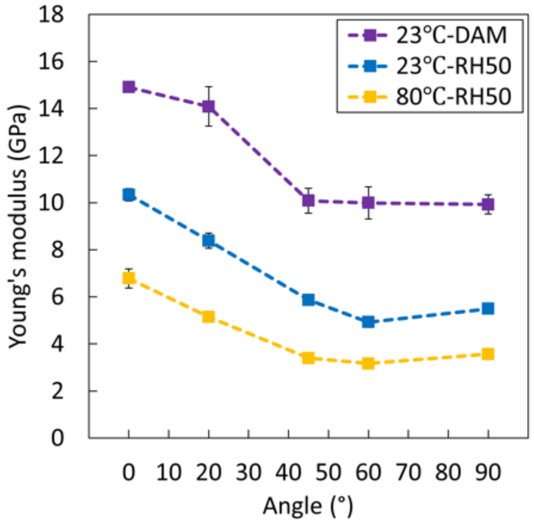
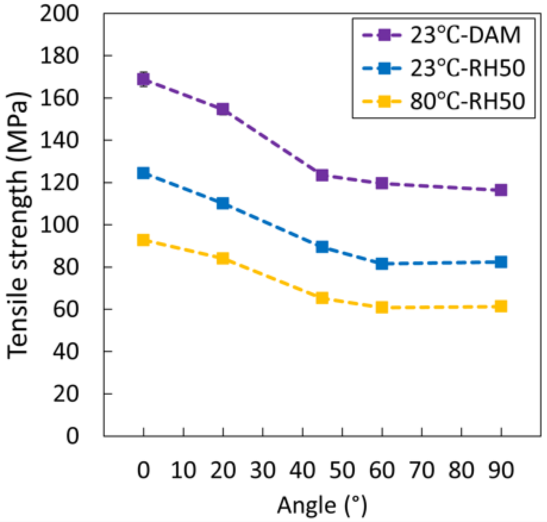
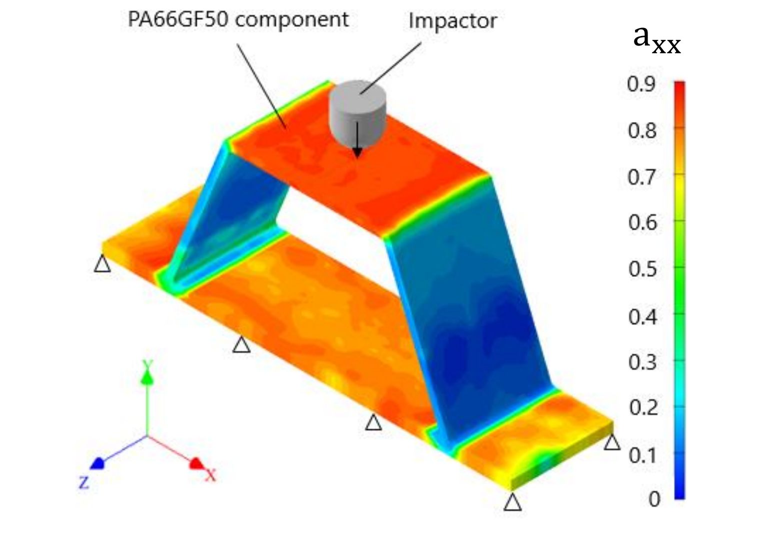
Effect of fibre orientation on tensile properties



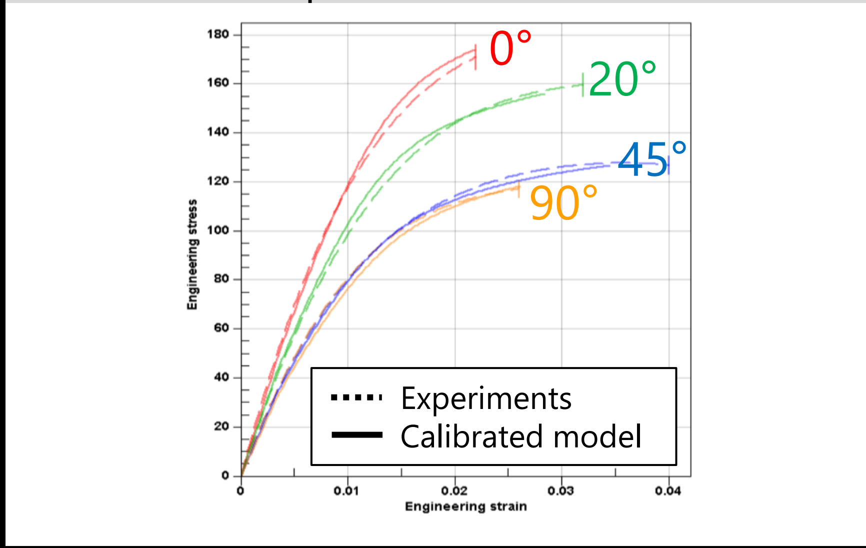


State-of-the-art coupled process-structural simulation (coupled FEA)

