The role of constituents on the compressive strength of composites

Soraia Pimenta

soraia.pimenta@imperial.ac.uk

M Patni, D Bikos, P Robinson, R Trask

Next Generation Fibre-Reinforced Composites

Bristol Composites Institute

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

UK Research and Innovation

Engineering and Physical Sciences Research Council

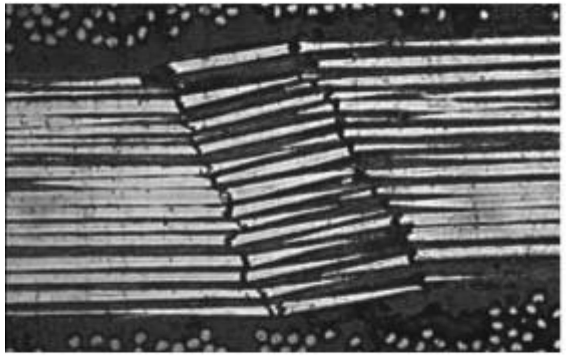
Introduction

Goals

- Enabling material development
- Increase accuracy of models
- Identify gaps in characterisation

Longitudinal compressive failure

- Kink-band formation:
  - Fibre misalignments
  - Matrix shear response

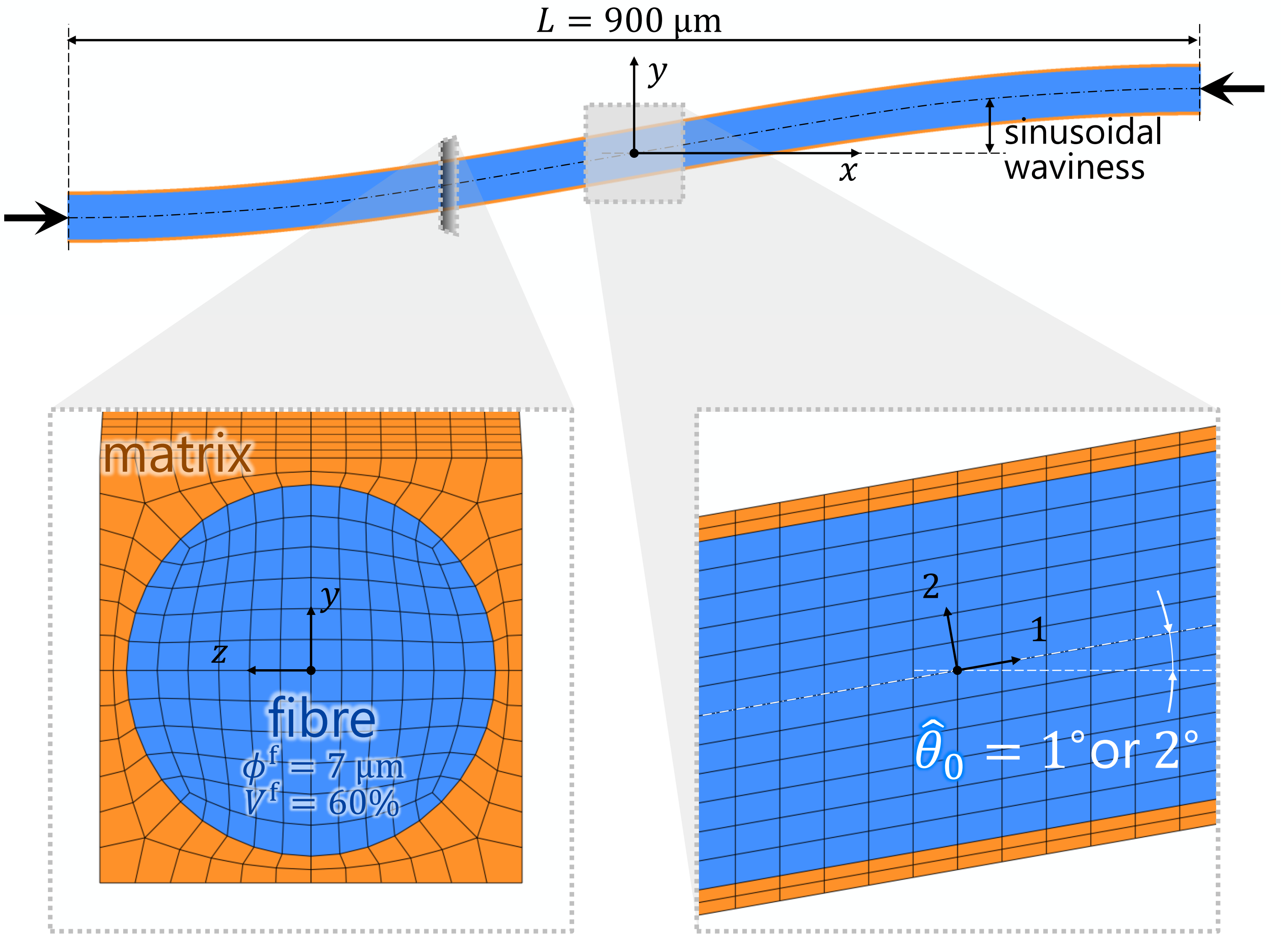


Outline

- Properties of the matrix
  - Shear non-linearity
  - Plasticity parameters
- Properties of the fibres
  - Shear (& transverse) modulus
- Properties of interface
  - Matrix- vs. interface- dominated failure
  - Interfacial shear strength
- Conclusions

FE models for compressive failure

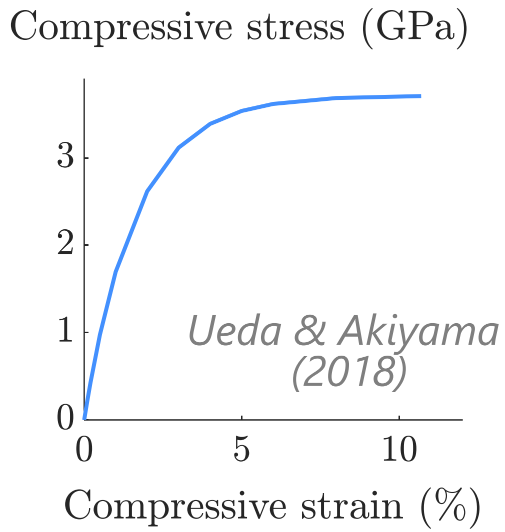
Fibre/matrix **unit cell** with periodic BCs



misalignment geometry: *Paluch (1996)*

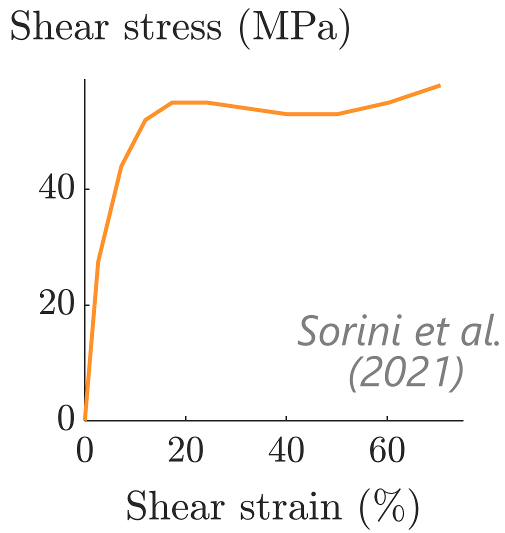
T300 **carbon** fibres

- Non-linear elastic longitudinal response
- Transversely isotropic



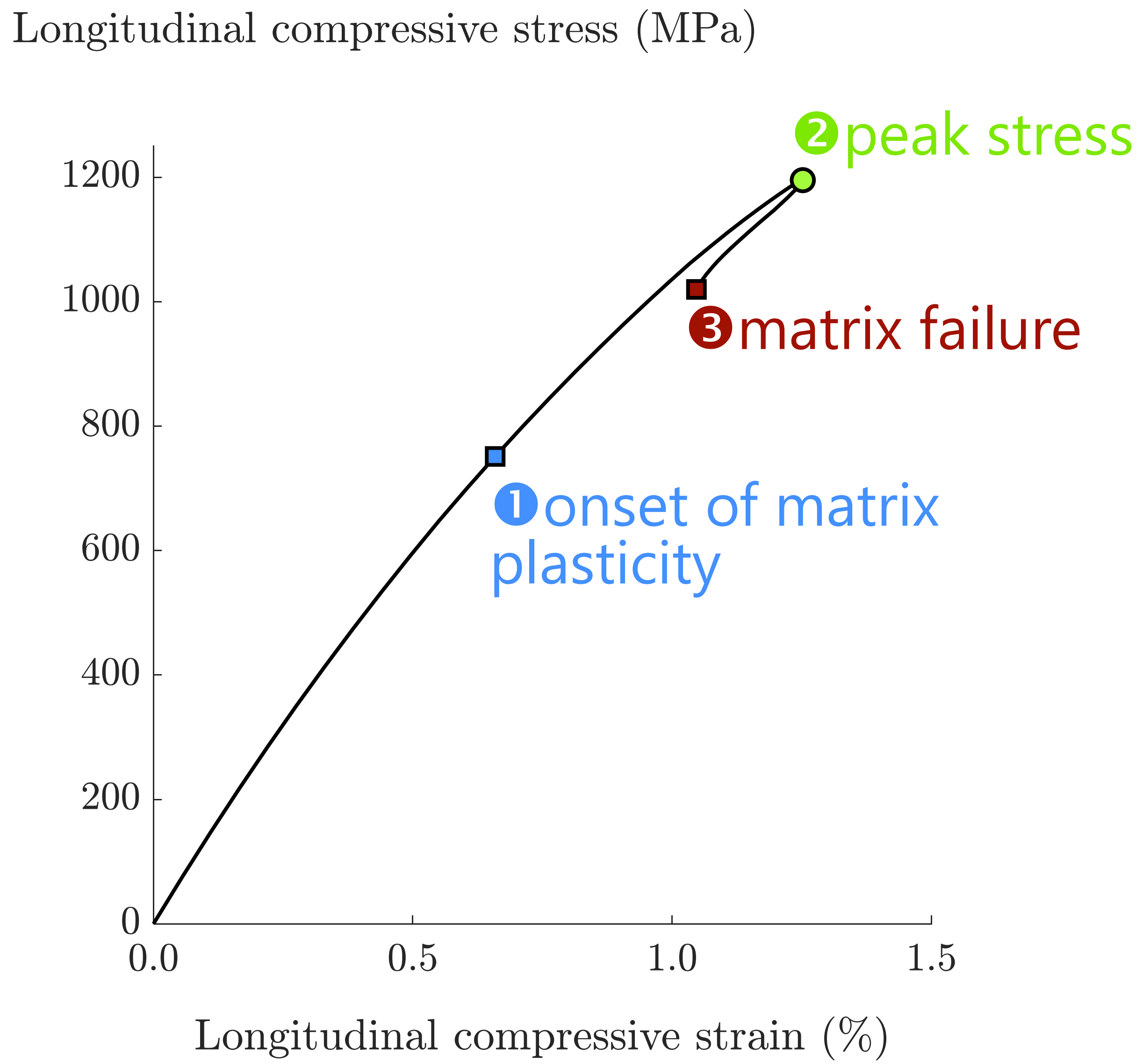
Epoxy matrix (Epon 862)

