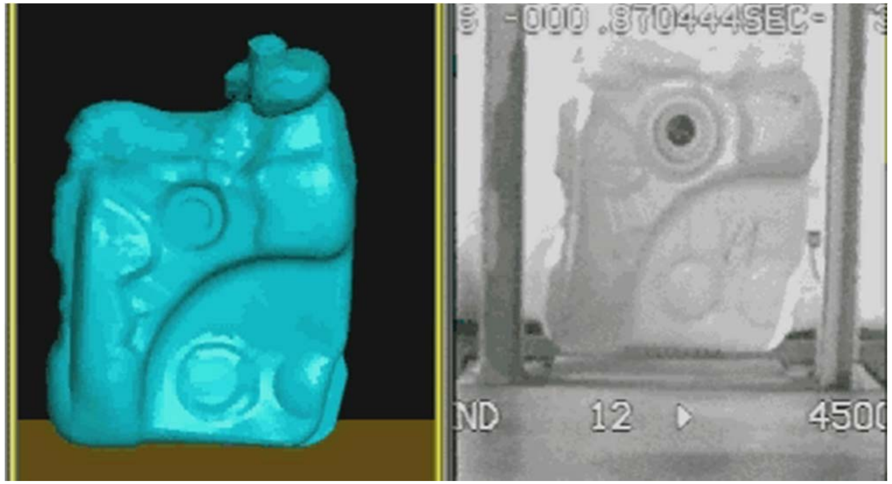
Einfluss der Materialmodellierung von thermoplastischen Kunststoffen auf Ergebnisse von numerischen Falltests



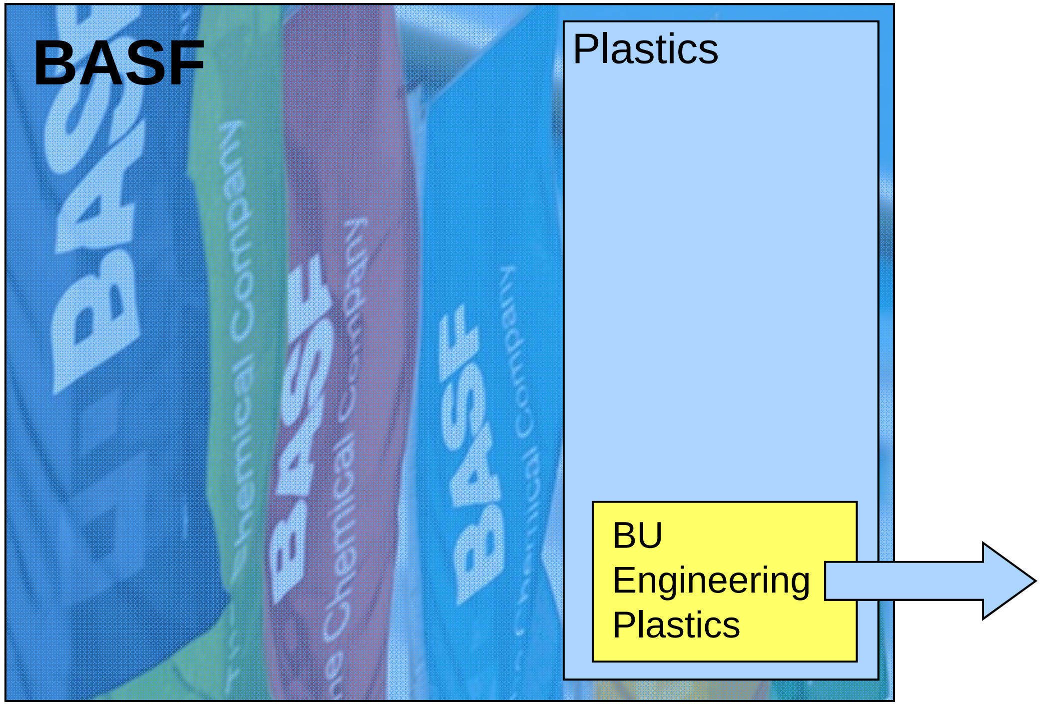
Torsten Hensel - Andreas Wüst - Stefan Glaser

Contents

- Motivation
  - Was ist das besondere an einer Falltestsimulation?
  - Erfahrungen aus der Praxis → Fallstricke
- Materialverhalten von Kunststoffen – BASF ULTRASIM™
  - Faserorientierung
  - Dehnratenabhängigkeit
  - Asymmetrie in Zug-Druck
  - Anisotropie
  - Versagensmodellierung
- Ausgewählte Beispiele
- Diskussion

BASF and CAE?

BASF – The Chemical Company



BASF

Plastics

BU Engineering Plastics

Thermoplastic Materials

+ Customer Support:

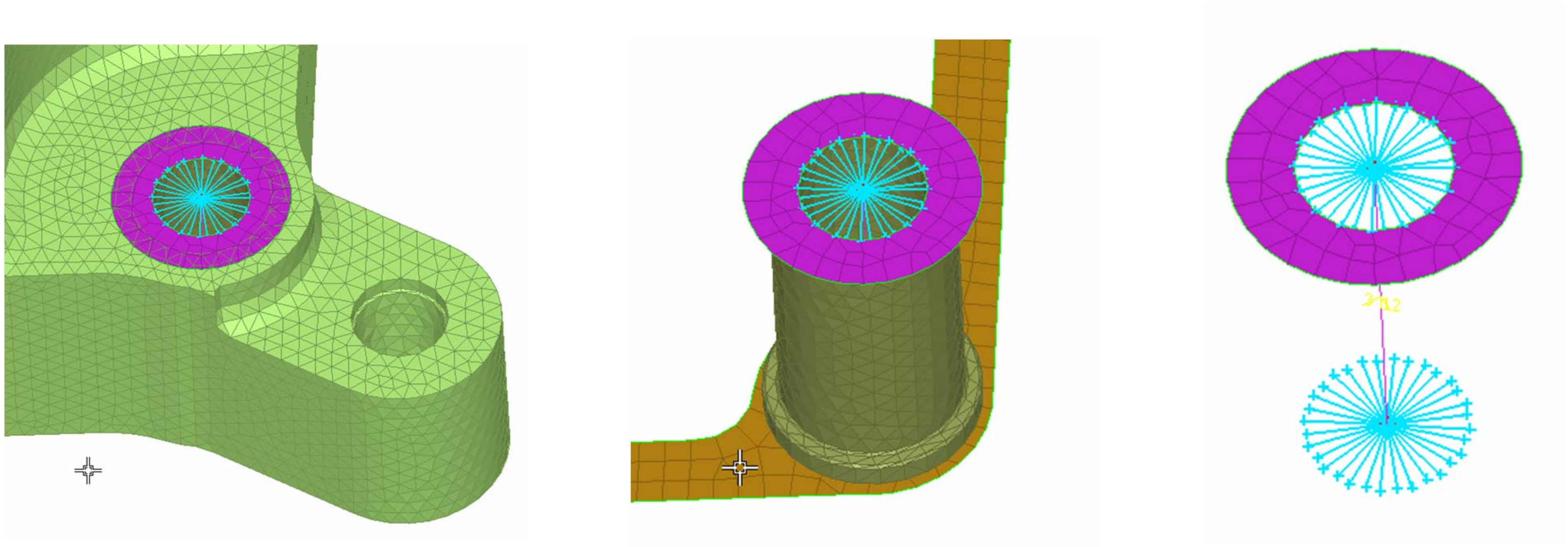
-
- Application Development Services
    - Material Modelling
    - Mechanical Analyses
    - Filling Analyses
    -
-

CAE

Motivation

- Was ist das besondere an einer Falltestsimulation?
  - Kinematisch anspruchsvoll
    - Kontaktabbildung, Postprocessing
  - Simplifikationen sind erschwert!
    - Verbindungsmodellierung (Schrauben, Kleben, …)
  - Abbildung von Material und Versagen ist eine zentrale Aufgabe
    - Nichtlinearitäten, Anisotropie, …
  - Lokale Größen dominieren
    - Netzfeinheit und Netzgüte
      - Resultat Absenkung → Steifigkeit → globale Größe
      - Resultat Versagen → Failure-Wert → lokale Größe

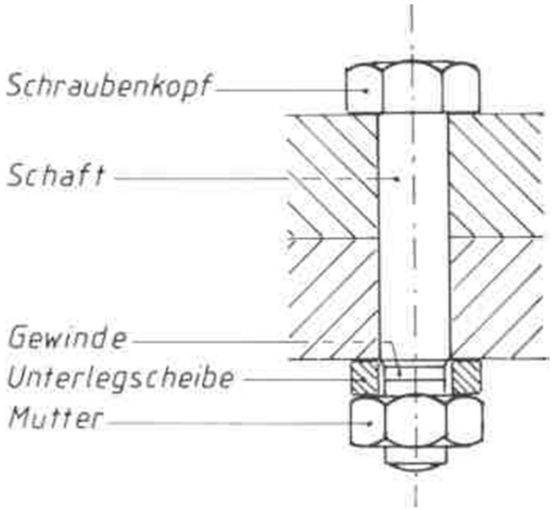
Vereinfachung Schraube

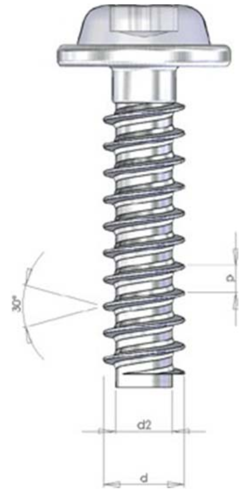


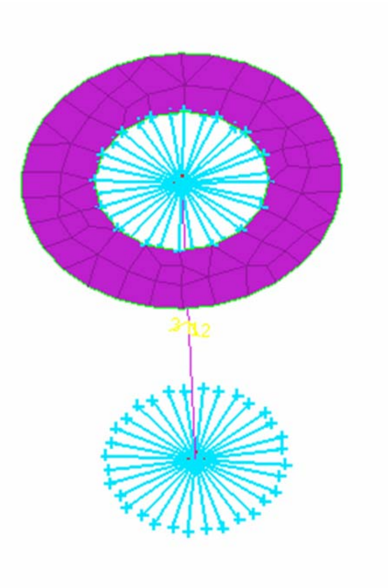
Schraube ist geometrisch nicht vorhanden!

Probleme:
- Krafteinleitung
- was passiert nach dem Versagen?

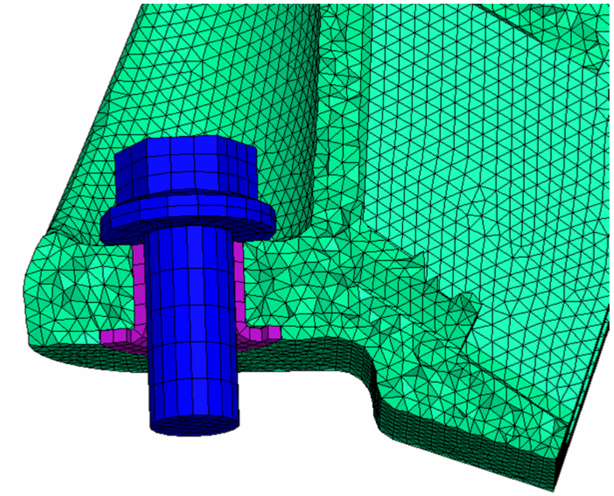
Vereinfachung Schraube







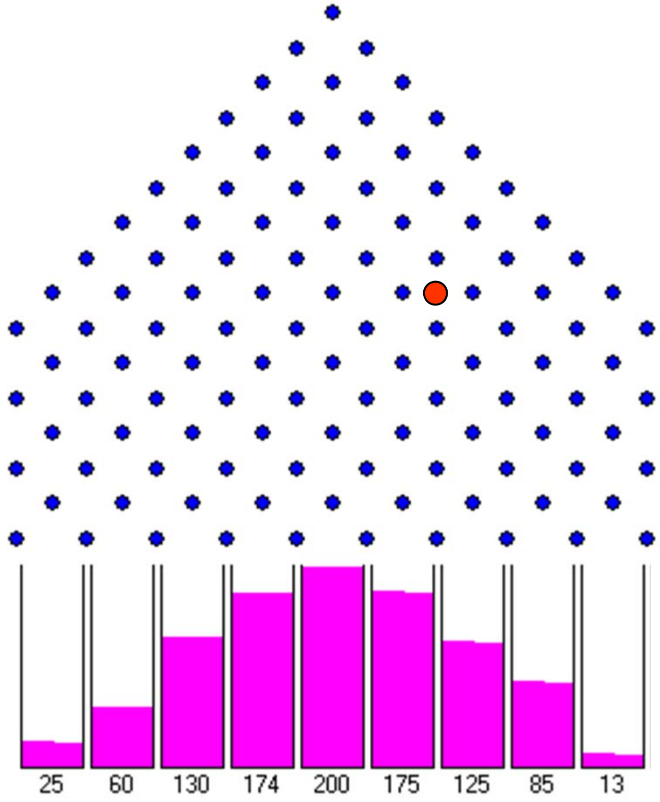
vereinfacht



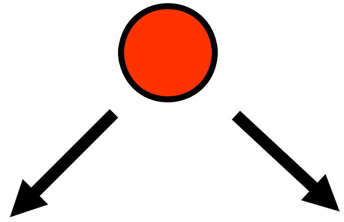
geometrisch korrekt

Gefahr: Bifurkation durch nichtphysikalisches Verhalten
Lösung schlägt einen anderen Pfad ein!

Galton Brett
Pfadabhängigkeit

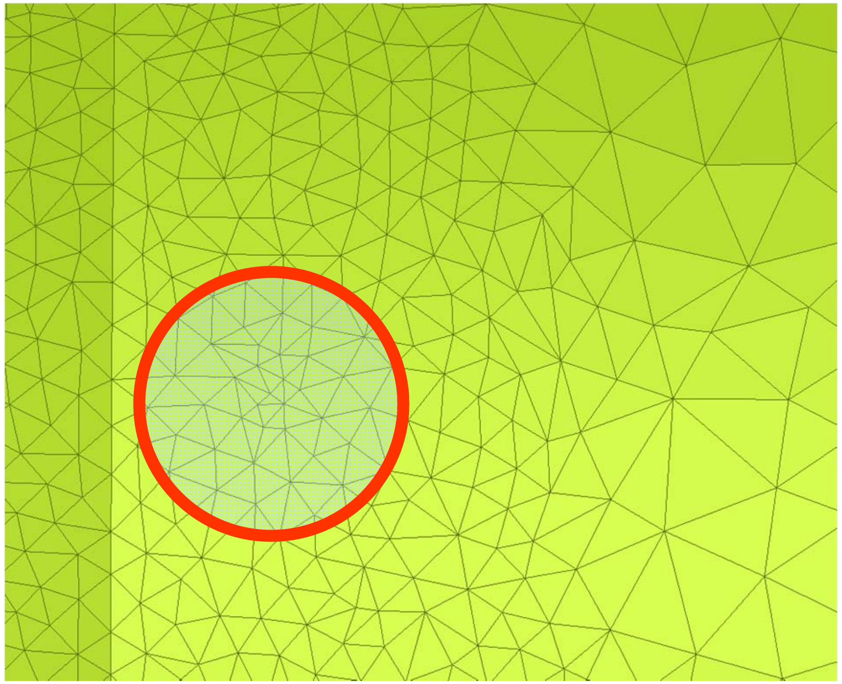


Bifurkation (Gabelung)



$$p = \frac{1}{2} \qquad\qquad p = \frac{1}{2}$$

Netzeinfluss - Netzgüte

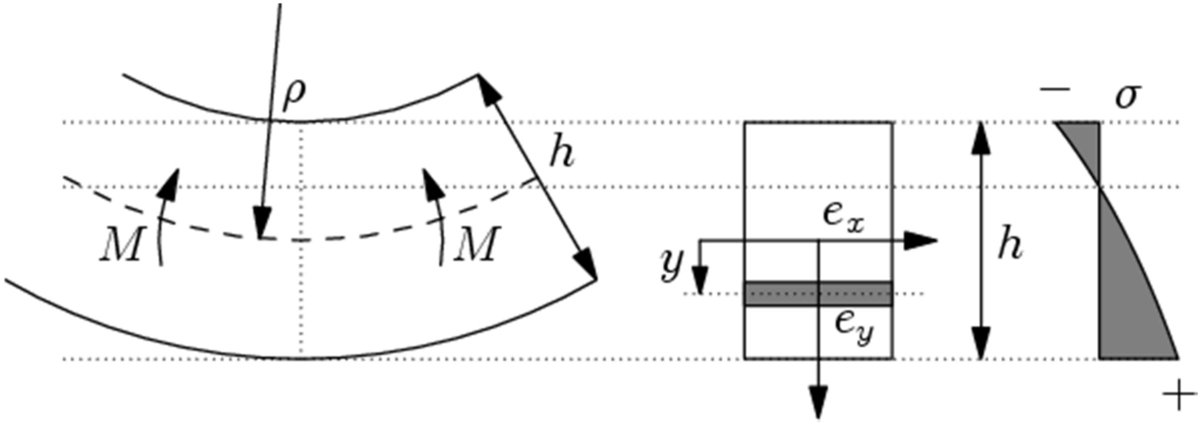


Resultat Absenkung → Steifigkeit → globale Größe
Resultat Versagen → Failure-Wert → lokale Größe

- Numerischer Einfluss schlechter Elemente kann dominieren

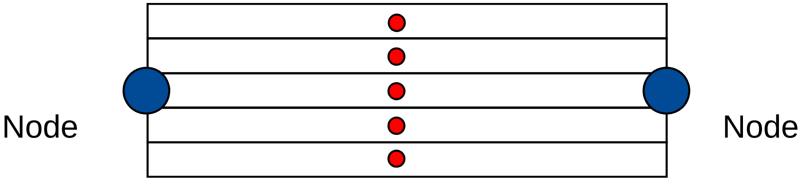
- Solidelemente → Netzchecks im Inneren beachten!