Process simulation (local fibre orientation)



Calibration of Digimat's elastic-plastic material model



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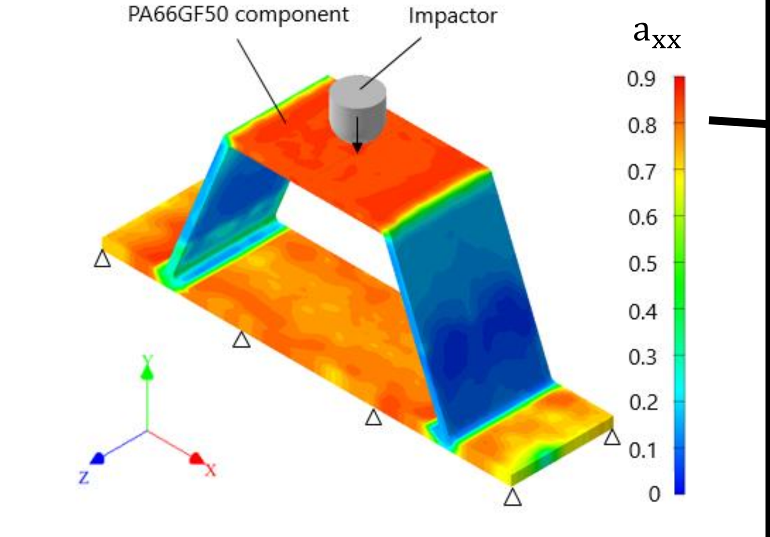

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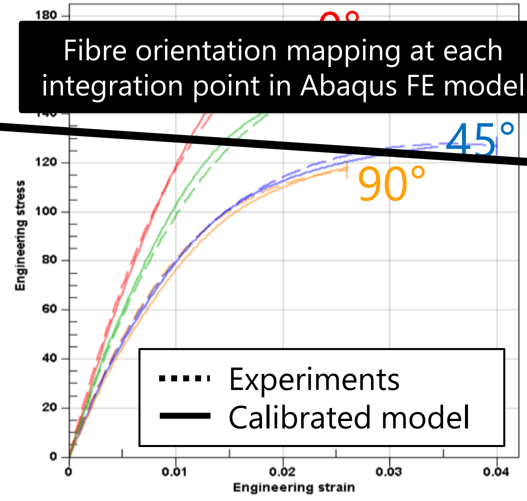
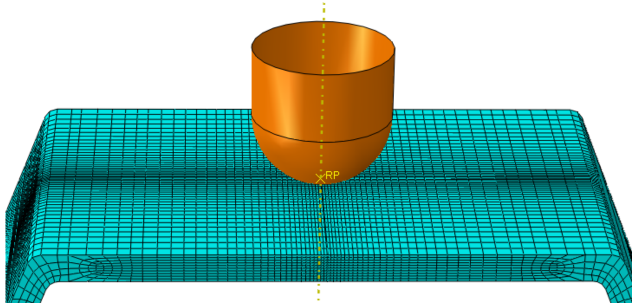


Fibre orientation mapping at each integration point in Abaqus FE model

Structural FE simulations coupled with
process simulation (coupled FEA)



Assign unique mechanical properties to each integration point based on mapped fibre orientation tensor

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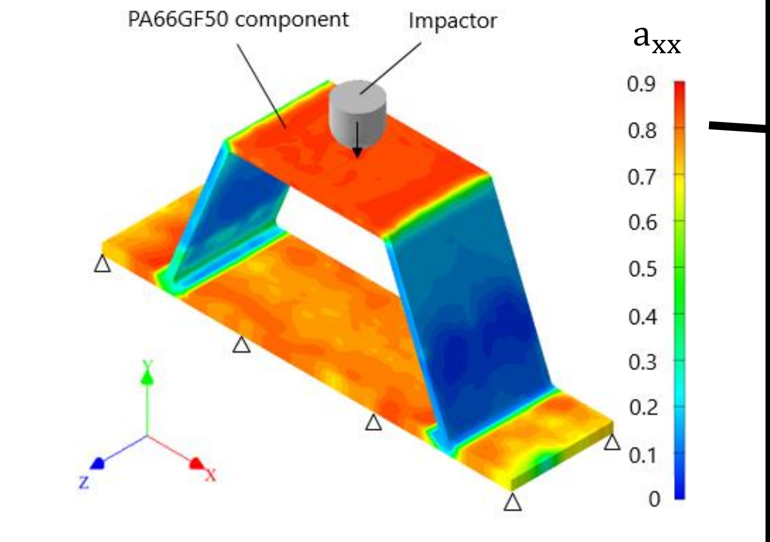
Process simulation (local fibre orientation)



