Short Fiber Reinforced Polymers: Part II - Anisotropic Extensions of the SAMP-Model

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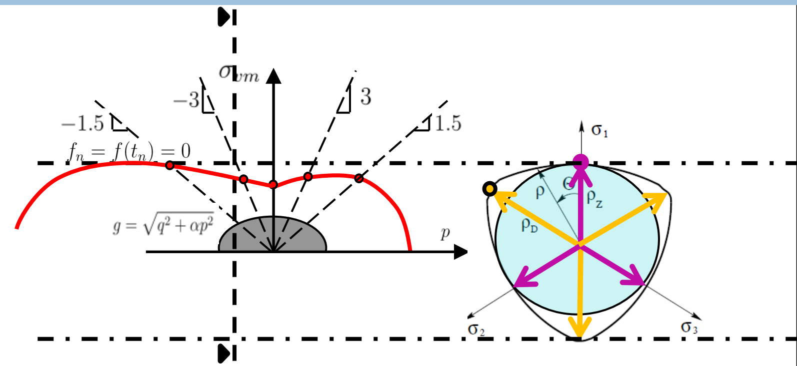
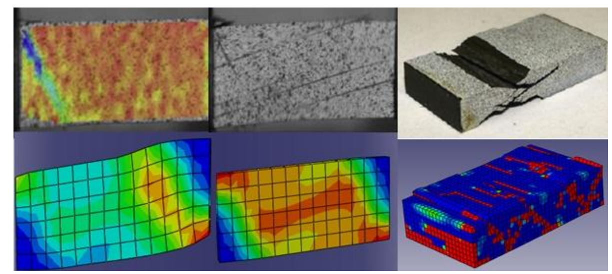
SAMP – Semi Analytical Models for Polymers

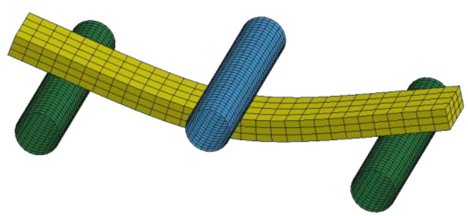
- **SAMP_isotropic**
  - **for unreinforced polymers, adhesives, epoxy resins**

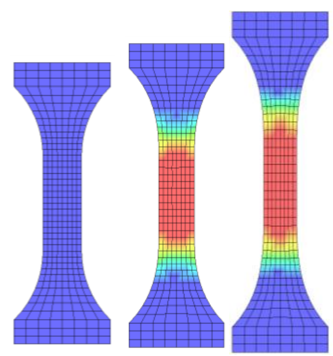


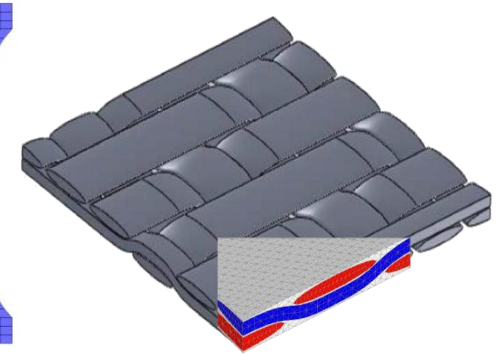
- **SAMP_transversely-isotropic**
  - **for endless fiber UD-composites (carbon – epoxy, glass – epoxy)**



- **SAMP_orthotropic/anisotropic**
  - **Short fiber reinforced thermoplastics**
  - **Organic sheets, textile fabrics**

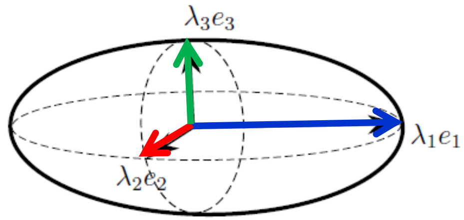




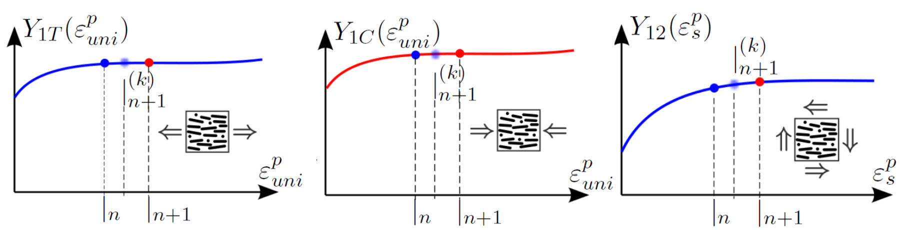


SAMP – Semi Analytical Models for Polymers

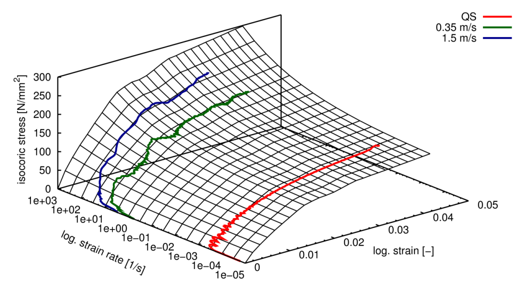
SAMP_isotropic **SAMP_transversely-isotropic** **SAMP_anisotropic**



- Anisotropy regarded by invariant formulation
  - ⇒ structural tensor as additional arguments in yield surface
- Pressure dependent yielding:
  - ⇒ Different yielding in compression, tension , shear and biaxial stress states



- Realistic prediction of volumetric plastic strains
- True viscoplastic formulation:
  - ⇒ Parameter formulation/tabulated data
- Fully 3D formulation, applicable in shell and solid elements

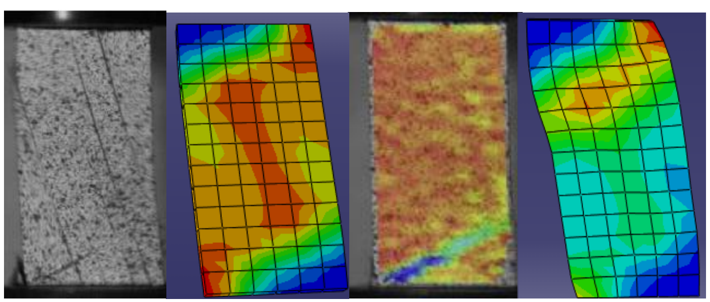


Anisotropic SAMP material models :

SAMP_transversely-isotropic / anisotropic

IM7-8552

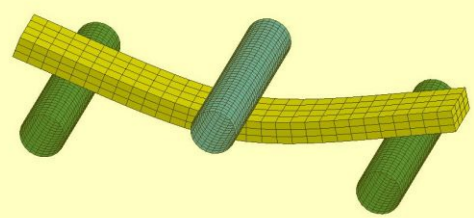
- UD carbon-epoxy
- Quasitstatic and dynamic off-axis compression tests
- High pressure tests

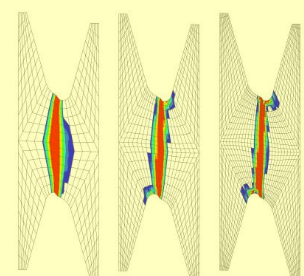


Tests: Camanho/Körber

PA6GF60

- Short fiber reinforced polymer
- Quasistatic tension, compression and shear tests
- Dynamic tensile tests
- Dynamic bending tests (4a Impetus)

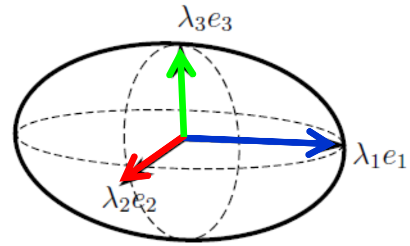




Tests: J.Schöpfer, Daimler, DKI

SAMP anisotropic: Yield surface formulation

- Structural tensors: $\mathbf{A} = \mathbf{a} \otimes \mathbf{a}$ $\mathbf{B} = \mathbf{b} \otimes \mathbf{b}$



…representing the main directions of the fiber orientation tensor.

