EXPERIMENTELLE ABLEITUNG EINES SIMPLIFIZIERTEN MATERIALMODELLS FÜR KURZFASERVERSTÄRKTE THERMOPLASTE UNTER CRASHBELASTUNG

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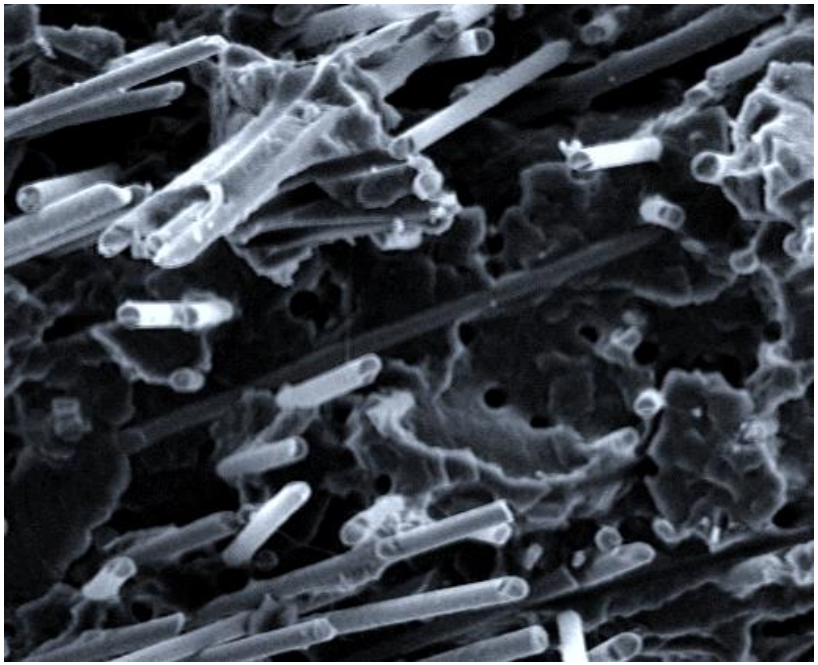
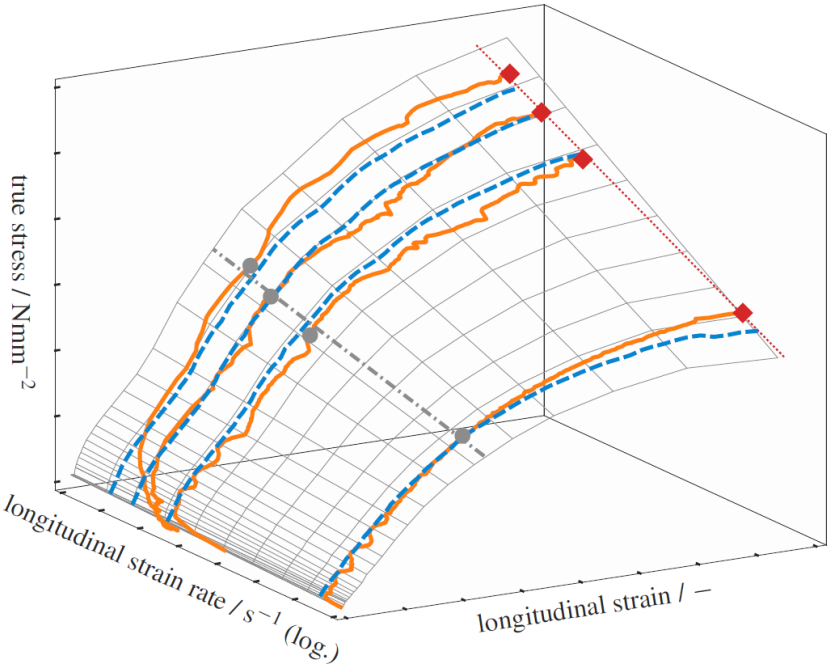
A SIMPLIFIED MATERIAL MODEL FOR SHORT FIBRE REINFORCED THERMOPLASTICS IN CRASHWORTHINESS APPLICATIONS

Felix Dillenberger [1], Stefan Kolling [2], Jens Schneider [3]





[1] Fraunhofer LBF, [2] THM Gießen, [3] TU Darmstadt

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CONTENTS

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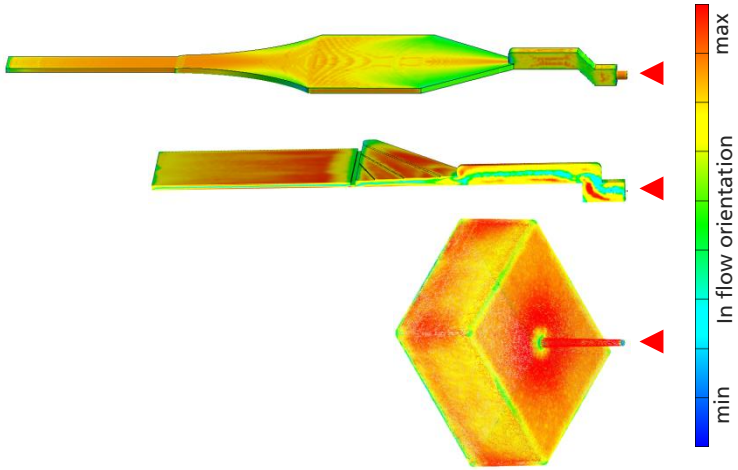
Short Fibre Reinforced Thermoplastics

Introduction/ Motivation

- Short fibre reinforcement leads to complex inhomogeneous anisotropic material behaviour depending on
  - Process parameters
  - Part geometry
  - Material properties



- Prediction of part behaviour by FE simulation
  - Information on fibre orientation necessary
    - Injection moulding simulation
    - or clustering/segmentation of specific regions
  - Adequate material model necessary

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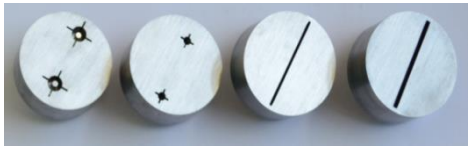
Evaluation of Typical Fibre Orientations