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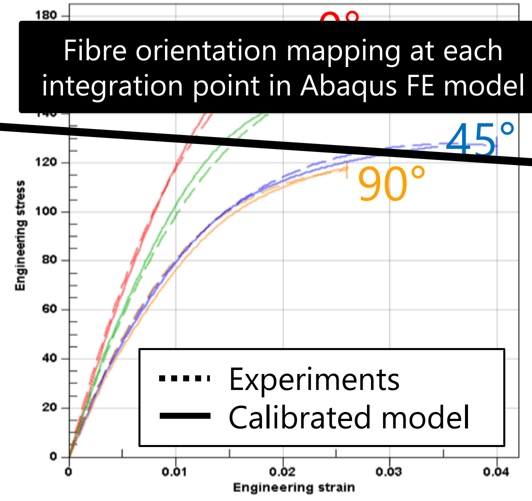

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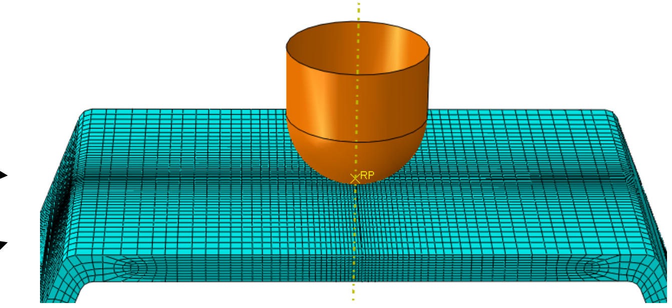

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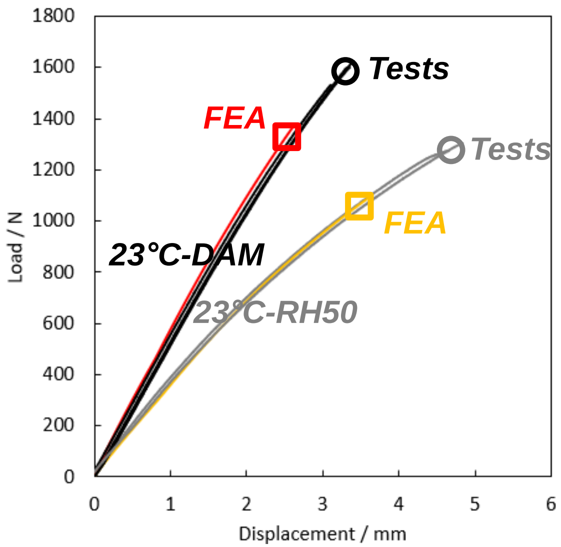
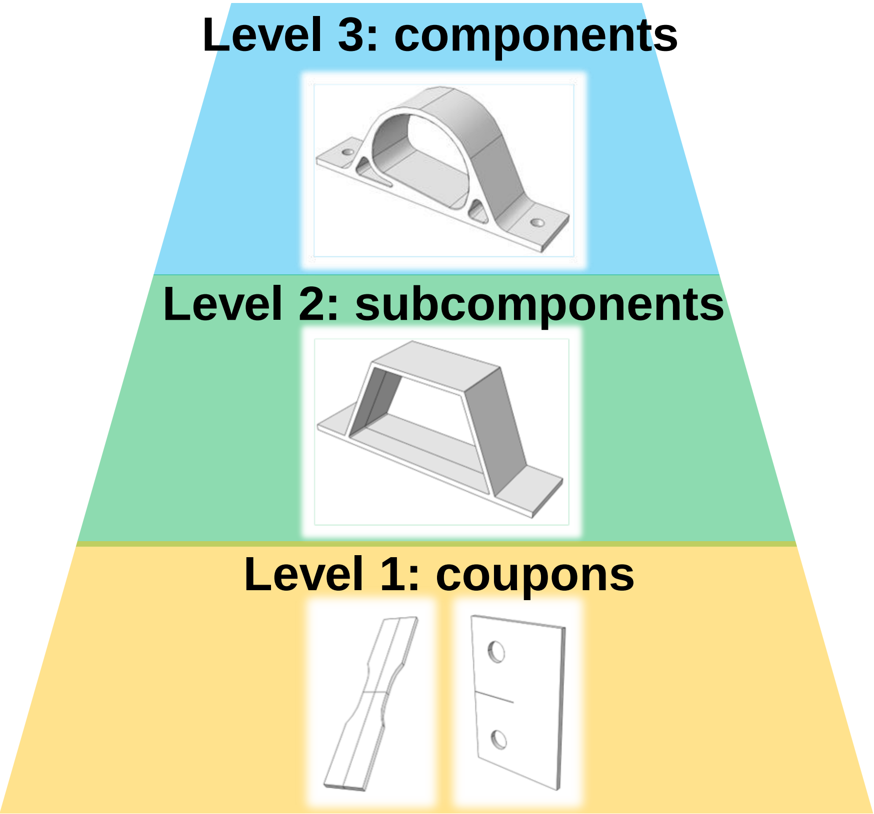
Coupled FEA with existing failure criteria for SFRPs