- Coordinate system free formulation
- Fiber orientation tensor is directly regarded in the constitutive equations
- Isotropic SAMP model (MAT187) is comprised as a special case

$$f = \alpha\, I_1 + \beta\, I_2 + \gamma\, I_3 + \delta\, I_5^2 + \epsilon\, I_6^2 + \zeta\, I_5 I_6 + \eta\, I_4^2 + \theta\, I_4\, I_5 + \iota\, I_4\, I_6 - 1$$

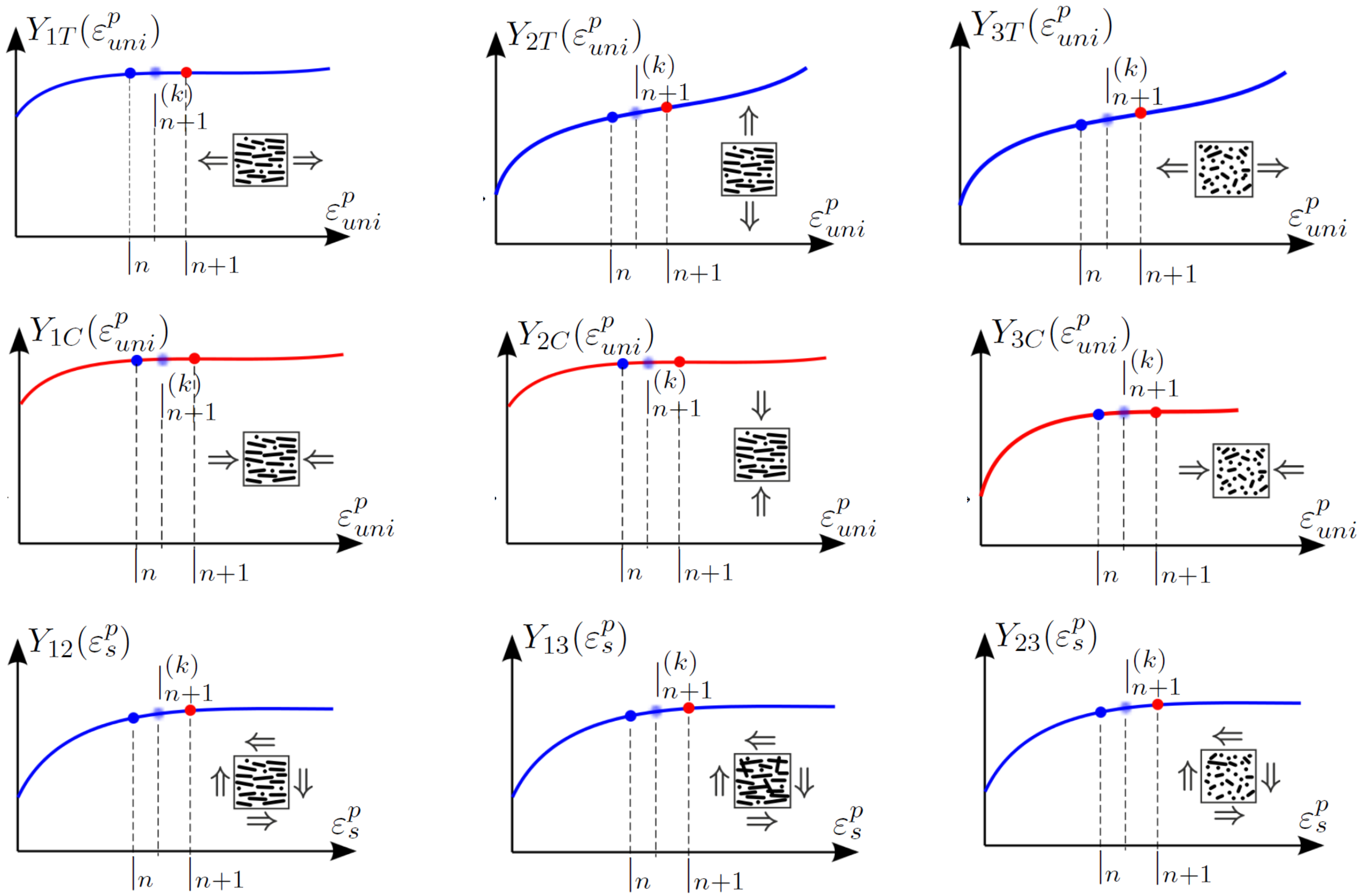
9 yield parameters → 9 material tests necessary

SAMP anisotropic: Different yielding in..

..tension:

..compression:

..shear:



$$f = \alpha\, I_1 + \beta\, I_2 + \gamma\, I_3 + \delta\, I_5^2 + \epsilon\, I_6^2 + \zeta\, I_5 I_6 + \eta\, I_4^2 + \theta\, I_4\, I_5 + \iota\, I_4\, I_6 - 1$$

SAMP transversely-isotropic: Numerical treatment

- Yield surface

$$f = \alpha_1 I_1 + \alpha_2 I_2 + \alpha_3 I_3 + \alpha_{32} I_3^2 + \alpha_4 I_4^2 - 1$$

$$f = \frac{1}{2}\boldsymbol{\sigma} : \mathbb{A} : \boldsymbol{\sigma} + \mathbf{B} : \boldsymbol{\sigma} - 1$$

- Operator-Split

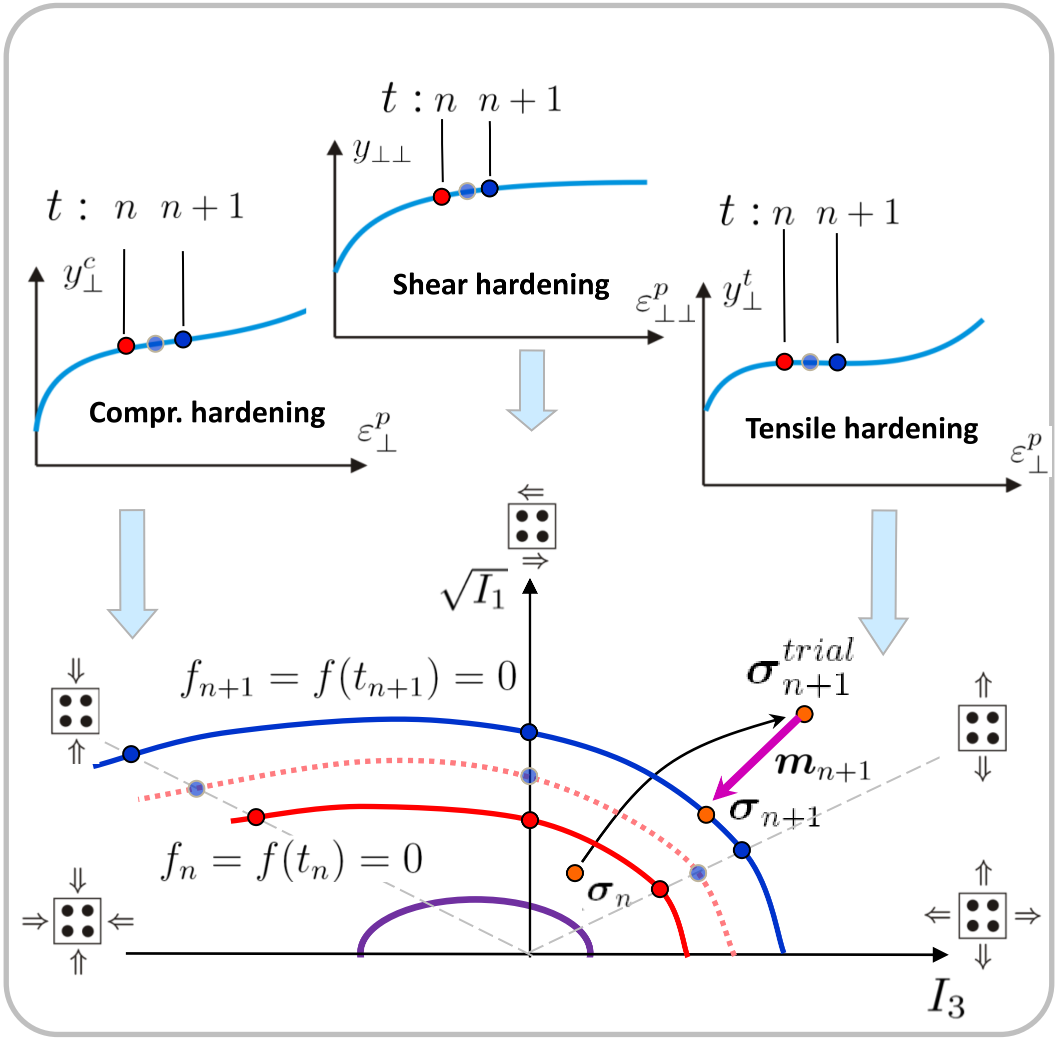
$$\begin{aligned} \boldsymbol{\sigma}^{tr}_{n+1} &= \mathbb{C}_e : \boldsymbol{\varepsilon}^{tr} \\ &= \boldsymbol{\sigma}_{n+1} + \gamma_{n+1}\mathbb{C}_e : \partial_{\boldsymbol{\sigma}} f \\ &= \boldsymbol{\sigma}_{n+1} + \gamma_{n+1}\mathbb{C}_e : [\mathbb{A} : \boldsymbol{\sigma} + \mathbf{B}] \\ &= [\mathbb{I} + \gamma_{n+1}\mathbb{C}_e : \mathbb{A}]\,\boldsymbol{\sigma}_{n+1} + \gamma_{n+1}\mathbb{C}_e : \mathbf{B} \end{aligned}$$

$$f_{n+1} = \frac{1}{2}\boldsymbol{\sigma}_{n+1} : \mathbb{A} : \boldsymbol{\sigma}_{n+1} + \mathbf{B} : \boldsymbol{\sigma}_{n+1} - 1 = 0$$