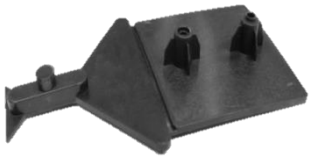
Injection Moulding of Specific Elements

- Assumption of typical fiber orientations in specific zones
- Specially developed flexible injection mould, for the analysis and classification of specific elements
  - Plates of variable thickness with Interchangeable inserts: easy processing, low production costs for new inserts
  - Variable Locking points: adjustable angle of flow



Examples

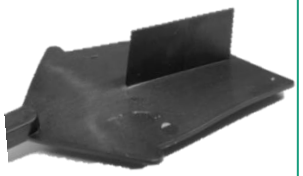
screw bosses 0°



rib, thick 0°

rib, thick 90°

rib, small 0°



➡ Anisotropy distribution has to be taken into account in material modelling

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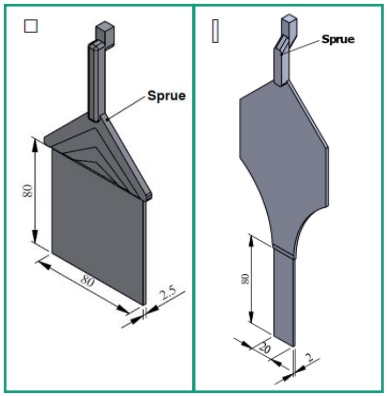
MATERIAL CHARACTERIZATION

Material Selection

- Materials
  - PP[A] : Polypropylene (MOPLEN HP500N) + additives
  - PPGF30[A] : PP[A] + 30% glass fibres ($l < 1\ mm, D \sim 13\ \mu m$)
    - Compouded in-house, identical additives in matrix material and composite
    - Fibre influence distinguishable

- Distinctly different orientation states:
  - Plate (□): non UD
  - Flat Bar (▯): ~ UD



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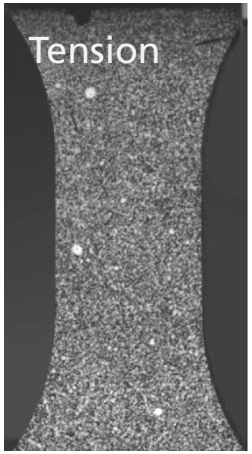
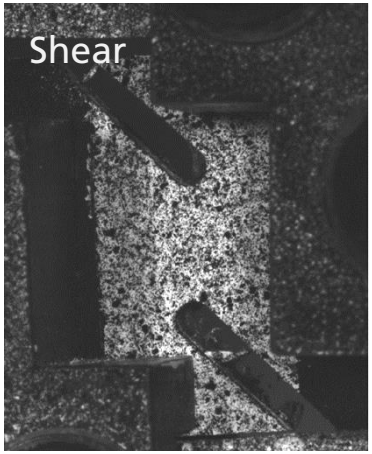
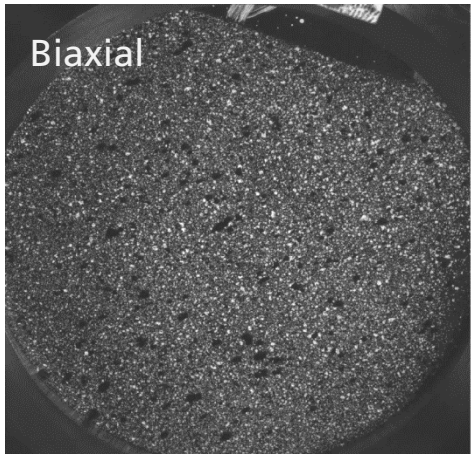
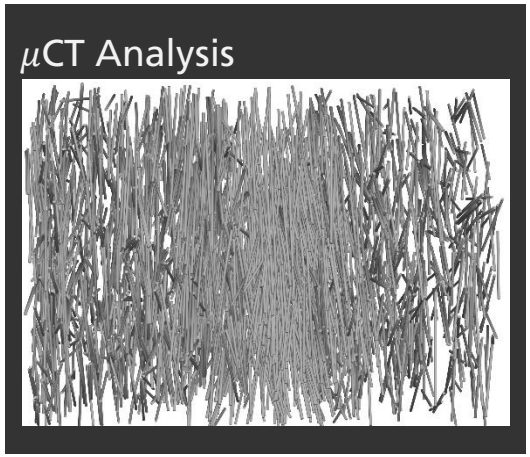
Mechanical Testing

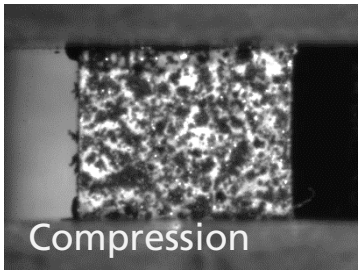
- Optical measurement of local strains: Grey-scale-correlation
- Quasistatic and dynamic testing speeds, T 23°C

