Current Problems in Material Modeling of Polymers: Glass-Fiber Reinforced Plastics

LS-DYNA Forum, Filderstadt 2013

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Content

- Generation of input data
- Influence of injection molding process
- Orientation of glass fibers
- Involving anisotropy for fiber reinforced plastics

“LS-DYNA history“ of fiber reinforced plastics

- 2004: Glaser/Wüst (BASF) present their concept for integrative simulation using micromechanical model.
- 2006: First applications of Glaser’s model presented by Frik (Opel).
- 2009: Adams et al. and Seyfarth et al. (e-Xstream) present the LS-DYNA MPP interface of DIGIMAT

- 2010: Nutini / Vitali (LyondellBasell) validate drop tests and three point bending tests using MAT_103
- 2011: Schöpfer et al. presented a full verification procedure of PAGF. They used a combined MAT_54 / MAT_108 model for validation

Input data generation for polymers (q.s.)

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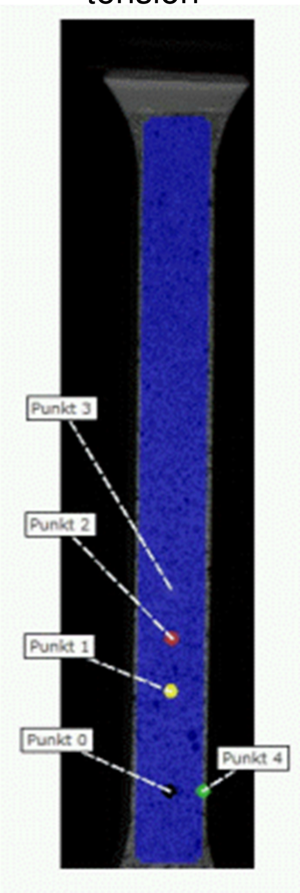
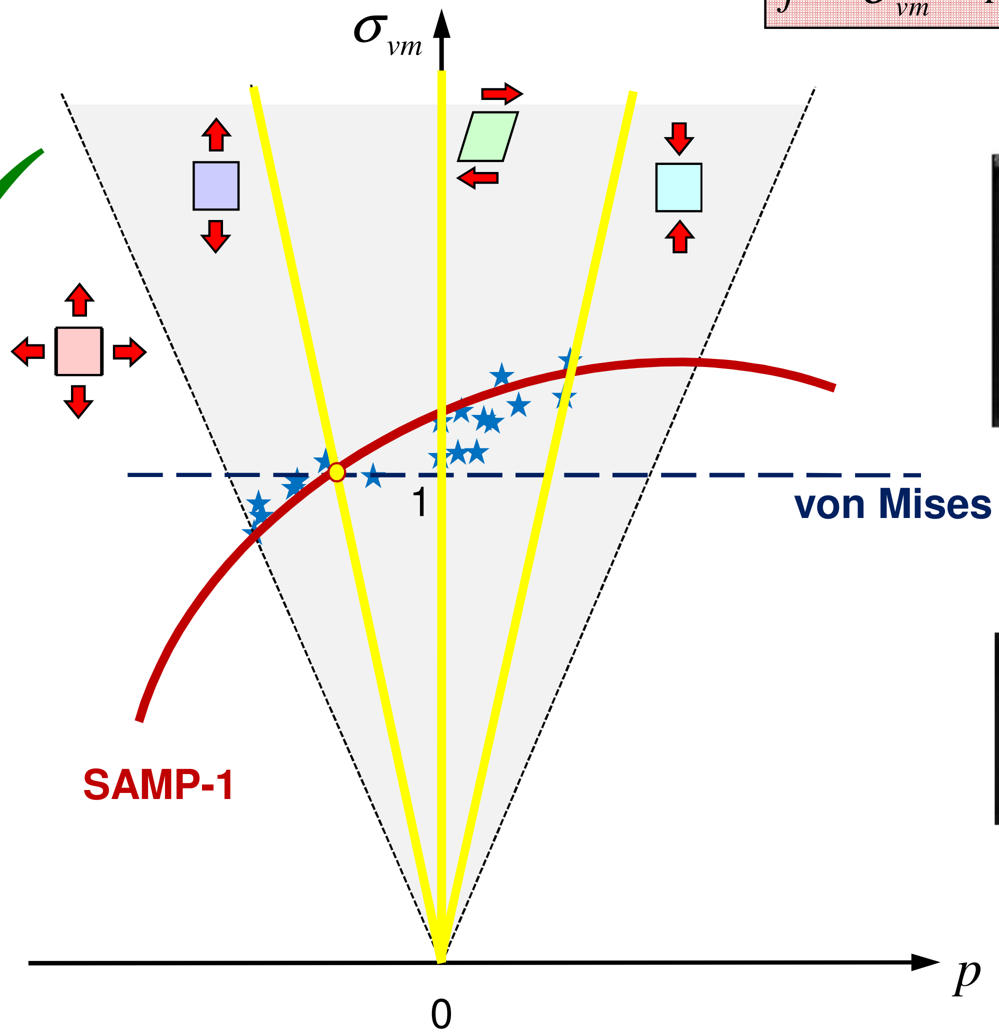
Example: PC (Bardenheier 1982)

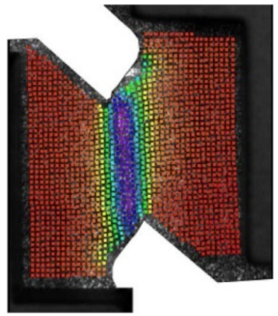
$$f = \sigma_{vm}^2 - A_0 - A_1 p - A_2 p^2 \le 0$$