Existing failure criteria for SFRPs (i.e. Tsai-Hill) under-predict the failure load: they consider failure initiation only and neglect material's fracture toughness

Objectives

Develop a Finite-Element (FE) methodology to predict failure of injection-moulded short-fibre reinforced Polyamide 6.6 composites (PA66-GF50), by accounting for the material's progressive failure



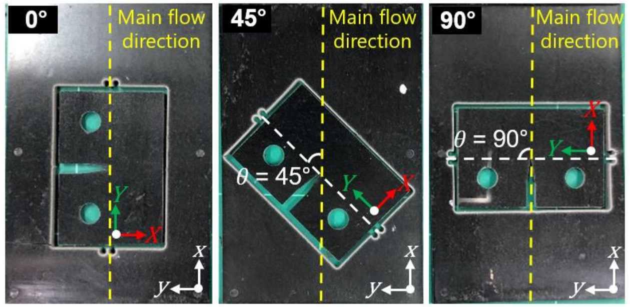
Applying the developed FE methodology to automotive components

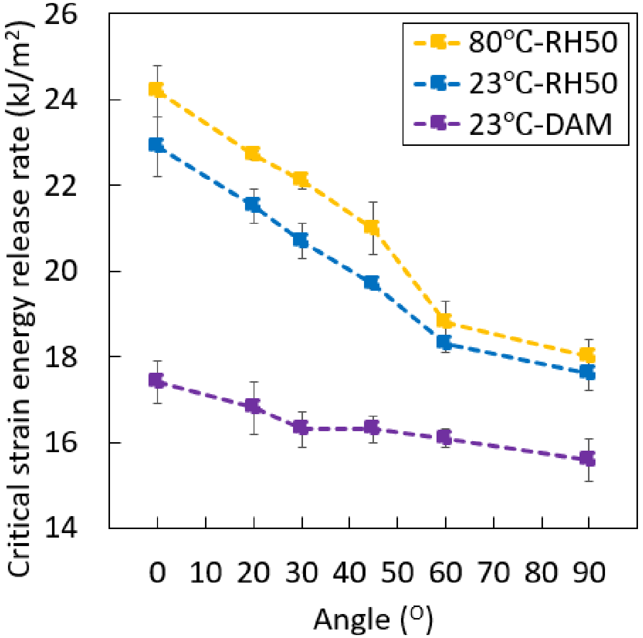
Developing a new FE methodology for failure prediction

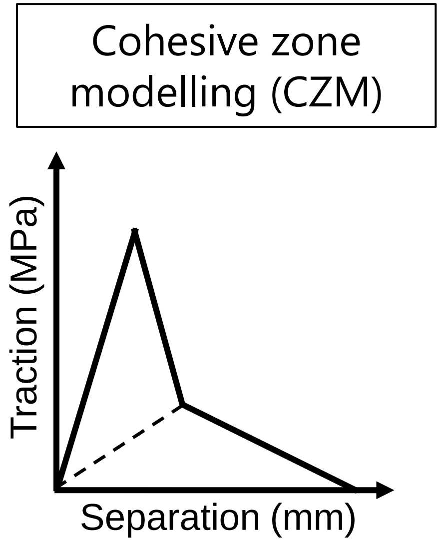
Characterising material properties

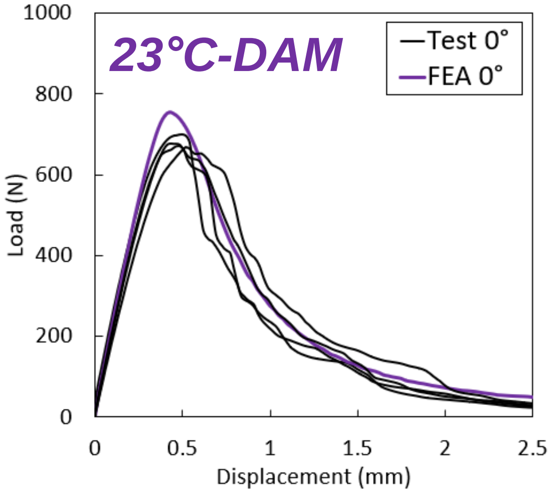
Level 1: coupons (Gc characterisation by CT tests)