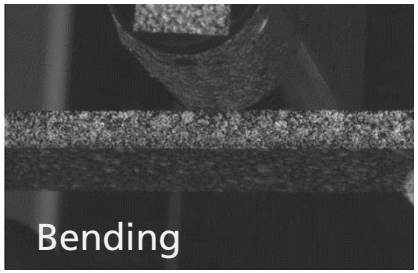


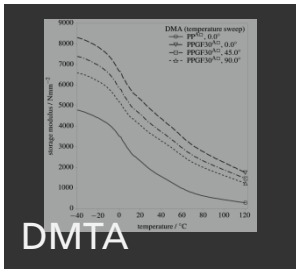


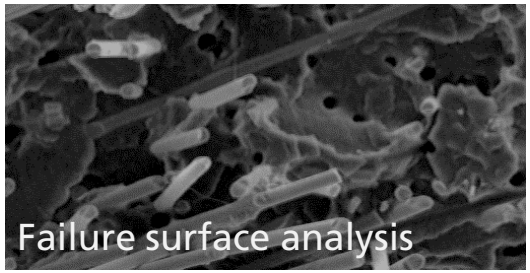












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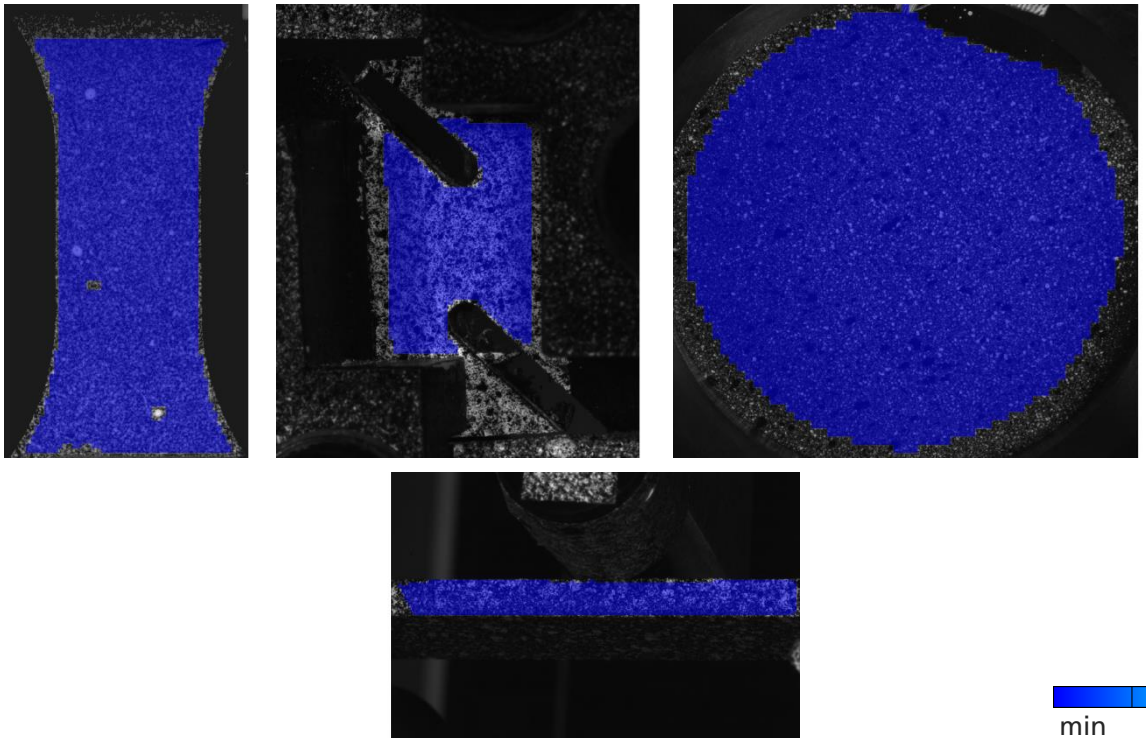

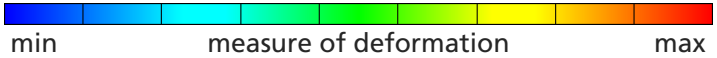

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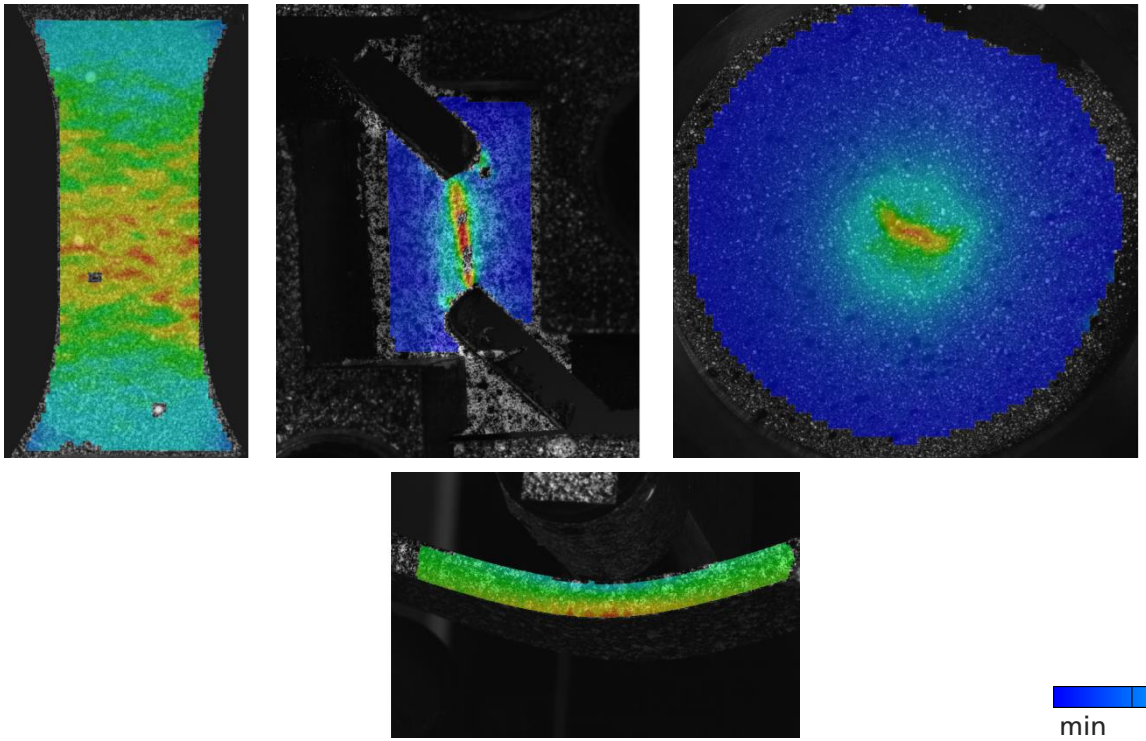