tension

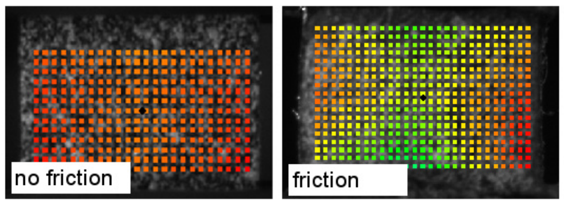




shear

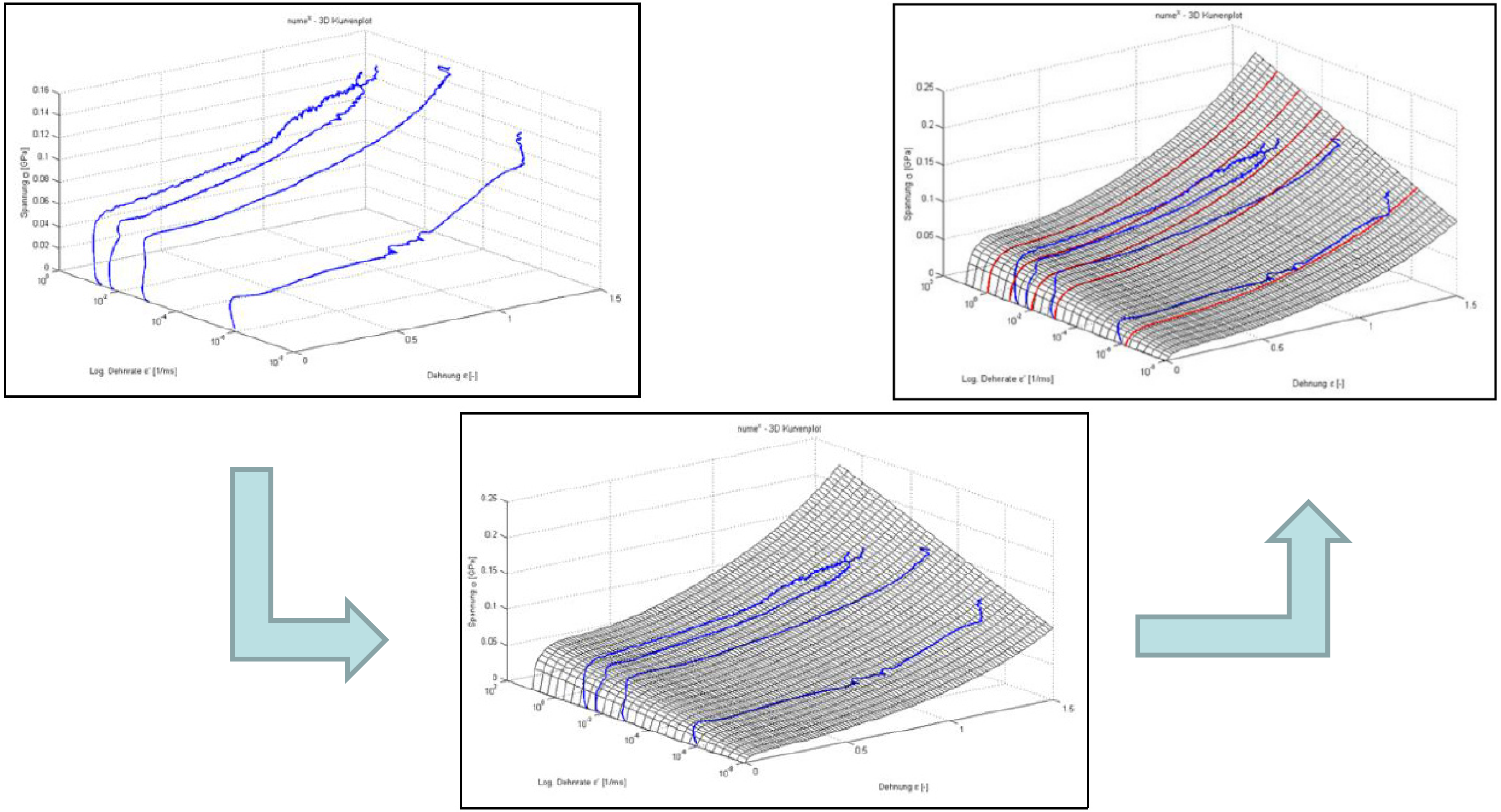


compression



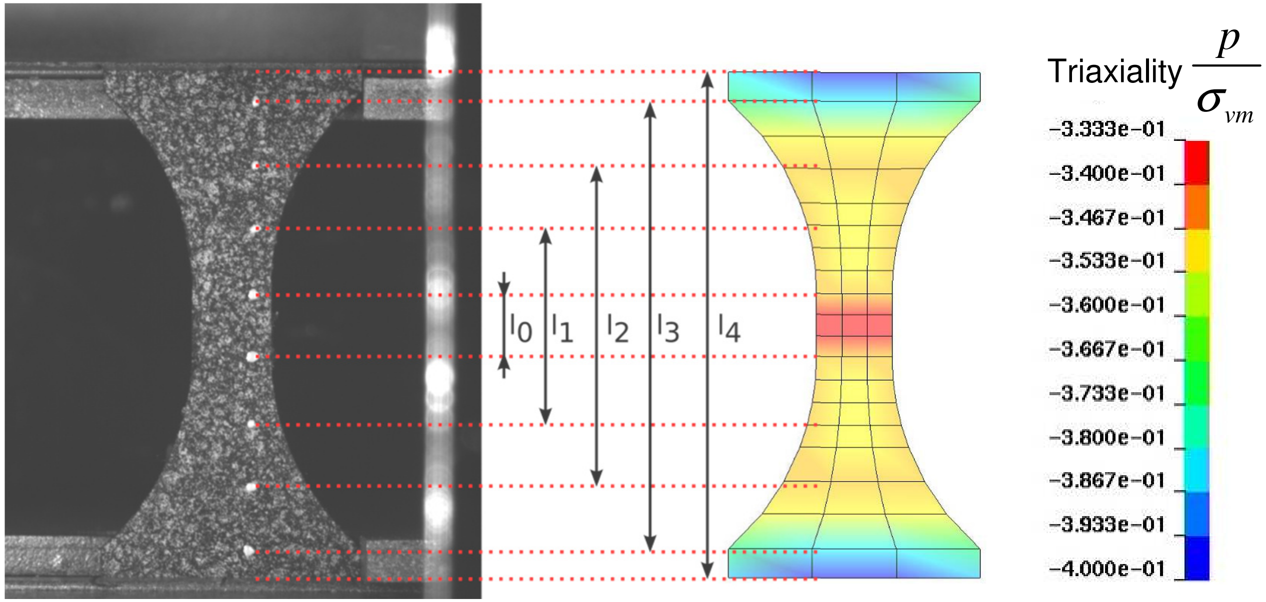
Input data generation for polymers (dyn.)

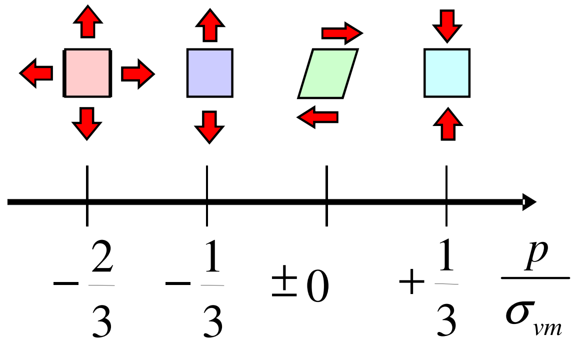
- Strain rate is not constant during tensile tests!