- Non-linear shear response
- Drucker-Prager plasticity

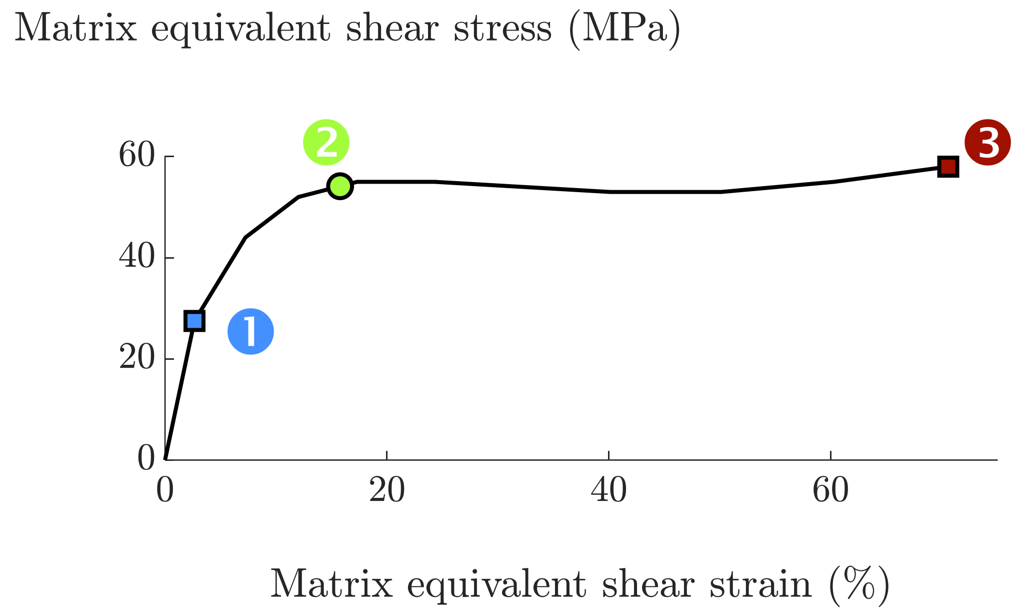


Sequence of events (baseline constitutive law, $\hat{\theta}_0 = 1^\circ$)

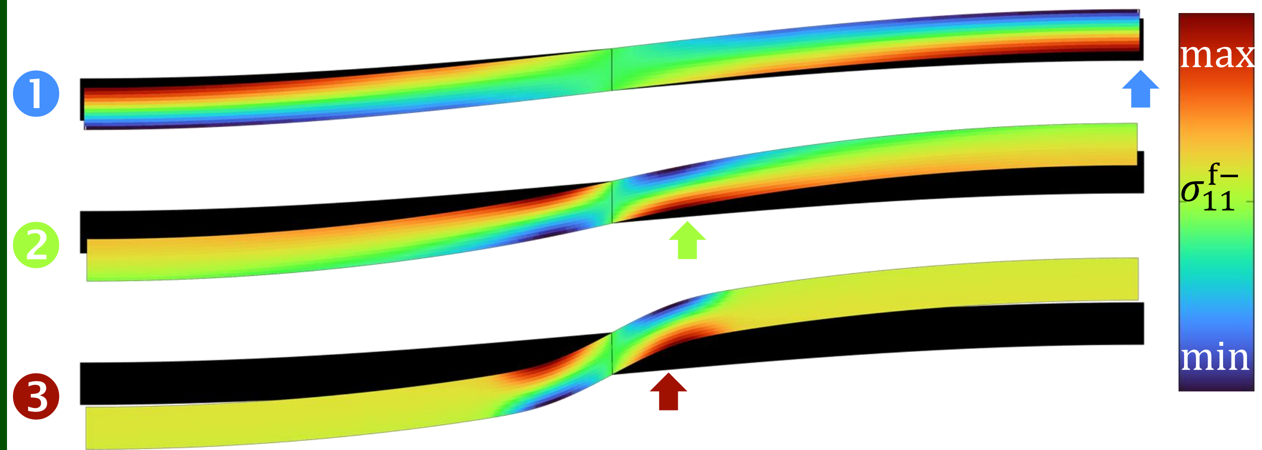
Global stress-strain curve



Matrix evolution at max. misalign.