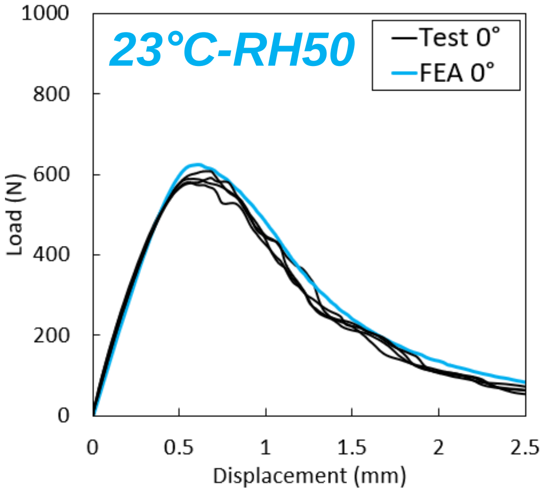
- Clear effect of fibre orientation and environmental conditions
- FE simulations with CZM showed excellent agreement not only the peak load but also the subsequent gradual load decrease

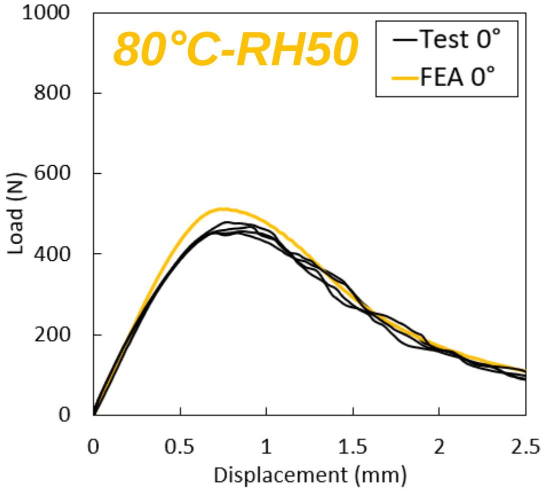










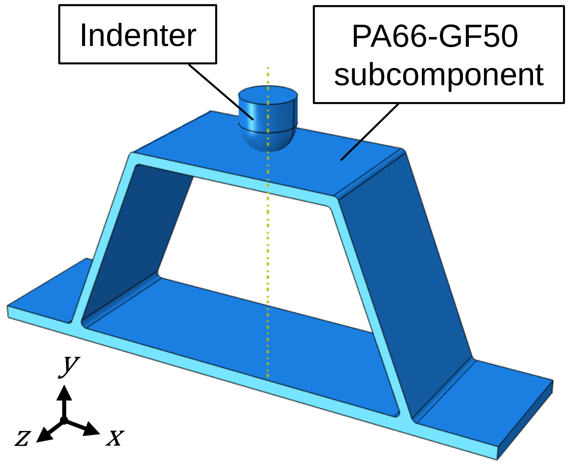


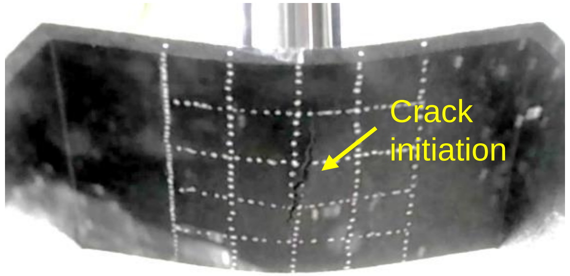
Y. Fujita et al. Initiation and propagation fracture toughness of injection-moulded short fibre composites under different environmental conditions. *Compos Sci Technol*, 2023.

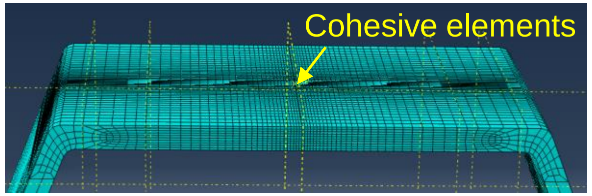
Level 2: subcomponents (developing FE methodology)

Cohesive zone modelling (CZM)