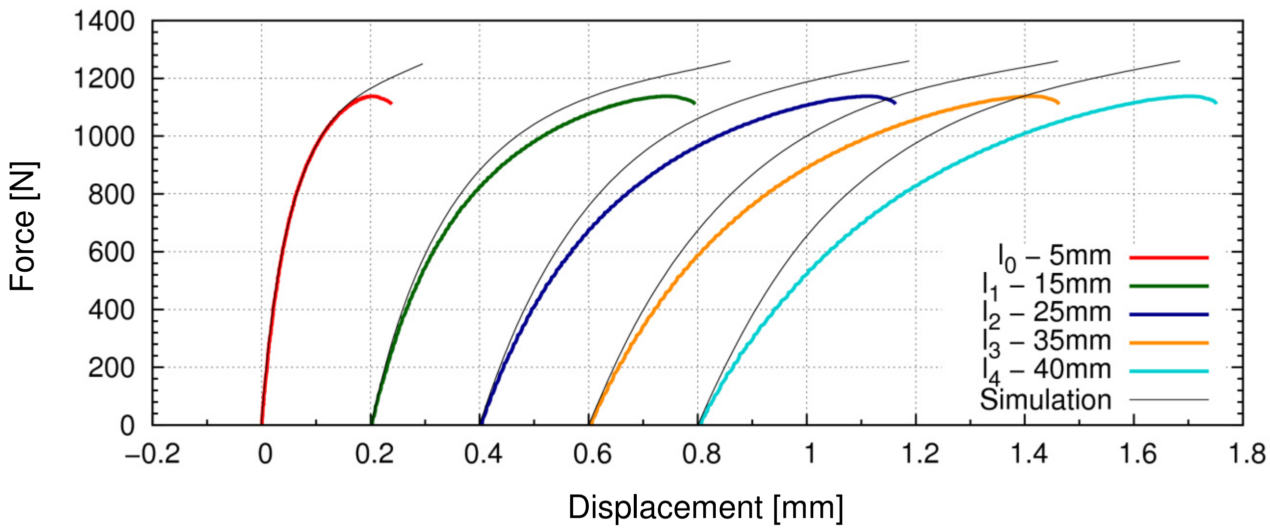


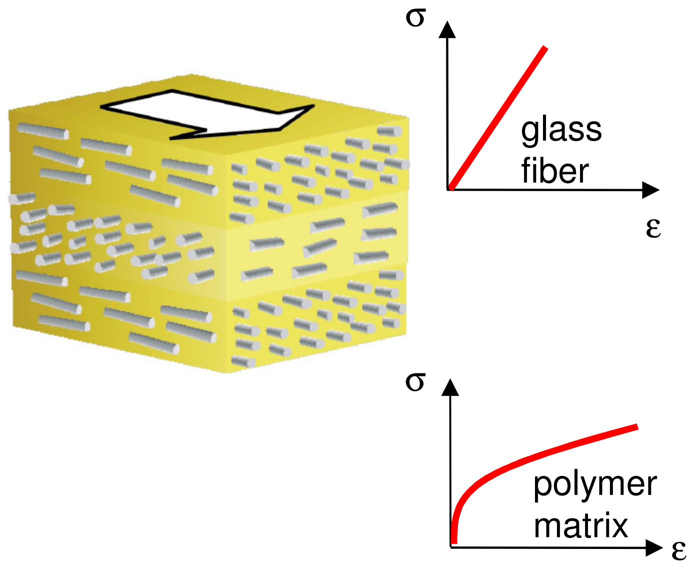
Reinforced polymers - PA6GF60

[J. Schöpfer, Dissertation 2011]