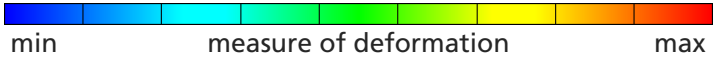

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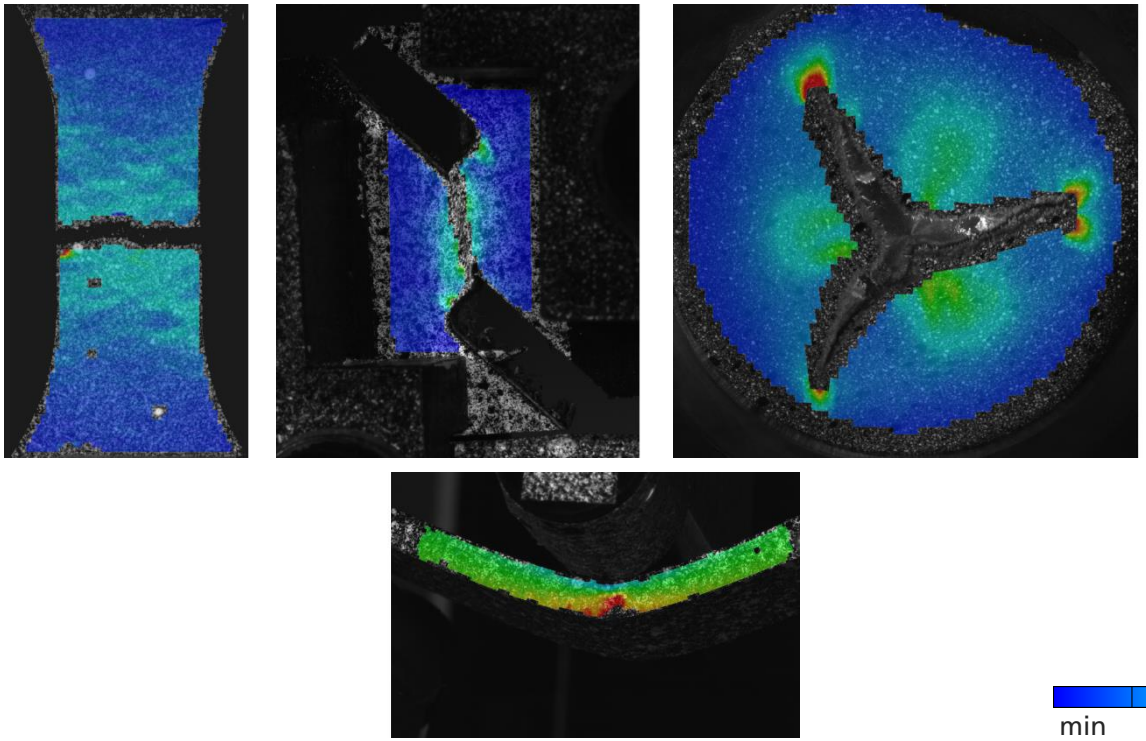

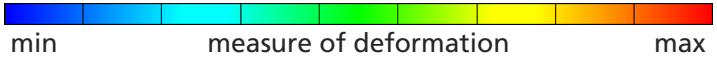

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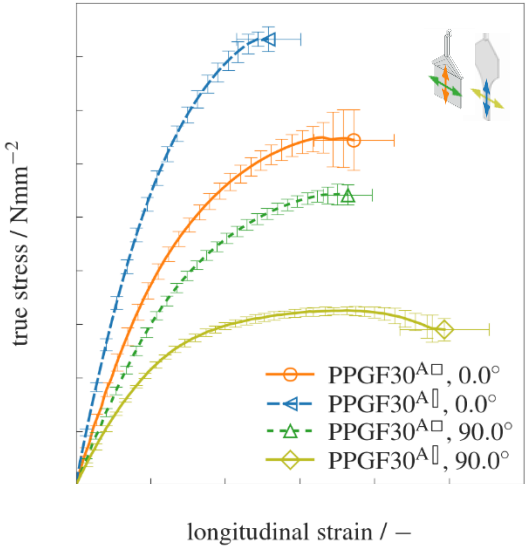
Experimental Results

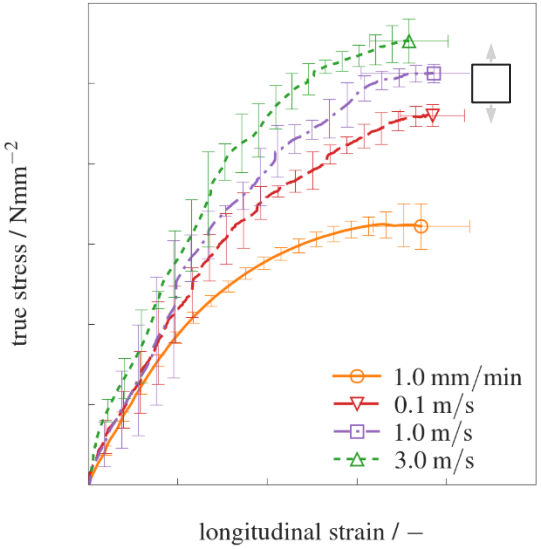
Mechanical Behaviour of PPGF30

- Anisotropy
- Strain rate dependency
- Load type dependency (compression-shear-tension)

