Forming simulations for unidirectional thermoplastic composites: Improvements in characterizing, modelling and validating in-plane shear

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Introduction

Unidirectional (UD) carbon fibre reinforced thermoplastic composites material are of interest to the aerospace industry to enable automated manufacturing of low-weight, structurally loaded components. However, challenges with complex part geometry and (tailored) layups can easily lead to defects during production. Composite forming simulation tools offer virtual process modelling to aid engineers during initial design or problem solving. This research aims to advance forming simulations for UD materials through improved material characterization and modelling.

In-plane shear characterization

The bias extension method was developed for use on cross-ply laminates from unidirectional material. This method is already established for in-plane shear characterization of woven composites. Datasets for two materials were generated with varying rates and temperatures. See [1].

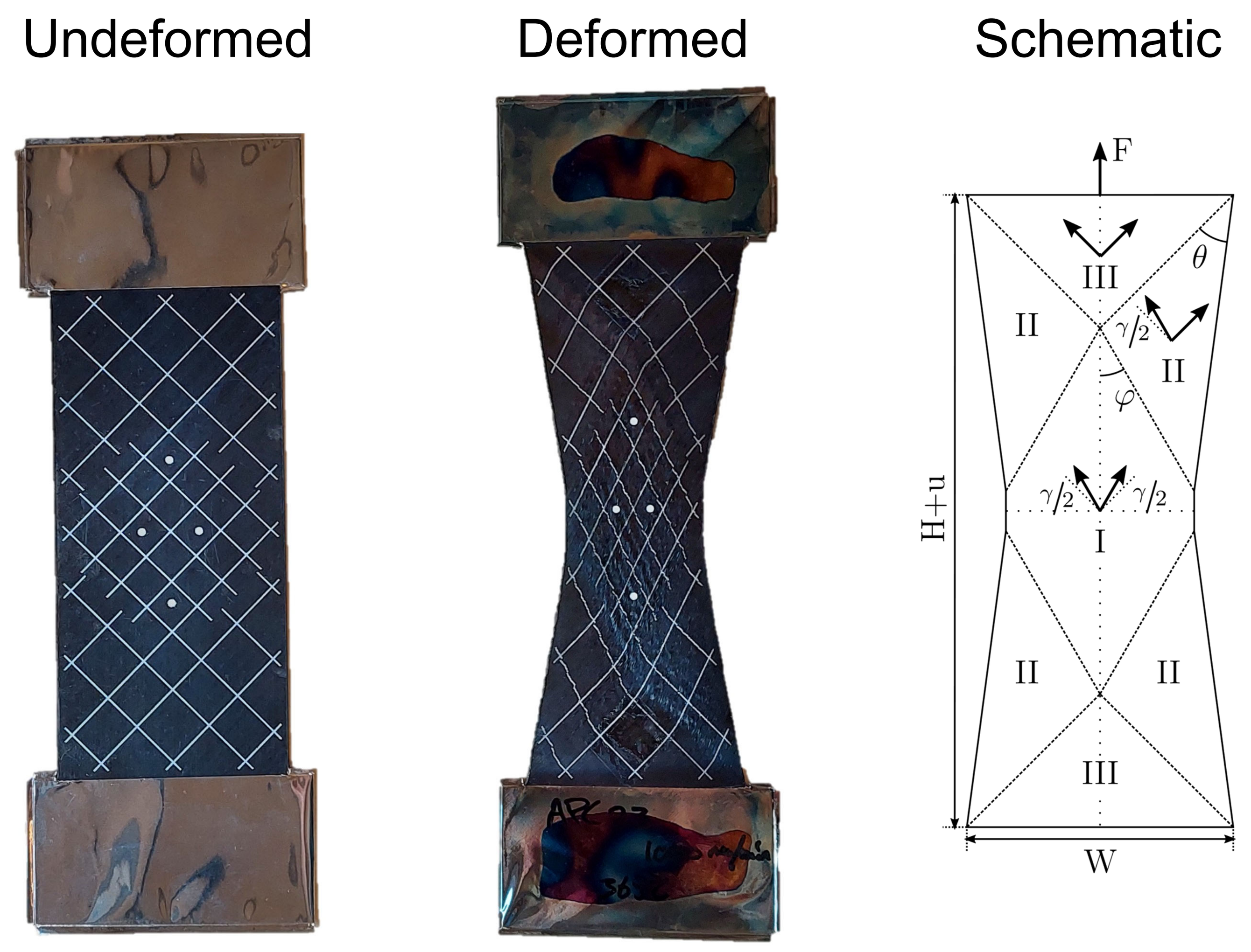


Figure 1: Bias extension test specimens and schematic deformation

The measured response is strongly dependent on rate and moderately dependent on temperature in molten condition. The non-linear force/shear angle curves are classified with start-up, steady state and large deformation regimes.