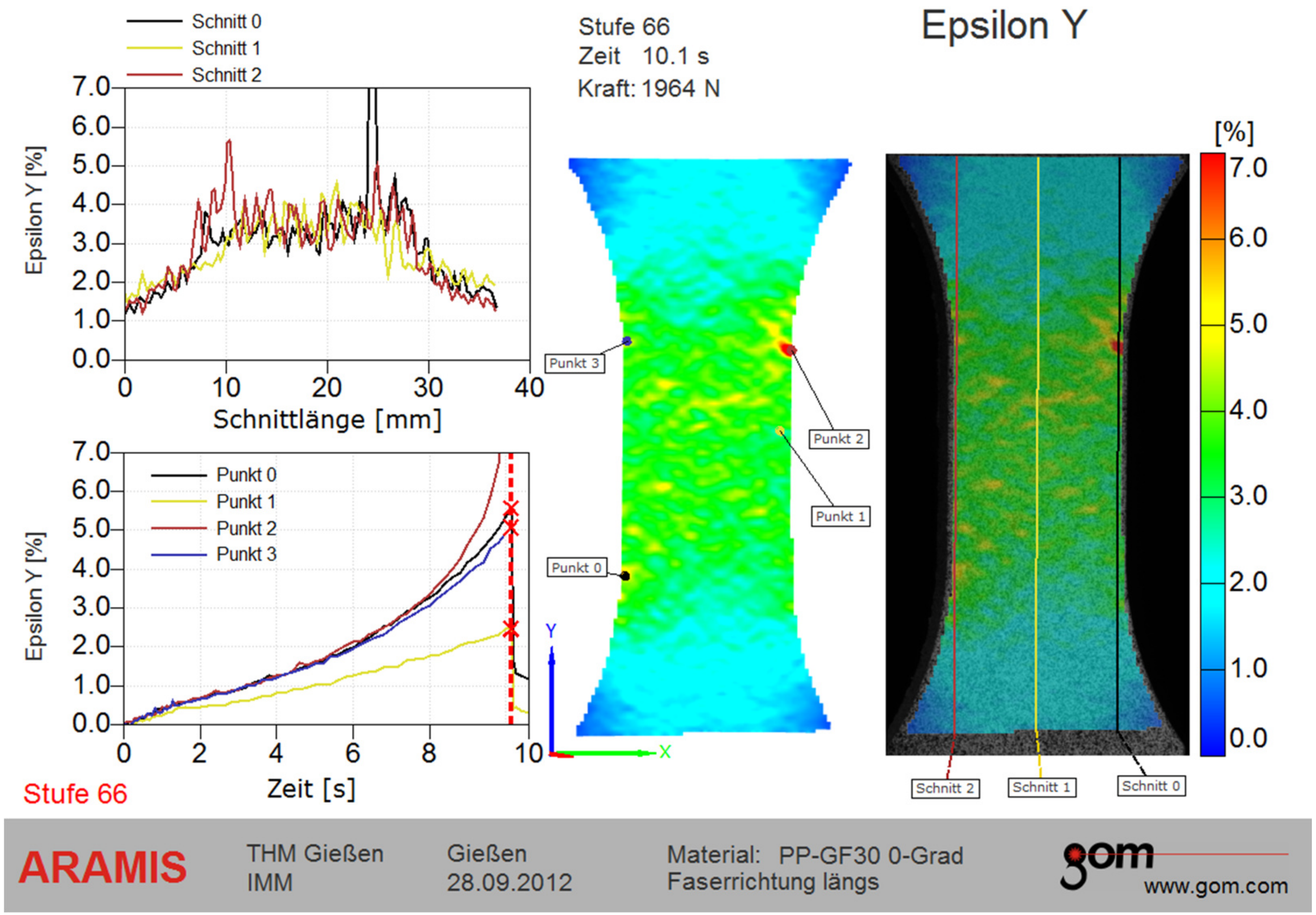






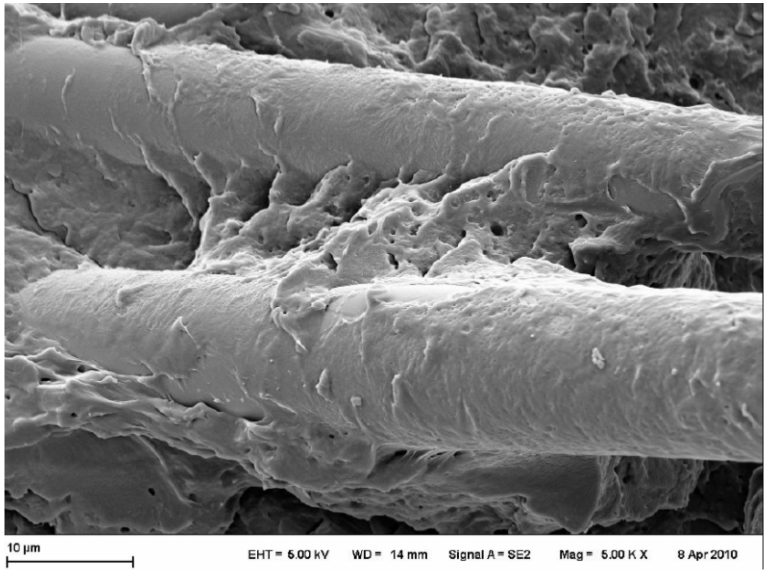
Strain distribution during tensile test

➢ Inhomogeneous strain distribution due to local fiber fracture



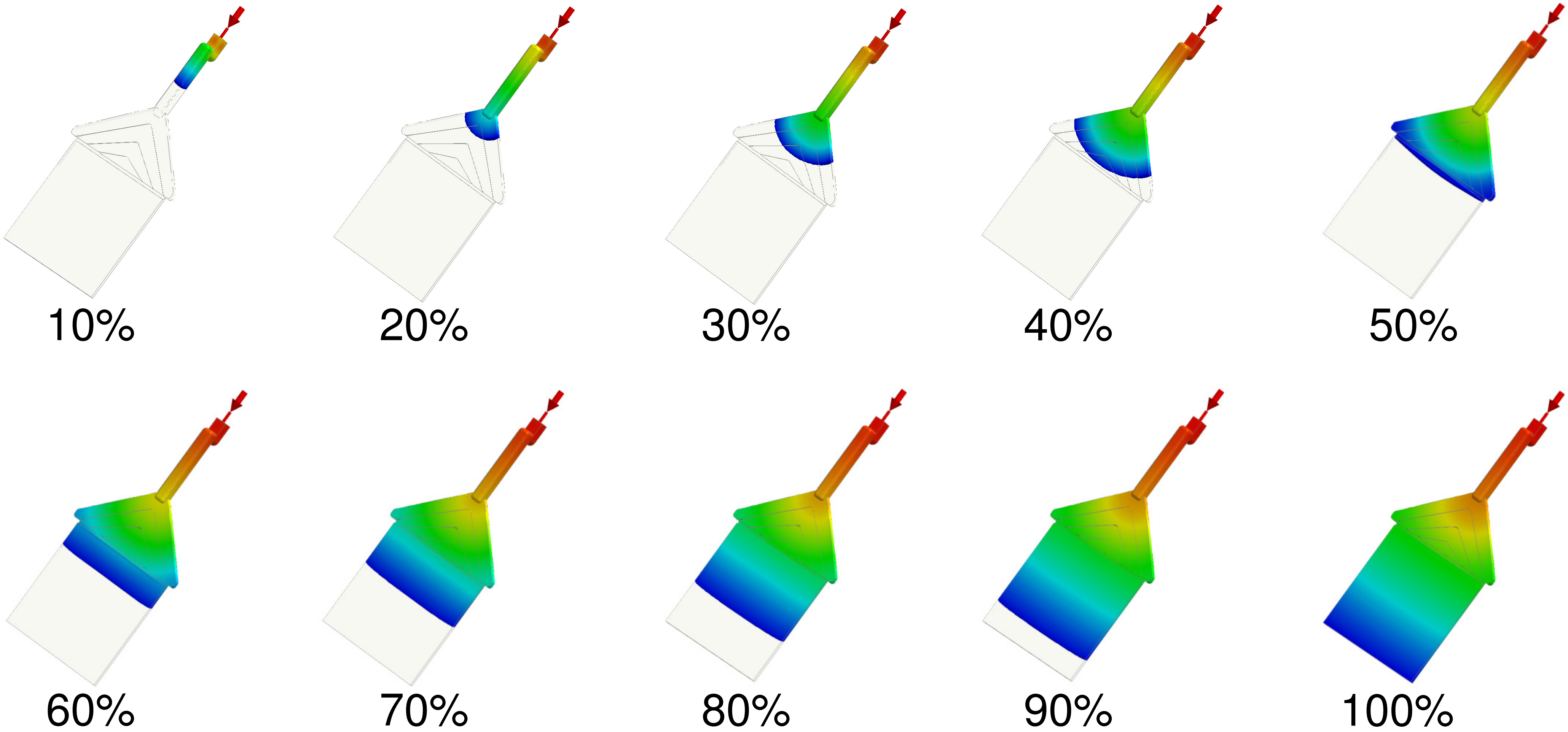
[J. Schöpfer, Dissertation 2011]

- Local behavior of the fibers is rather complex!