Netzeinfluss - Netzfeinheit

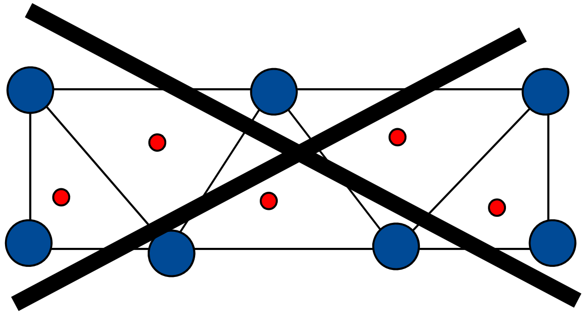


Schale unter Biegung

Shell-Element



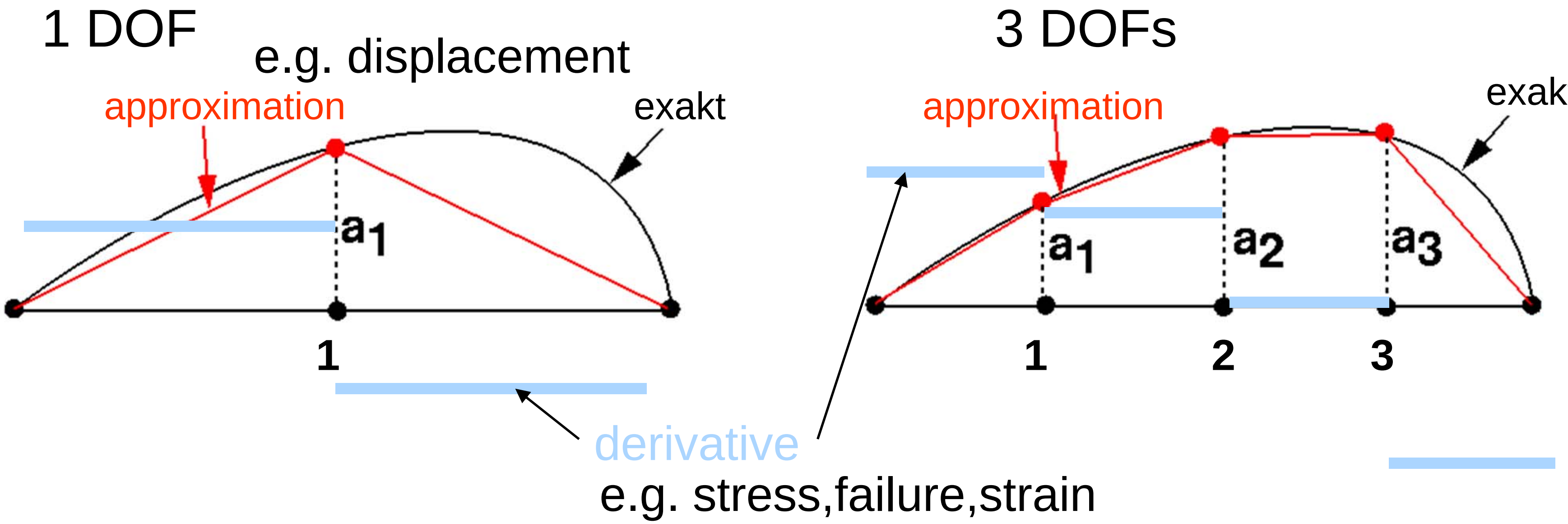
Solid-Element



● Integration Point

Netzfeinheit

Finite Element approximation
Linear Interpolation 1-dimensional


1 DOF

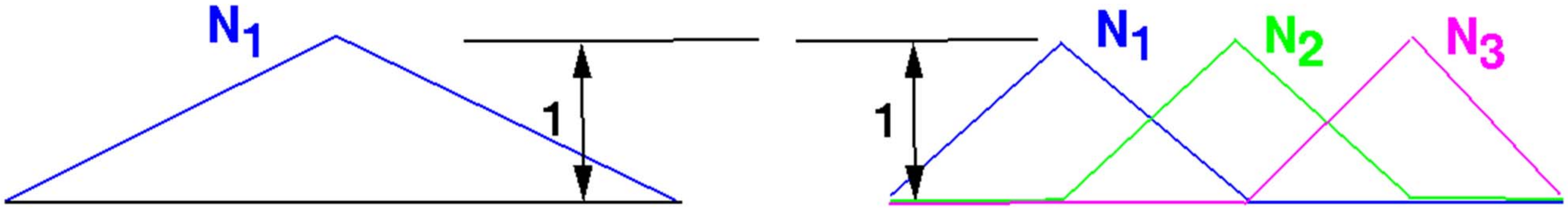
e.g. displacement

3 DOFs

derivative

e.g. stress,failure,strain

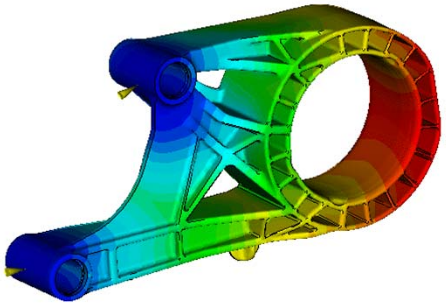
Shape function



Integrative Simulation ULTRASIM™

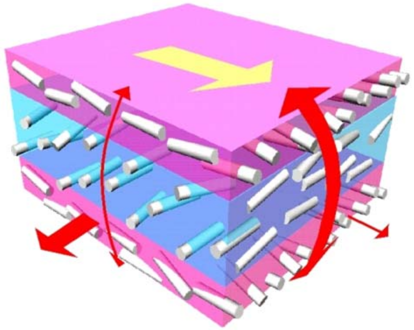
for short fiber reinforced thermoplastics

Process

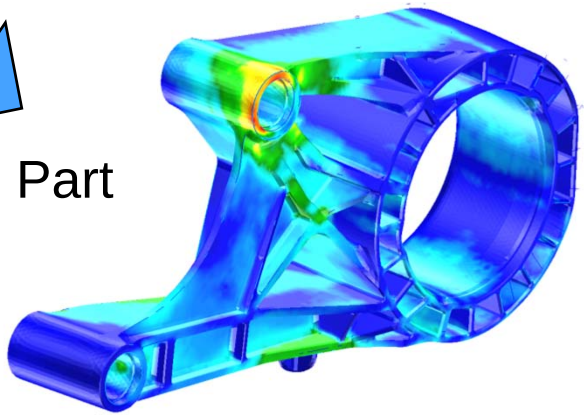


Measurement

Material

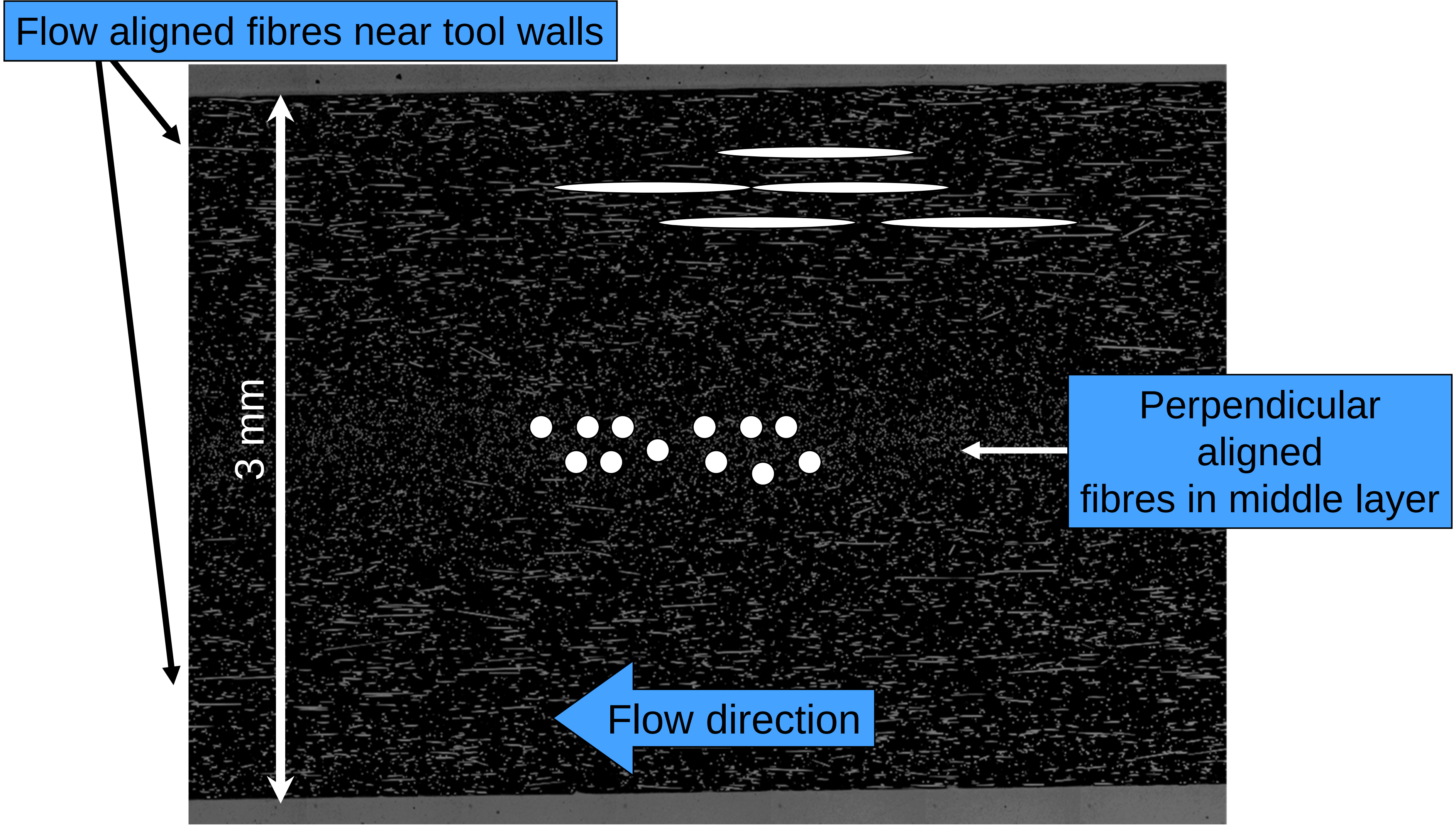


Part



- Anisotropic
- Nonlinear
- Strain-rate sensitive
- Tensile-compression asymmetric
- Failure modelling
- Temperature dependent