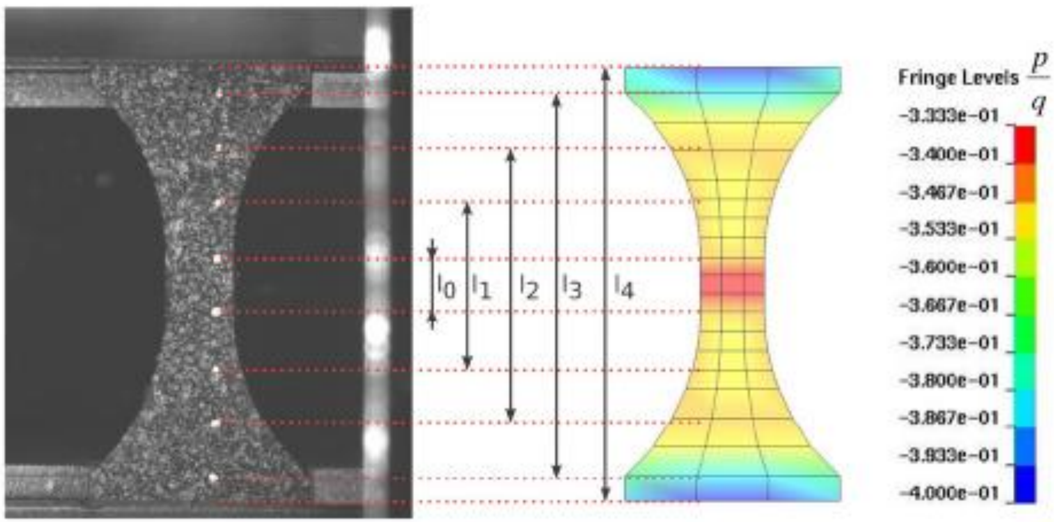
- Non-associated flow rule - plastic potential :

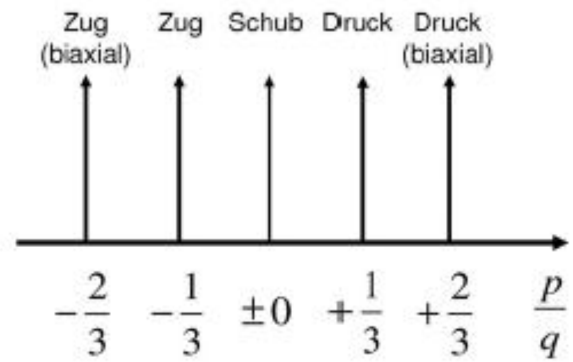
$$g = \beta_1 I_1 + \beta_2 I_2 + \beta_3 I_3 + \beta_{32} I_3^2 + \beta_4 I_4^2 - 1$$

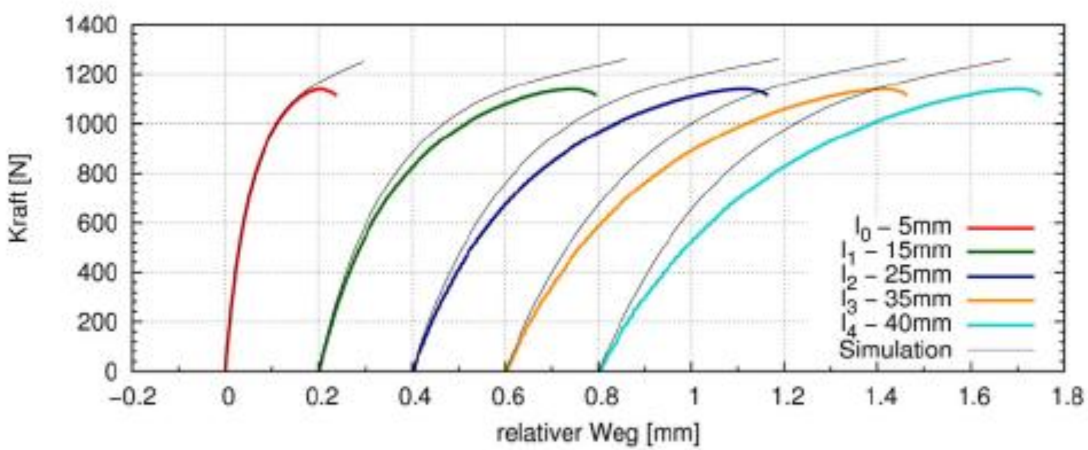
$$\boldsymbol{\varepsilon}^p_{n+1} = \boldsymbol{\varepsilon}_n + \gamma_{n+1}\,\partial g(\boldsymbol{\sigma}_{n+1})/\partial \boldsymbol{\sigma}_{n+1}$$



PA6GF60: Triaxiality in uniaxial tensile tests





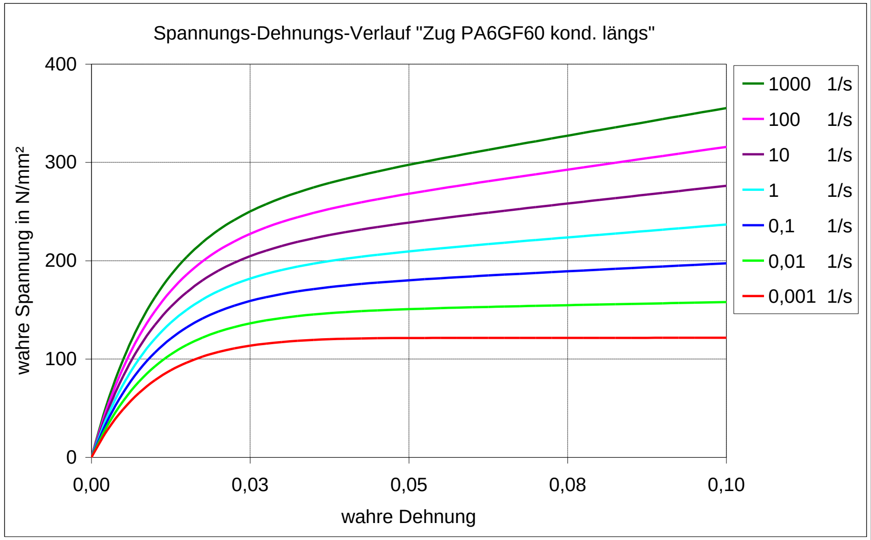


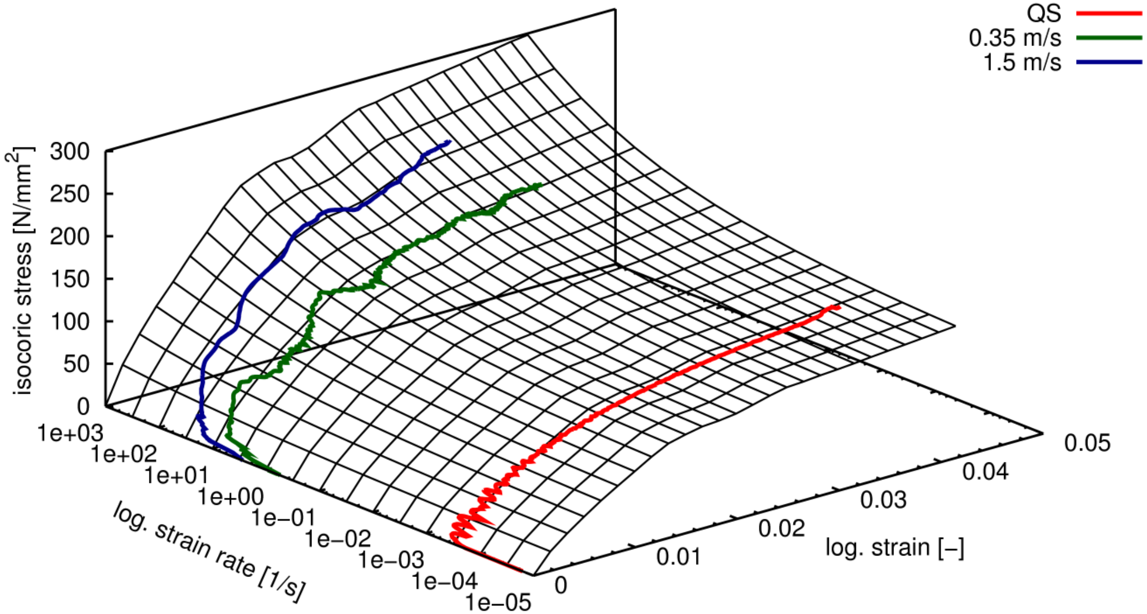
- → Anisotropie ist schon beim Angleich der Modelle auf Zugversuche zu berücksichtigen
- → Auswertung des Kraft-Weg-Verlaufs über die gesamte Probenlänge führt bei isotropen Modellen zu fehlerhaften Ergebnissen

Entnommen aus Diss. Schöpfer

PA6GF60: Strain rate effects - Cowper-Symonds formulation

$$\sigma_y \quad \dot{\varepsilon}, \varepsilon_p \quad = \sigma_y \quad 0, \varepsilon_p \quad \left[1 + \left(\frac{\dot{\varepsilon}}{C} \right)^{\frac{1}{p}} \right]$$