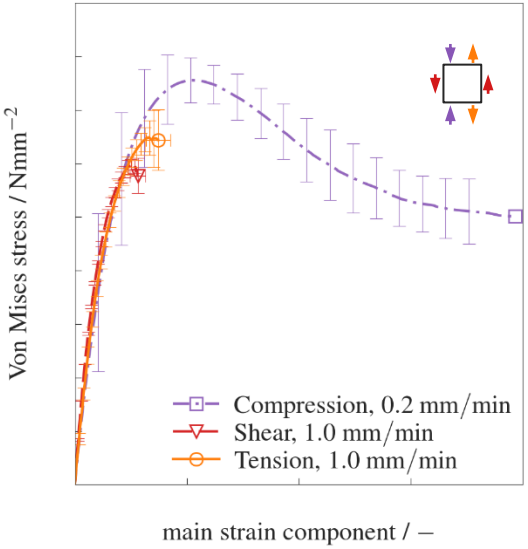
PPGF30, Source part dependency



PPGF30, Strain rate dependency



PPGF30, Load type dependency



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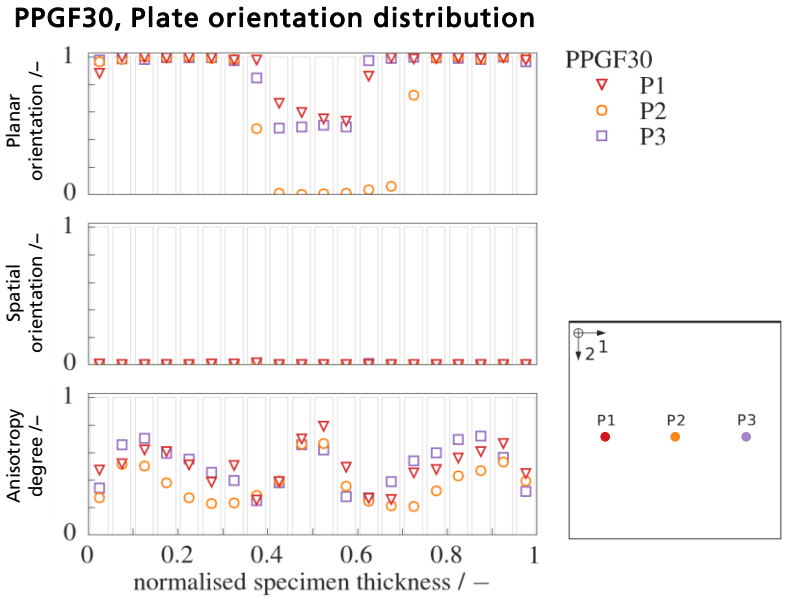
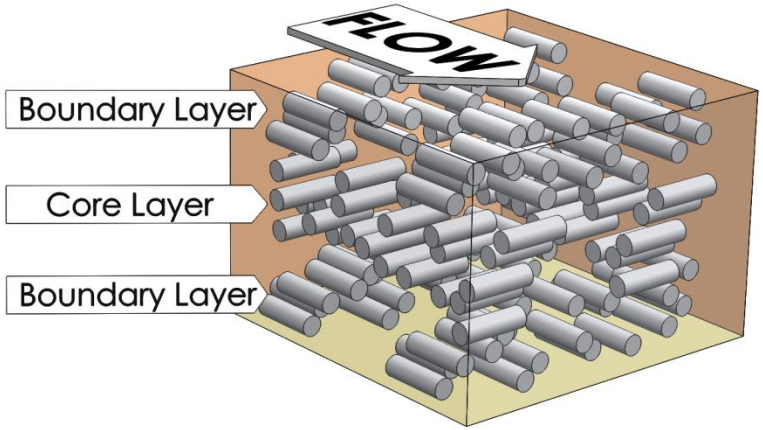
Experimental Results

Microstructure

- Automatic Algorithm LBF GF-DETECT: analysis of μCT data
  - 3D representation of each fibre (l, D, Position, Orientation)
  - Description of orientation state of fibres by orientation tensor
- Through thickness distribution





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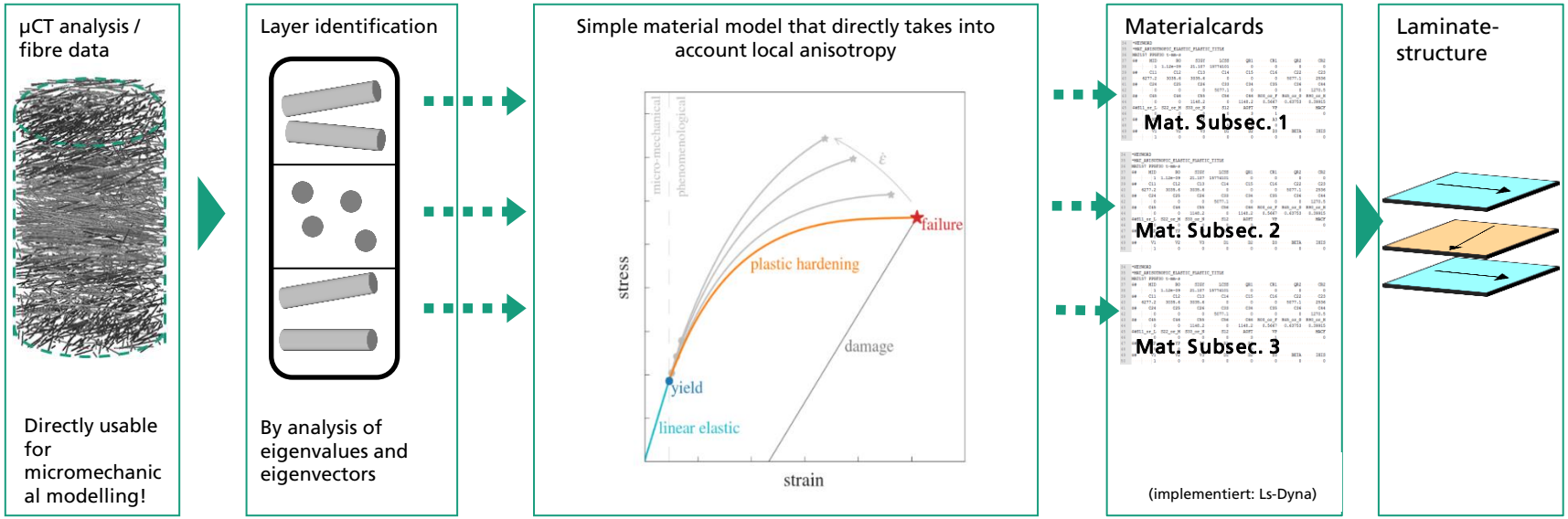
MATERIAL MODELLING

Material Modelling

Overview

- Section/layer identification from CT data -> derivation of a material modelling layer
- For each layer: derivation of mechanical characteristics from orientation tensor