Cross section PA GF30



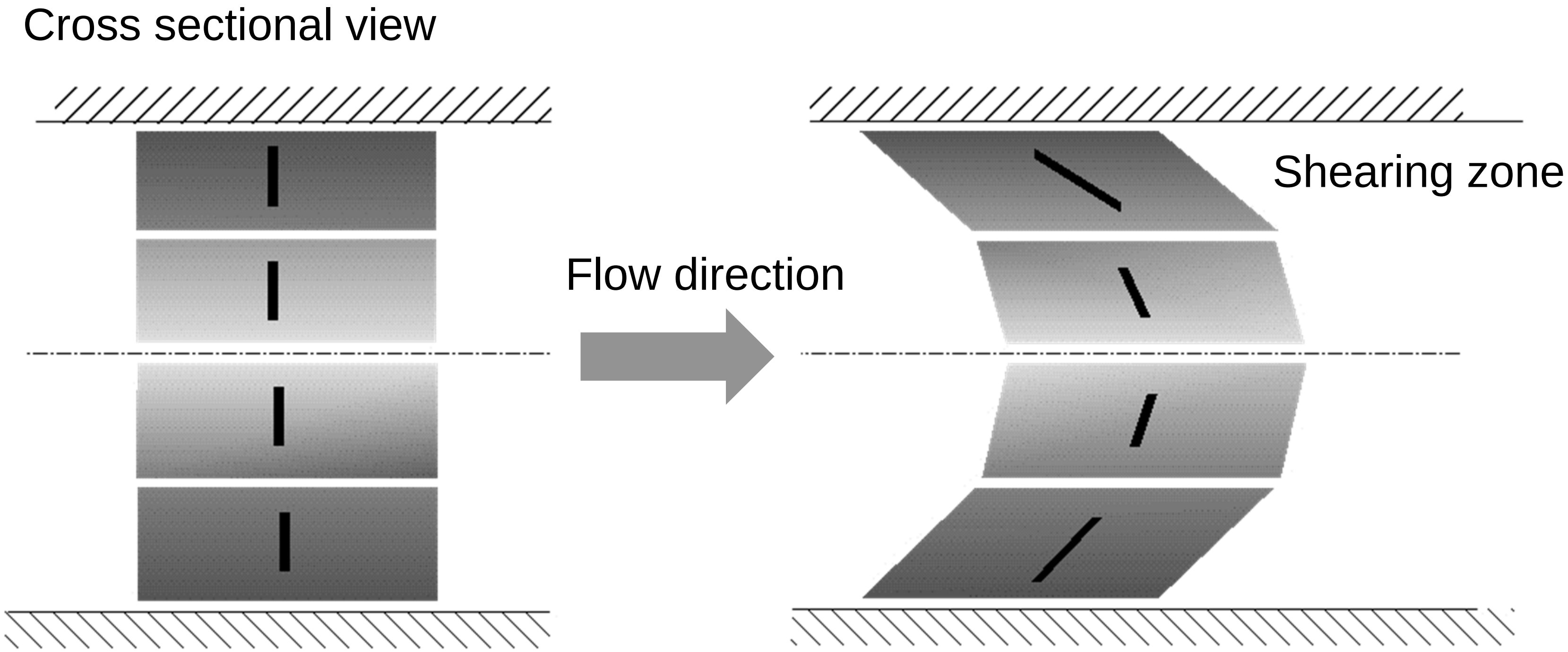
Flow aligned fibres near tool walls

Perpendicular aligned fibres in middle layer

Flow direction

Evolution of Fiber Orientation in Mould Filling Process

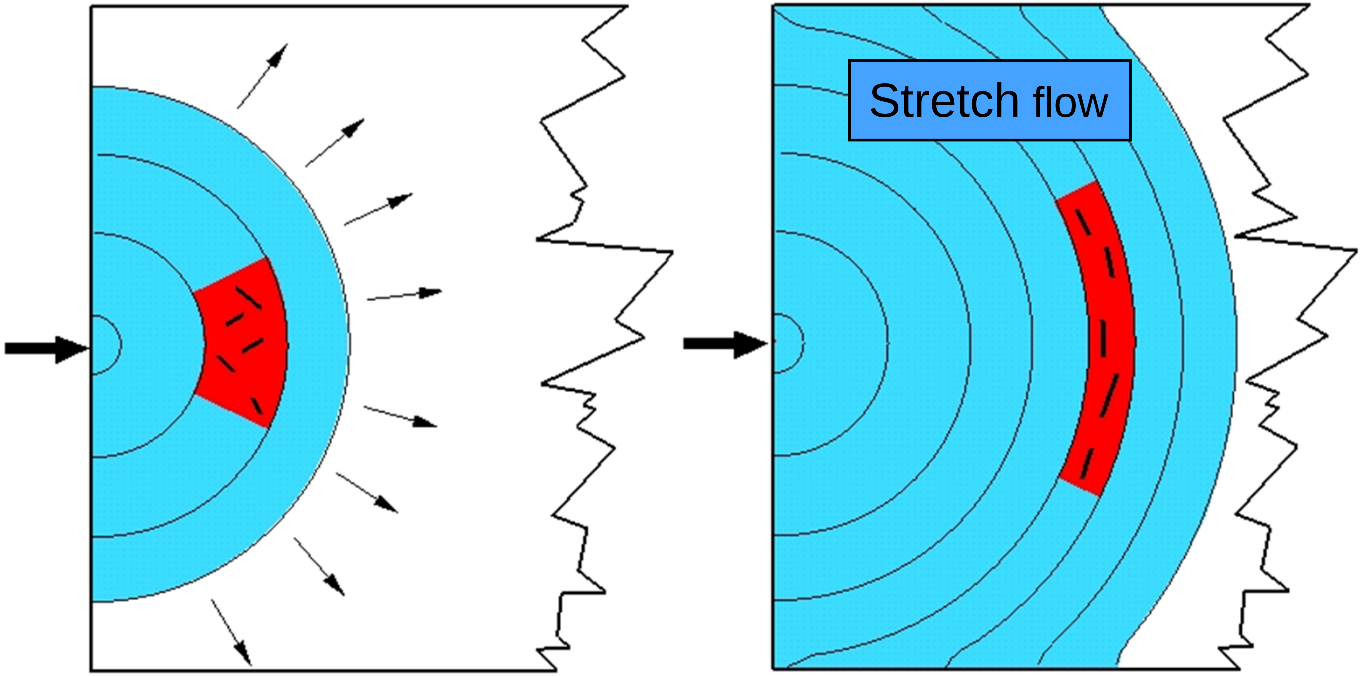
BASF
The Chemical Company



Due to shearing in the boundary layers
the fibers are oriented in flow direction

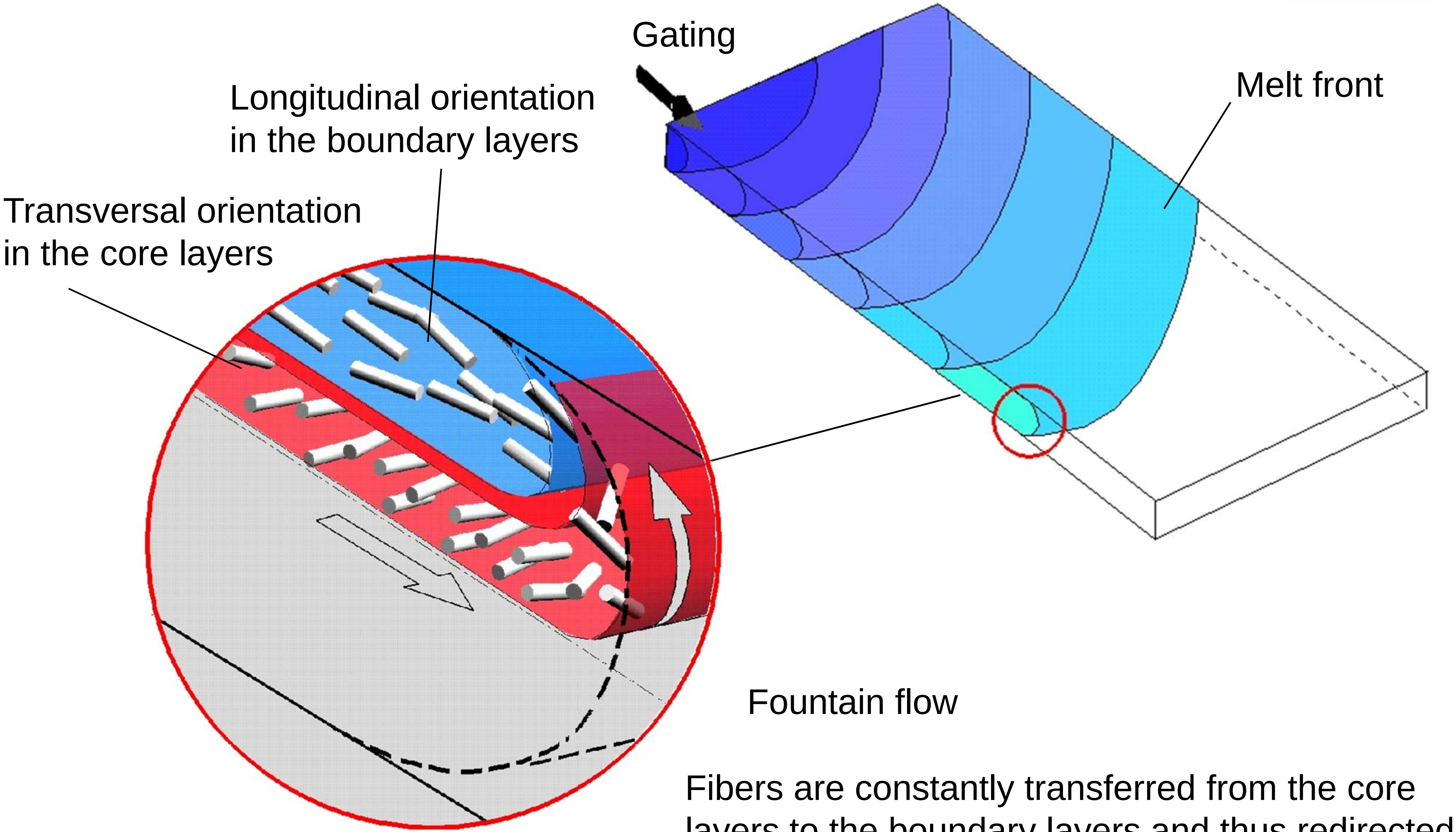
Evolution of Fiber Orientation in Mould Filling Process

Upper view



Fibers are being oriented in stretching direction

Evolution of Fiber Orientation in Mould Filling Process



Gating

Melt front

Longitudinal orientation
in the boundary layers

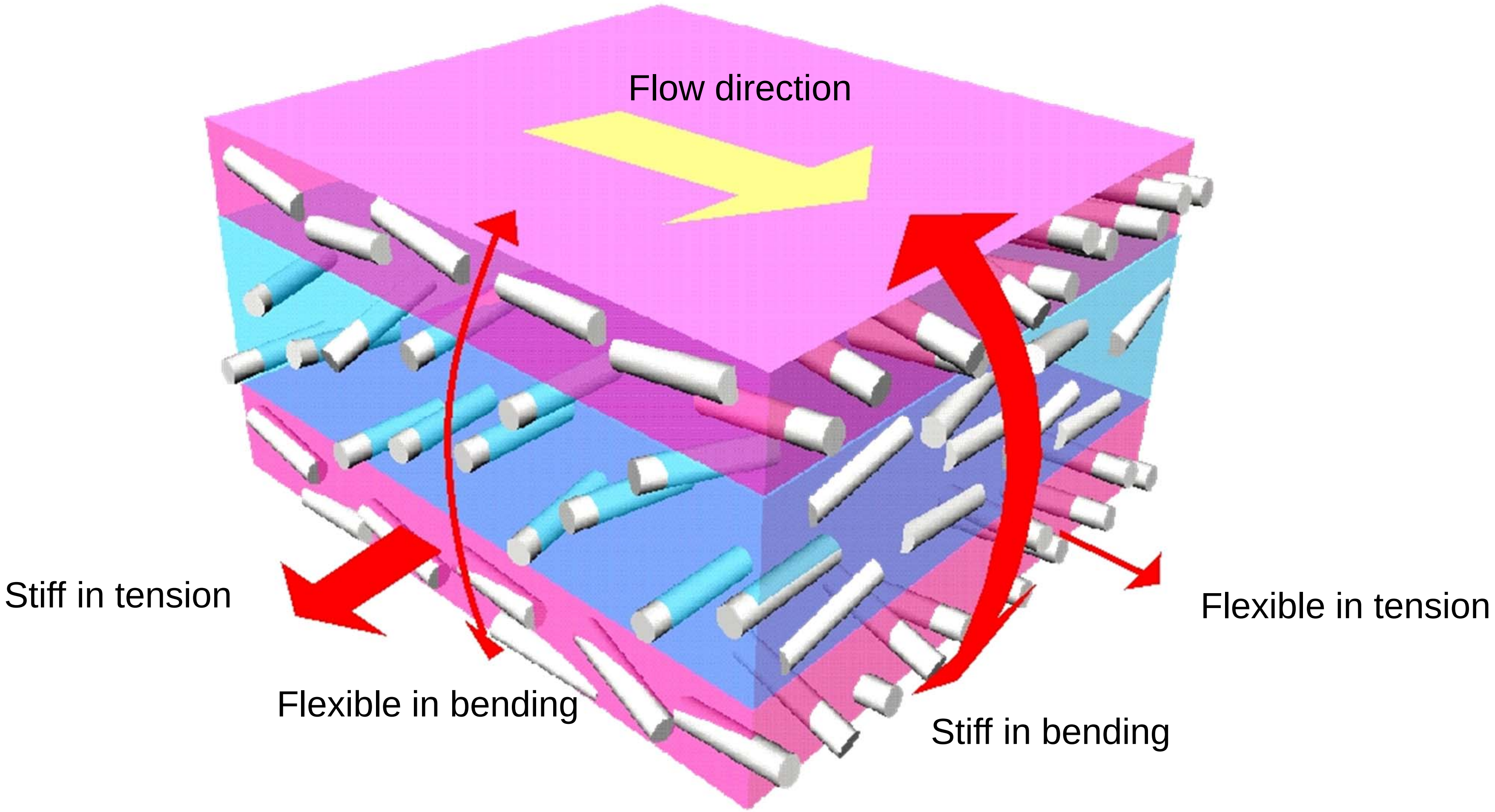
Transversal orientation
in the core layers

Fountain flow

Fibers are constantly transferred from the core layers to the boundary layers and thus redirected