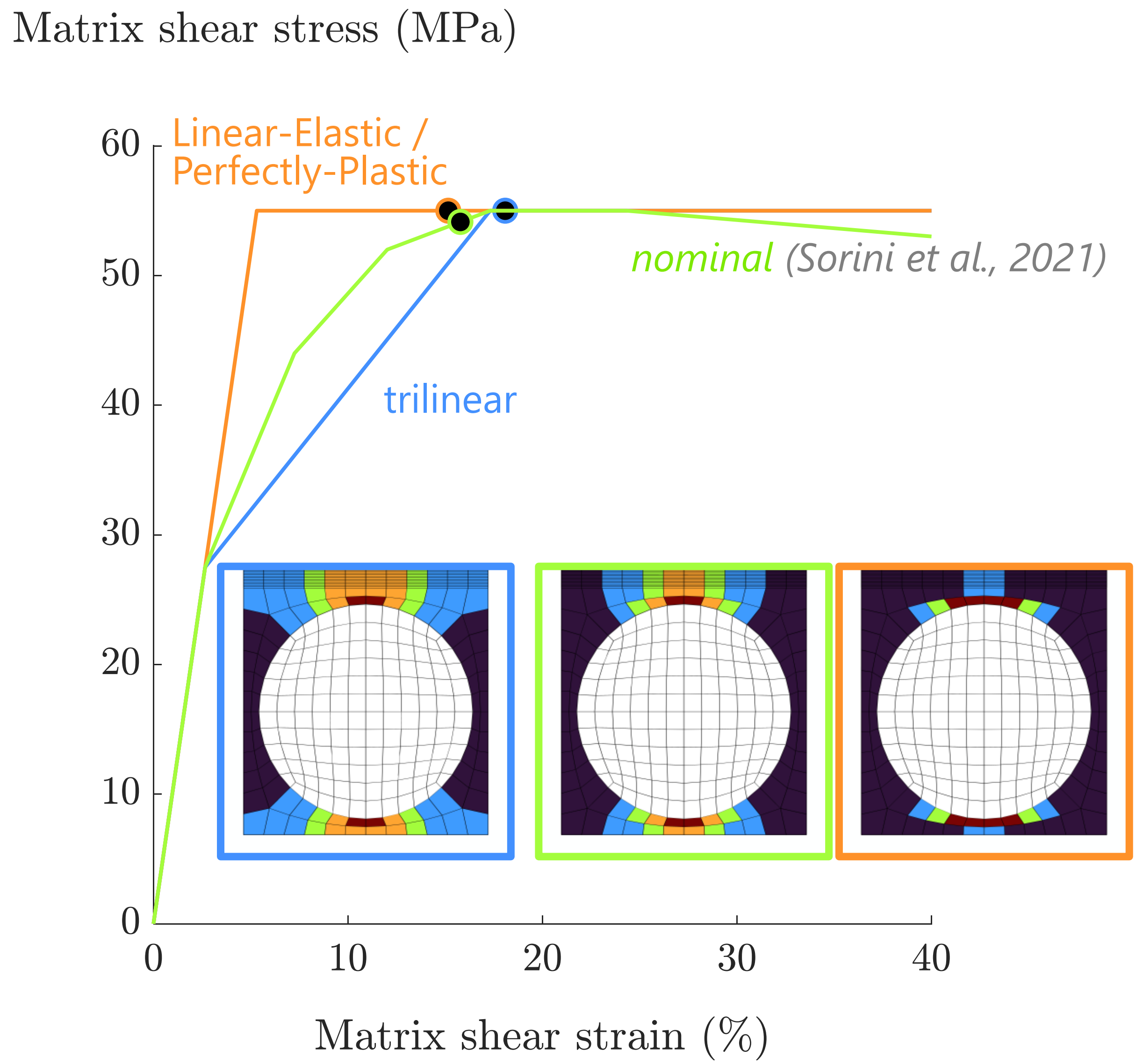


Longitudinal fibre compression fields

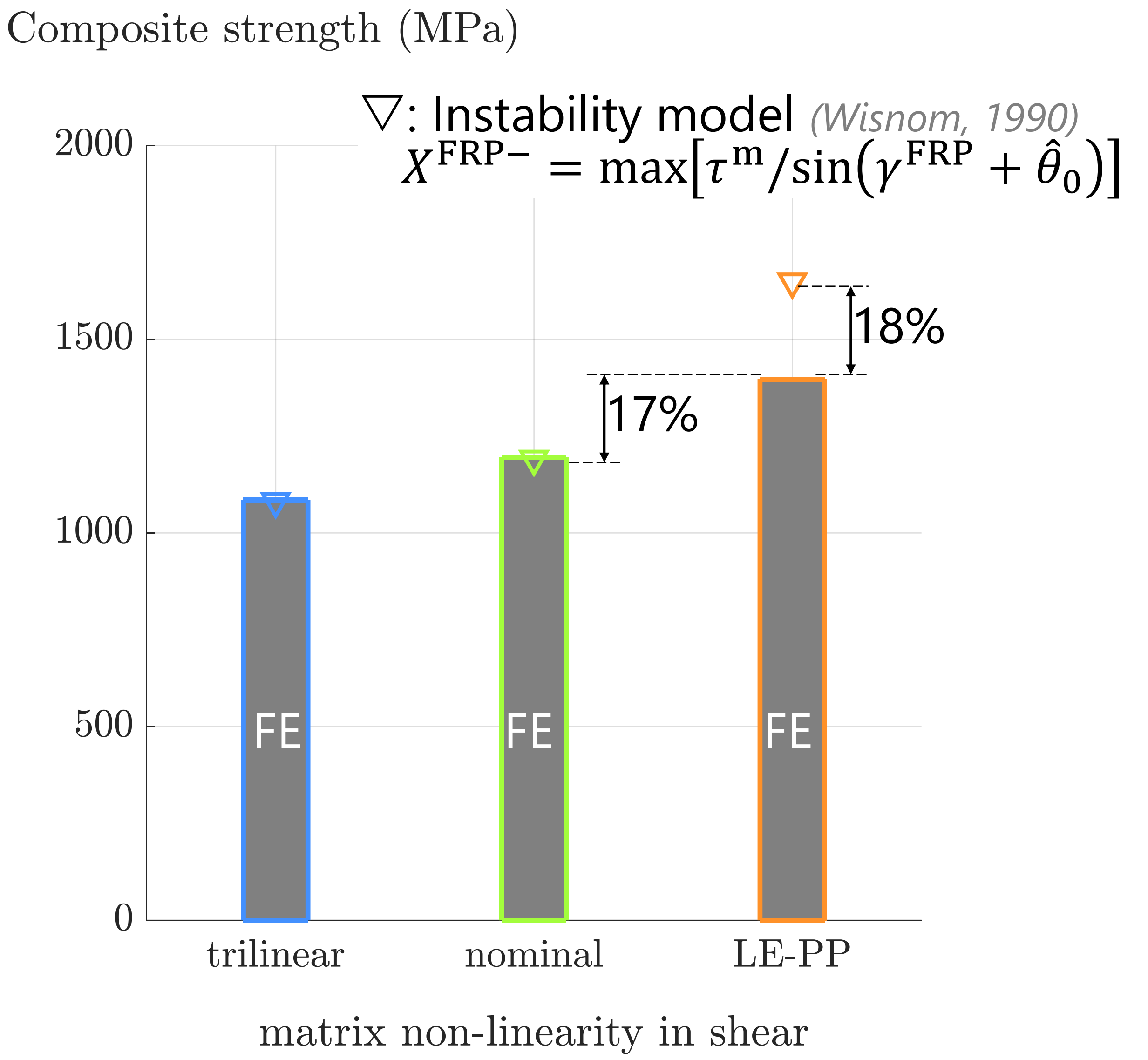


Matrix non-linearity ($\hat{\theta}_0 = 1°$)