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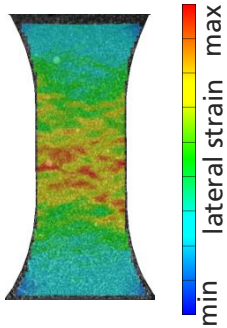
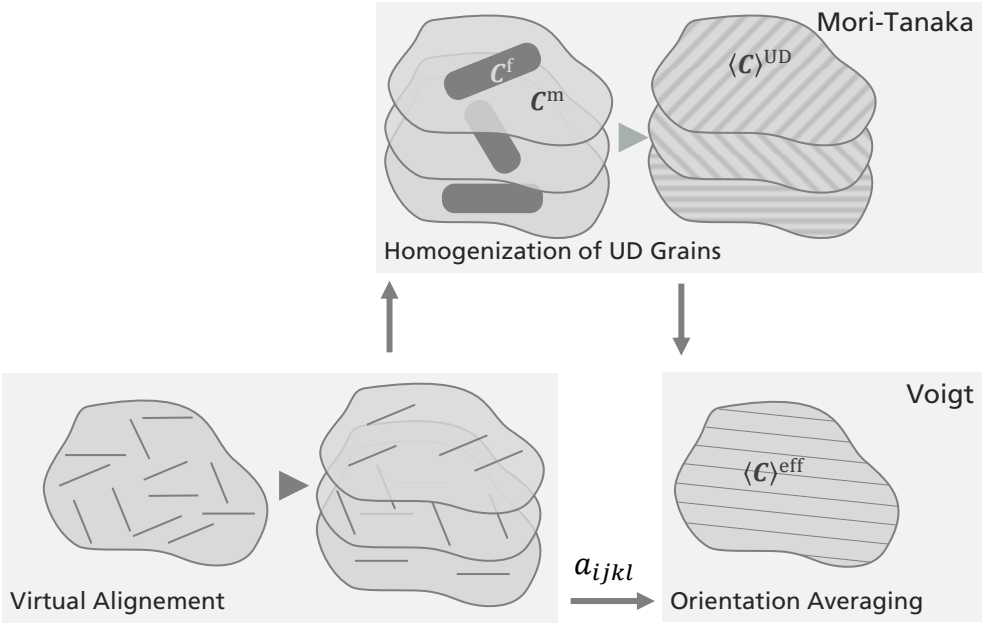
Modelling of Linear Elastic Behaviour

Overall Homogenization Scheme

- Taking into account orientation/ aspect ratio distribution
  - Virtual decomposition: $\langle \boldsymbol{C} \rangle^{\mathrm{UD}} = f(\frac{l}{d}, \nu^{\mathrm{f}}, C^{\mathrm{m}}, C^{\mathrm{f}})$





[Tucker 1987, 1990]

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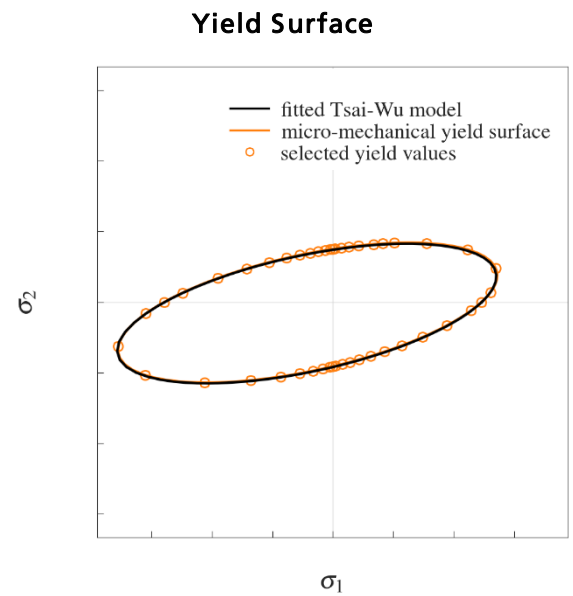
Modelling of Plastic Behaviour

- Transition from microscale to macroscale at yield surface
  - relate matrix yield stress to effective yield (Stress concentration tensor)
  - SAMP yield function for matrix phase
    $(\sigma_{\mathrm{vm}}^{m})^2 - A_0 - A_1 p - A_2 p^2 \leq 0$

- Fitting of micromechanical SAMP yield points at arbitrary stress states to macroscopic phenomenological yield surface
  - Tsai Wu $\phi = \boldsymbol{F}_i \boldsymbol{\sigma}_i + \boldsymbol{F}_{ij} \boldsymbol{\sigma}_i \boldsymbol{\sigma}_j - 1 = 0$
    - Will reduce to SAMP yield surface for the case of zero fibre volume fraction
    - Anisotropic and asymmetric

$$\phi\left(\boldsymbol{\sigma}, \bar{\varepsilon}_{pl}, Y_{t,1|2|3}, Y_{c,1|2|3}, Y_{s,23|13|12}, Y_{b,23|13|12}\right) = 0$$



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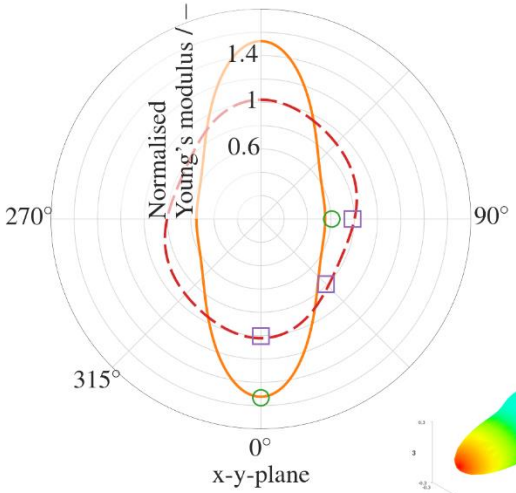
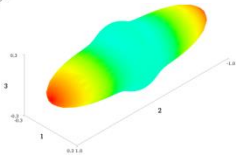
Validation of Micromechanical Model