- Assignment of cohesive elements (CE) to fracture plane

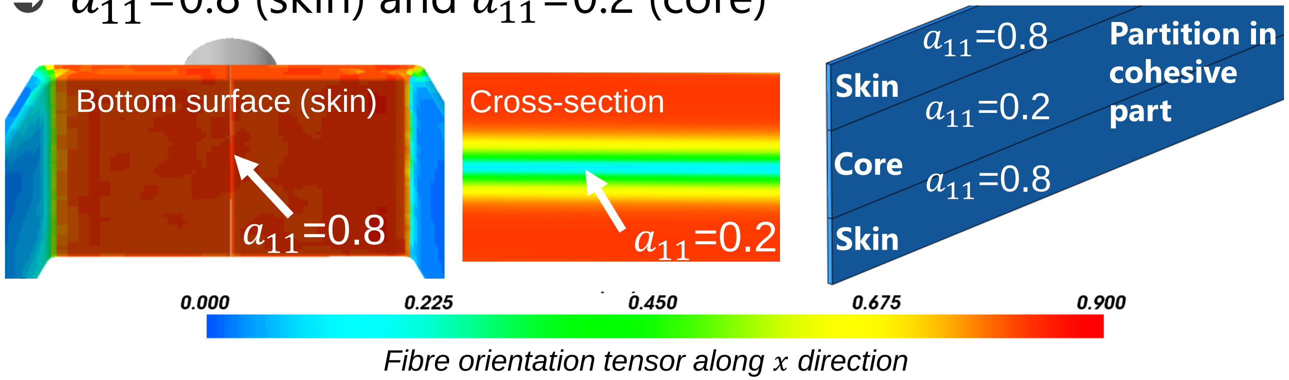






Assignment of properties based on fibre orientation in the component

- a_{11}=0.8 (skin) and a_{11}=0.2 (core)



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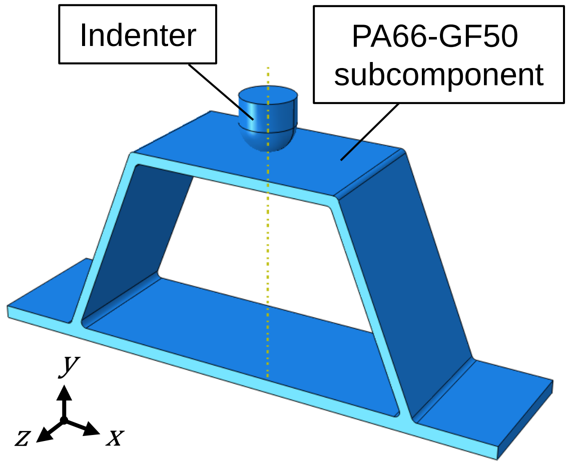
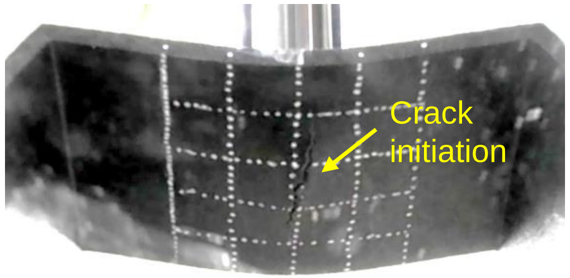
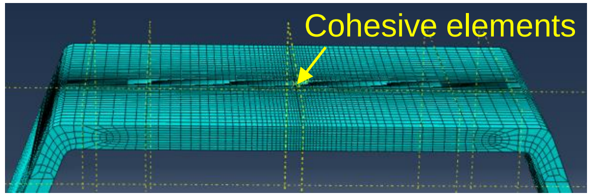
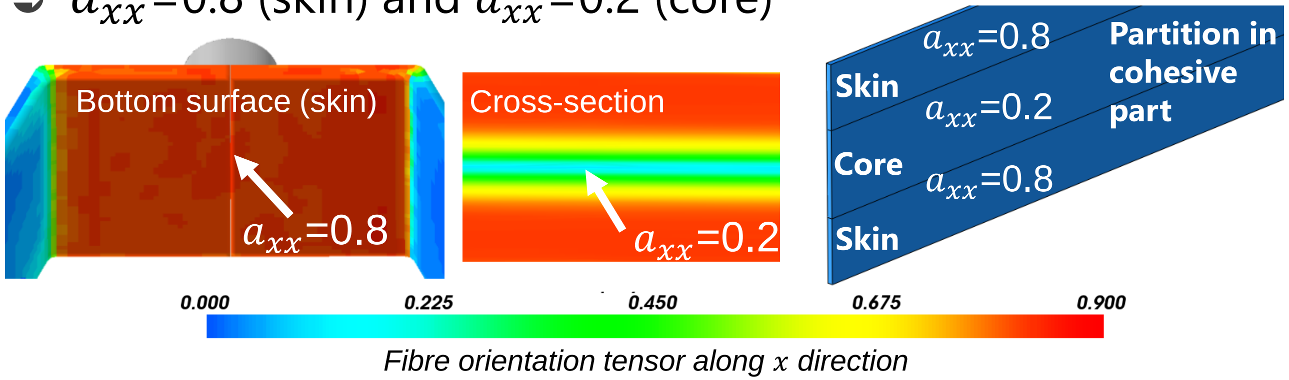