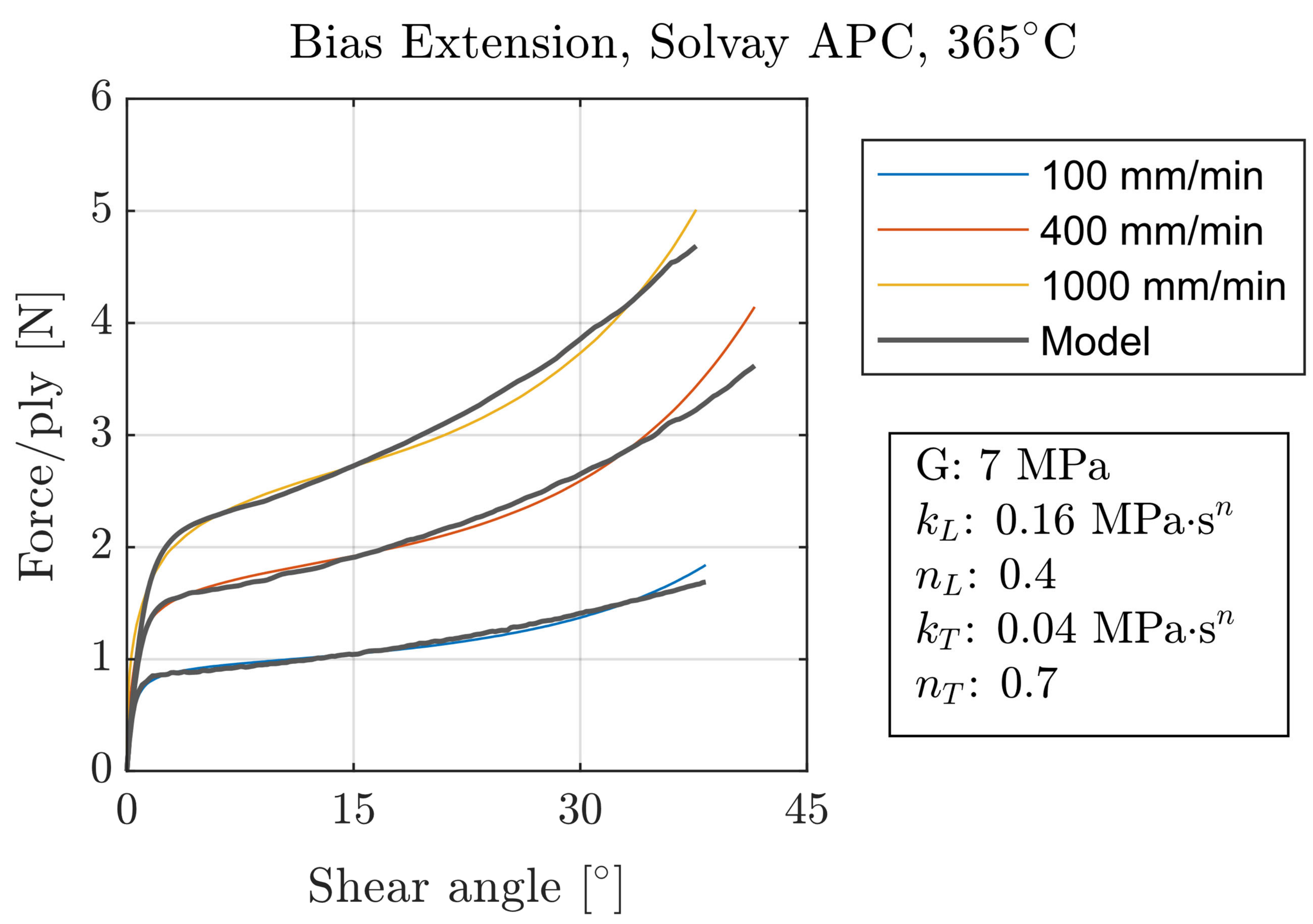
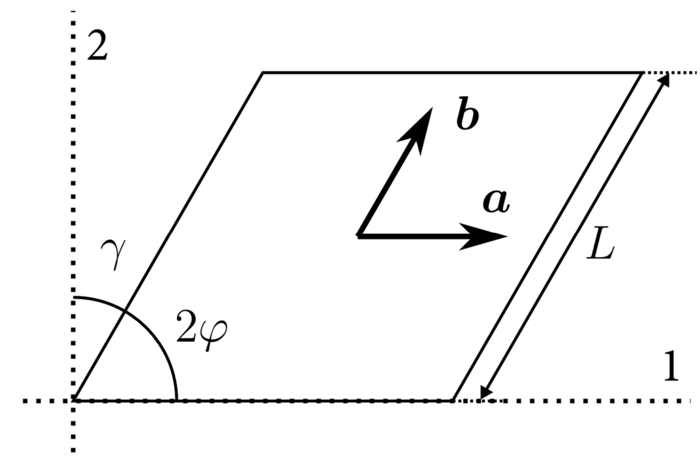