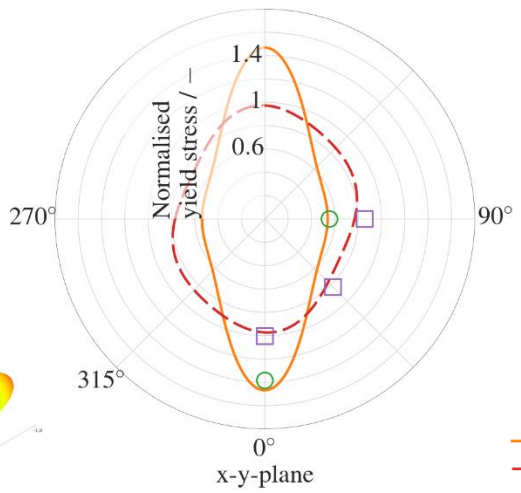
- Reasonable approximation of experimental results over wide range of orientation degrees: (□ = non UD, ▯ ~ UD)

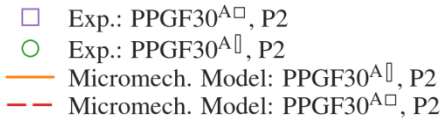
PPGF30, Tensile stiffness





PPGF30, Yield stress





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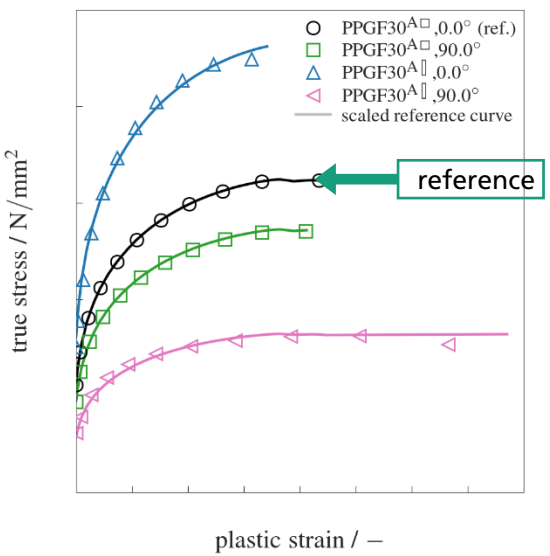
Modelling of Hardening

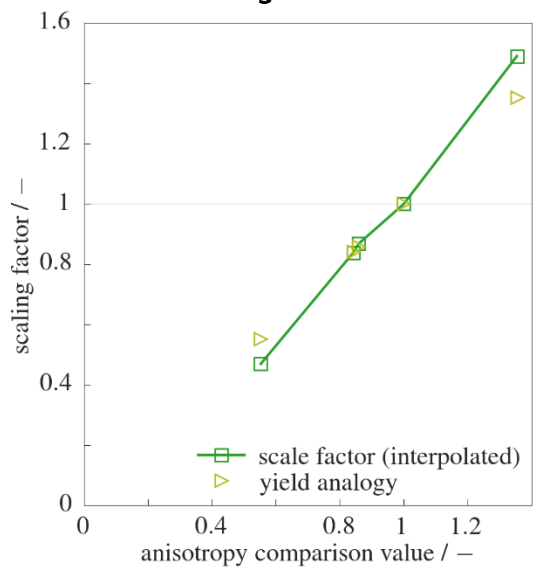
Phenomenological Approach

- Qualitative similarity of hardening curves (scalability)
- Definition of directional anisotropy comparison value $\xi(\boldsymbol{A})$: ~Linear scaling factor
  - Correlation: scaling factor <-> anisotropy comparison value

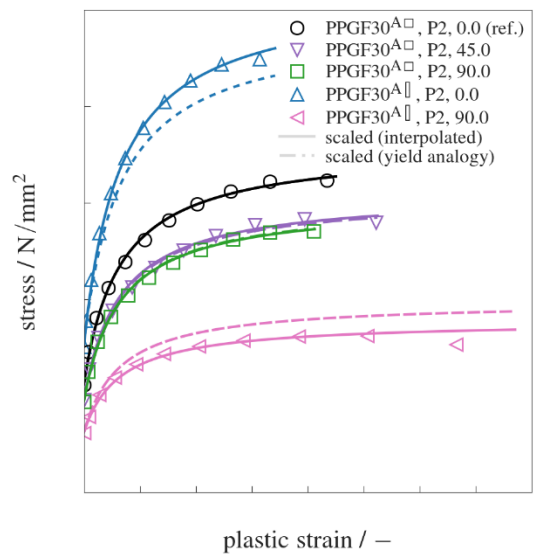
Scaling approach



Scaling factor



Fitted data



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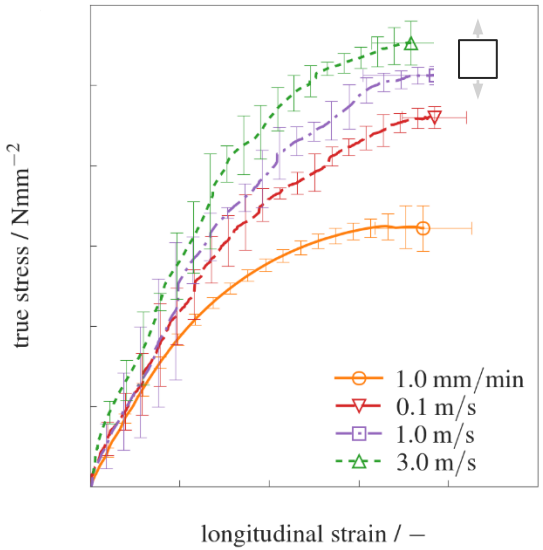
Modelling of Hardening

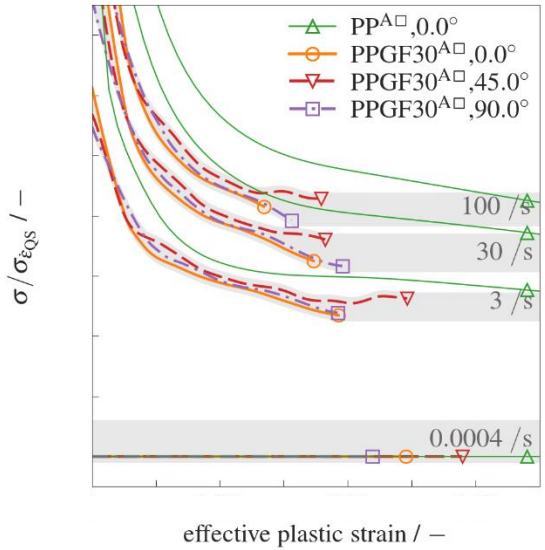
Strain Rate Dependency

- Dynamic loading of different materials, parts and orientations
  - Strain rate dependency depends on fibre volume fraction
  - Orientation, anisotropy degree influence ~negligible

PPGF30, Strain rate dependency



Strain rate dependency (plast.)