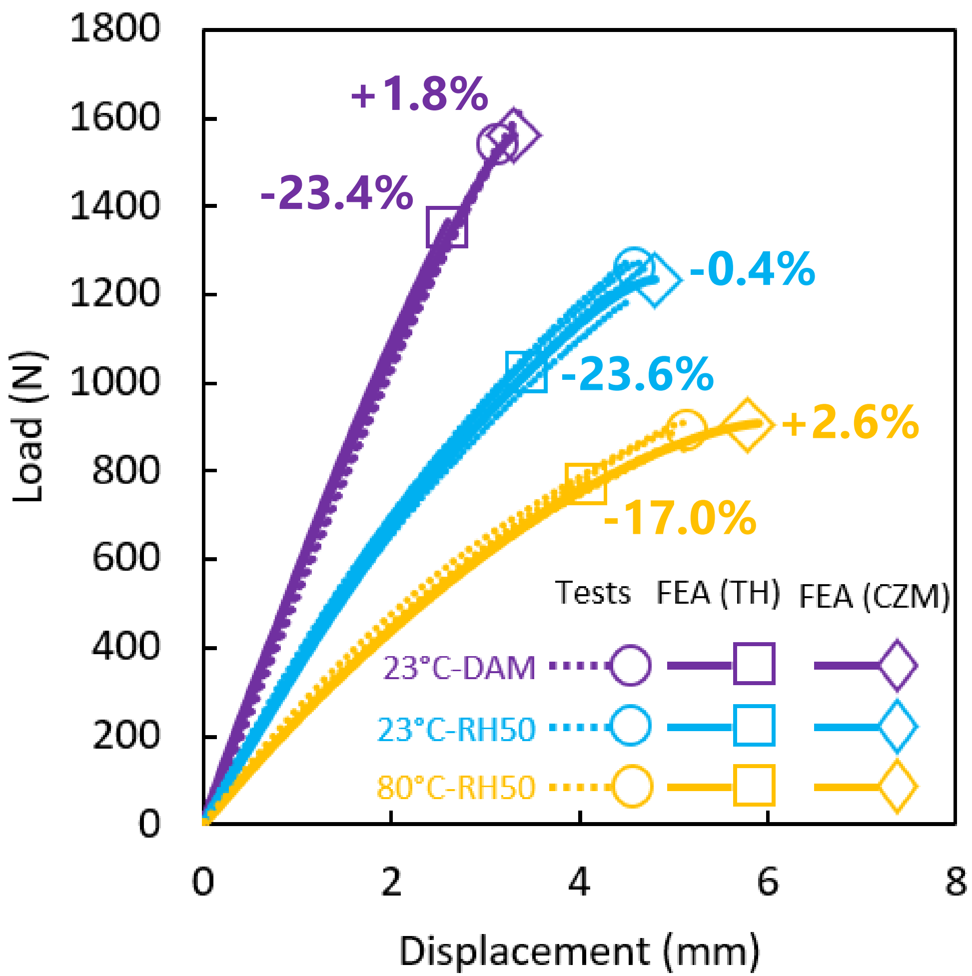
Assignment of properties based on fibre orientation in the component

- a_{xx}=0.8 (skin) and a_{xx}=0.2 (core)



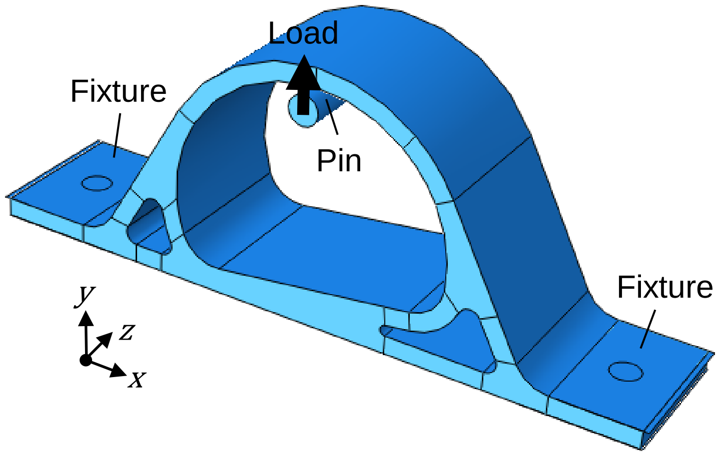
Extrapolation of material properties

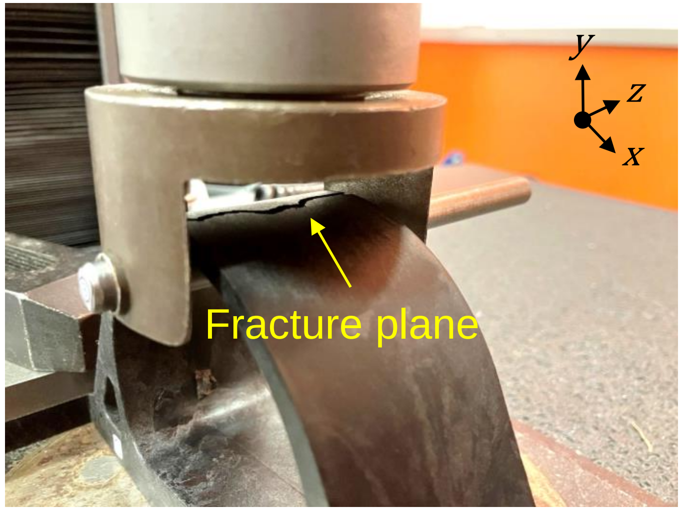
- FEA (CZM) showed excellent agreement of maximum failure load (within 2.6%)