Mechanical behaviour of anisotropic layered shells

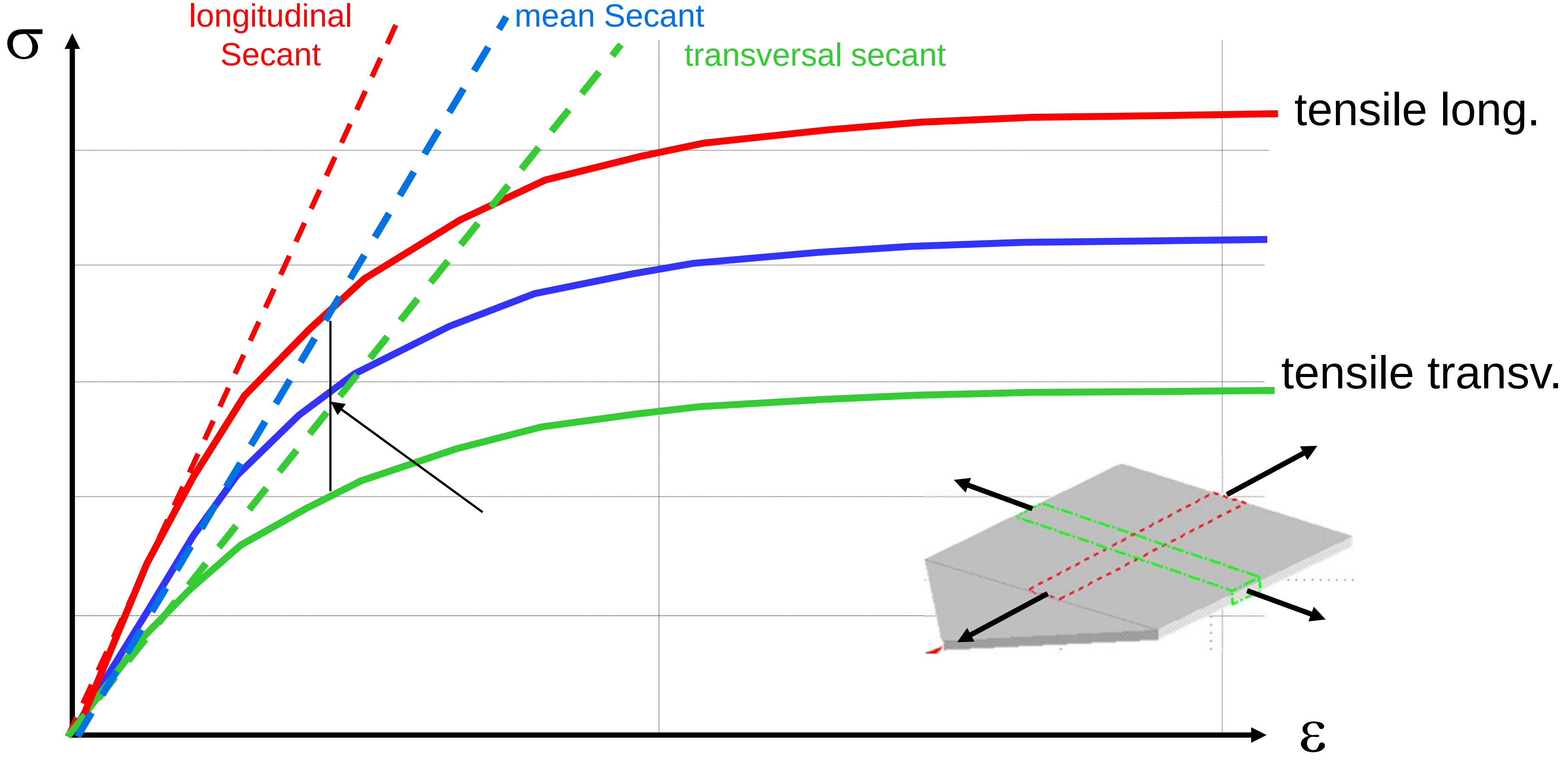
BASF
The Chemical Company



Motivation for Anisotropic Material Modelling

BASF
The Chemical Company

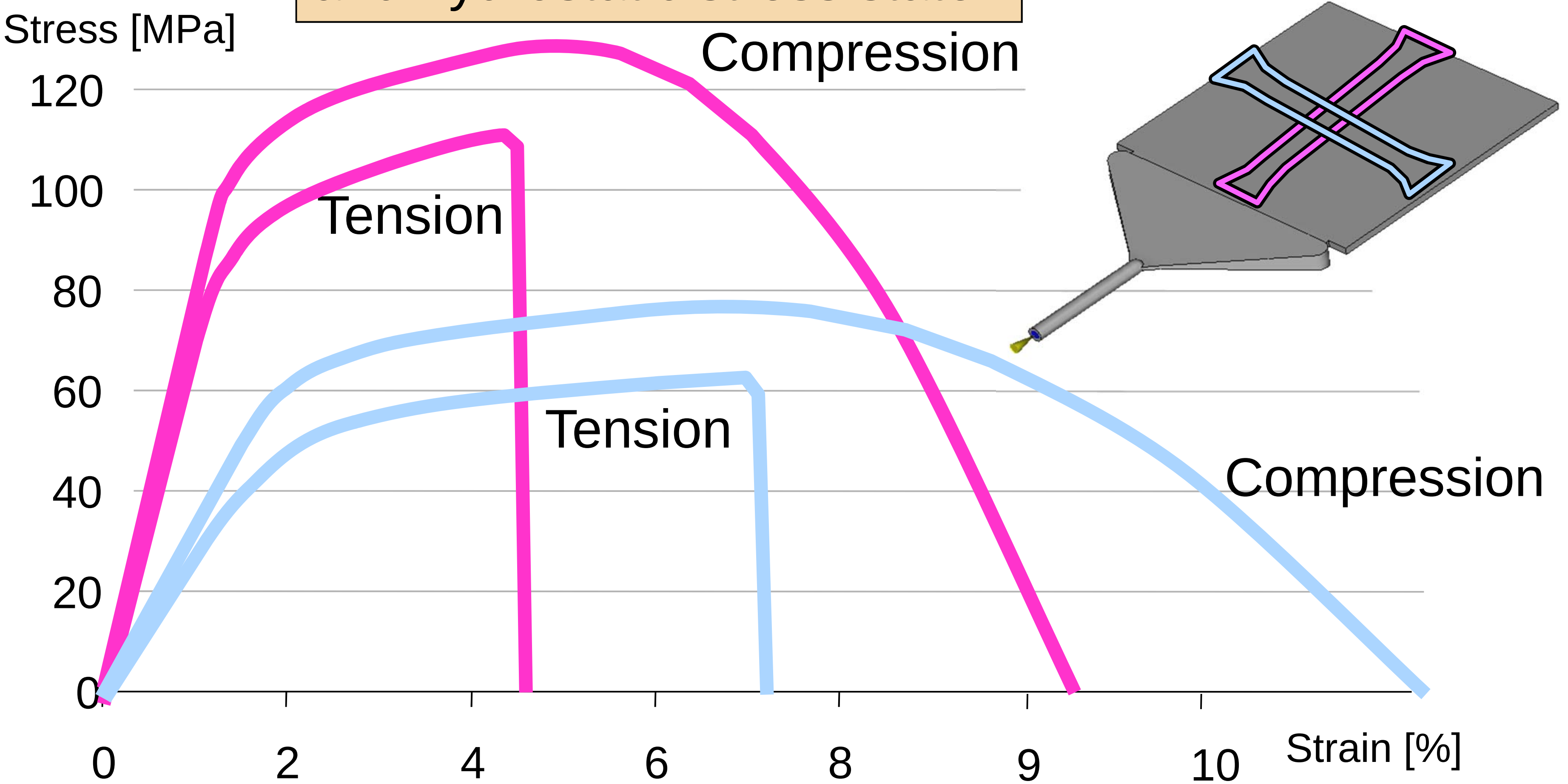
Anisotropy due to fiber orientation



Fiber reinforced Polymer, Stress-Strain

influence: fiber orientation
and hydrostatic stress state

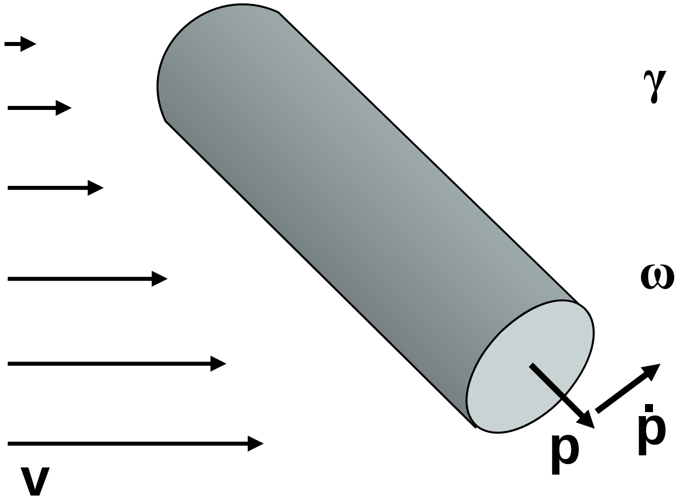
Injection moulded plate



Evolution of fiber orientation

Jefferey 1922

$$\dot{\mathbf{p}} = -\boldsymbol{\omega}\cdot\mathbf{p} + \lambda\left(\boldsymbol{\gamma}\cdot\mathbf{p} - (\mathbf{p}\cdot\boldsymbol{\gamma}\cdot\mathbf{p})\mathbf{p}\right) - \frac{D_r}{\psi}\frac{\partial\psi}{\partial\mathbf{p}} \qquad ; \quad \lambda = \frac{(l/\mathrm{d})^2-1}{(l/\mathrm{d})^2+1}$$



$$\boldsymbol{\gamma} = sym\left[\frac{\partial\mathbf{v}}{\partial\mathbf{x}}\right]$$ Rate of deformation

$$\boldsymbol{\omega} = skew\left[\frac{\partial\mathbf{v}}{\partial\mathbf{x}}\right]$$ Vorticity

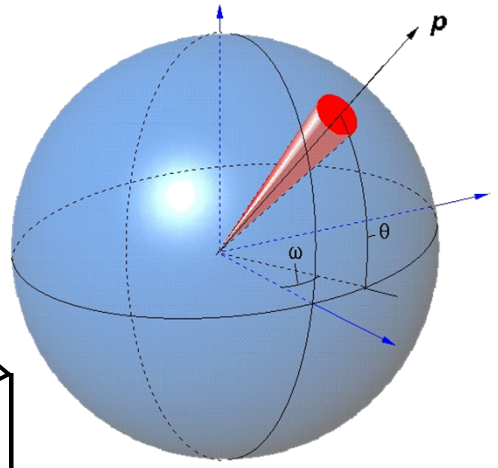
Orientation distribution function

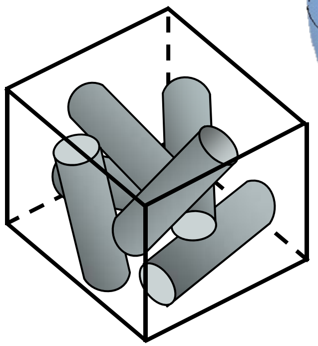
Orientation tensors

$$\mathbf{a} = \int_{\omega} \mathbf{p} \otimes \mathbf{p}\, \psi(\mathbf{p})\, d\omega$$

$$\mathbf{a}^4 = \int_{\omega} \mathbf{p} \otimes \mathbf{p} \otimes \mathbf{p} \otimes \mathbf{p}\, \psi(\mathrm{p})\, d\omega$$

(Tucker 1987)

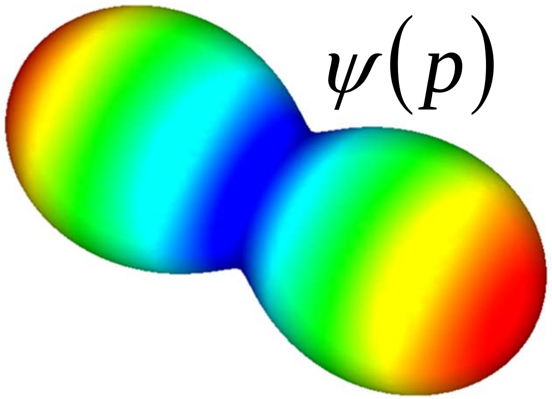




Taylor expansion of ODF

$$\psi(\mathbf{p}) = \frac{1}{4\pi} + \frac{15}{8\pi} + dev(\mathbf{a}) : dev(\mathbf{p} \otimes \mathbf{p})$$

$$+ \frac{315}{32\pi} dev(\mathbf{a}^4) :: dev(\mathbf{p} \otimes \mathbf{p} \otimes \mathbf{p} \otimes \mathbf{p}) + \ldots$$

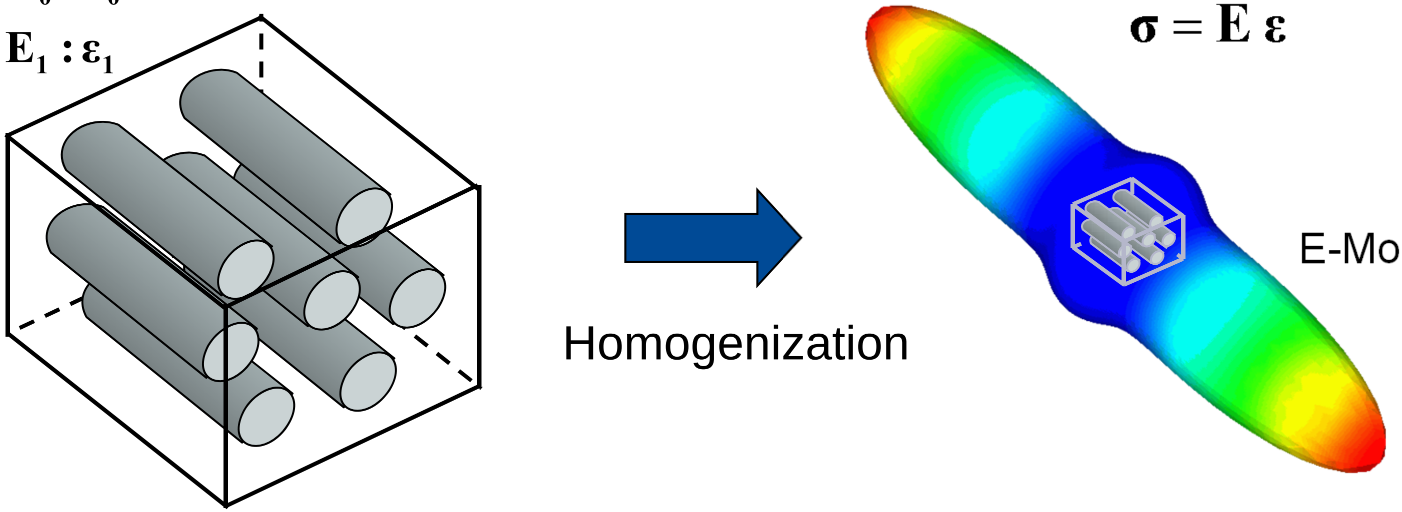


Homogenization of fibers and polymer

Mean Field Theory (Mori and Tanaka,Tandon and Weng)

$$\boldsymbol{\sigma}_0 = \mathbf{E}_0 : \boldsymbol{\varepsilon}_0$$

$$\boldsymbol{\sigma}_1 = \mathbf{E}_1 : \boldsymbol{\varepsilon}_1$$



$$\bar{\boldsymbol{\sigma}} = \bar{\mathbf{E}}\,\bar{\boldsymbol{\varepsilon}}$$

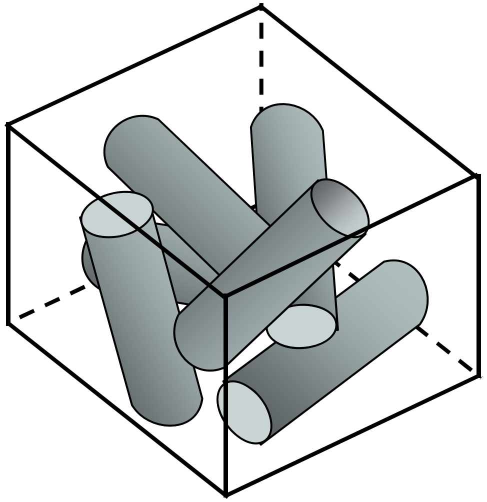
$$\bar{\mathbf{E}} = \left[c_1\mathbf{E}_1 : \mathbf{B}^{\varepsilon} + (1-c_1)\mathbf{E}_0\right] : \left[c_1\mathbf{B}^{\varepsilon} + (1-c_1)\mathbf{I}\right]^{-1}$$

$$\mathbf{B}^{\varepsilon} = \left(\mathbf{I} + \mathcal{E}_{(\mathbf{I},\omega)} : \left[\mathbf{E}_0^{-1} : \mathbf{E}_1 - \mathbf{I}\right]\right)^{-1}$$

$\mathcal{E}_{(\mathbf{I},\omega)}$ **: Eshelby Tensor**

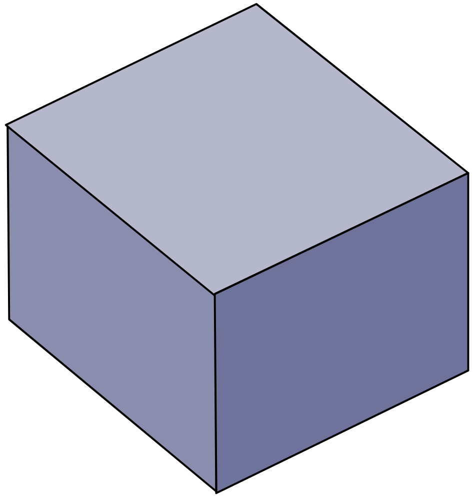
Material modelling for composite materials

Micro Scale

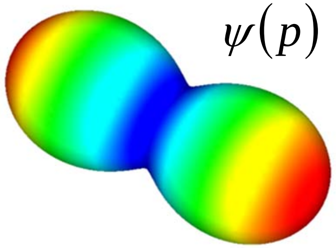


Homogenization:

Macro Scale

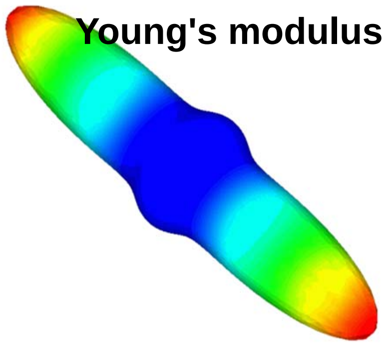


Orientation distribution function



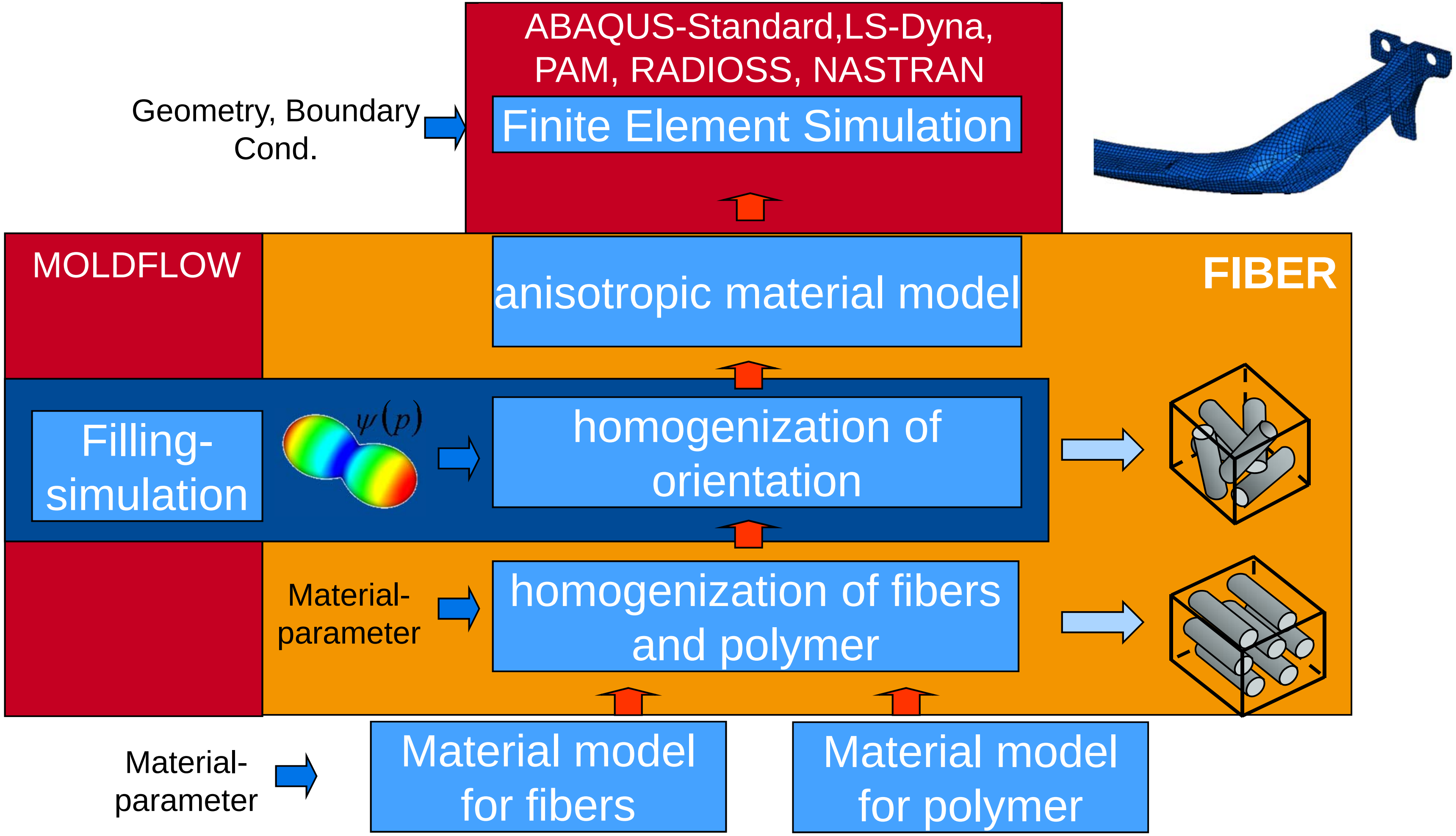
$\psi(p)$

Young's modulus



Integrative Simulation ULTRASIM™

Data flow structure



Geometry, Boundary Cond.