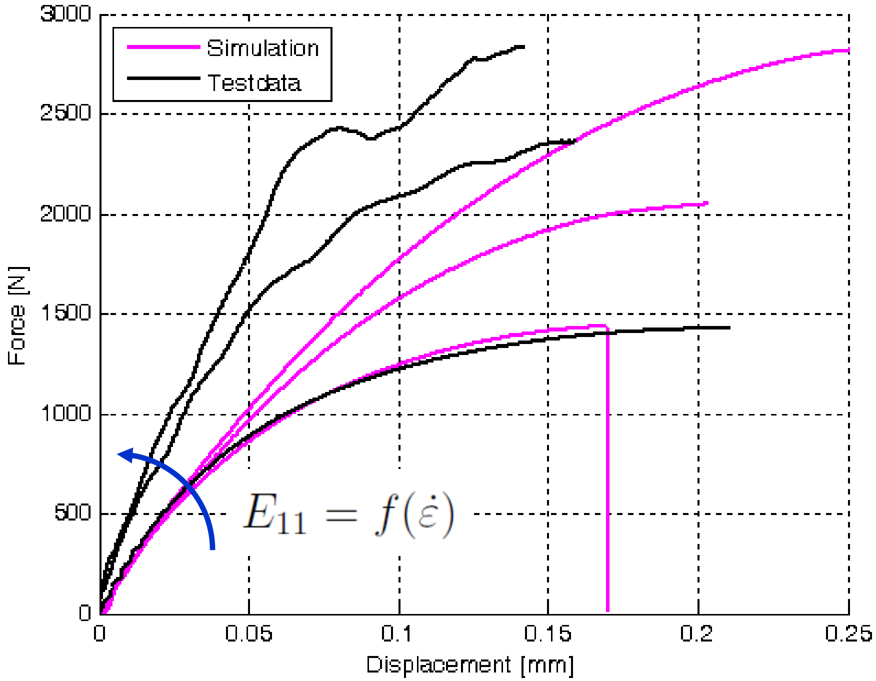


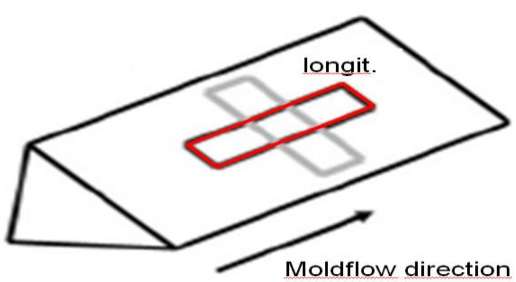


Entnommen aus Diss. Schöpfer

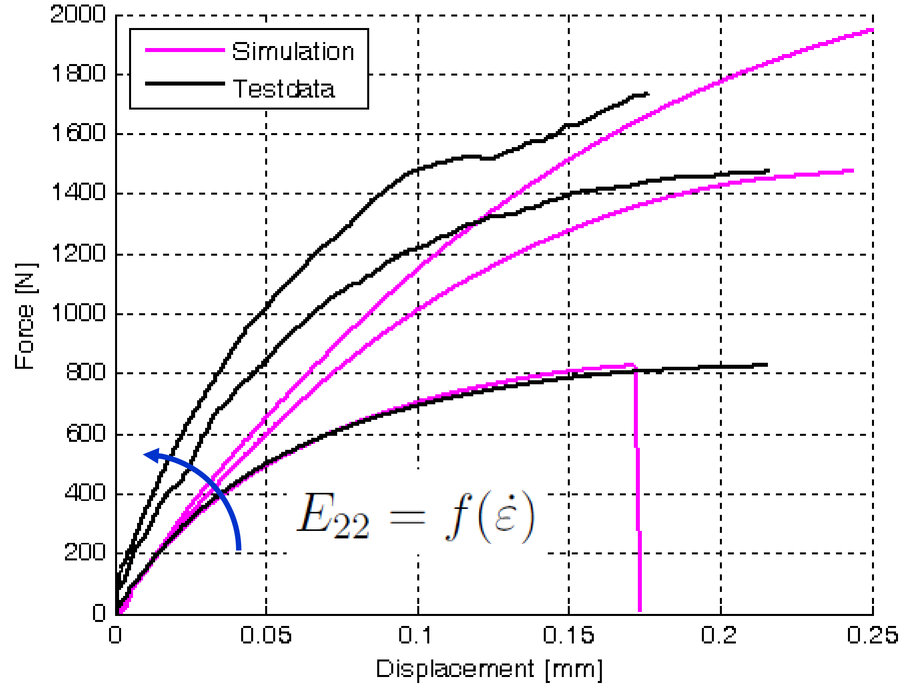
PA6GF60: Simulation results dynamic tensile tests