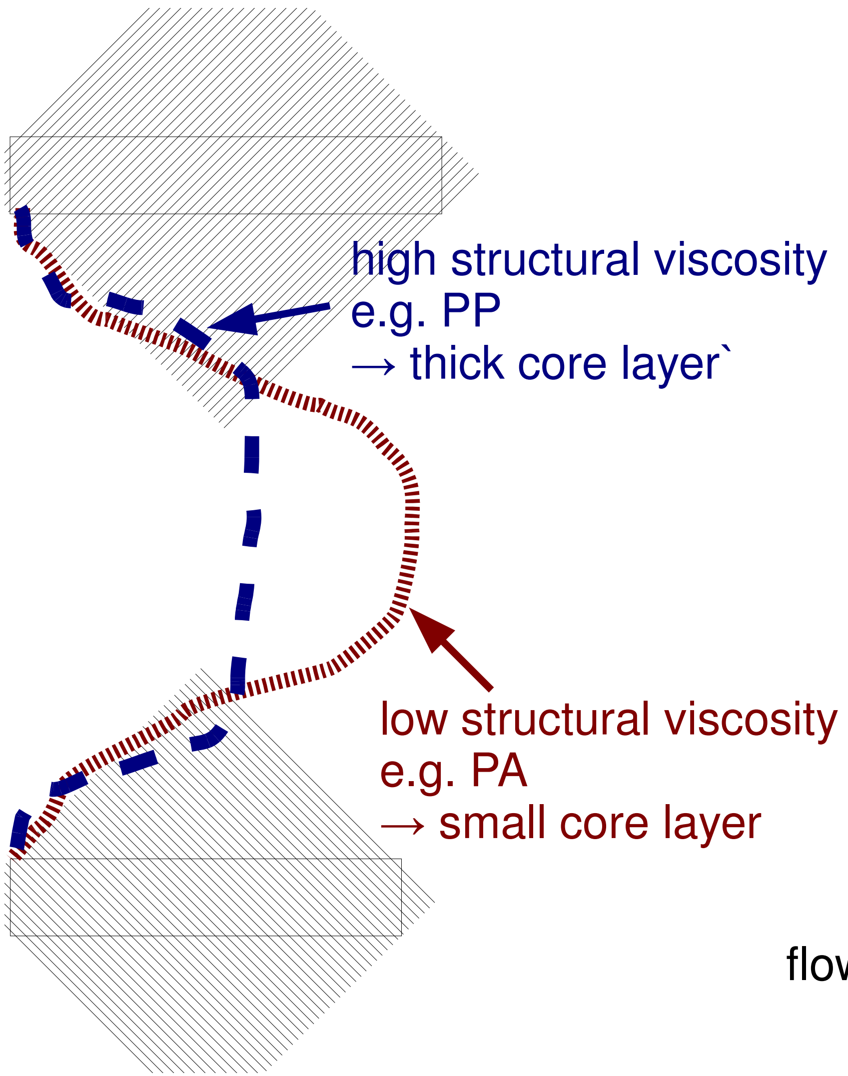


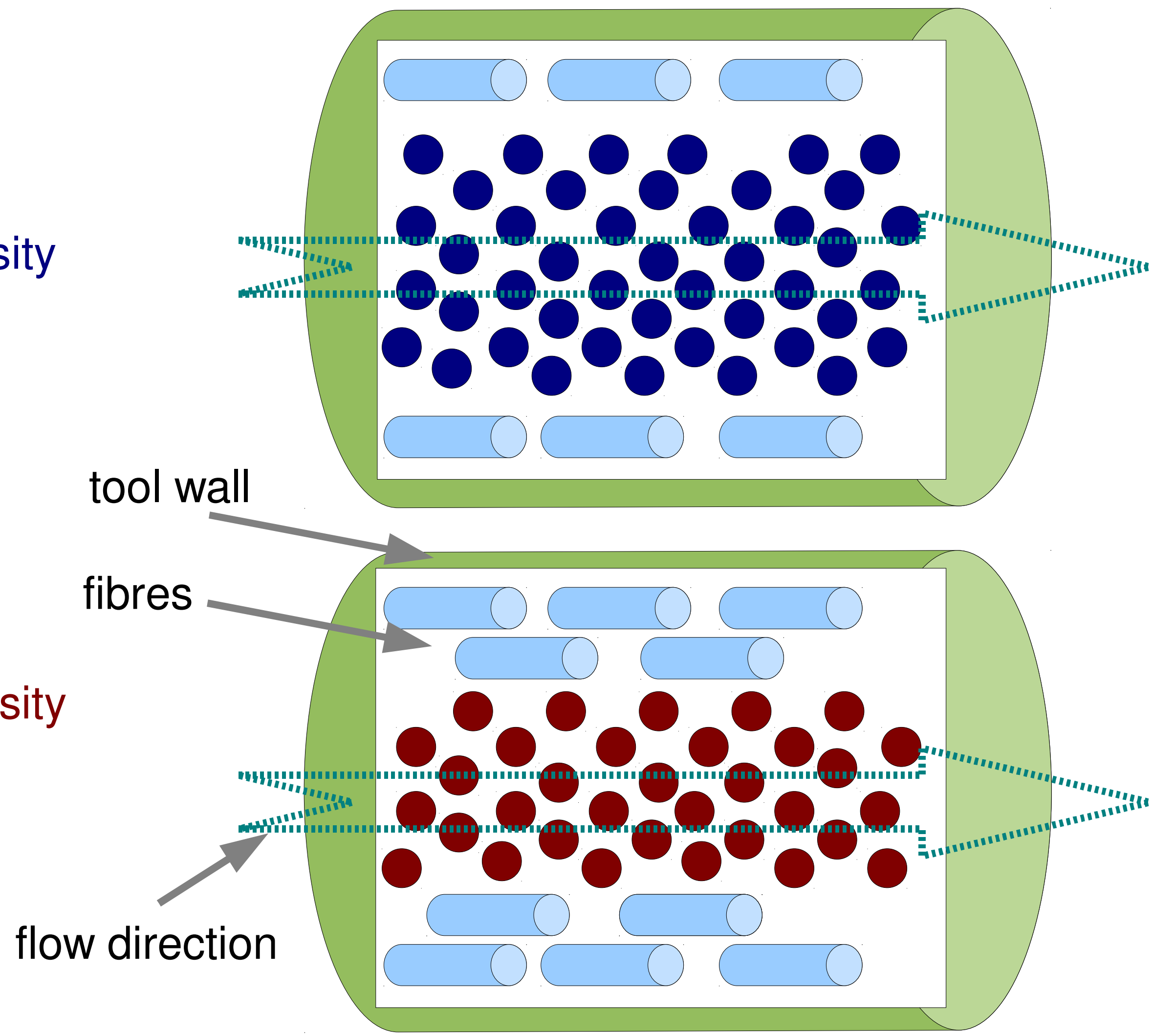
- Fiber distribution can be obtained numerically by injection molding analysis
- Validation of the analysis can be performed by µCT-Analysis

Injection molding analysis



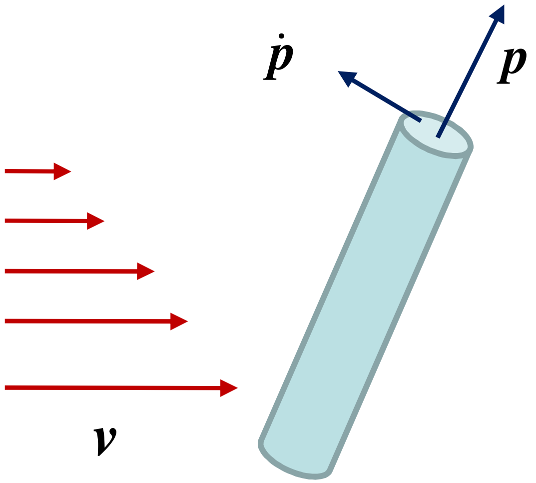
Fluid flow & fibre orientation





Fiber orientation analysis

- Evolution of fiber orientation (Jeffrey 1922, Folgar&Tucker 1984)



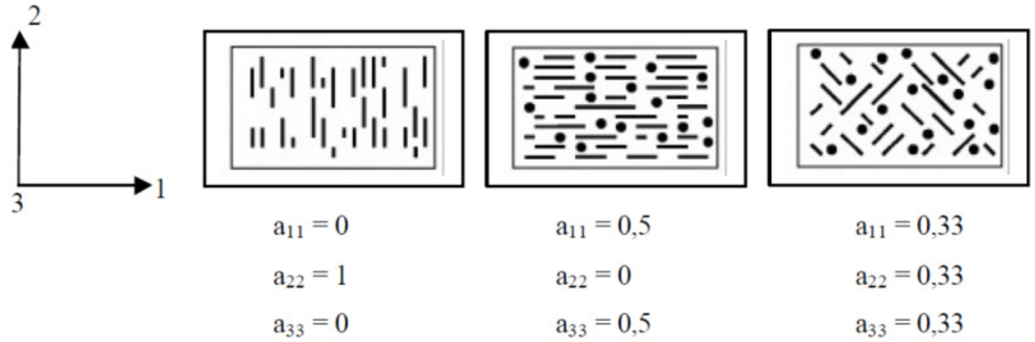
$$\dot{\boldsymbol{p}} = -\nabla^{skew}\boldsymbol{v}\cdot\boldsymbol{p} + \lambda\left[\nabla^{sym}\boldsymbol{v}\,\boldsymbol{p} - \left(\boldsymbol{p}\cdot\nabla^{sym}\boldsymbol{v}\,\boldsymbol{p}\right)\boldsymbol{p}\right] - \frac{Dr}{\psi}\frac{\partial\psi}{\partial\boldsymbol{p}}$$