ABAQUS-Standard,LS-Dyna, PAM, RADIOSS, NASTRAN

Finite Element Simulation

MOLDFLOW

FIBER

anisotropic material model

Filling-simulation

homogenization of orientation

Material-parameter

homogenization of fibers and polymer

Material-parameter

Material model for fibers

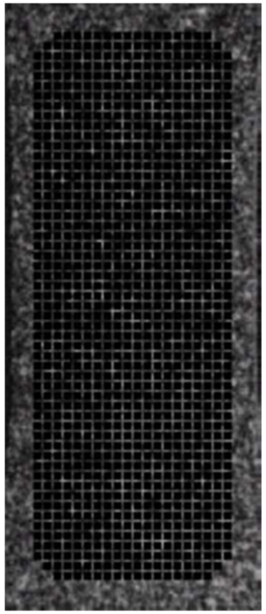
Material model for polymer

- elastic
- brittle

- elastic
- Elastic-plastic
- viscoplastic

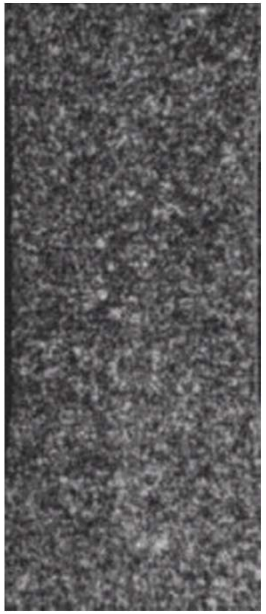
Material Measurements

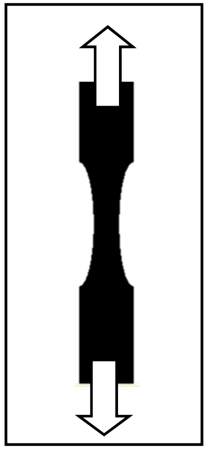
Data Flow



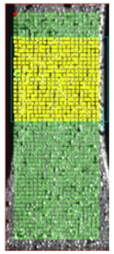
GOM - ARAMIS

Deformation Gradient $\mathbf{F} = \dfrac{\partial \mathbf{x}}{\partial \mathbf{X}}$





$Force(t)$

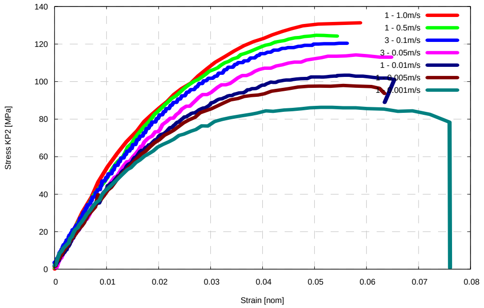


BASF Software

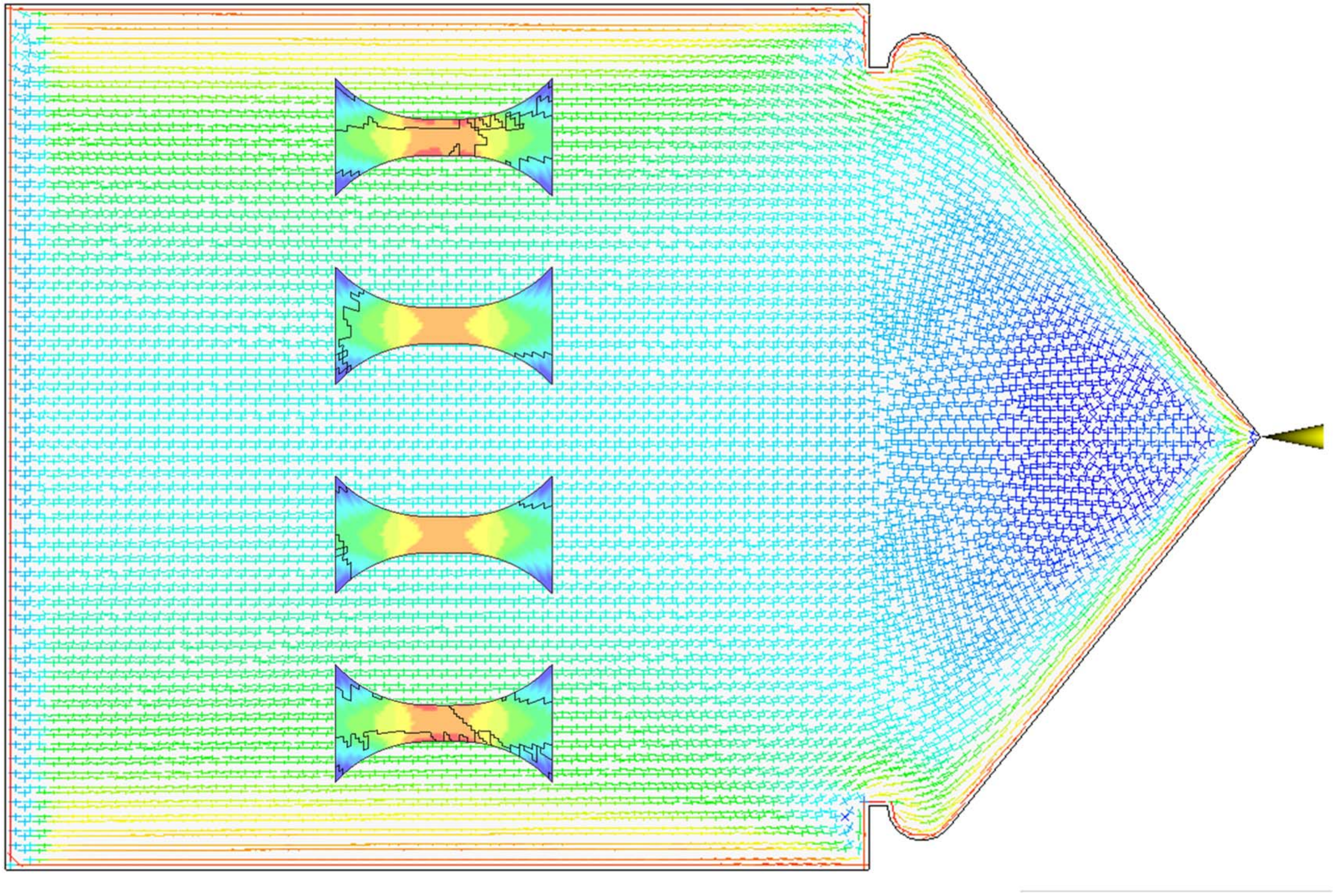
$\mathbf{F} = \dfrac{\partial \mathbf{x}}{\partial \mathbf{X}} \longrightarrow$ Strain: $\mathbf{E} = \frac{1}{2}(\mathbf{F}^T\mathbf{F} - \mathbf{G})$

$\mathbf{e} = \frac{1}{2}(\mathbf{g} - \mathbf{F}^{-T}\mathbf{F}^{-1})$

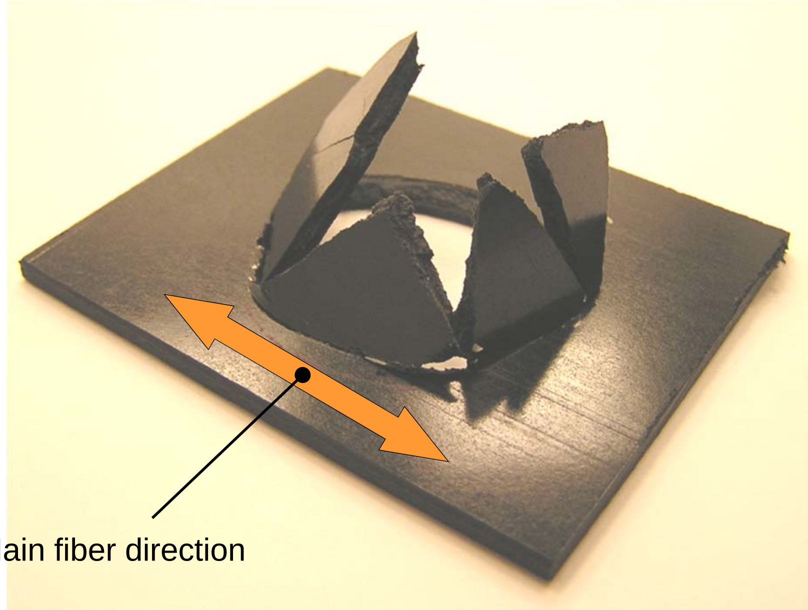
$S^{11} = \dfrac{Force(t)}{A_0}$ Stress: $\boldsymbol{\sigma} = \dfrac{1}{J}\mathbf{F}\mathbf{S}\mathbf{F}^T$