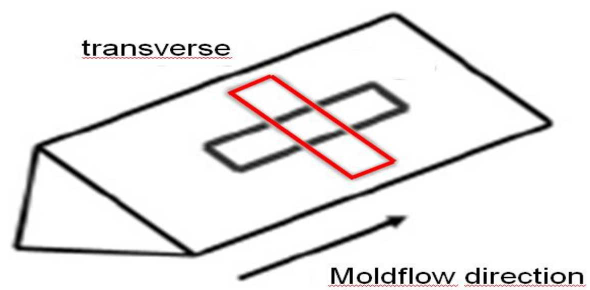
Longitudinal fiber orientation



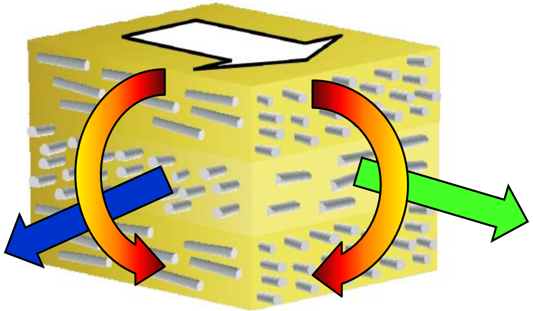


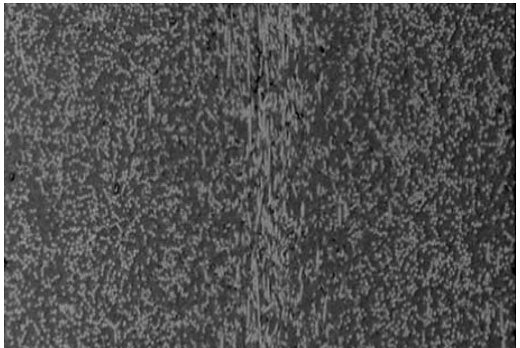
Transverse fiber orientation



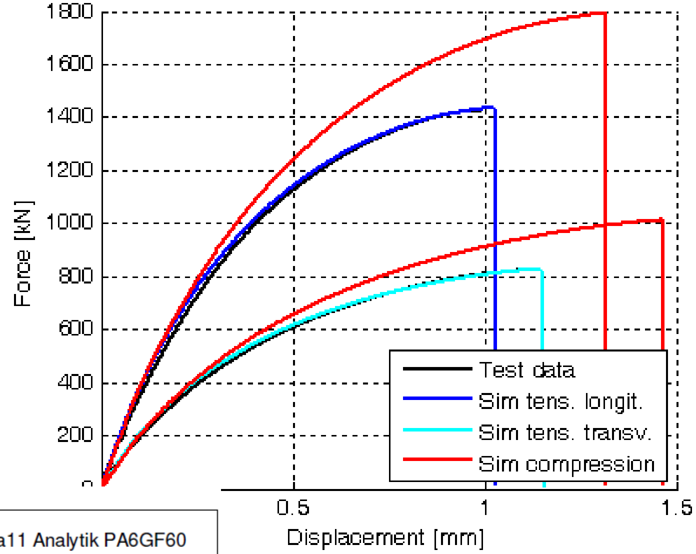


PA6GF60: Simulation results quasi-static tests

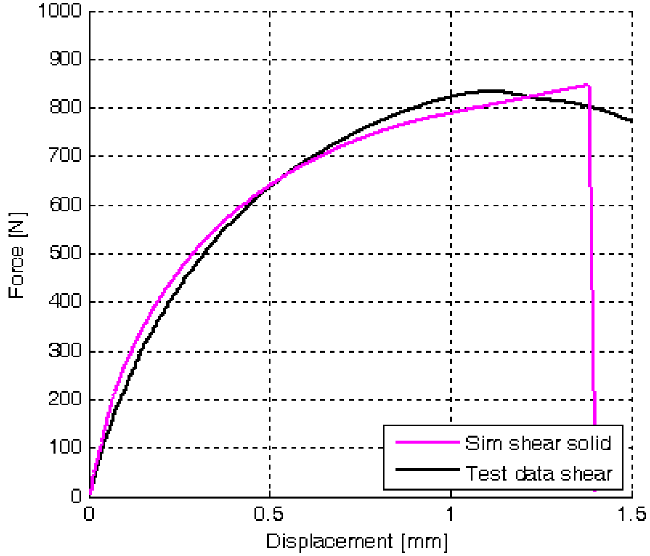


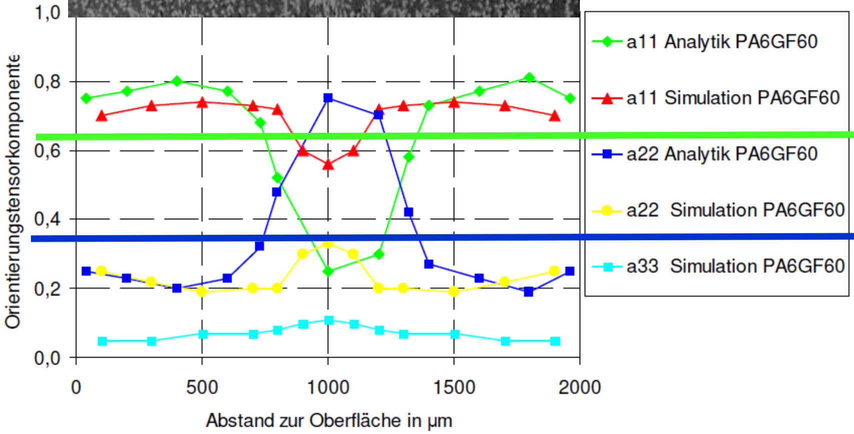


Tension and compression



Shear



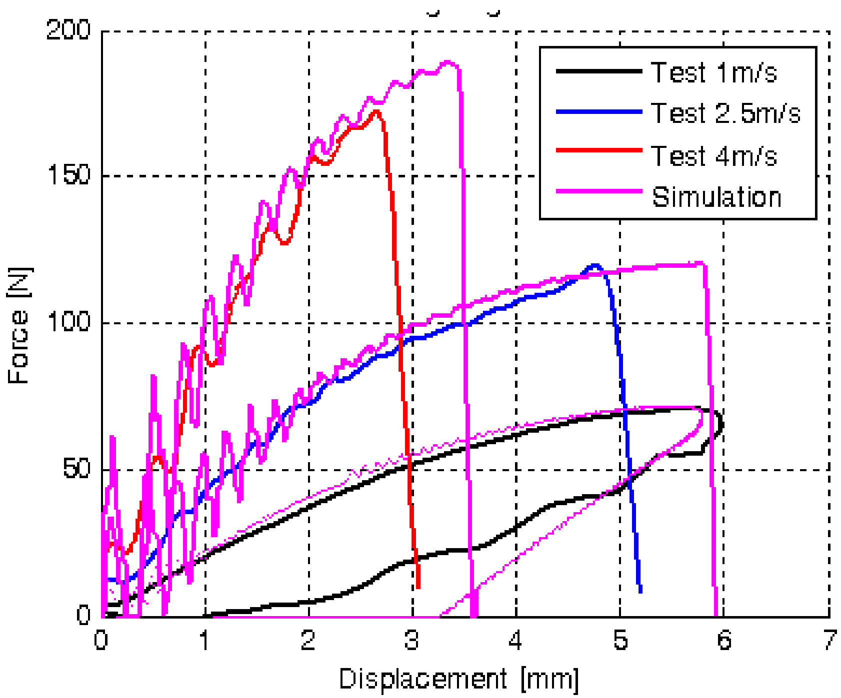


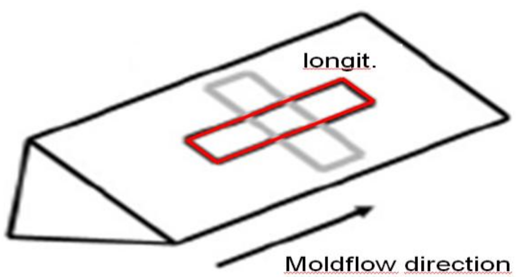
64% assumed fiber alignment in longitudinal direction

36% assumed fiber alignment in transverse direction

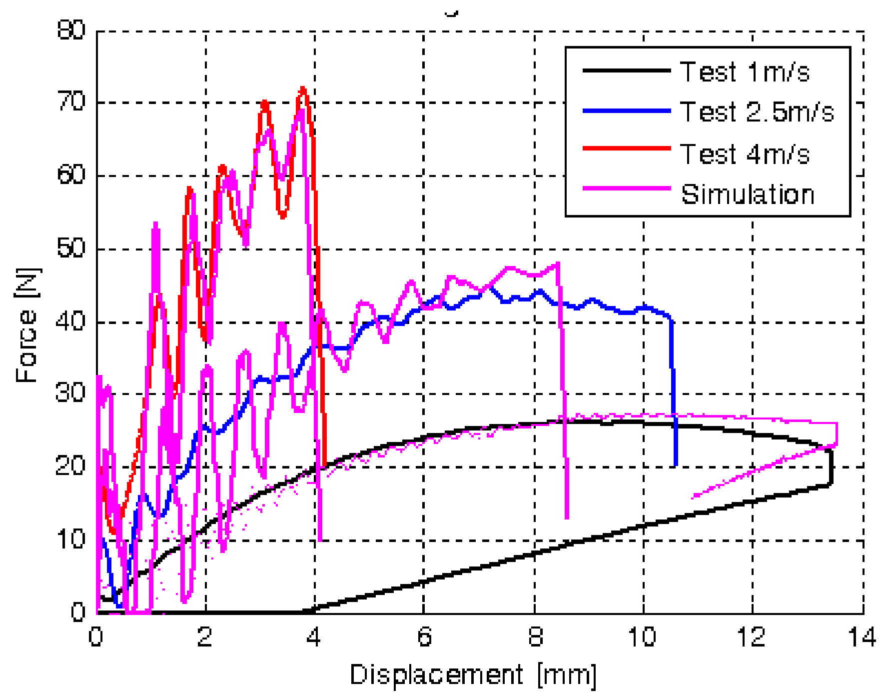
PA6GF60: Simulation results 3-point bending tests

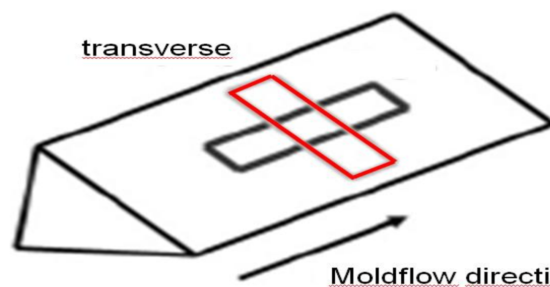
Longitudinal fiber orientation





Transverse fiber orientation



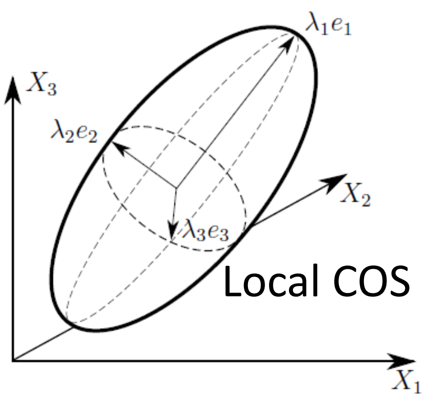


SAMP anisotropic: Mathematical description of fiber orientation

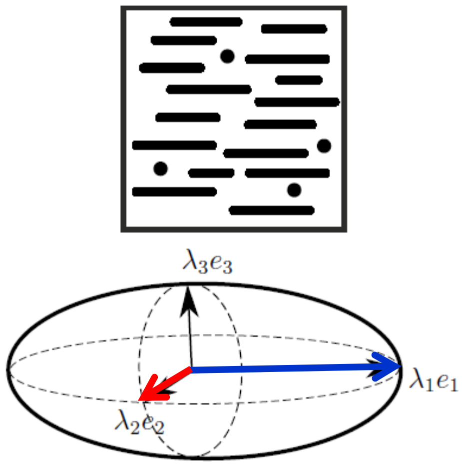
Fiber orientation tensor:

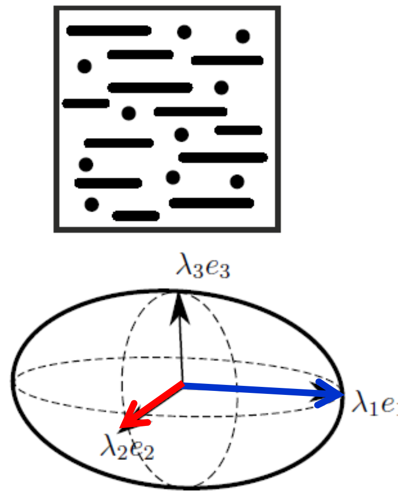
$$a_{11} = 0.80 \quad a_{22} = 0.20 \quad a_{33} = 0.00$$

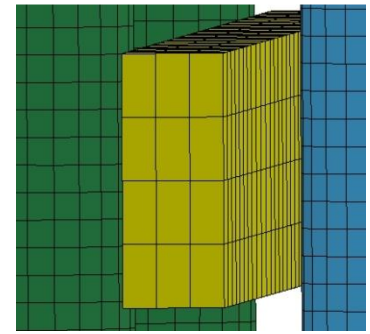
$$a_{11} = 0.60 \quad a_{22} = 0.40 \quad a_{33} = 0.00$$