$$\lambda = \frac{(l/\mathrm{d})^2 - 1}{(l/\mathrm{d})^2 + 1}$$ = fiber geometry

Dr = fiber interaction coefficient

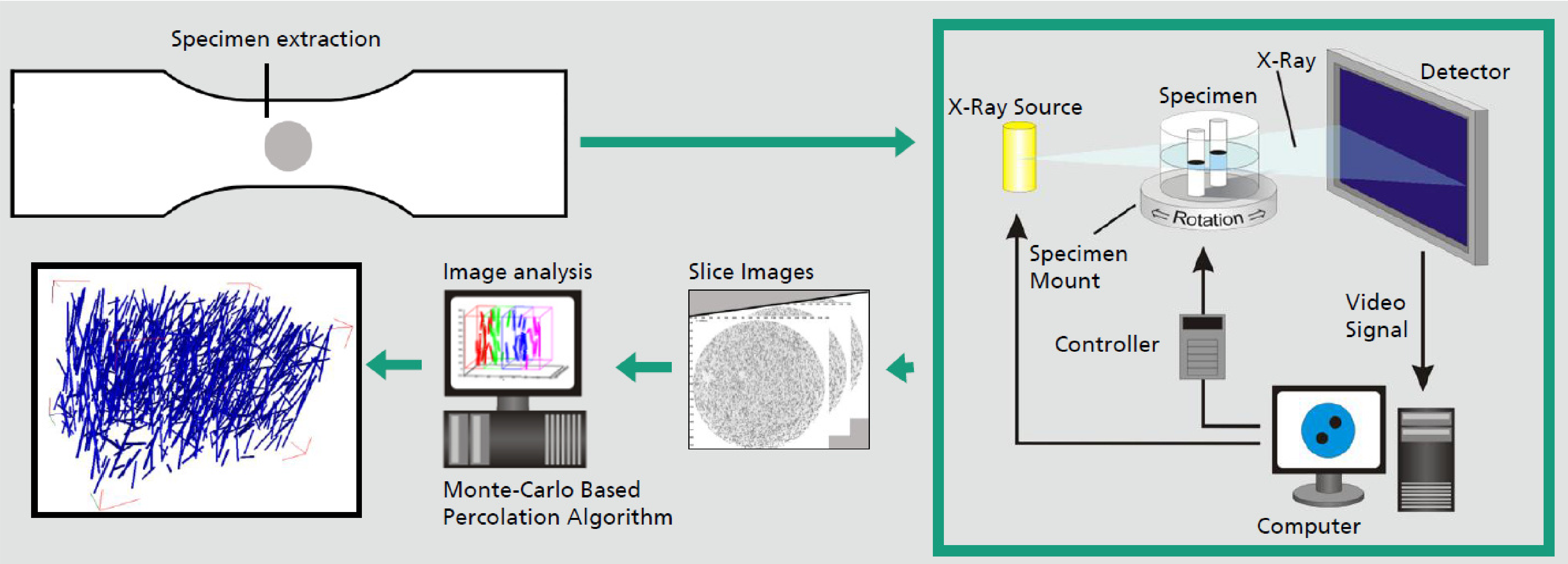
- Fiber orientation tensor

$$a_{ij} = \oint \Psi(\mathbf{p})p_i p_j d\mathbf{p}$$



Fiber analysis using computer-tomography

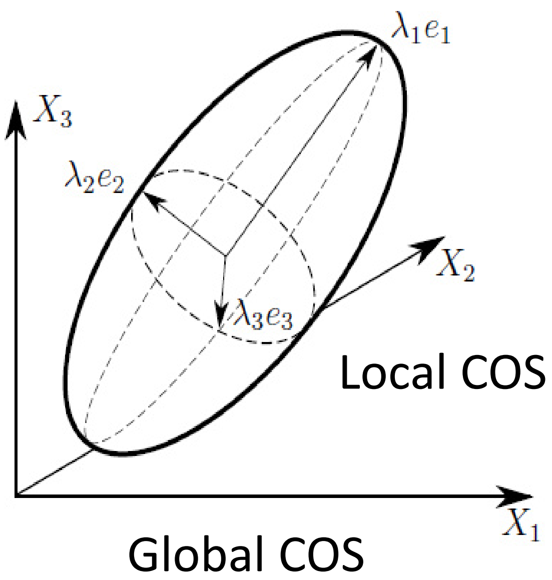
- Experimental fully 3D-identification of the fiber orientation tensor at the Fraunhofer LBF, Darmstadt

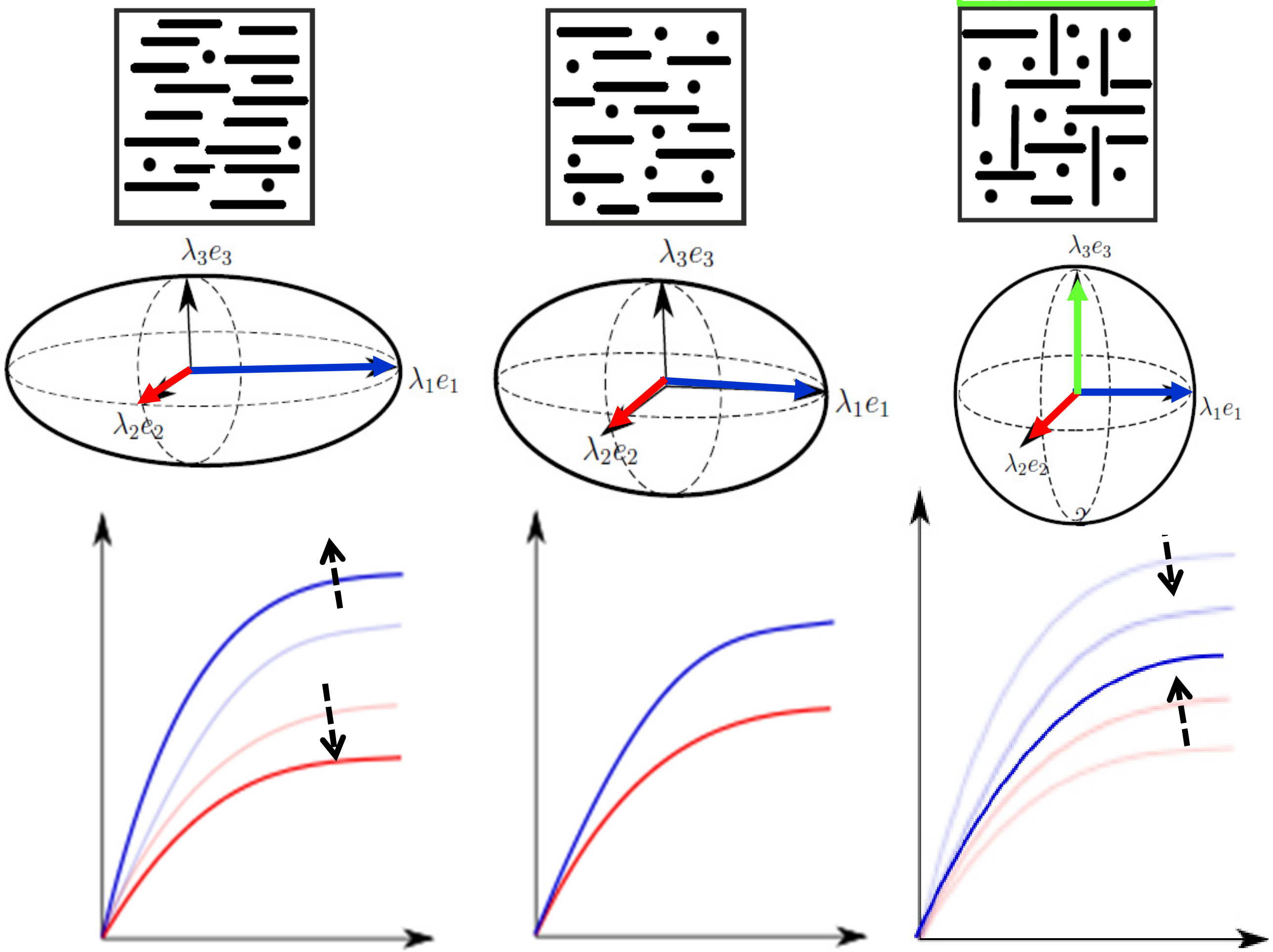


SAMP-anisotropic including fiber orientation

Fiber orientation tensor:

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

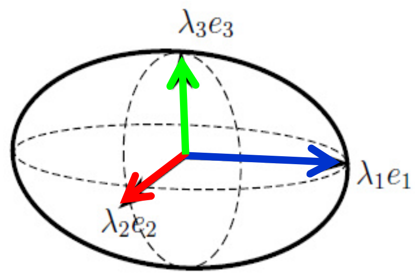




Tensile behavior :

SAMP anisotropic: Yield surface formulation

- Structural tensors: $\mathbf{A} = \mathbf{a} \otimes \mathbf{a}$ $\mathbf{B} = \mathbf{b} \otimes \mathbf{b}$
- Decomposition of stress tensor $\boldsymbol{\sigma} = \boldsymbol{\sigma}^{\text{pind}} + \boldsymbol{\sigma}^{\text{reac}}$ in reaction stress tensor and plasticity inducing stresses