Matrix shear constitutive law



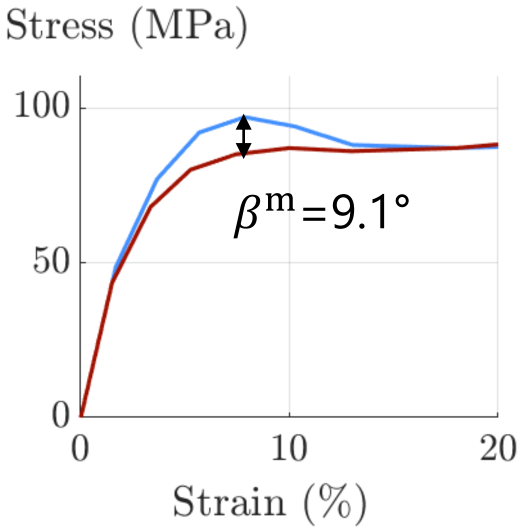
Composite compressive strength

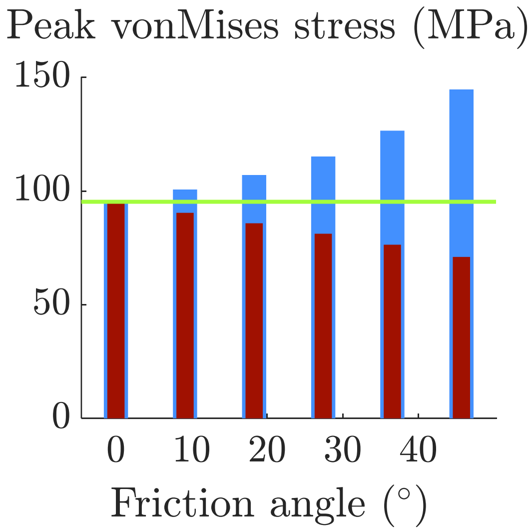


Matrix plasticity: material parameters

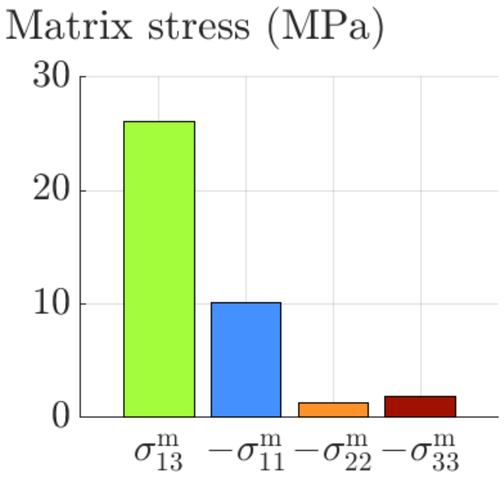
Friction angle

- Controls tension/compression/shear asymmetry



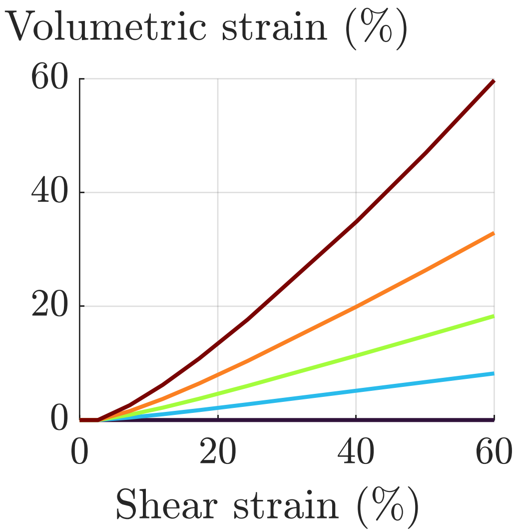


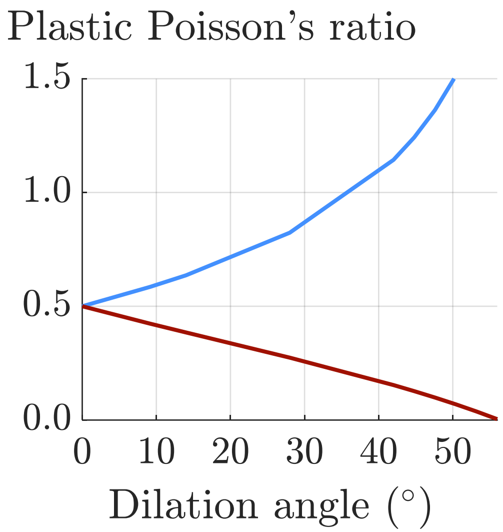
- Matrix under complex 3D stress state



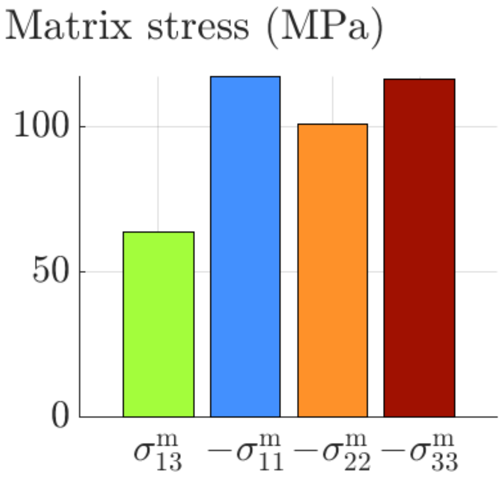
Dilation angle

- Controls volumetric strains ("dilation") during plastic deformation



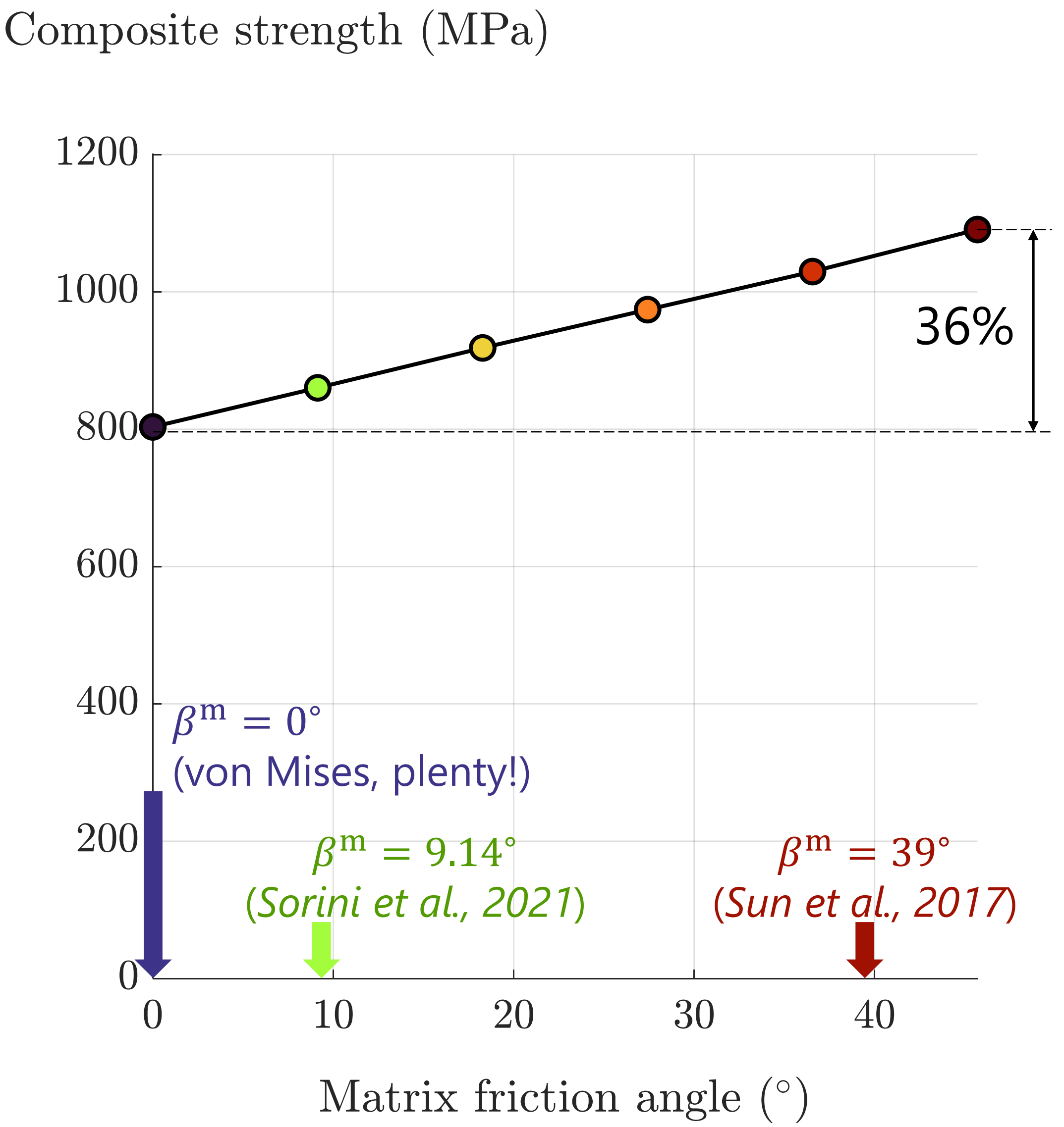


- Fibres constrain matrix dilation during plasticity

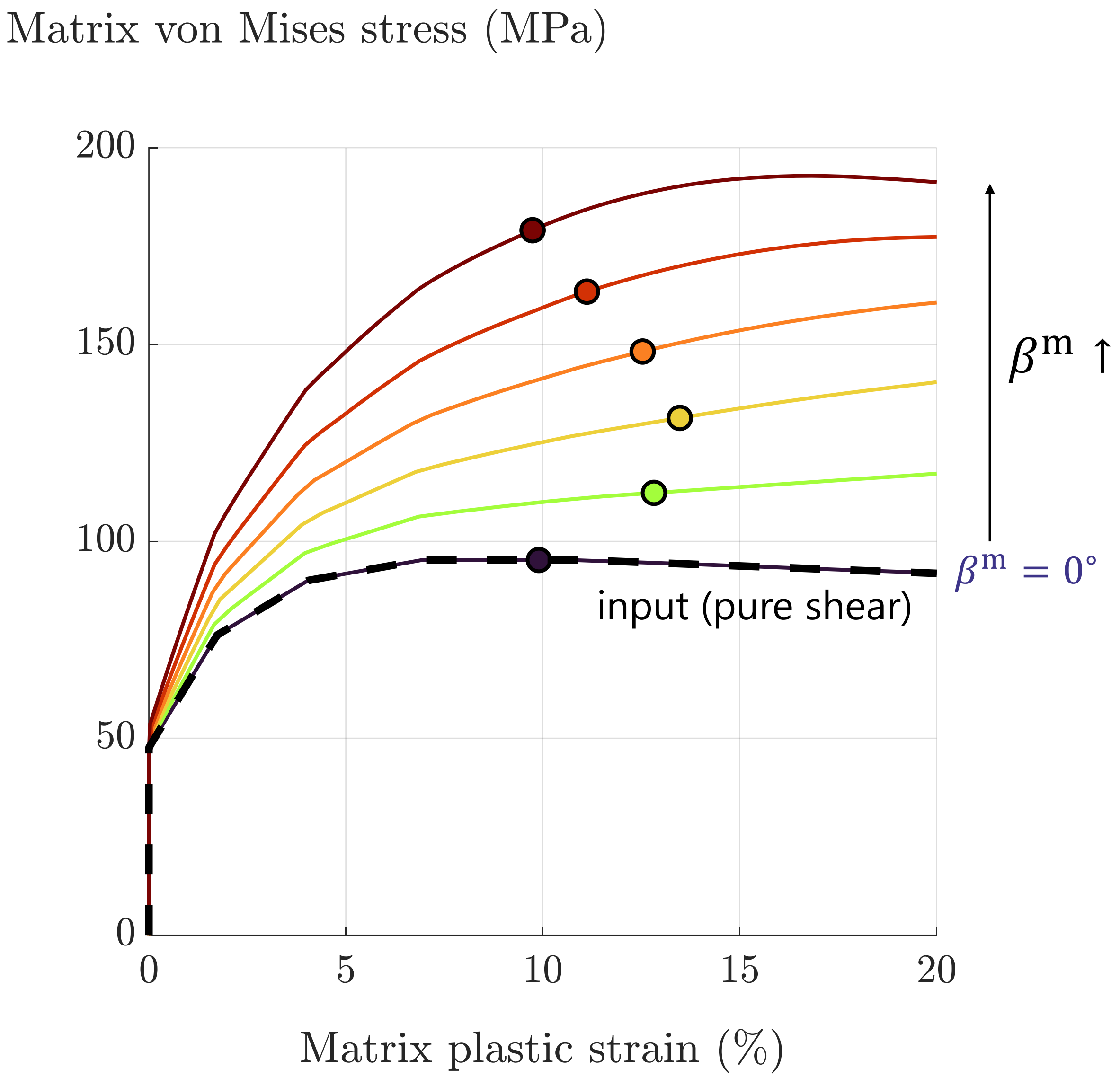


Matrix plasticity: friction angle, β^{m} ($\hat{\theta}_0 = 2°$)