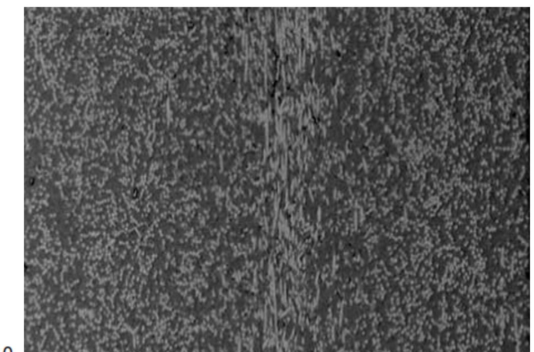


Global COS

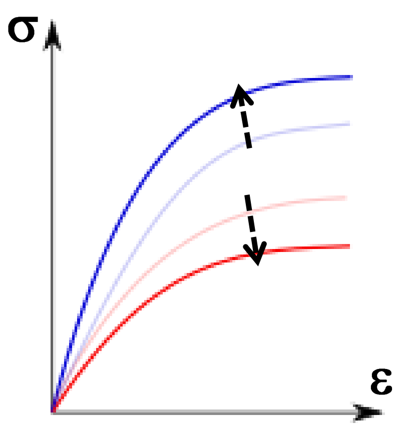


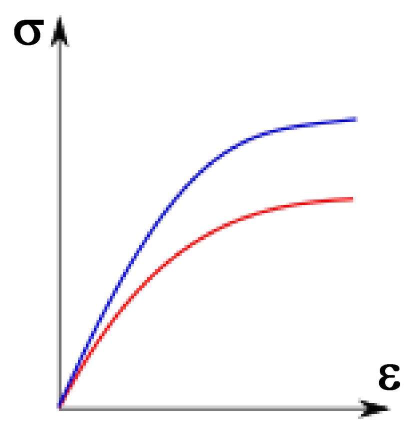


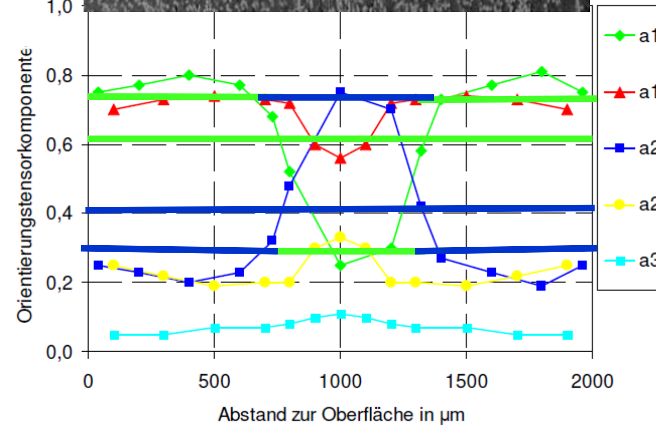




Tensile behavior :

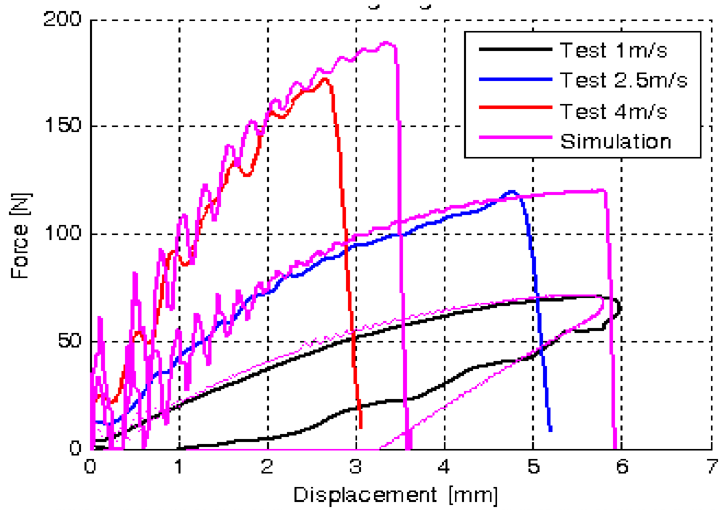


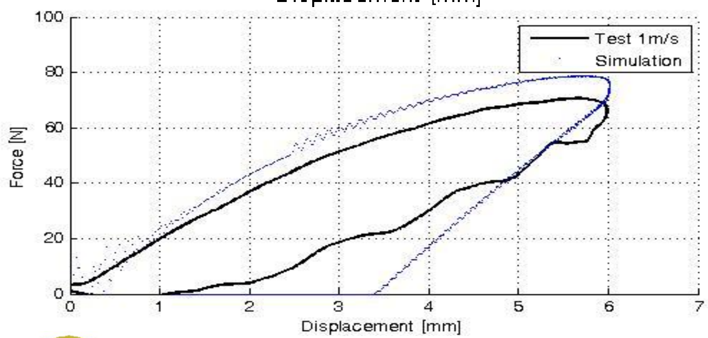




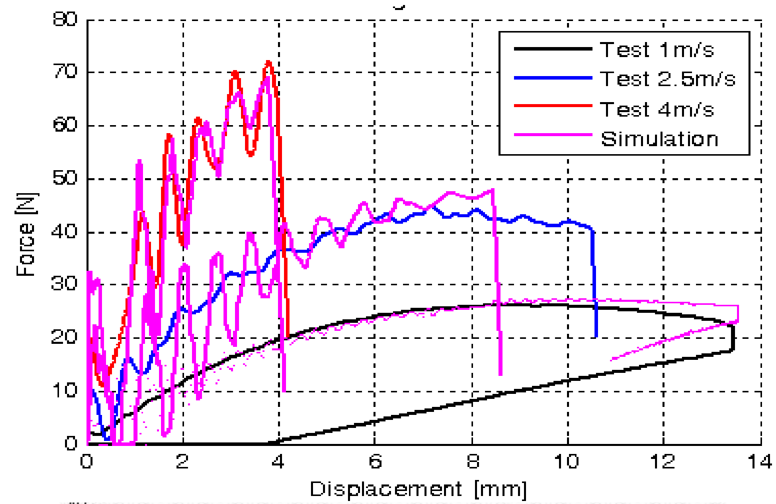
PA6GF60: Simulation results 3-point bending tests