Johnson-Cook:

$$Y(\varepsilon_{pl}, \dot{\varepsilon}) = Y_{QS}(\varepsilon_{pl}) * \left(1 + C(\varepsilon)\ln\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)\right)$$

Gsell-Jonas:

$$Y(\varepsilon_{pl}, \dot{\varepsilon}) = Y_{QS}(\varepsilon_{pl}) * \left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)^{m(\varepsilon)}$$

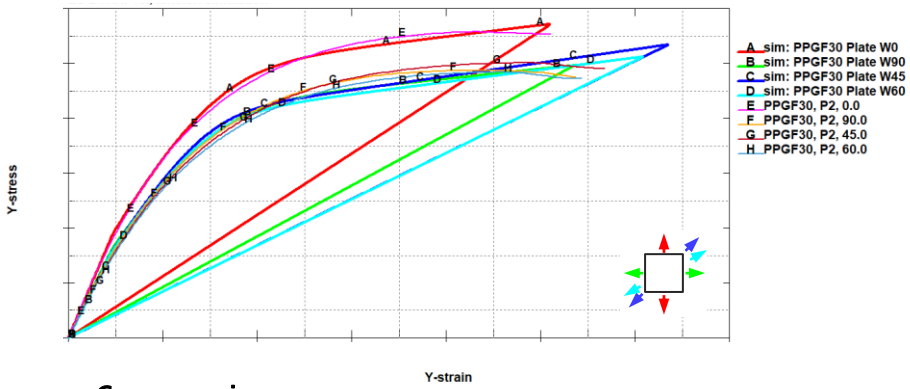
IMPLEMENTATION

Material Modell Implementation

Validation with commercial SFRP (30% glass fibres)*

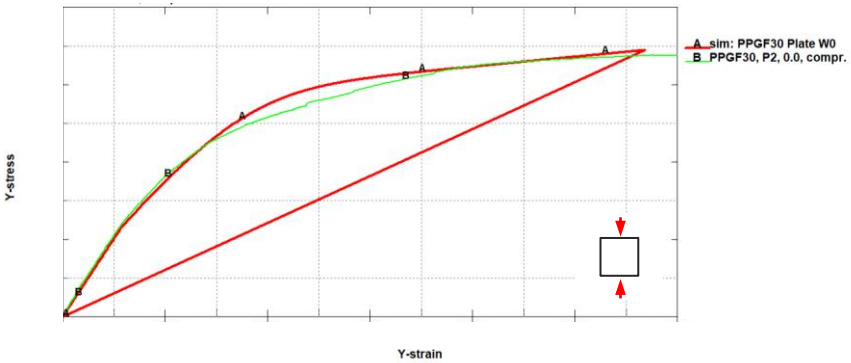
- Implementation into explicit LS-Dyna usermat: Input of orientation tensor data via history variables

Tension

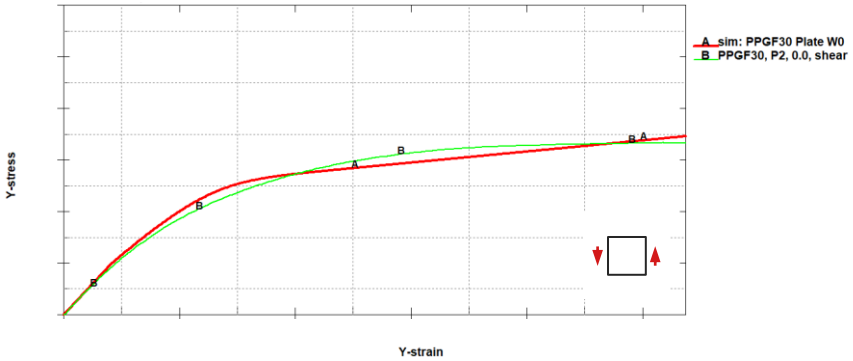


single-element-model

Compression

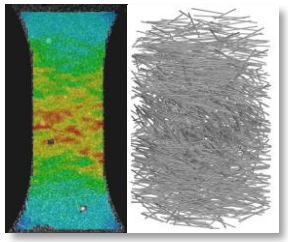


Shear

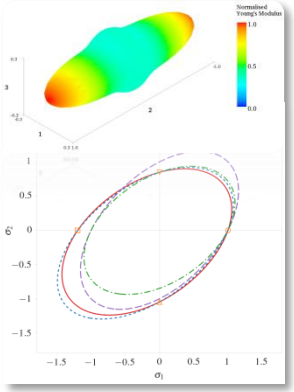


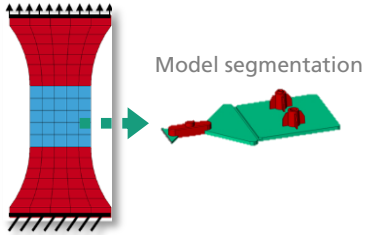
SUMMARY AND OUTLOOK

Summary and Outlook



- Mechanical Characterization:
  - Self-compounded Material, injection moulded sample parts
  - Quasi-static and dynamic tests at different orientations and loads, µ-CT Analysis
- Modelling
  - Linear elasticity by Mori-Tanaka and Voigt averaging
  - Macroscopic yield surface from micromechanical assumptions
  - Plasticity model using empirical/ phenomenological approach
    - Simplified approach considering hardening, strain rate dependency and damage, anisotropic yield surface and flow potential
  - Parametrisation methods are applicable to existing material models (mat157)
- FE implementation
  - Explicit usermat, including micromechanical model
- Outlook Material Model
  - Simulation of coupon experiments
  - Integration of failure criterion
  - Application to segmented FE models





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Thank you

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