Average Fiber orientation and Failure variable



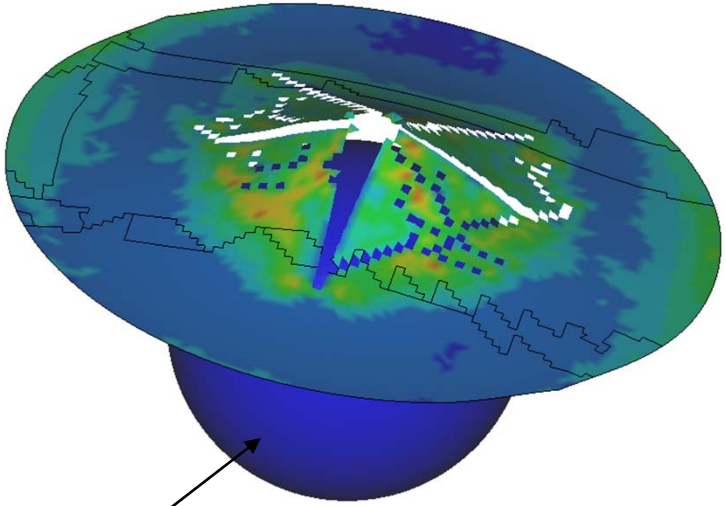
Penetration Experiment



Main fiber direction

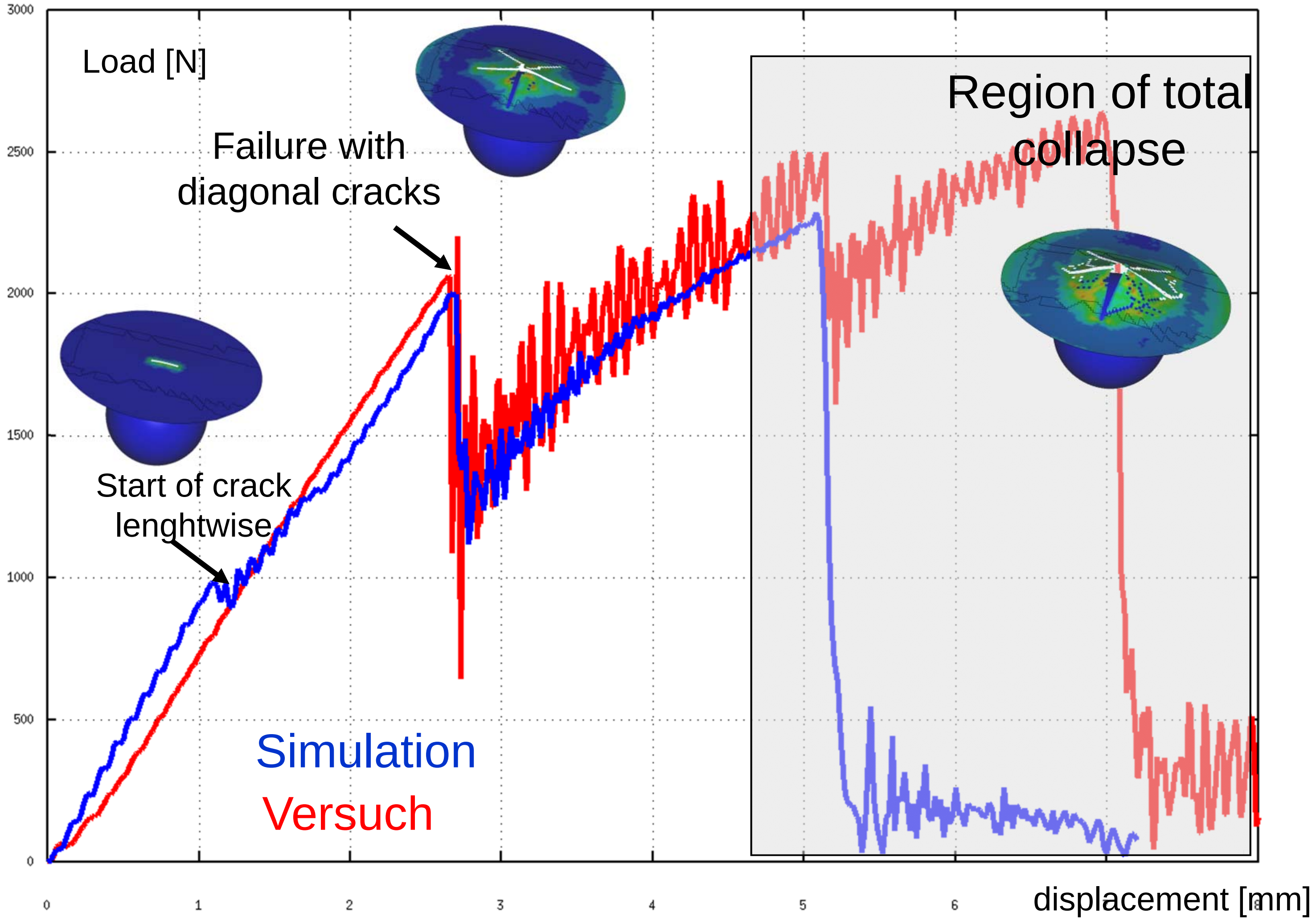
Biaxial Stress

Fixed by axisymmetric die



punch

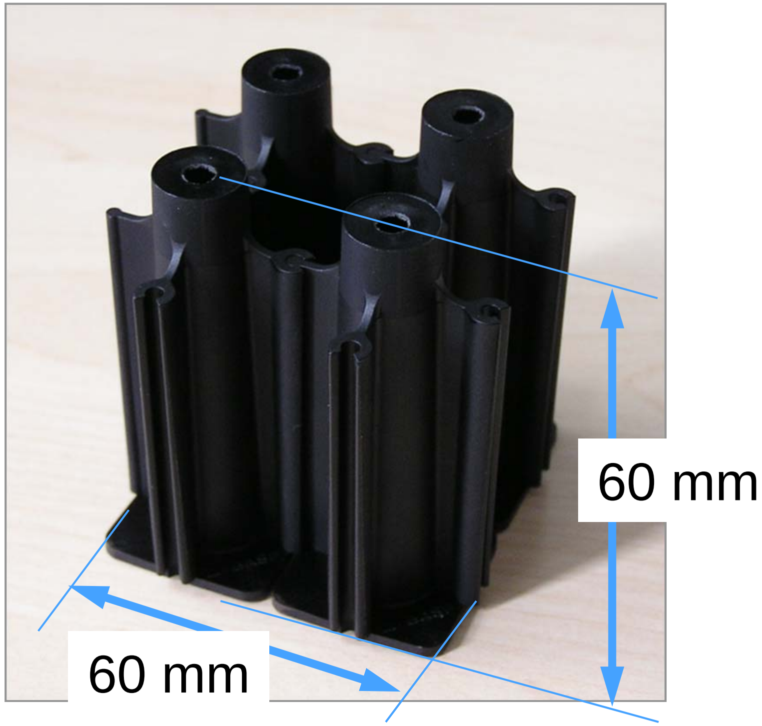
Simulation of penetration experiment

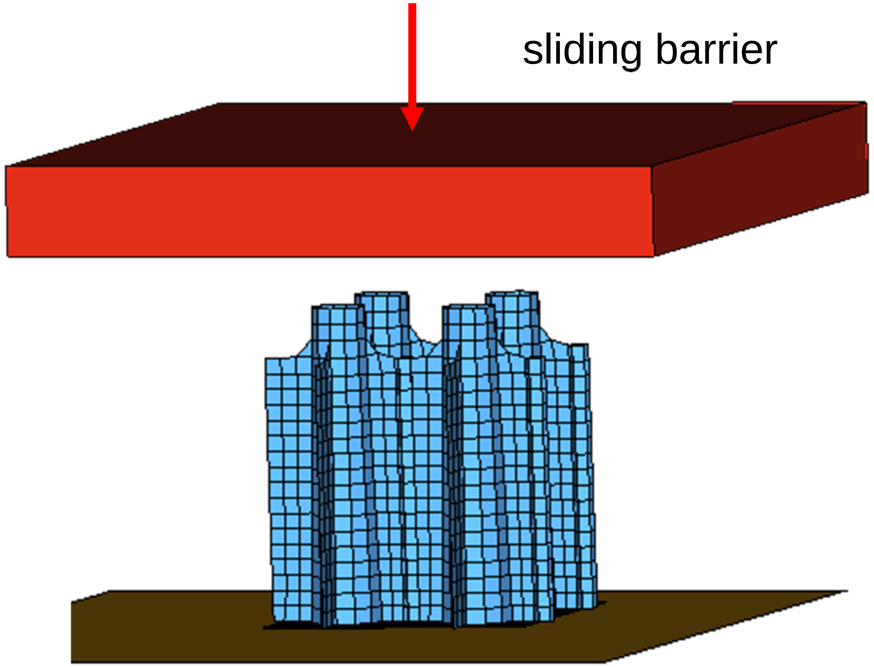


Test Specimen for compression load

Specimen is designed for controlled collapse

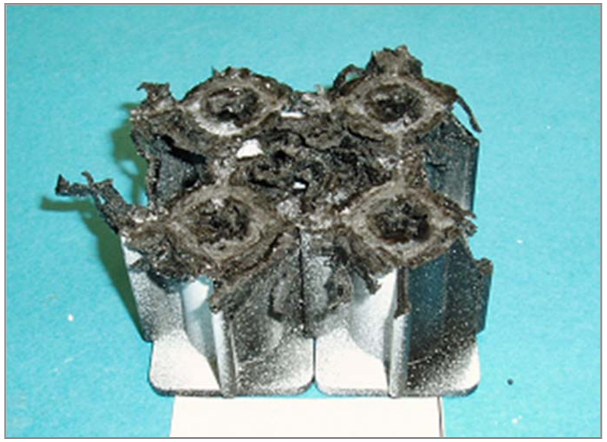
Material: B3WG6 CR (PA6 GF30%)



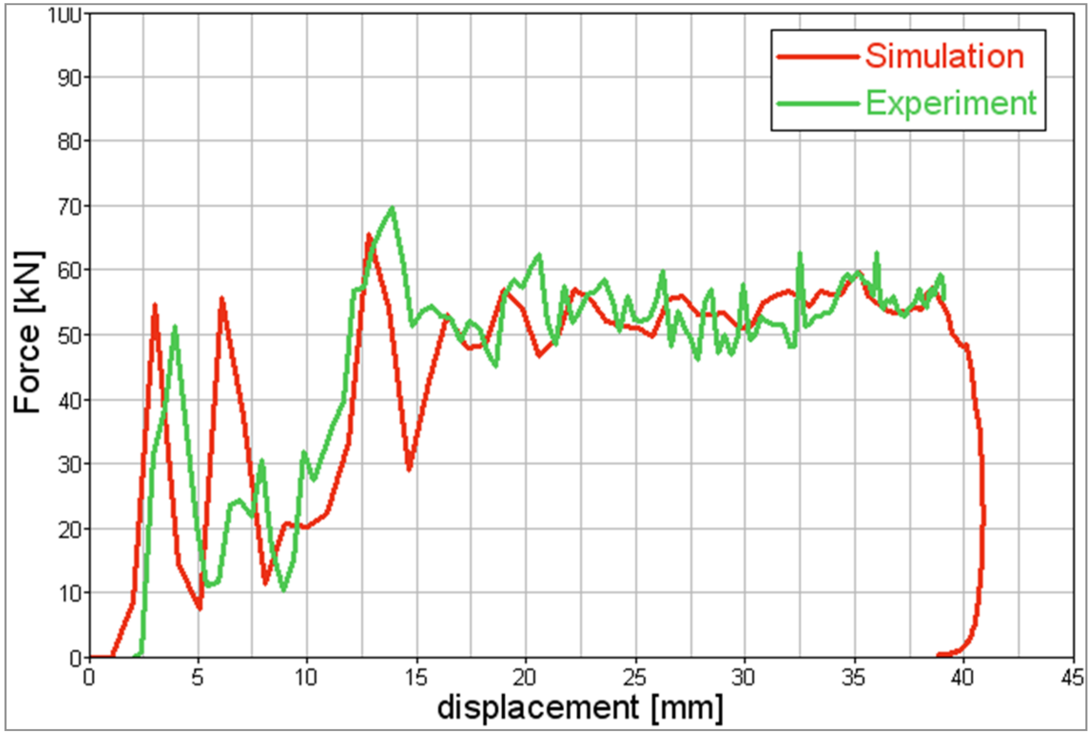


Test-specimen under compression load

Simulation and Experiment



60 mm

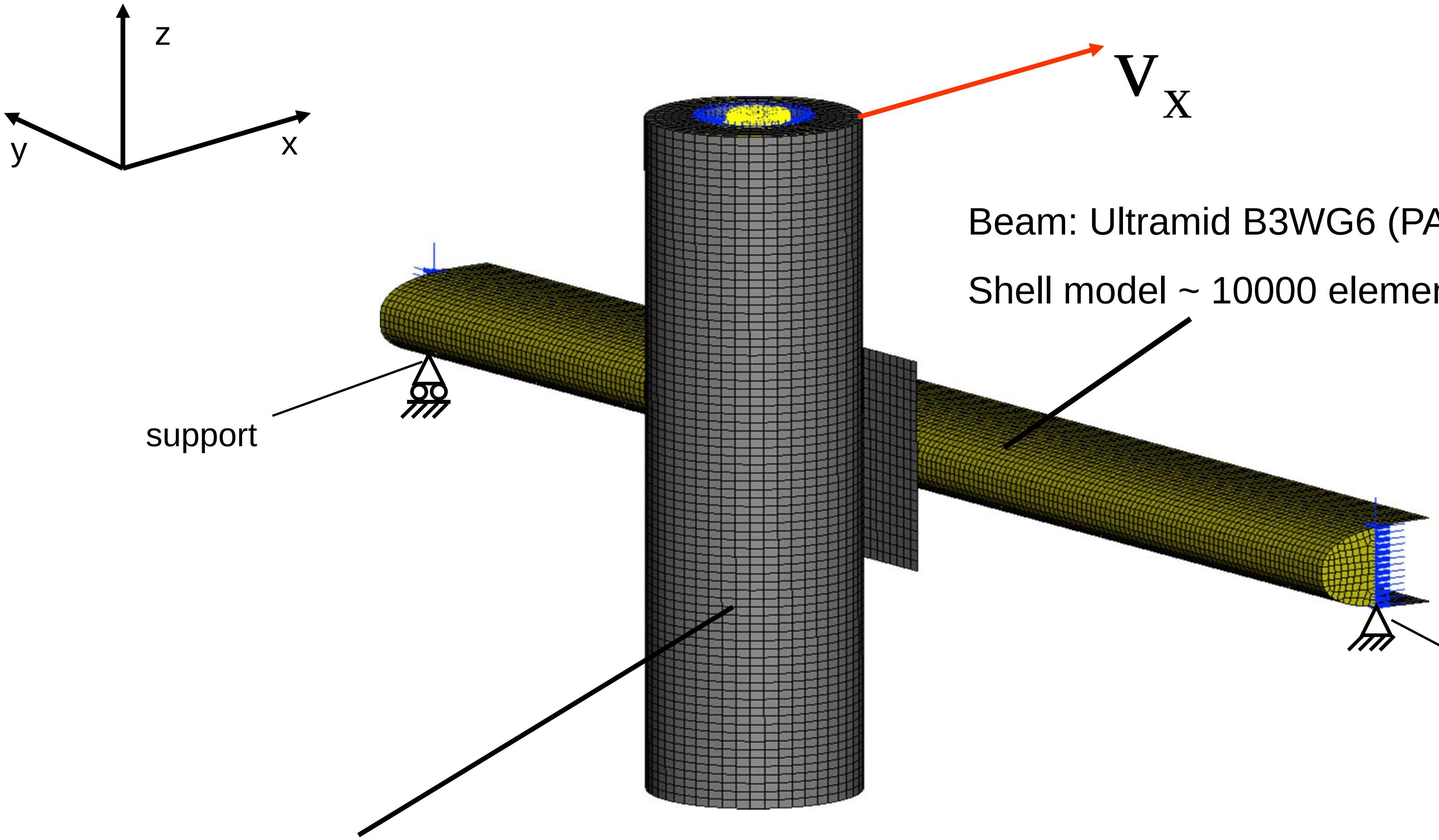


Illustrated Example

Importance of Fiber Orientation

Mechanical test set-up

Lower leg shot on supported beam



Beam: Ultramid B3WG6 (PA6-GF30)

Shell model ~ 10000 elements

Impactor

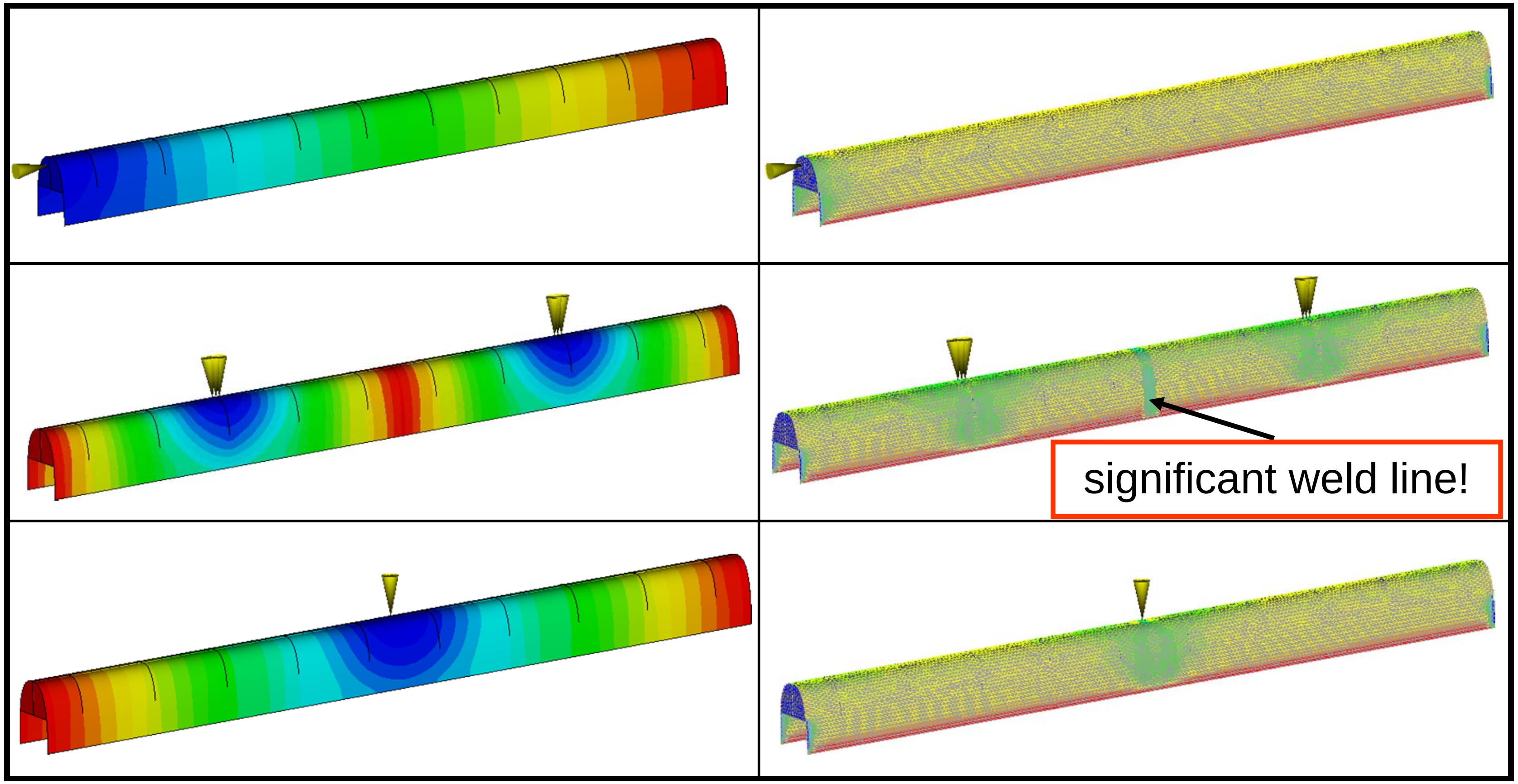
$m = 4.7\text{kg}$

Illustrated Example

Importance of Fiber Orientation

Filling pattern and fiber orientation
Filling calculation with MOLDFLOW

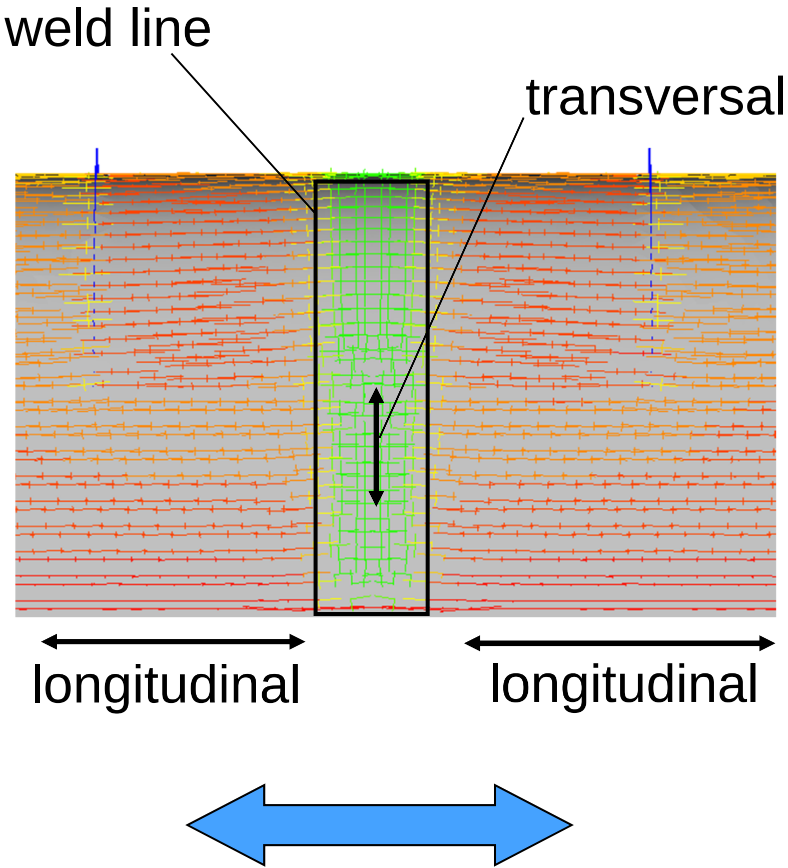
Filling pattern | Fiber orientation



significant weld line!