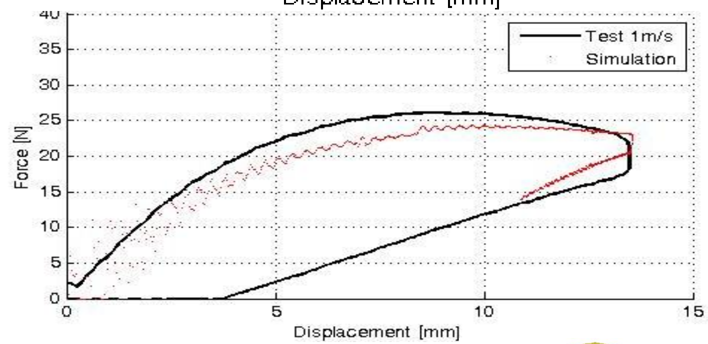
Longitudinal fiber orientation

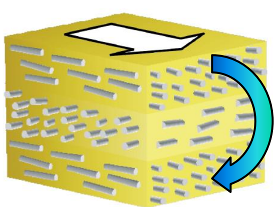


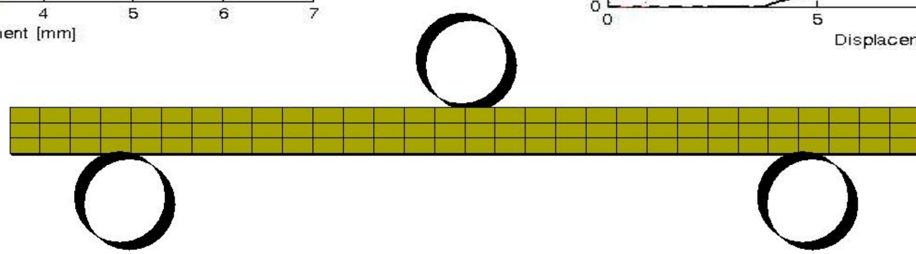


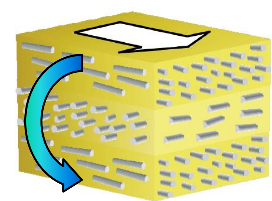
Transverse fiber orientation





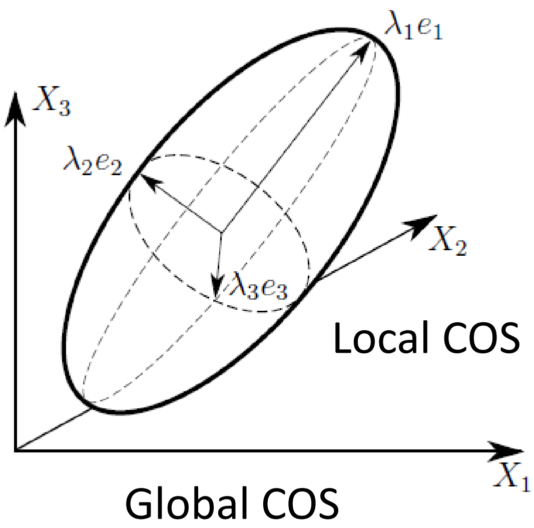




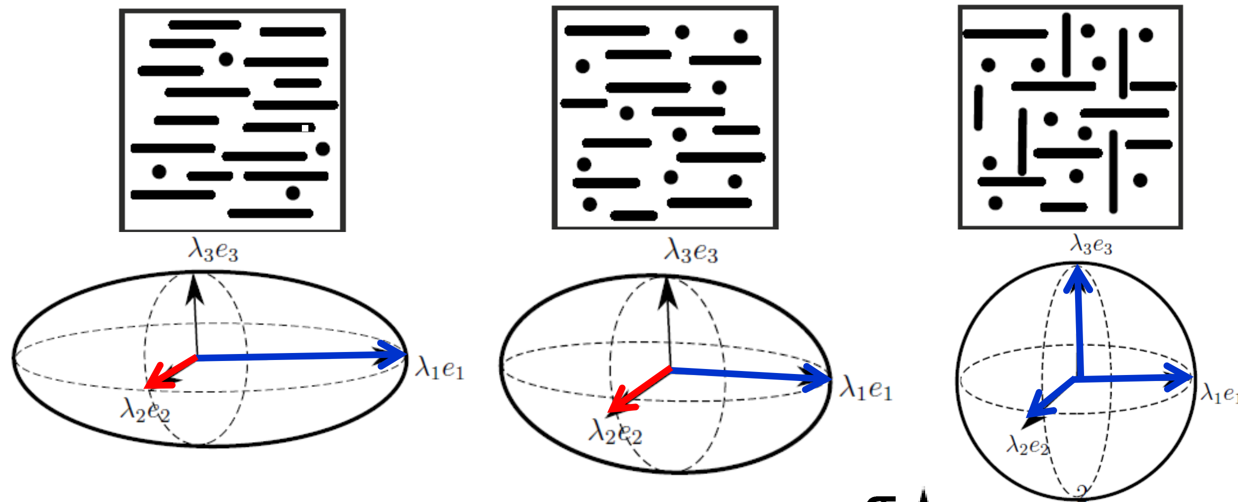


SAMP anisotropic: Mathematical description of fiber orientation

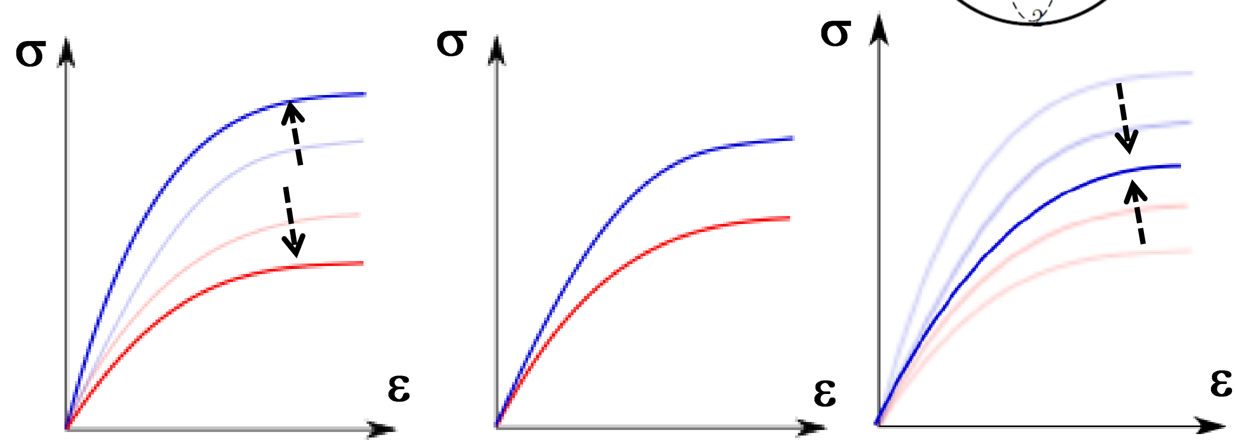
Fiber orientation tensor:



$a_{11} = 0.80$	$a_{11} = 0.60$	$a_{11} = 0.33$
$a_{22} = 0.20$	$a_{22} = 0.40$	$a_{22} = 0.33$
$a_{33} = 0.00$	$a_{33} = 0.00$	$a_{33} = 0.33$



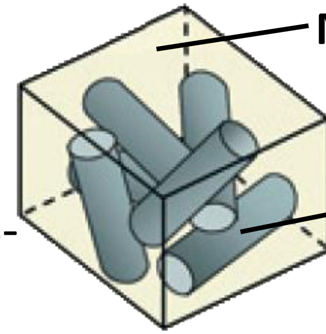
Tensile behavior :



Concept: Using Micromechanics for interpolation/extrapolation

Micromechanic approach:

Implementation of homogenization (Zohdi), using the isotropic SAMP material model in UMAT (Abaqus/LS-DYNA)

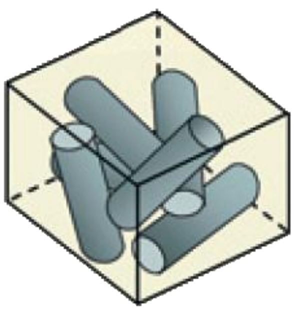


Matrix: Isotropic SAMP-model

Fibers: Elastic material model

UMAT (Abaqus/ LS-DYNA)

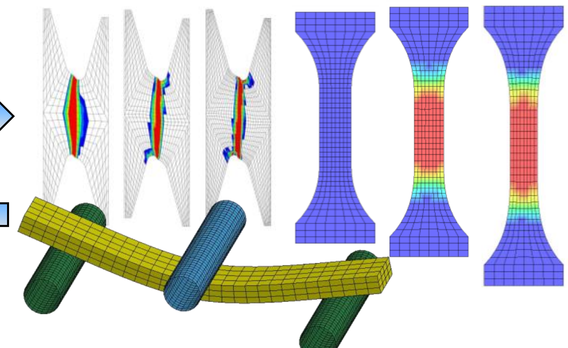
Micromechanics

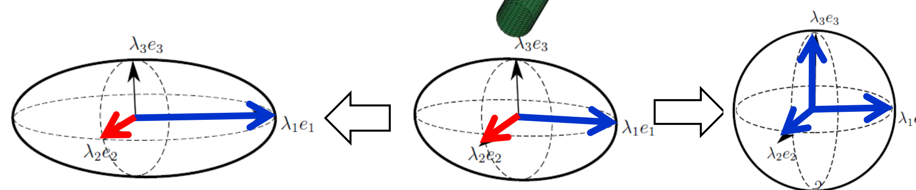


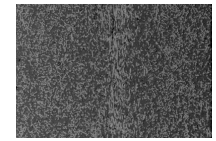
Inverse parameter identification

for isotropic SAMP model

Experiments



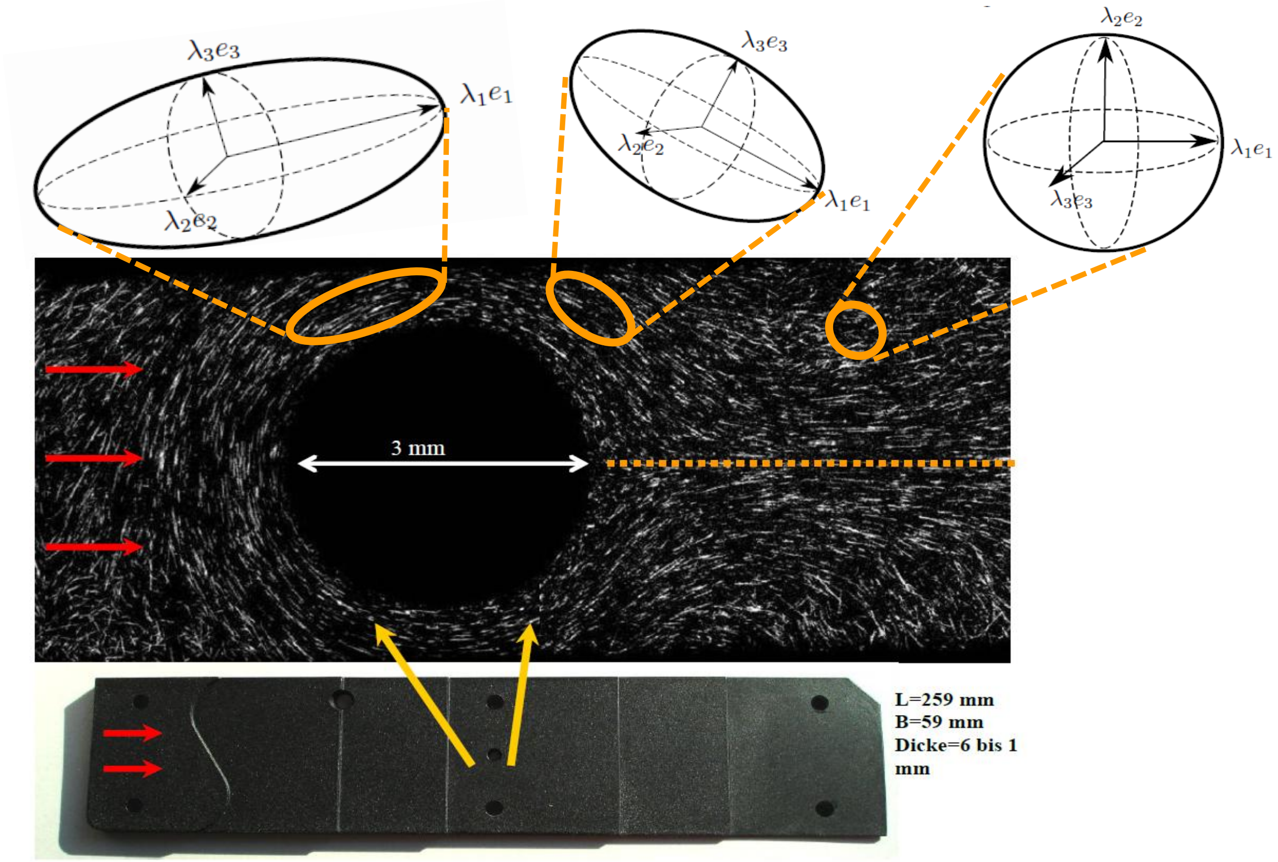




- Extrapolation to arbitrary fiber orientations
- Micromechanics just used in order to feed the anisotropic SAMP model