- Orthotropic invariants

$$
\begin{aligned}
I_1 &:= \frac{1}{2}\,\mathrm{tr}\,(\boldsymbol{\sigma}^{\text{pind}})^2 - \mathbf{a}\,(\boldsymbol{\sigma}^{\text{pind}})^2\,\mathbf{a} - \mathbf{b}\,(\boldsymbol{\sigma}^{\text{pind}})^2\,\mathbf{b} \\
I_2 &:= \mathbf{a}\,(\boldsymbol{\sigma}^{\text{pind}})^2\,\mathbf{a}\,, \\
I_3 &:= \mathbf{b}\,(\boldsymbol{\sigma}^{\text{pind}})^2\,\mathbf{b}\,.
\end{aligned}
$$

$$
\begin{aligned}
I_4 &:= \mathrm{tr}\,\boldsymbol{\sigma} - \mathbf{a}\boldsymbol{\sigma}\mathbf{a} - \mathbf{b}\boldsymbol{\sigma}\mathbf{b} \\
I_5 &:= \frac{3}{2}\mathbf{a}\boldsymbol{\sigma}^{\text{dev}}\mathbf{a} \\
I_6 &:= \frac{3}{2}\mathbf{b}\boldsymbol{\sigma}^{\text{dev}}\mathbf{b}
\end{aligned}
$$

- Orthotropic yield surface formulation

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

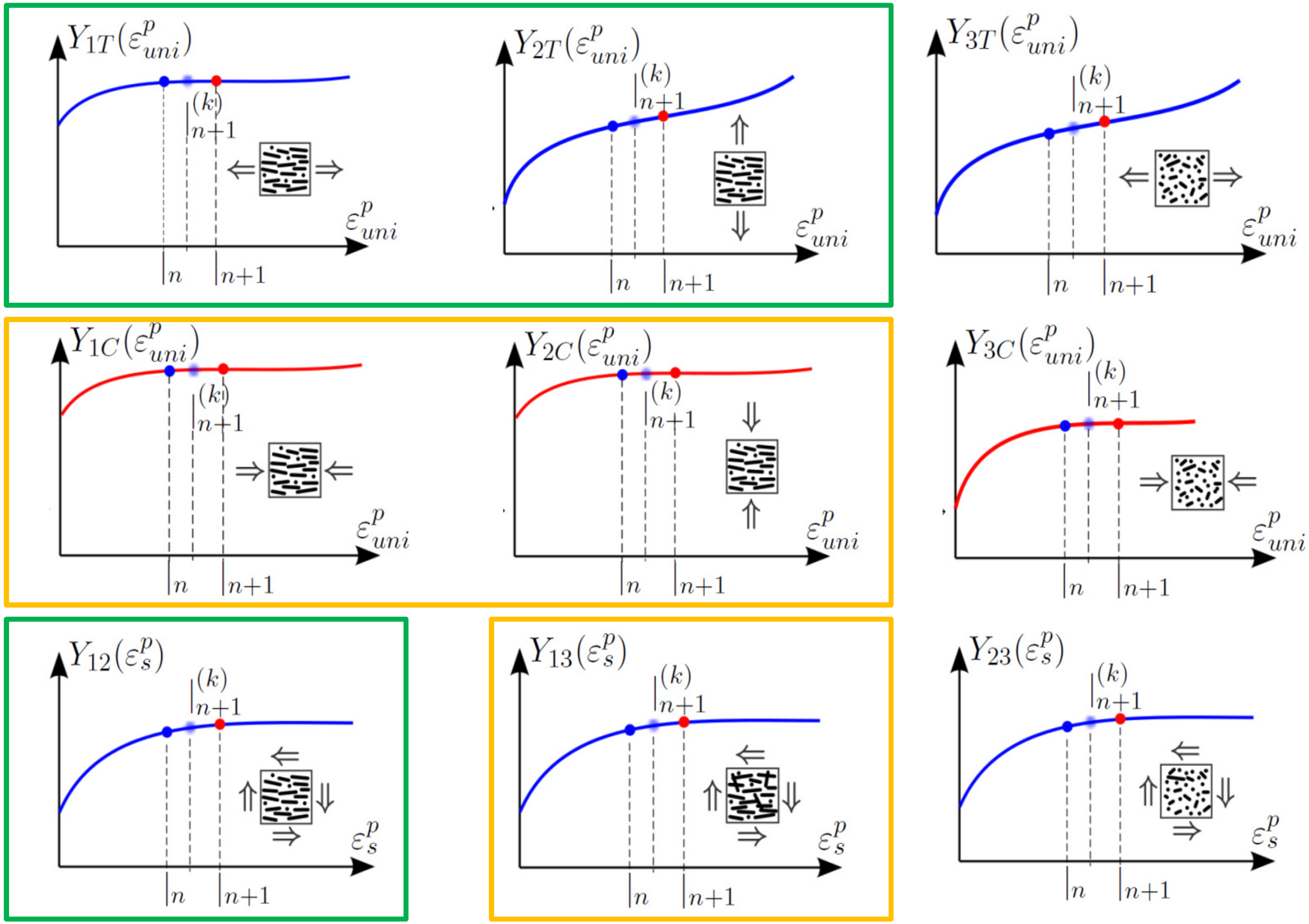
9 yield parameters → 9 material tests necessary

SAMP anisotropic: Different yielding in..

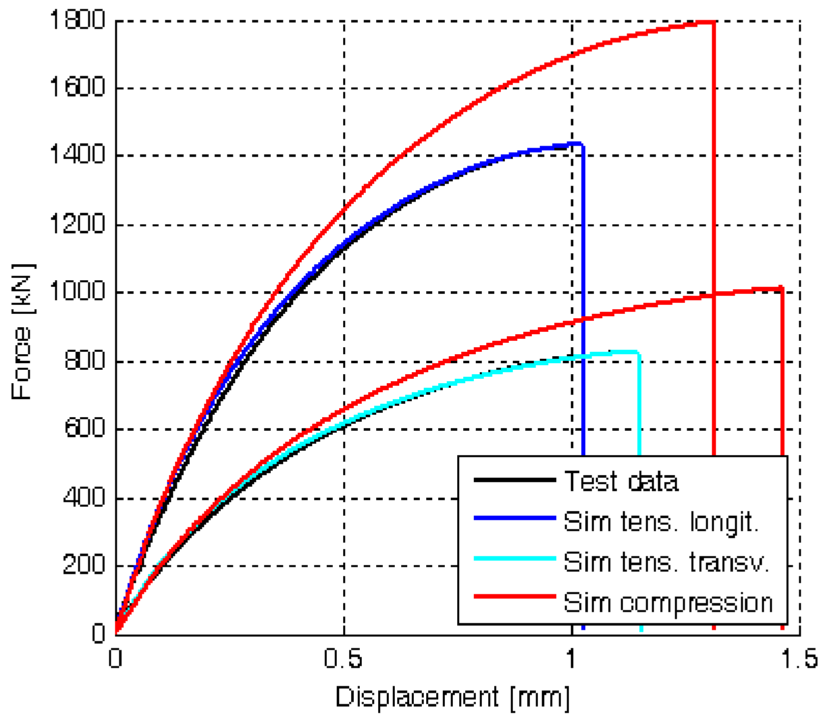
.. tension:

.. compression:

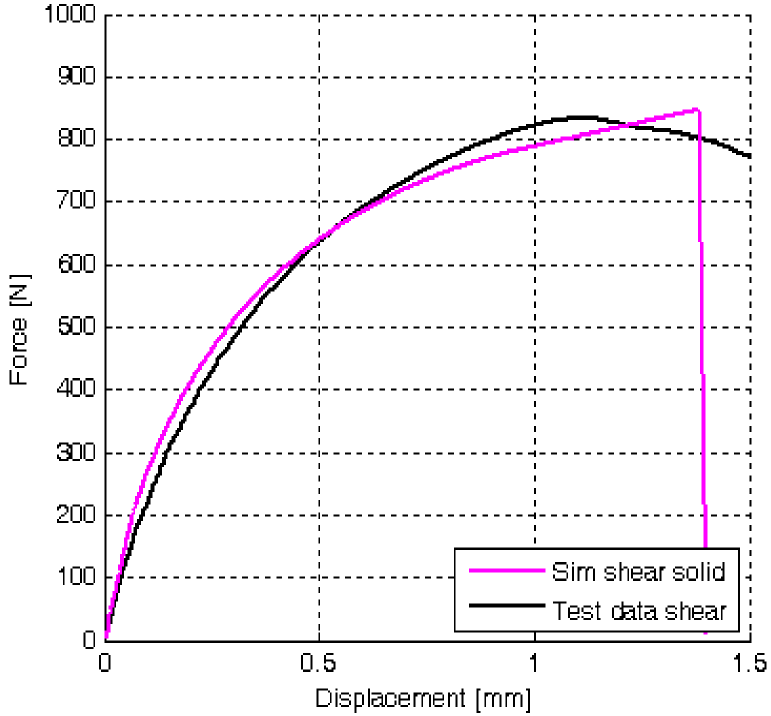
.. shear:



Tension and compression



Shear



- ➢ Note that there is no test data available under compression. The tension-compression asymmetry has been obtained via three-point-bending tests by reverse engineering

PA6GF60: Simulation results 3-point bending tests

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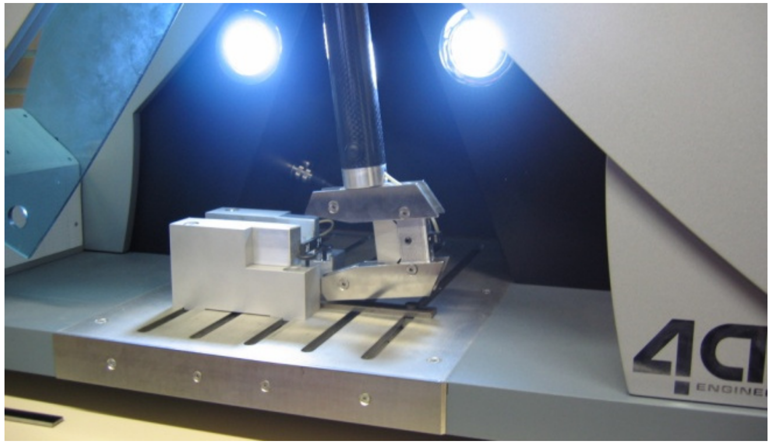
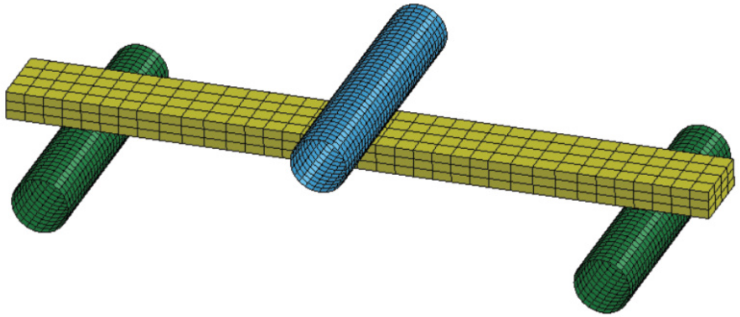
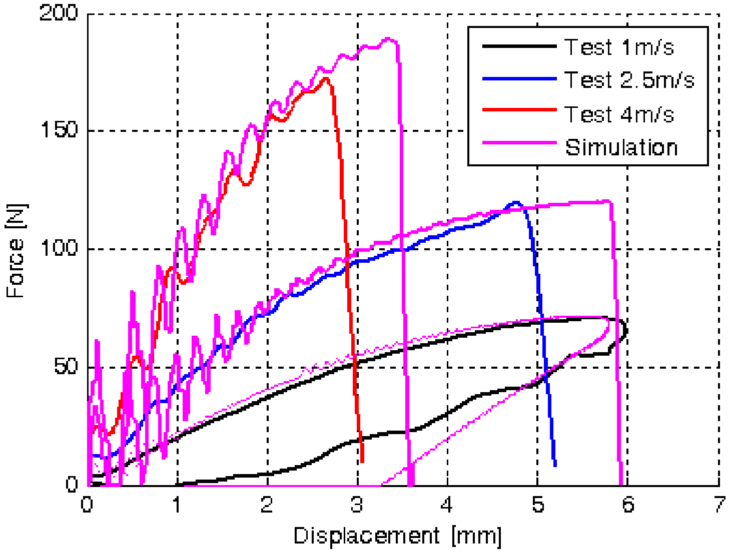
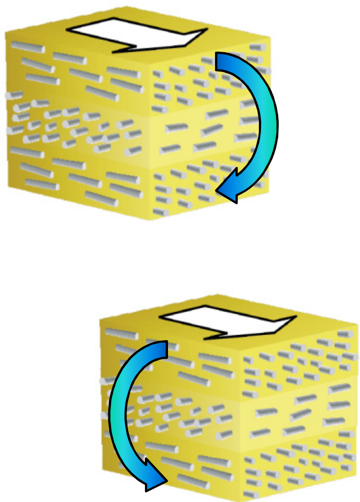


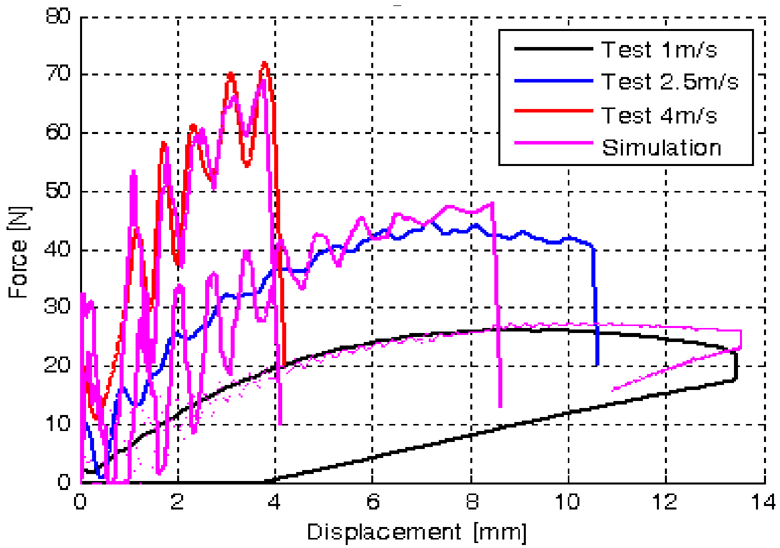


Longitudinal fiber orientation

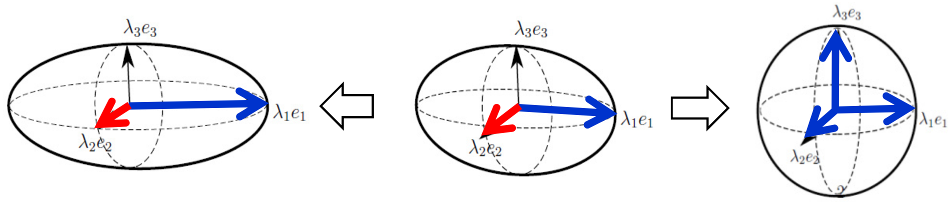




Transverse fiber orientation



- Based on MAT_SAMP-1, an anisotropic version of this model has been implemented into LS-DYNA
- Information of the fiber orientation tensor is required at Gauss points
- Extrapolation / interpolation to arbitrary fiber orientations using micromechanics



- Consideration of the process chain from injection molding simulation to crash simulation becomes feasible without further external codes
- Validation of component tests (Nutini's box tests) are next steps