Effect on composite strength

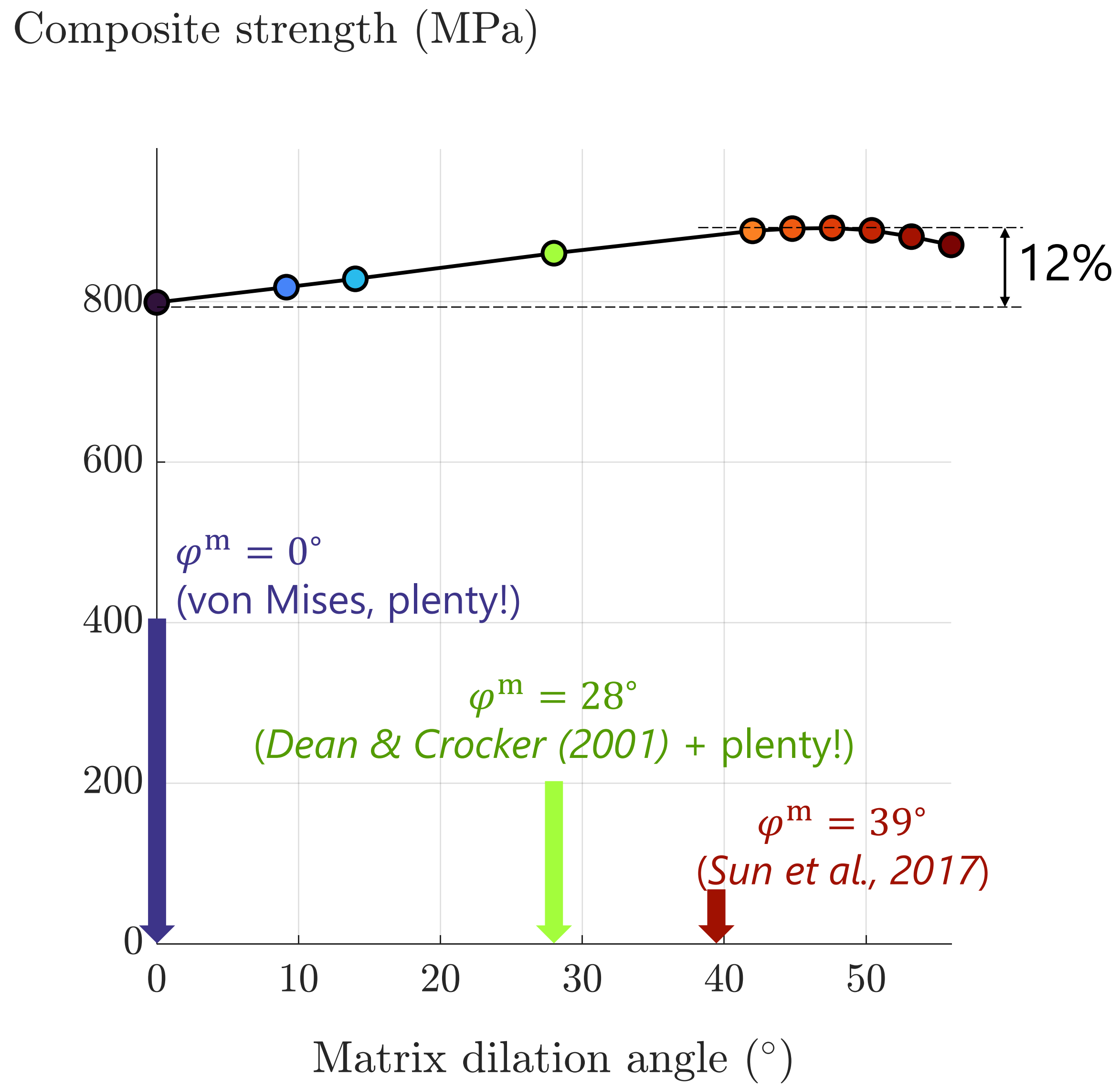


Apparent constitutive law

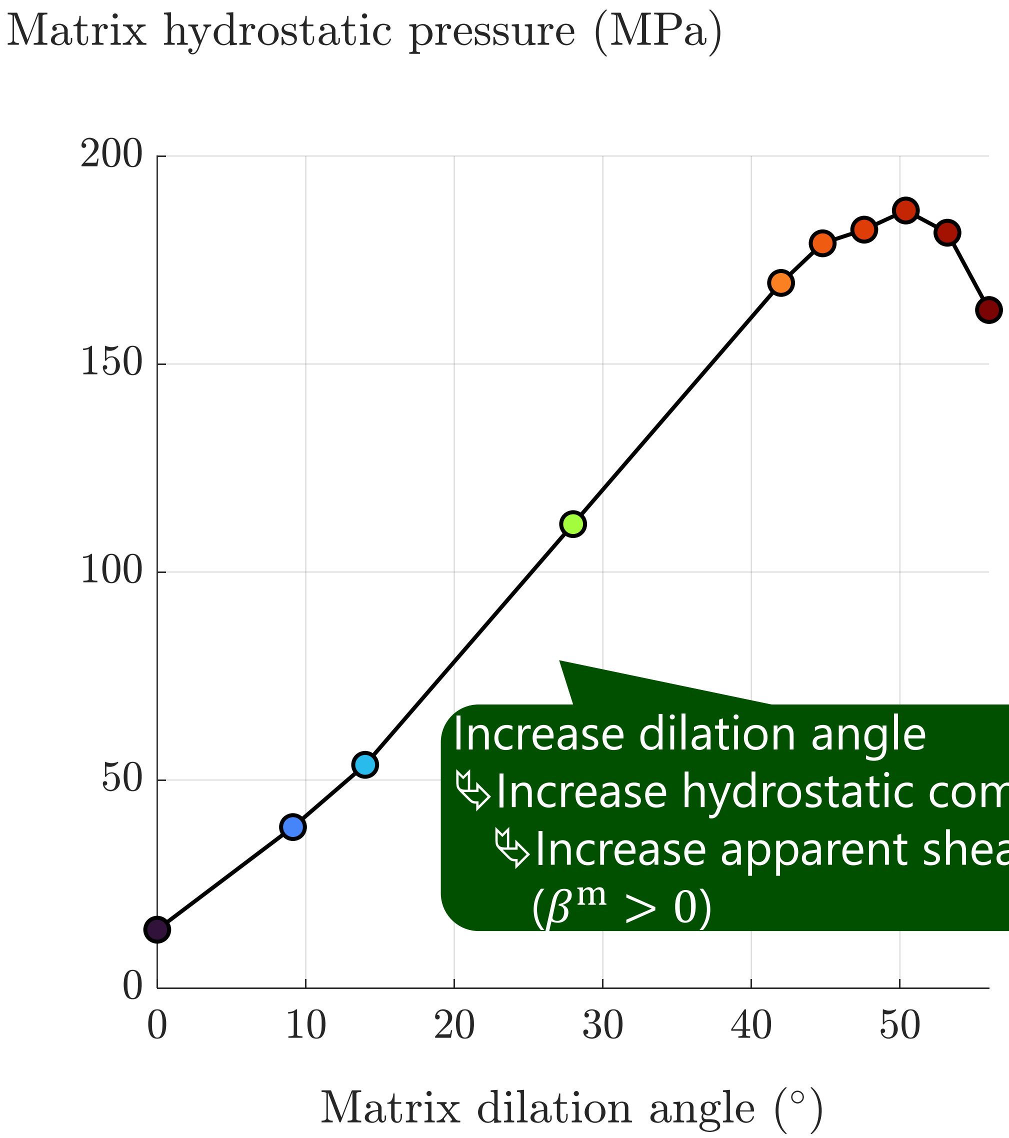


Matrix plasticity: dilation angle, φ^{m} ($\hat{\theta}_0 = 2°$)

Effect on composite strength



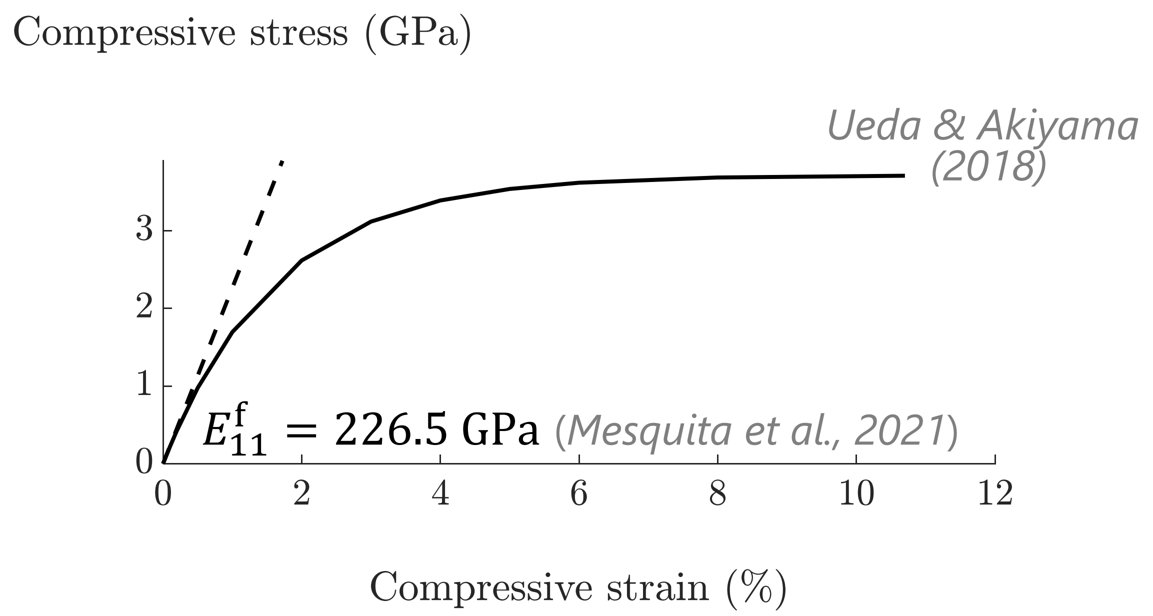
Hydrostatic pressure at peak



Increase dilation angle
↳Increase hydrostatic compression
↳Increase apparent shear strength ($\beta^{\mathrm{m}} > 0$)

Fibre elastic response (T300 carbon fibres)

Non-linear longitudinal response

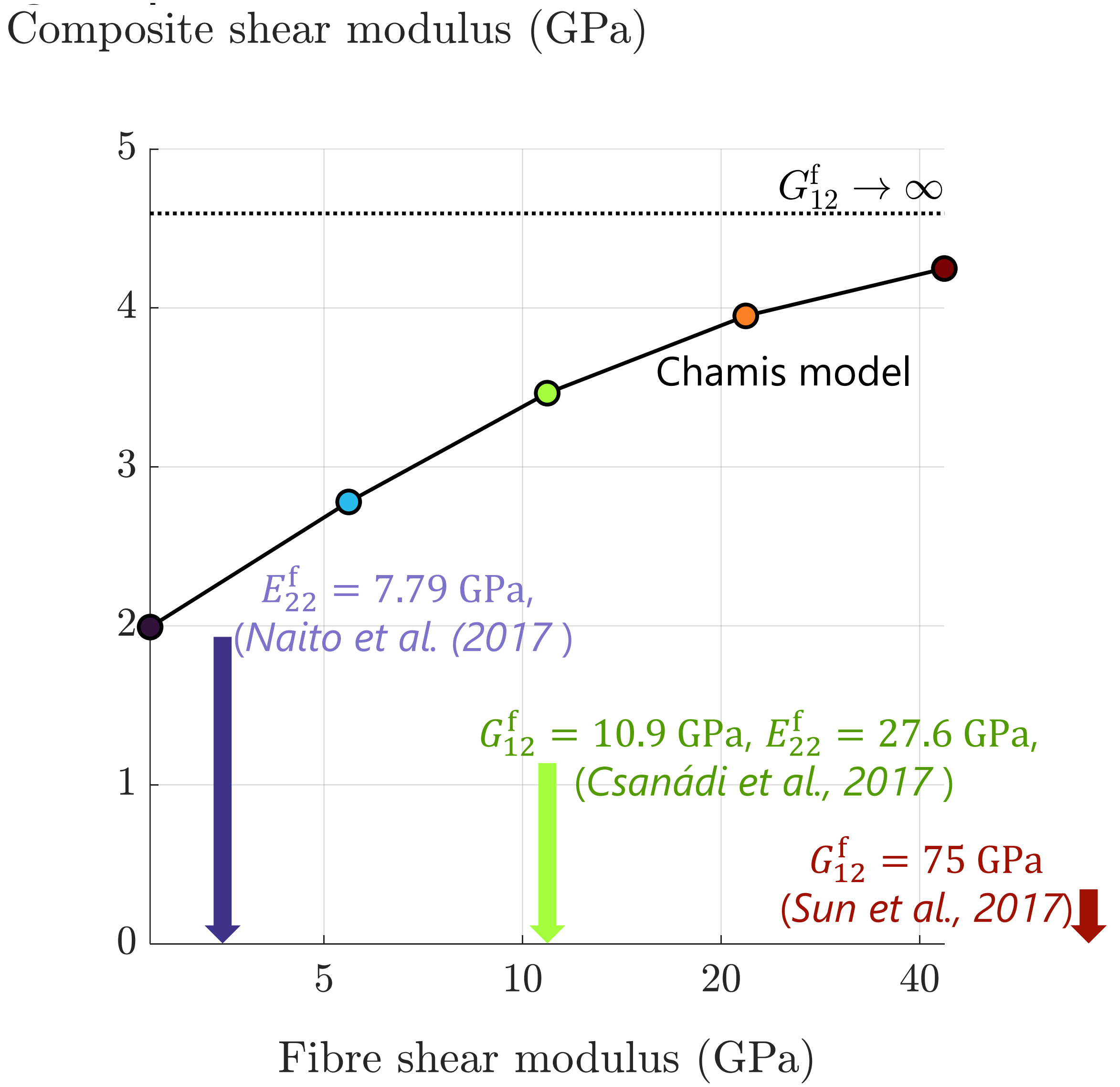


Transversely isotropic (linear)