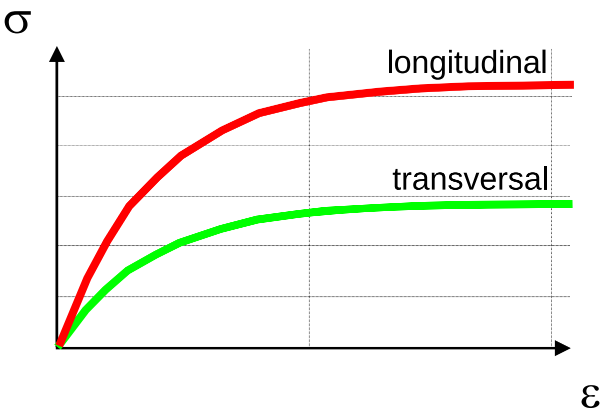
Detail of fiber orientation in weld line

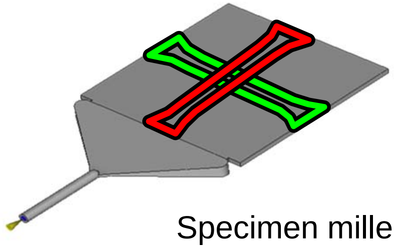
Case B



Main stress direction in bending

σ-ε diagram



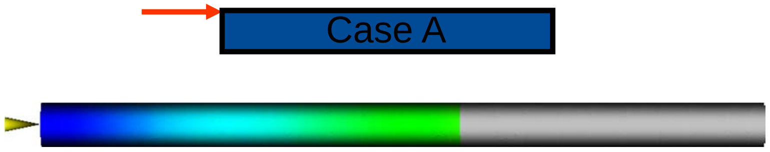


Specimen milled out of
injection molded plate

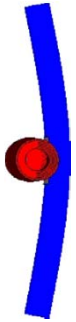
Illustrated Example

Importance of Fiber Orientation

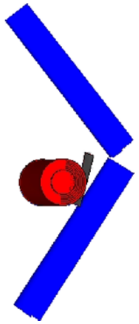
Results with v=11.2 m/s

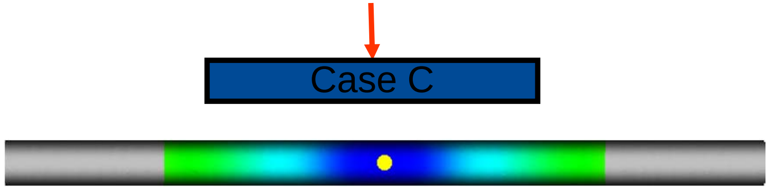


Case A: Part without failure!

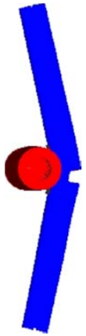


Case B: Failure!





Case C: Failure!