SAMP anisotropic: Modeling shortfiber reinforced thermoplastics

Local fiber orientations :

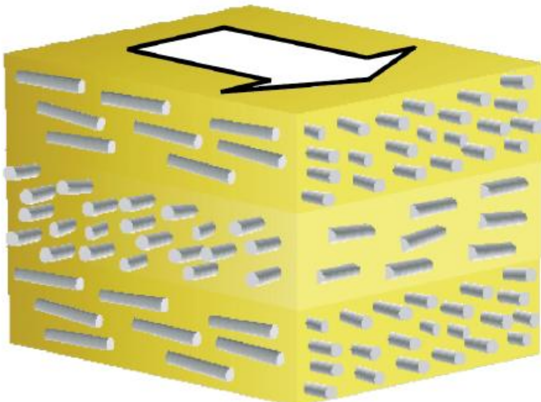


- Just one material card required
- Just one set of parameters required
- Isotropic SAMP Model is recovered as a special case in SAMP_anisotropic

- **Phenomenological approach with SAMP-anisotropic**
- **Fiber orientations required as additional information in each GAUSS Point**

SAMP anisotropic: Modeling shortfiber reinforced thermoplastics

Fiber orientation due to injection molding process

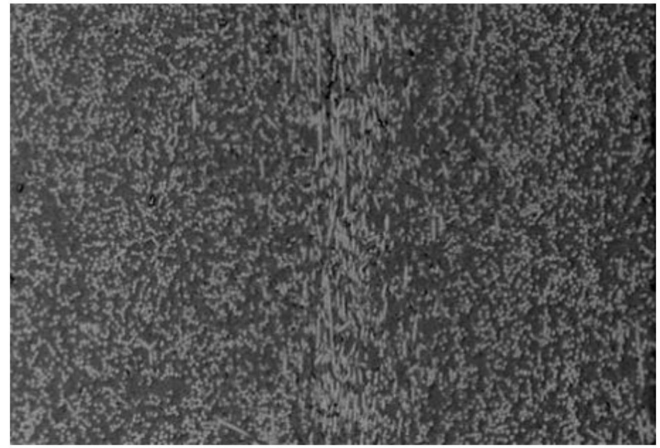


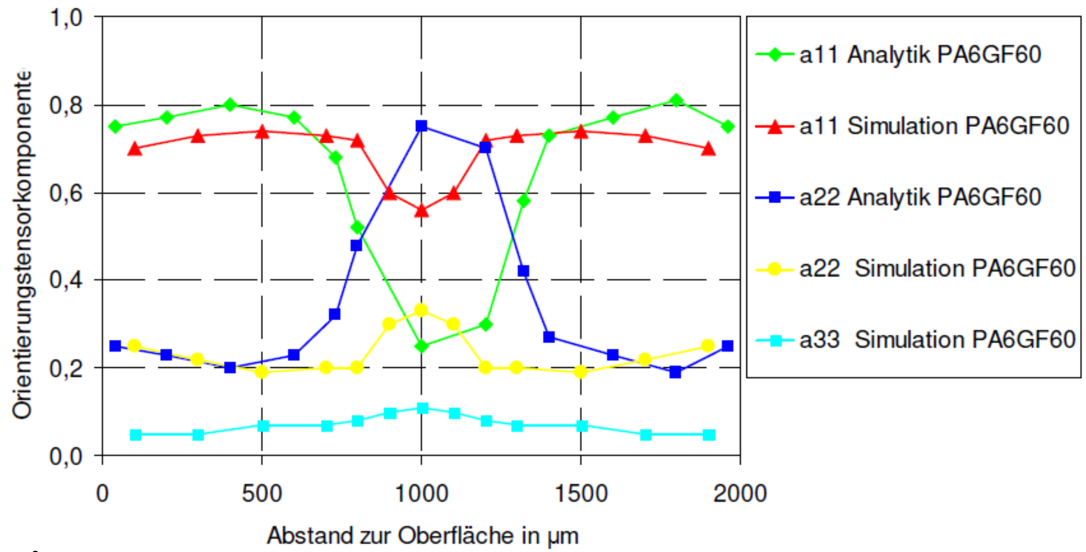
PART_POLYMER

… for consideration of fiber orientation in each Gauss point

Process chain :

Injection molding simulation → Crash Simulation





Entnommen aus Diss. Schöpfer

Summary

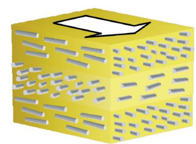
Objective: DYNA Implementation of anisotropic SAMP Material Models

- **SAMP_anisotropic..**

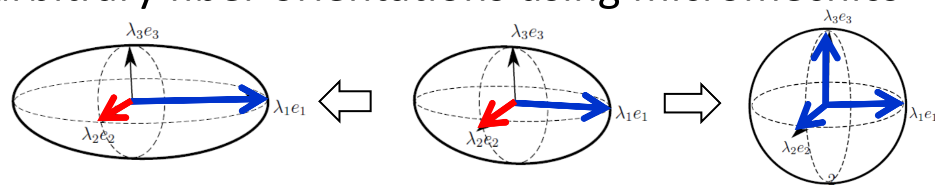
..for short fiber reinforced thermoplastics:

- Fiber orientation tensor required at GAUSS points

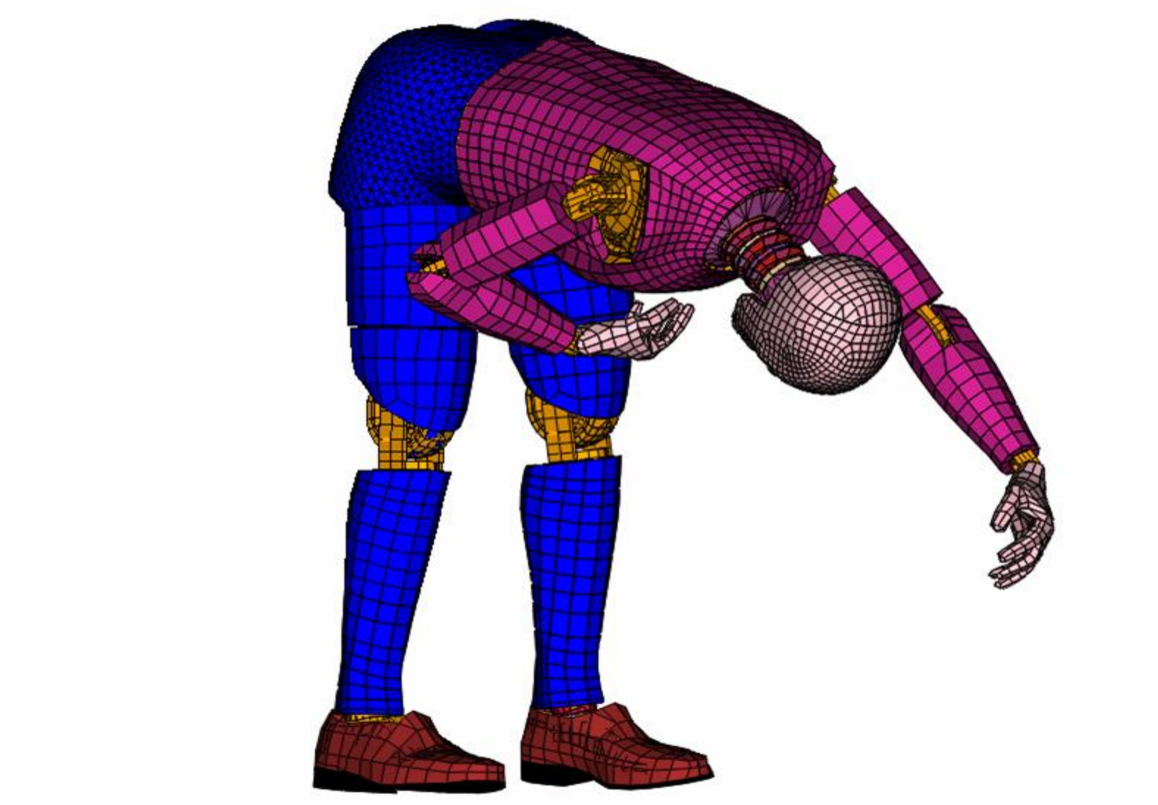
→ PART_POLYMER



- Extrapolation / interpolation to arbitrary fiber orientations using micromechics



- Phenomenological modeling of injection molding components using the anisotropic SAMP - Model
- Process chain: injection molding simulation –> crash simulation



Thanks for your attention!