- Baseline elastic constants:
  Csanádi et al. (2017)

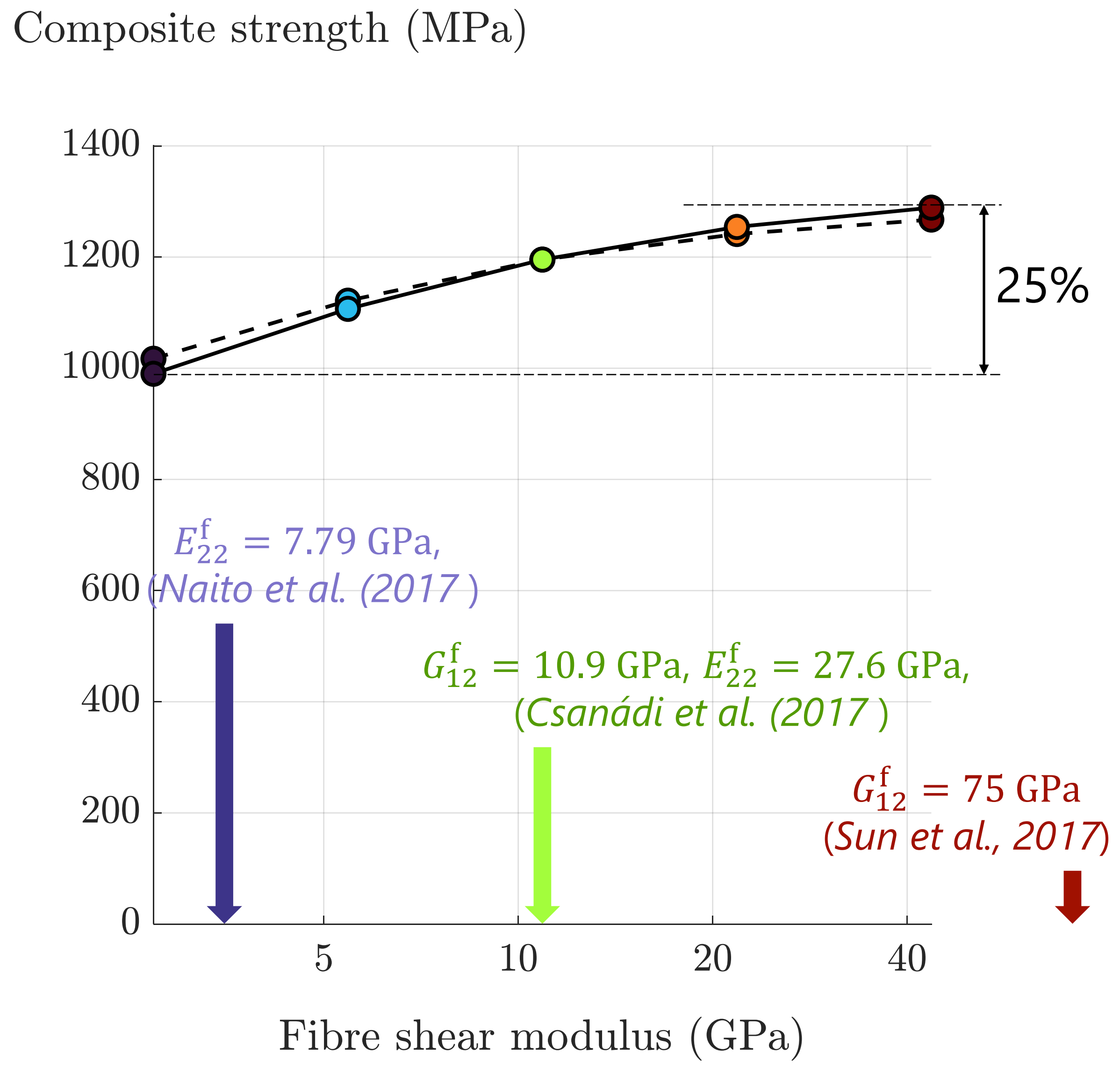
$$E_{22}^{f} = E_{33}^{f} = 27.6 \text{ GPa}$$
$$G_{12}^{f} = G_{13}^{f} = 10.9 \text{ GPa}$$
$$\nu^{f} = 0.3$$