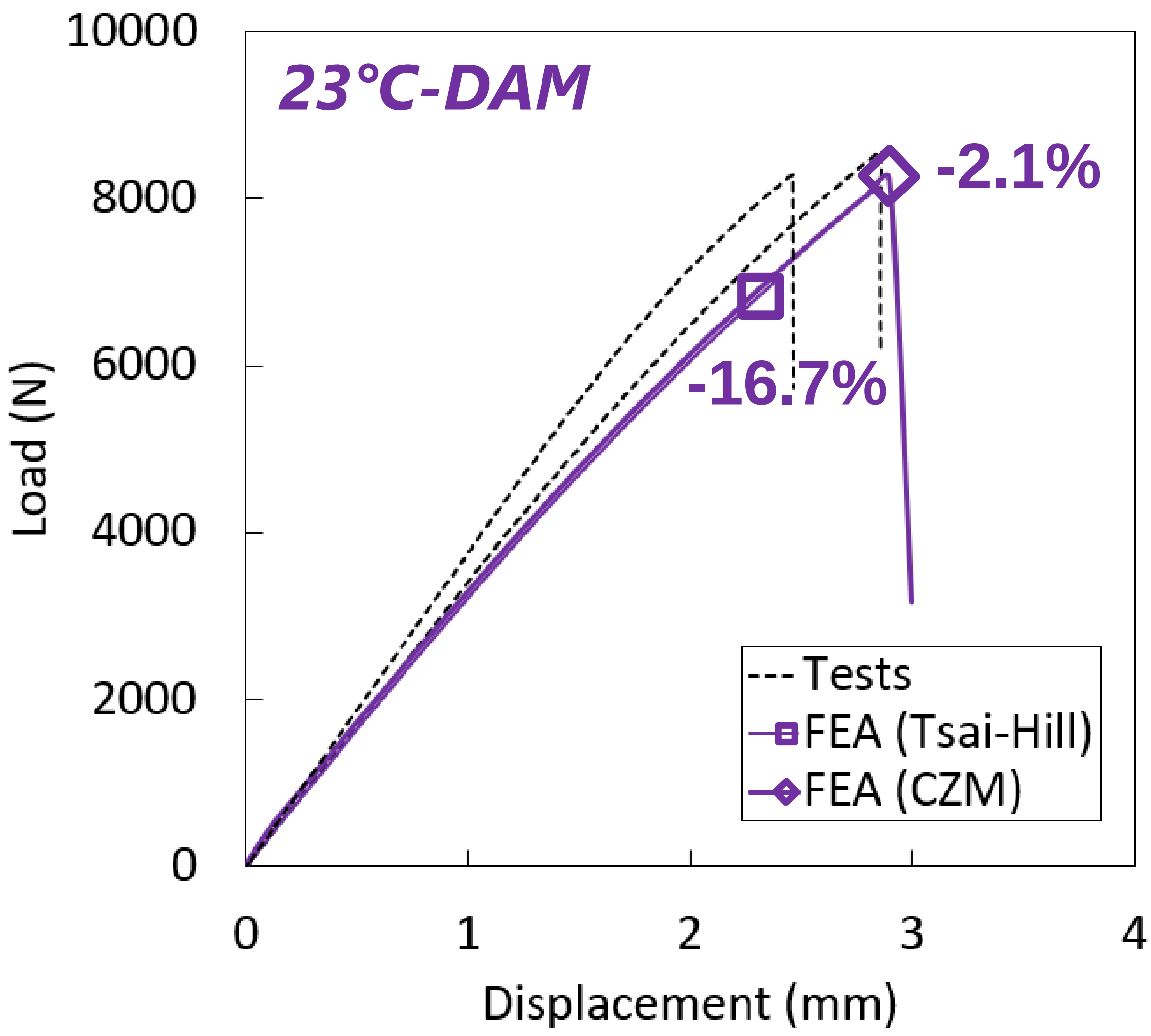


Level 3: components (application of the developed methodology)

➲ FEA (CZM) showed excellent agreement of failure load (error: 2.1%)







Conclusions

Poster number: P039

FEA using CZM have been demonstrated to accurately predict the failure of injection-moulded PA66-GF50 components based on experimentally-measured fracture toughness

- *Provide more confidence in the design of the components in industry*
- *Contribute to design lighter and more costly-effective components*