Figure 2: Bias extension experimental results and model

Bias Extension model

The trellis shear deformation is dominant during bias extension testing. For small deformation it is the same as simple shear, but a planar extensional flow transverse to the fibre occurs at larger deformation due to inextensibility and incompressibility.



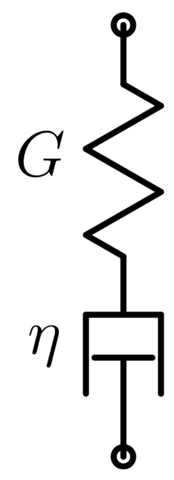
$$\boldsymbol{D} = \dot{\varphi}\begin{bmatrix} 0 & -1 & 0 \\ -1 & \dfrac{2}{\tan(2\varphi)} & 0 \\ 0 & 0 & \dfrac{-2}{\tan(2\varphi)} \end{bmatrix}$$

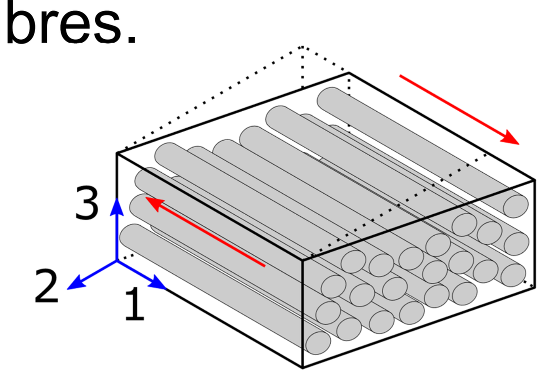
Power equilibrium is considered to model an analytical force response, with contributions from extra stresses in two distinct deformation regions.

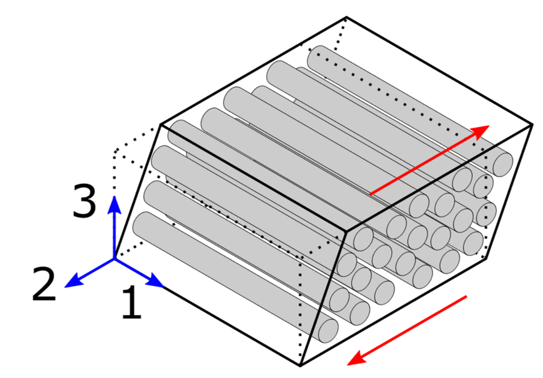
$$F\dot{u} = \int_V \boldsymbol{\sigma}\colon\boldsymbol{D}\, dV = V_I(\tau_I\colon D_I) + 4V_{II}(\tau_{II}\colon D_{II})$$

Material model

In-plane shear is modelled with a 1D Maxwell model and utilizes a power law longitudinal viscosity. A power law transverse viscosity models the deformation perpendicular to the fibres.







$$\eta_L = k_L|2D_{12}|^{n_L-1}$$

$$\tau_{12} = G\cdot\varepsilon_s \quad \dot{\varepsilon}_s = 2D_{12} - \frac{G\varepsilon_s}{\eta_L}$$

$$\eta_T = k_T\cdot|2D_{22}|^{n_T-1}$$

$$\tau_{22} = 2\eta_T D_{22}$$

$$\tau_{33} = 2\eta_T D_{33}$$

Validating simulations

Formed parts with pre-applied dot patterns are analysed to measure the experimental in-plane shear deformation and can be employed as validation cases for simulation models.