Effect on composite's shear modulus

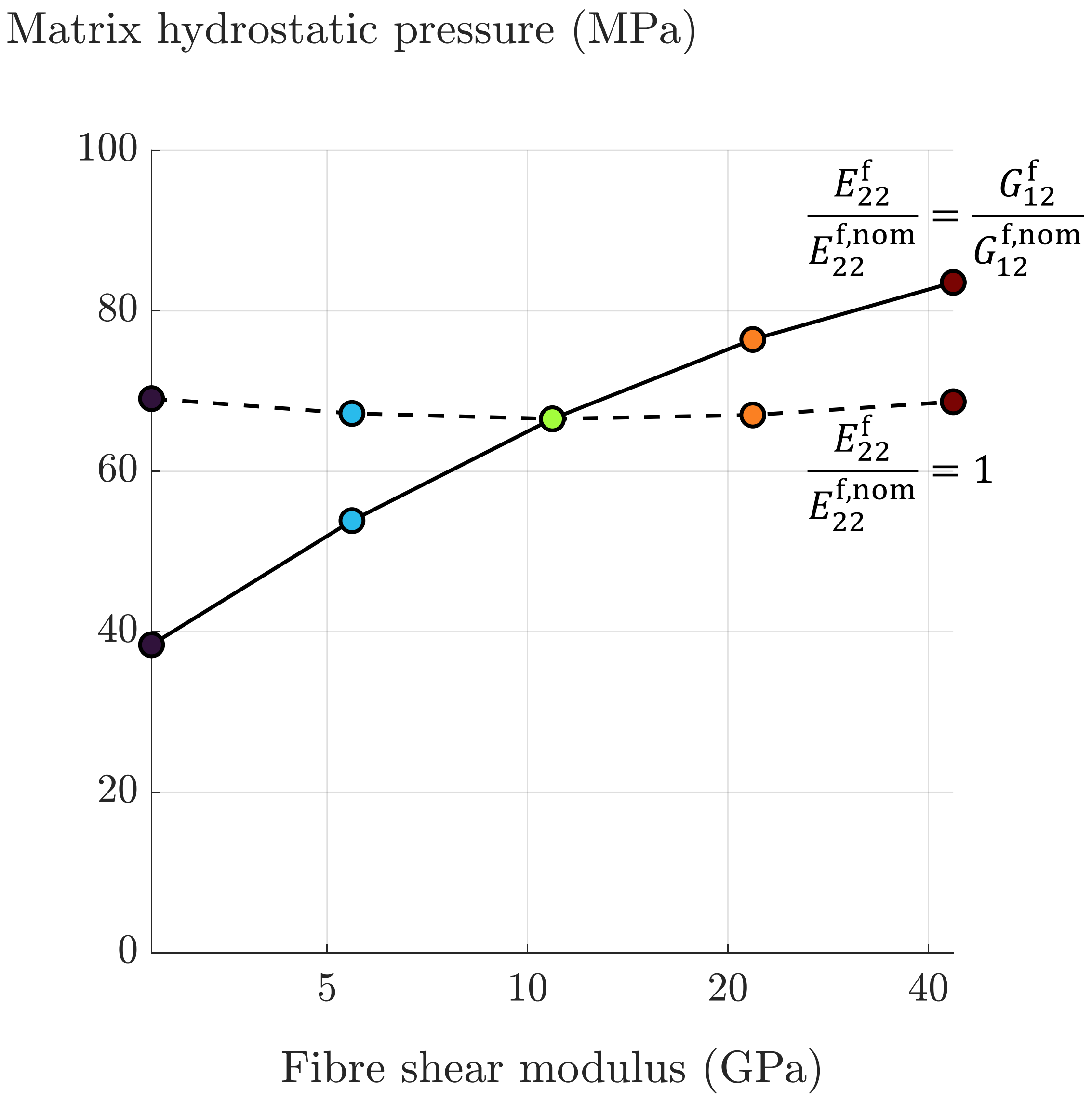


Fibre shear and transverse moduli $(\hat{\theta}_0 = 1°)$

Effect on composite strength

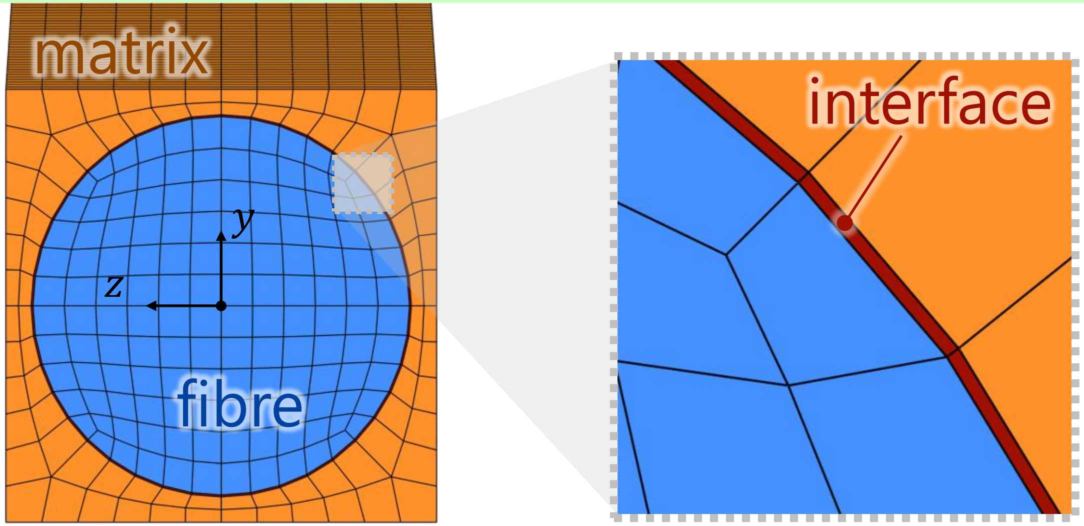


Hydrostatic pressure at peak



Interface: modelling

Cohesive element modelling

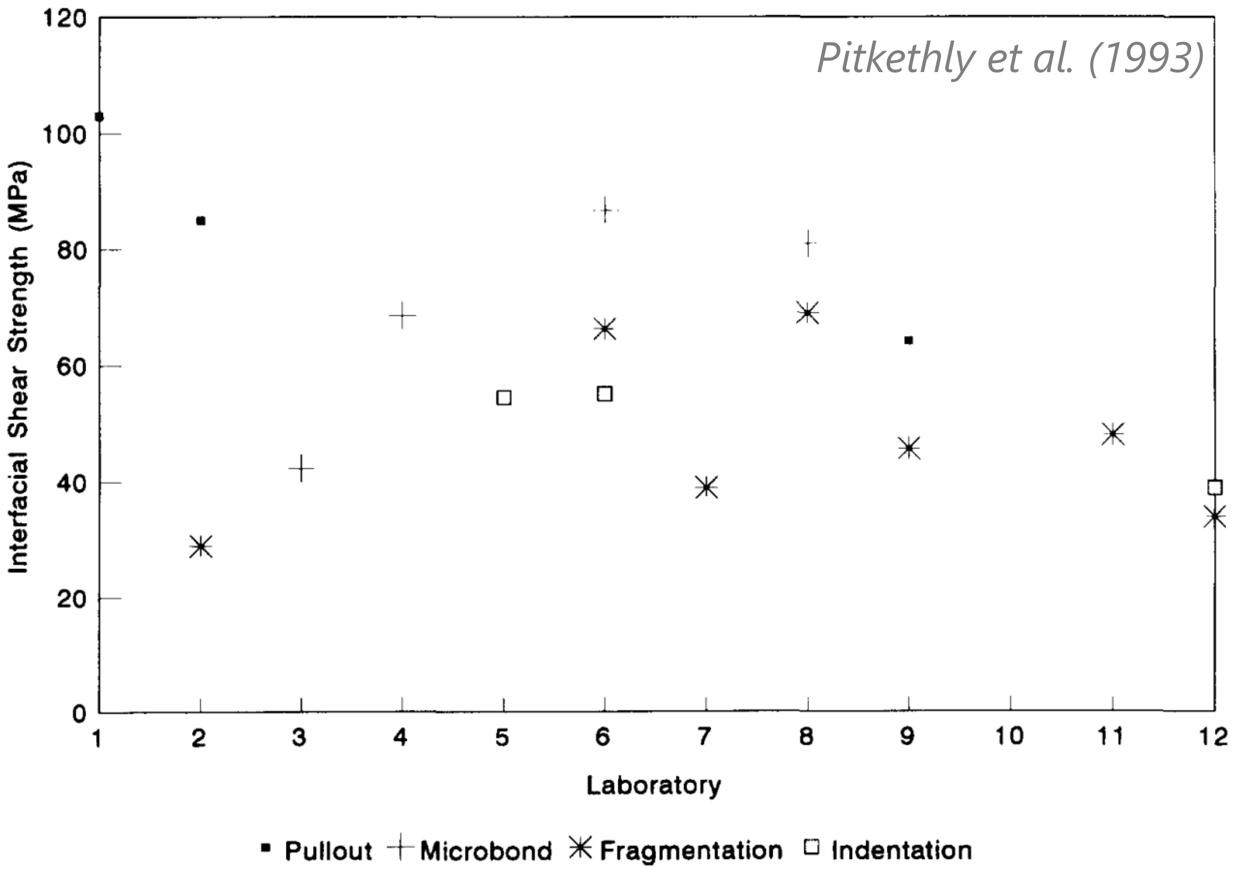


Cohesive properties

- **Same shear modulus & strength as matrix**
- Fracture toughness: 2-10 J/m^2 (no influence), *Zhou et al. (2018)*
- Failure initiation & propagation: quadratic interaction

Interfacial shear strength

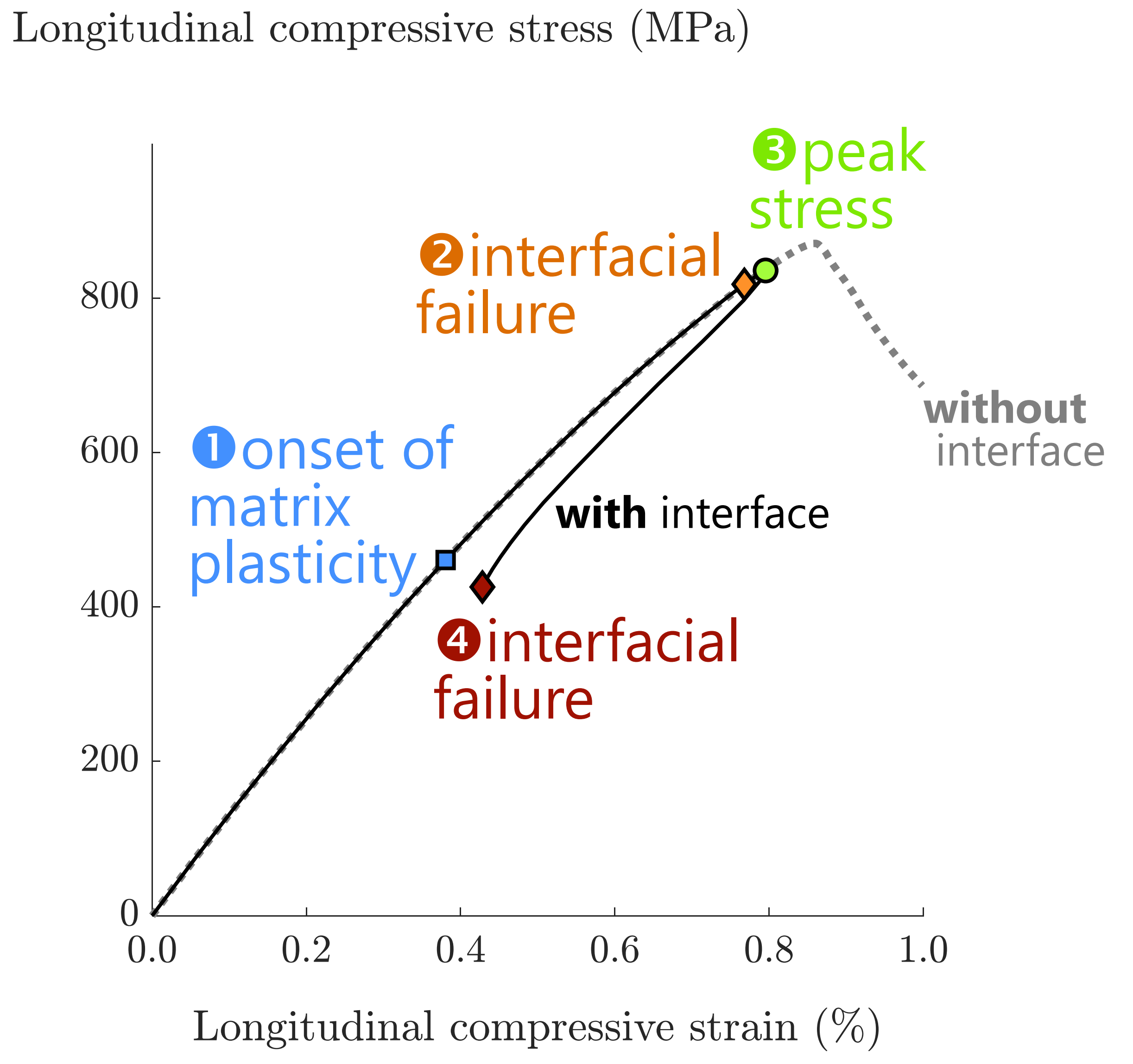
- Experimental data for same composite



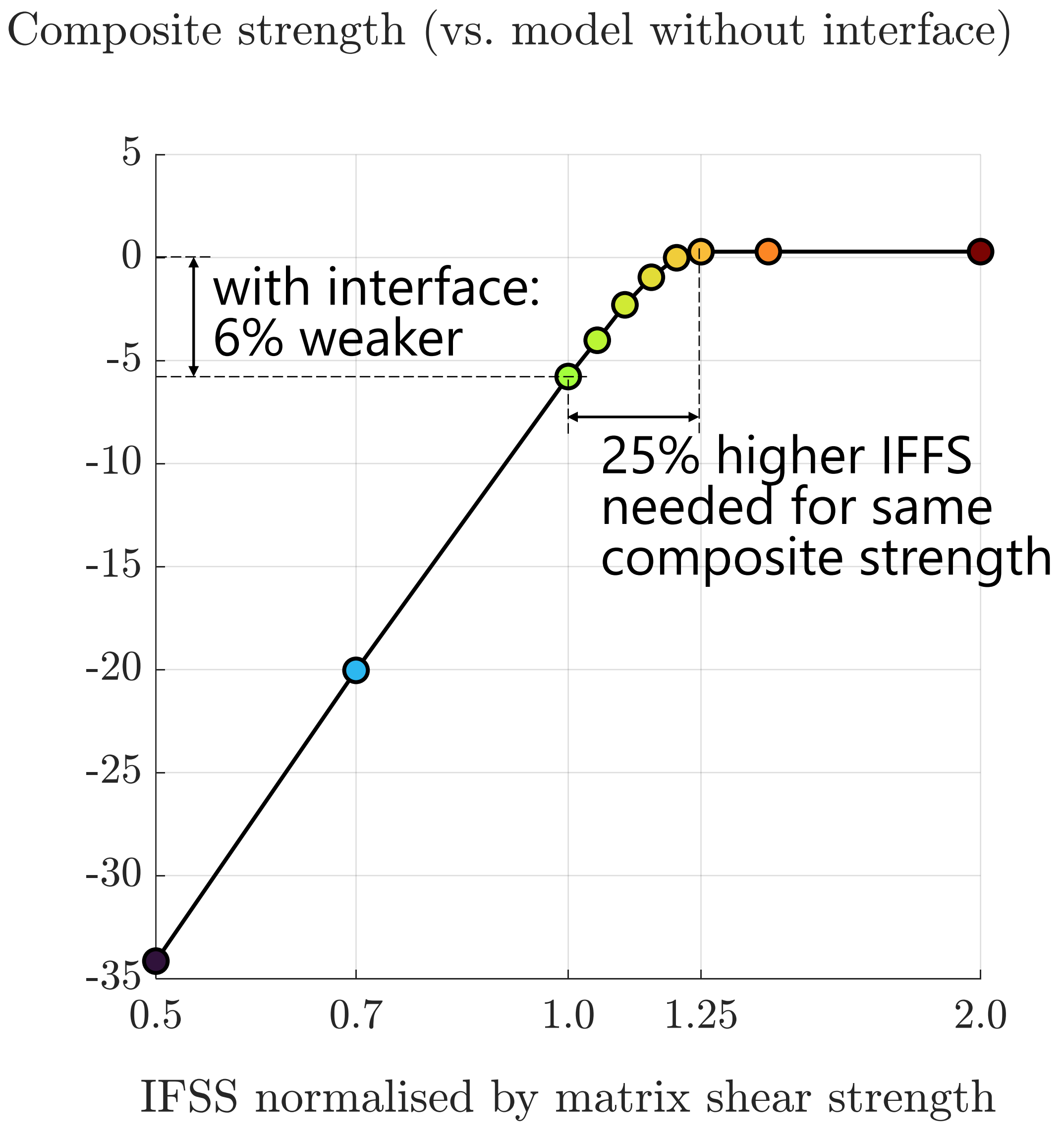
- Huge experimental uncertainty!

Interface: effect on compressive response

With vs. **without** interface



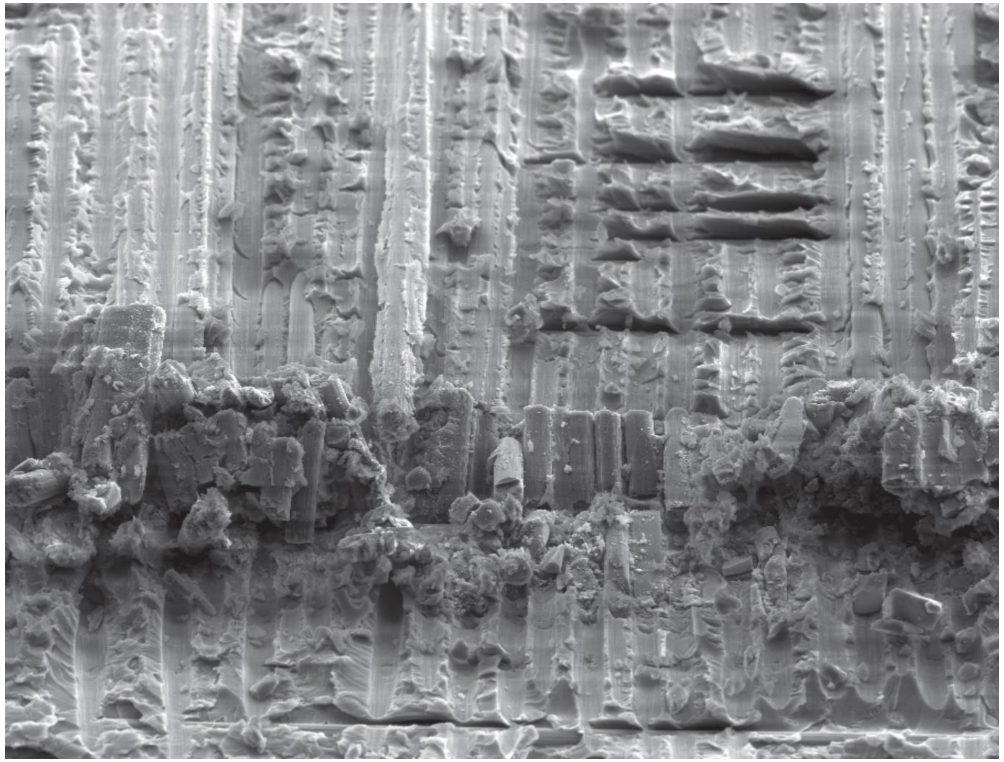
Effect on composite strength



Interface: preventing plasticity on matrix

Fractography

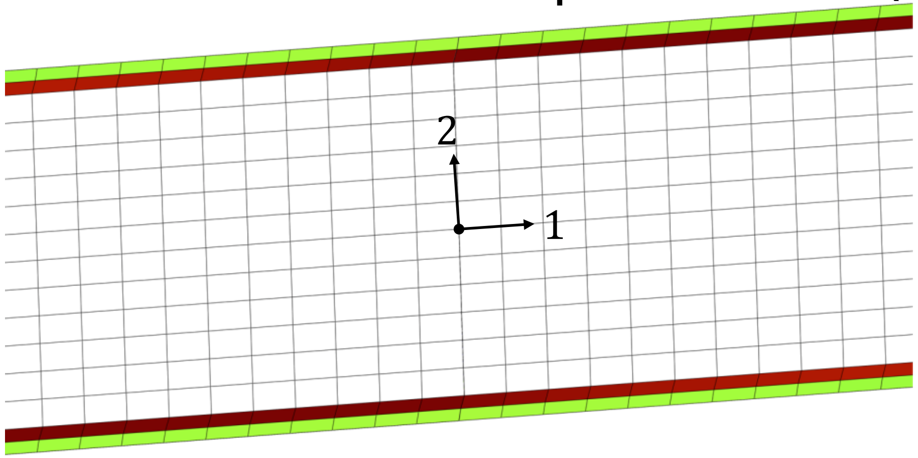
- Does interfacial failure really prevent plasticity in the matrix?



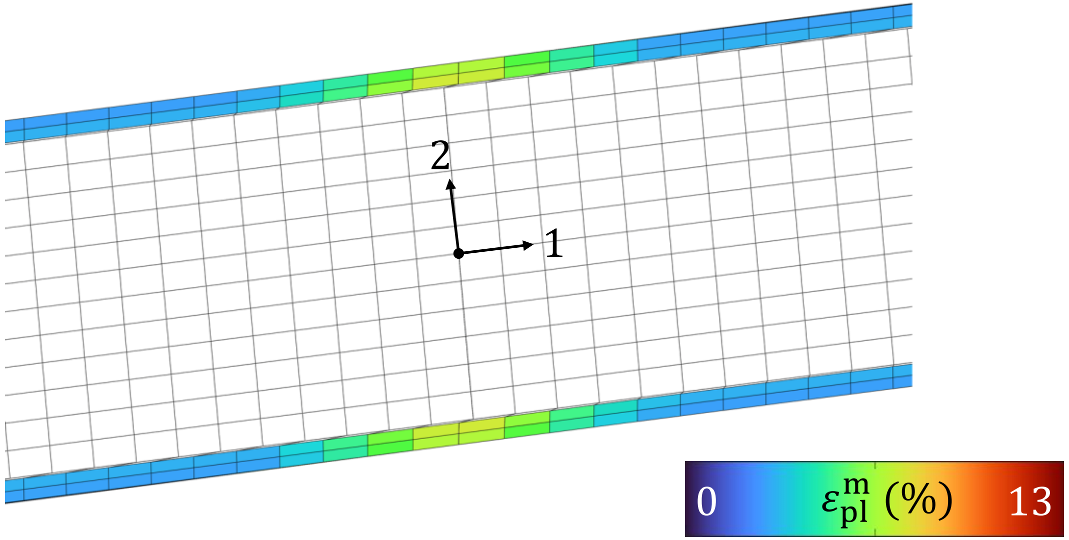
"Band of out-of-place microbucking"
(Greenhalgh, 2009)

Equivalent plastic strains in matrix

- **Without interface**, peak stress (3)



- **With interface**, interfacial failure (4)



Conclusions

- Matrix:
  - Plasticity
    - Materials: confinement & strengthening
    - Characterisation: friction & dilation angles
  - Shear non-linearity
    - Characterisation: include strain @ peak
    - Models: beware of LE-PP assumption & strain localisation
- Fibres:
  - Materials: increase shear stiffness
  - Models: account for finite shear stiffness
  - Characterisation: shear modulus
- Interfaces:
  - Characterisation: IFSS (consistency) & complex 3D loading
  - Models: are CZM adequate?

"**Pure shear and compression-shear** characterisation of polymer matrix… "
Bohao Zhang
Wednesday 2nd, 3.20 pm

"Experimental characterisation of the **dilation angle** of polymers"
Gustavo Quino Quispe
Thursday 3rd, 10.00 am

NextCOMP

Next Generation
Fibre-Reinforced Composites

https://nextcomp.ac.uk

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A collaboration between Imperial College London and University of Bristol

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