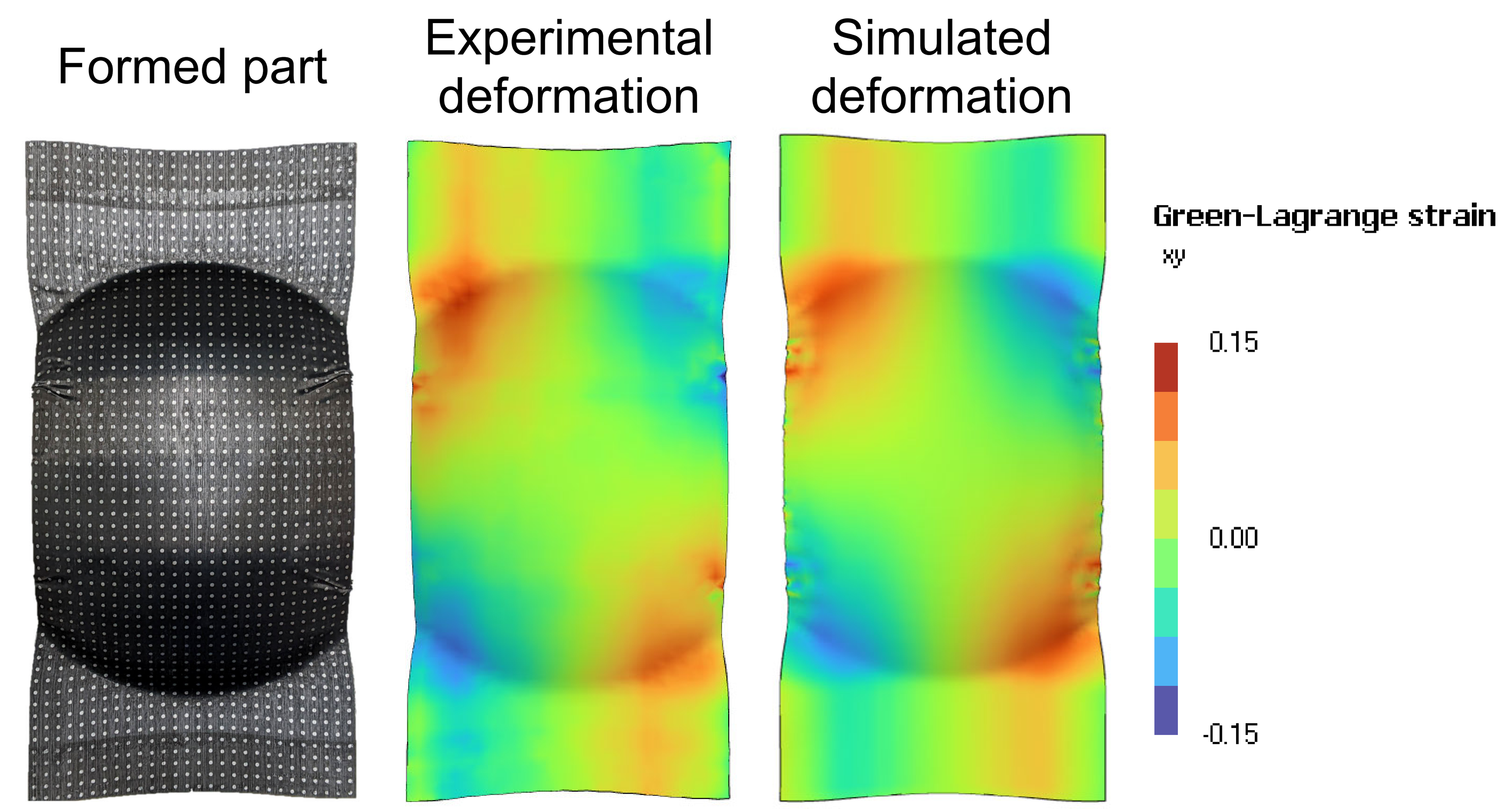


Figure 3: Dome validation geometry. Comparison of in-plane shear deformation.

References

[1] Brands et al. Front. Mater. 9:863952 doi: 10.3389/fmats.2022.863952