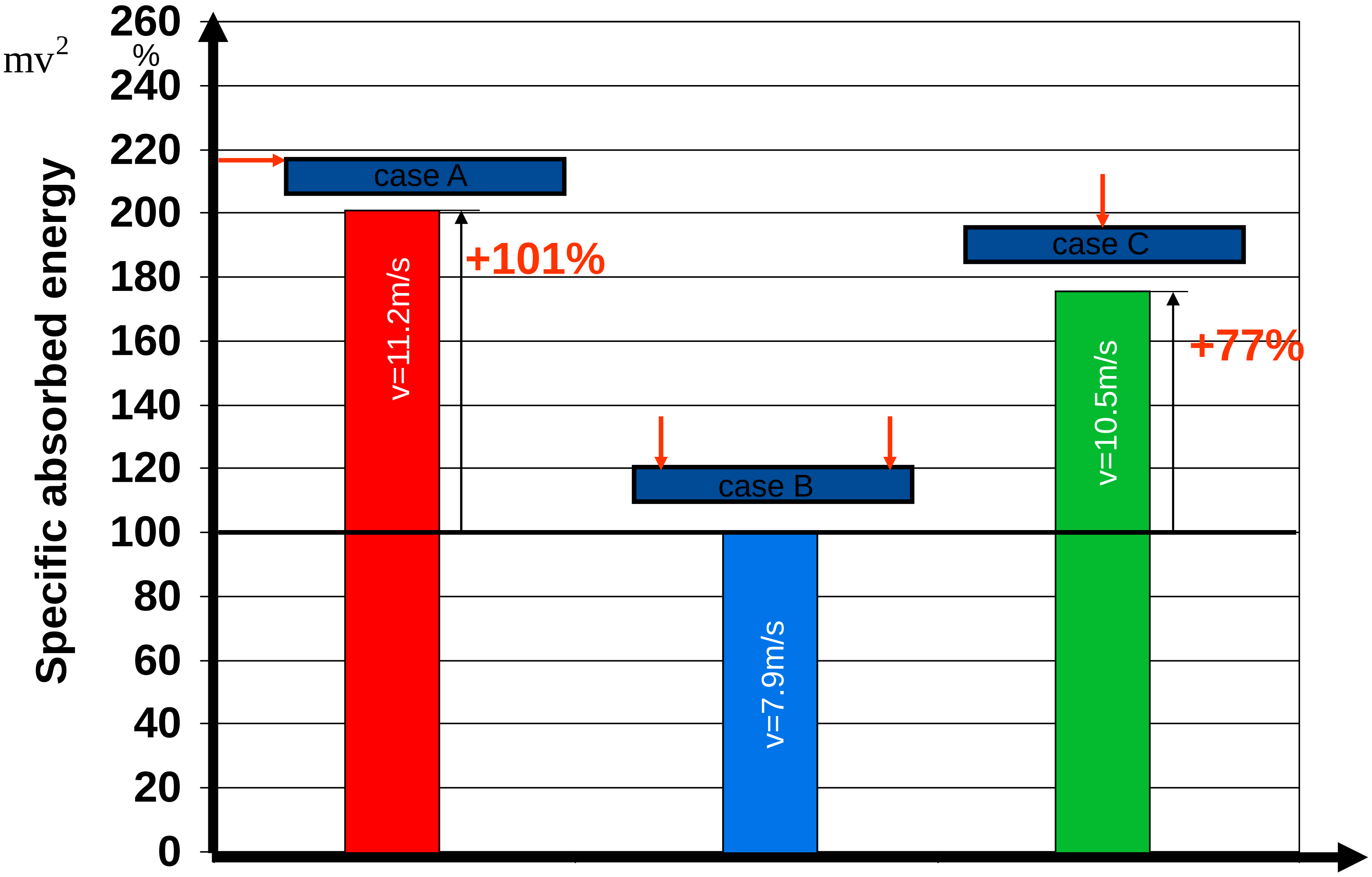
Illustrated Example

Importance of Fiber Orientation

Comparison of absorbed energy

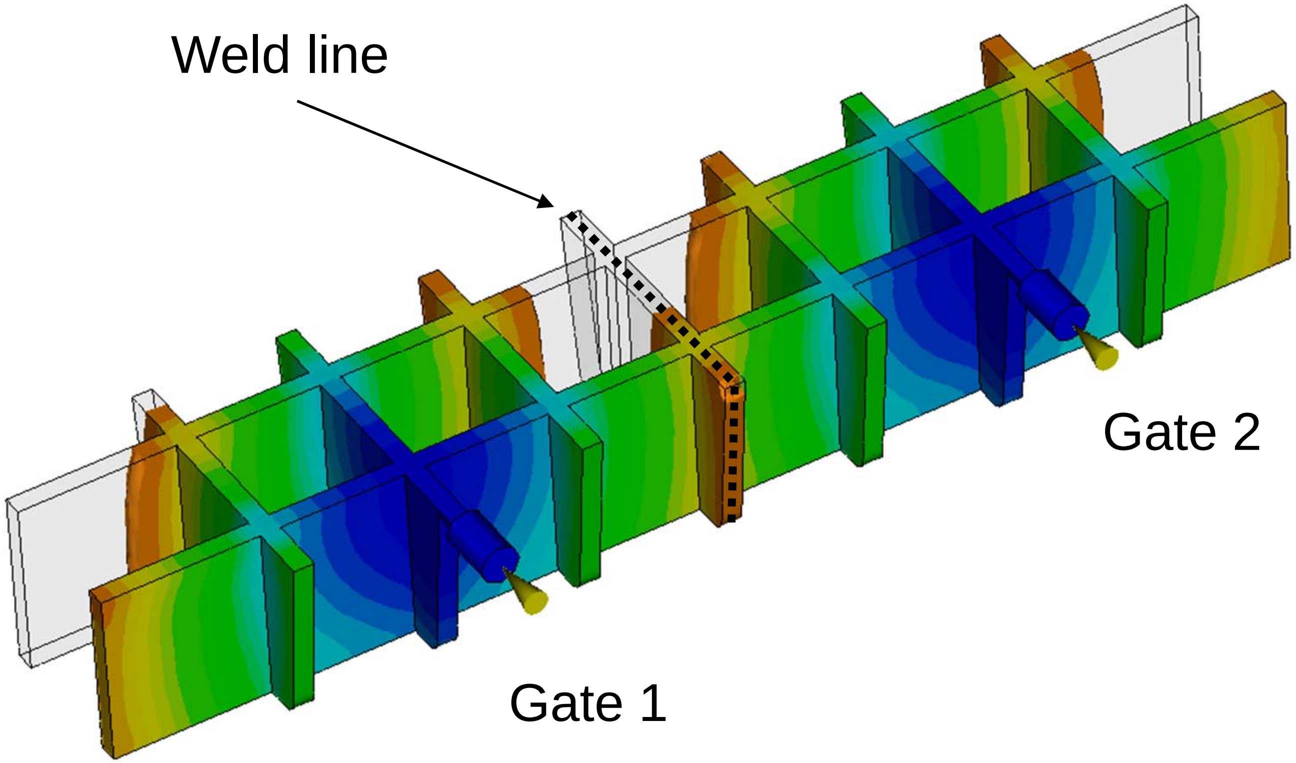
BASF
The Chemical Company

$$E = \frac{1}{2} m v^2$$



Filling pattern and weld line

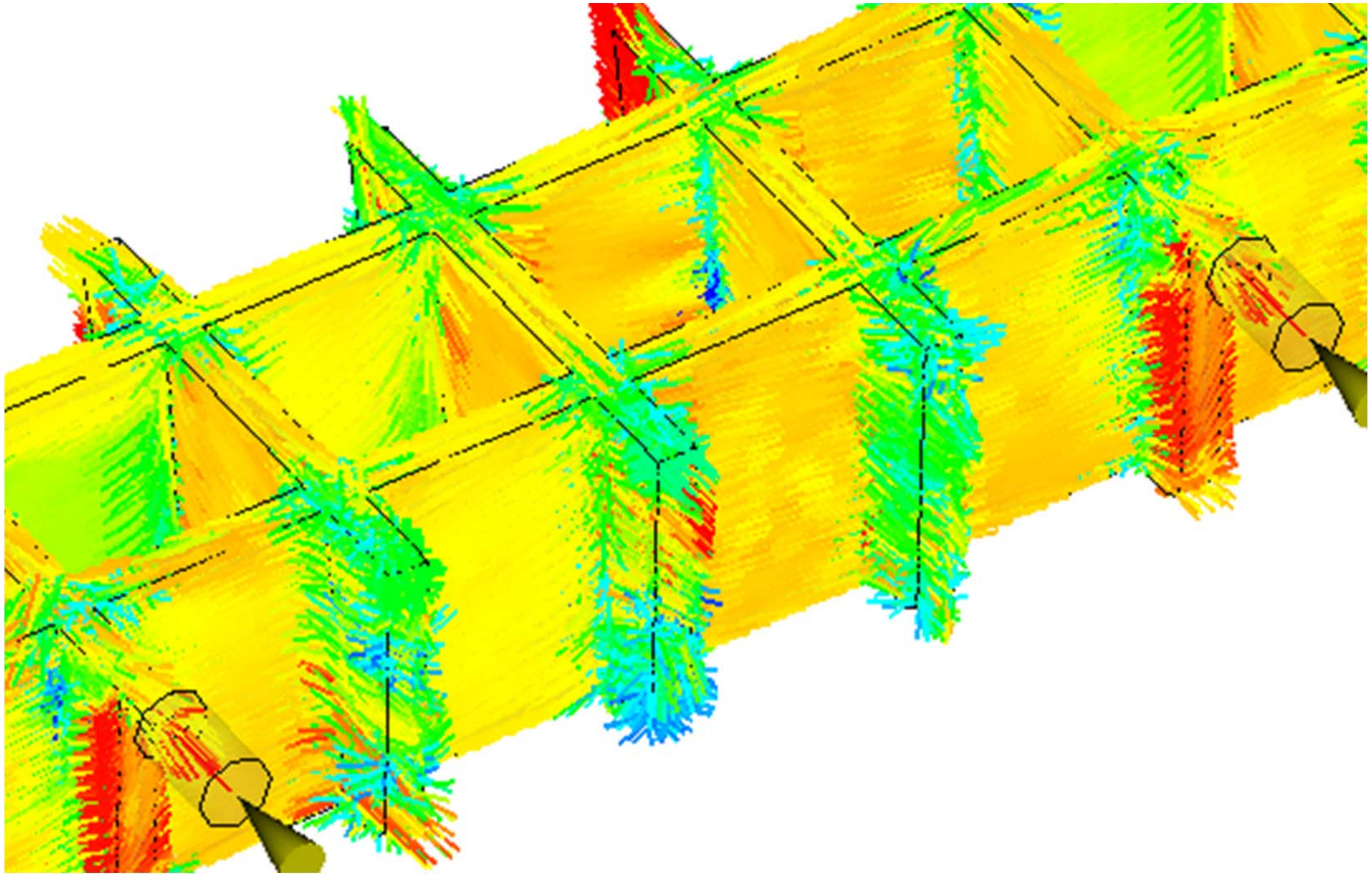
BASF
The Chemical Company


Weld line

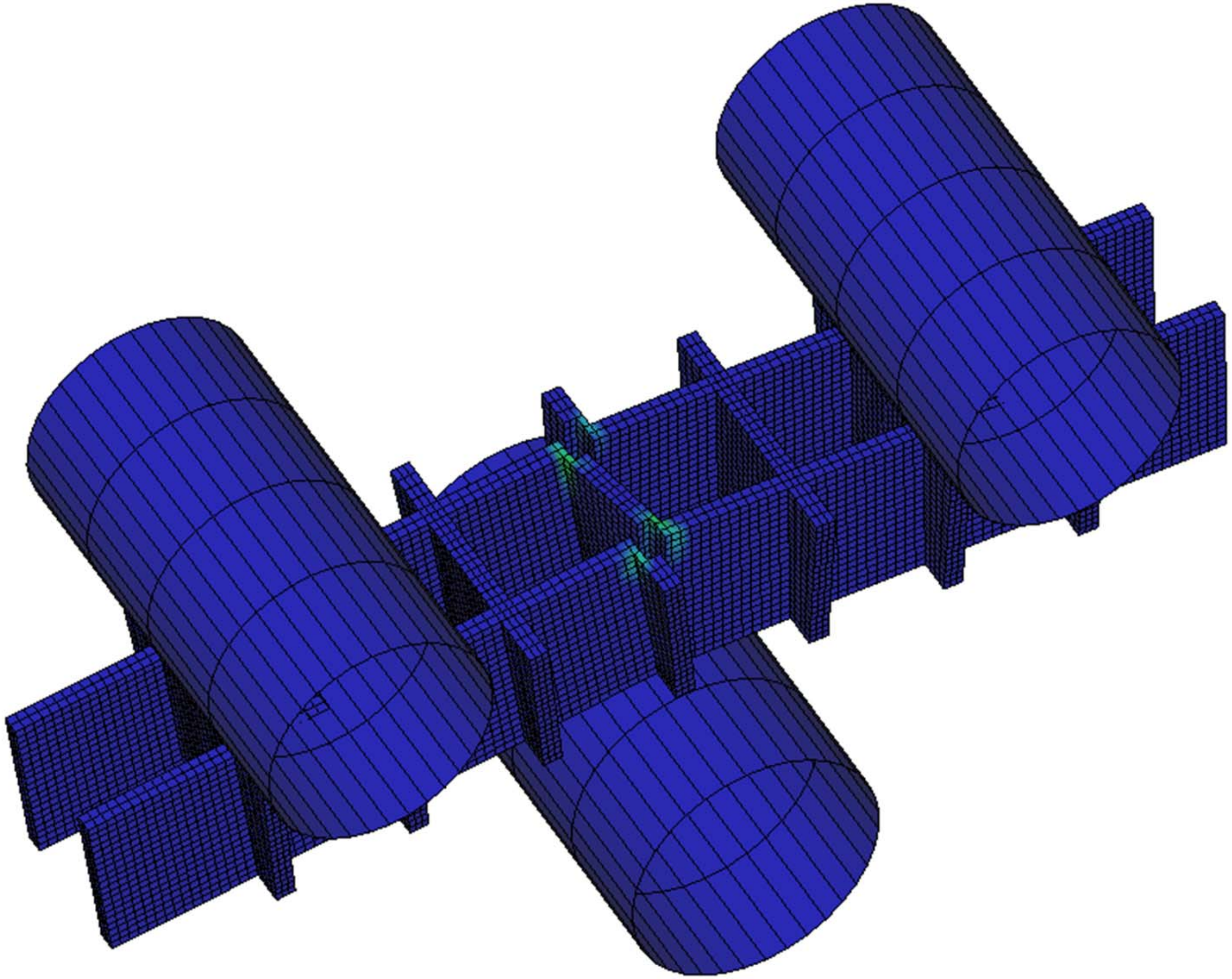
Gate 2

Gate 1

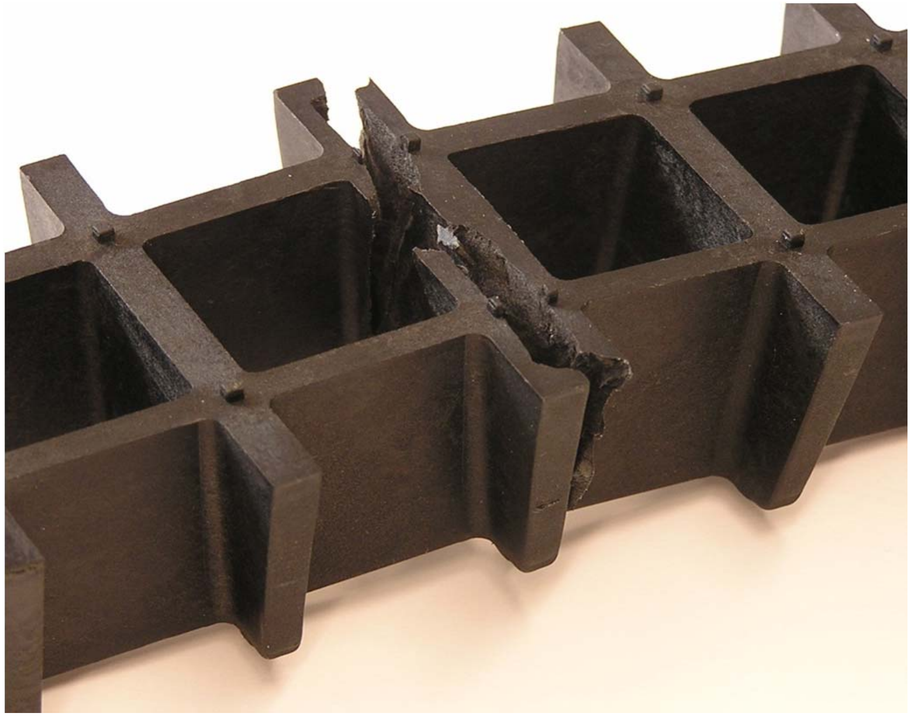
Fiber orientation

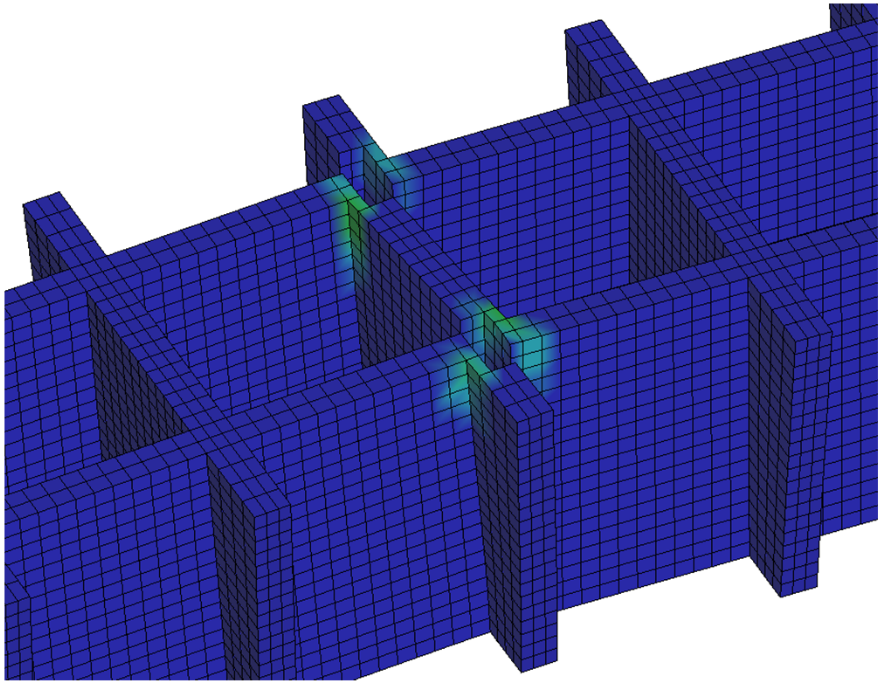


Symmetric bending

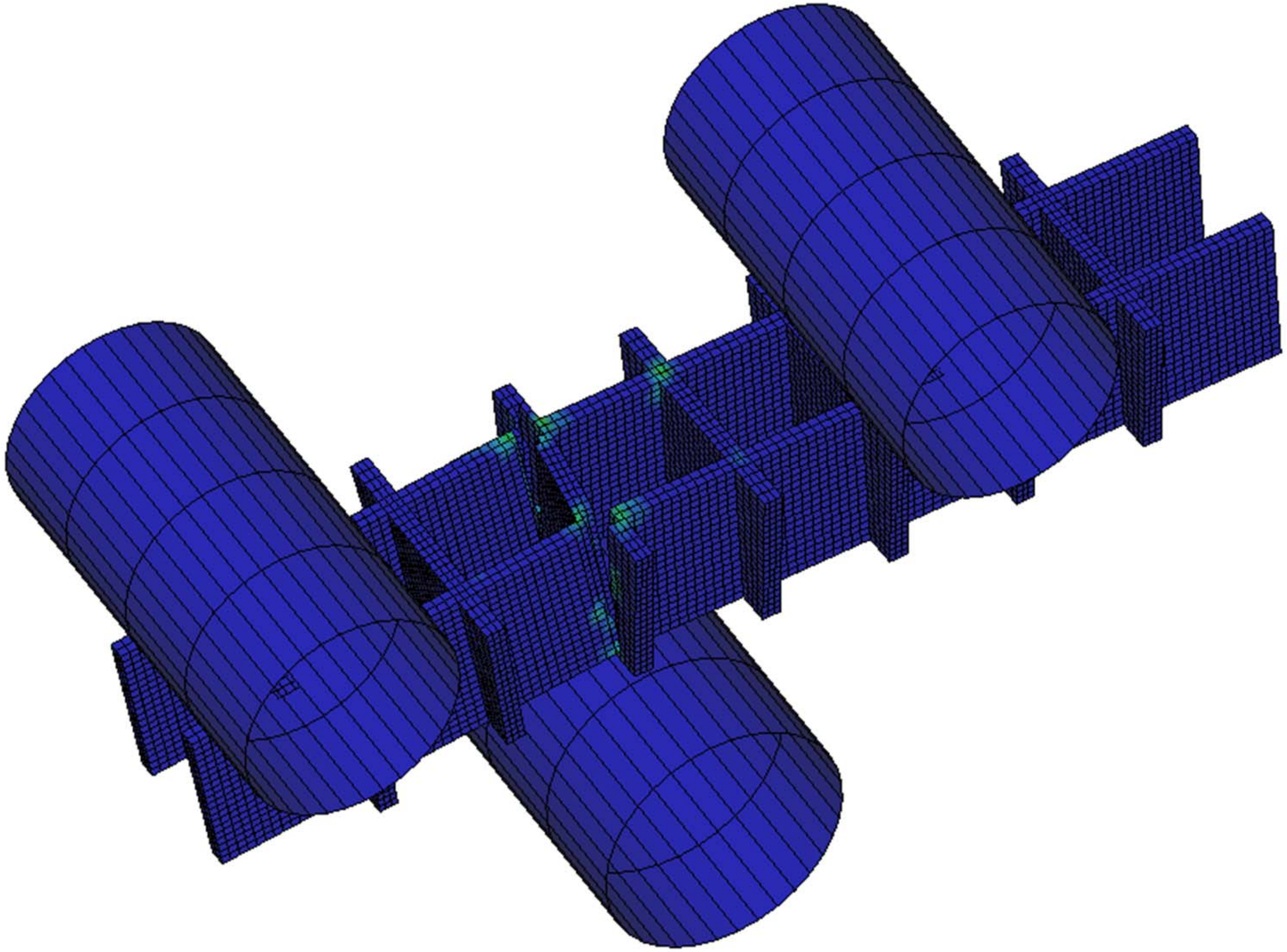


Failure in weld line - symmetric bending

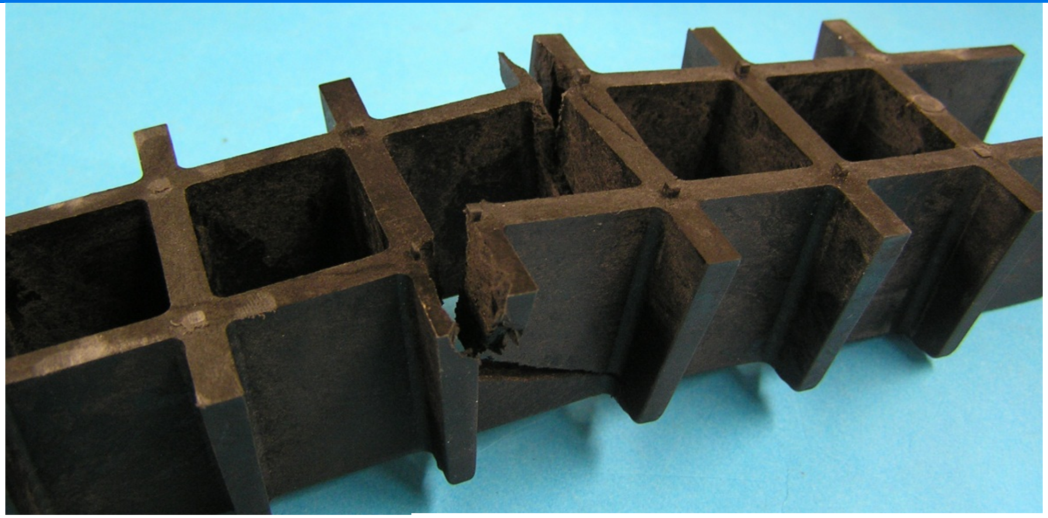


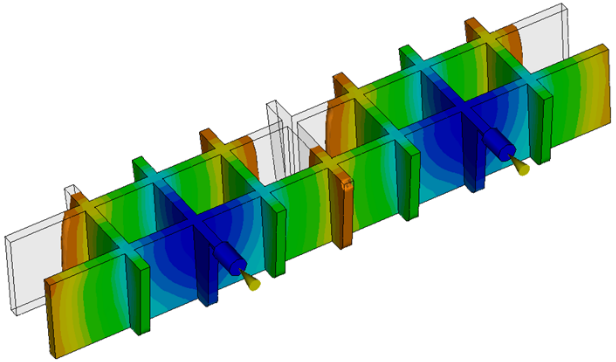


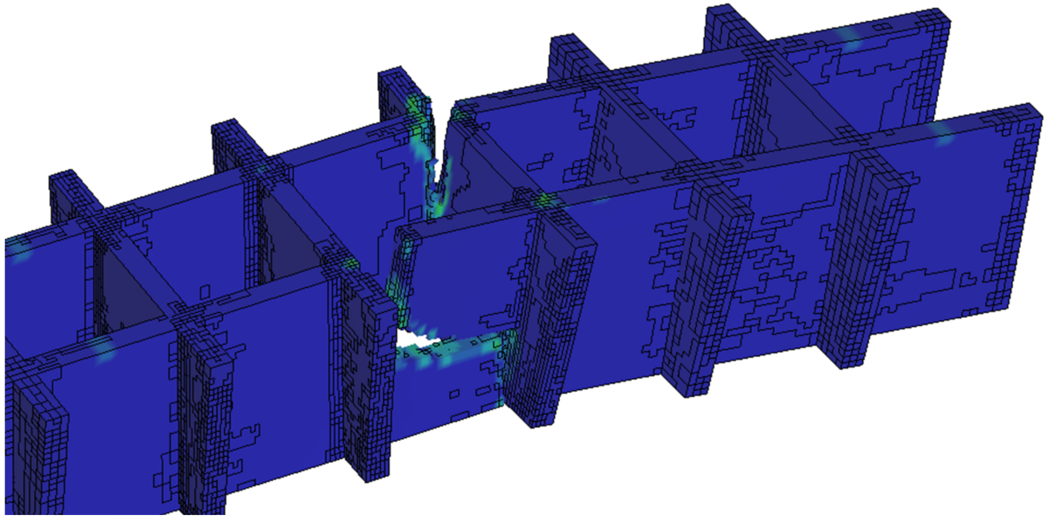
Bending with offset



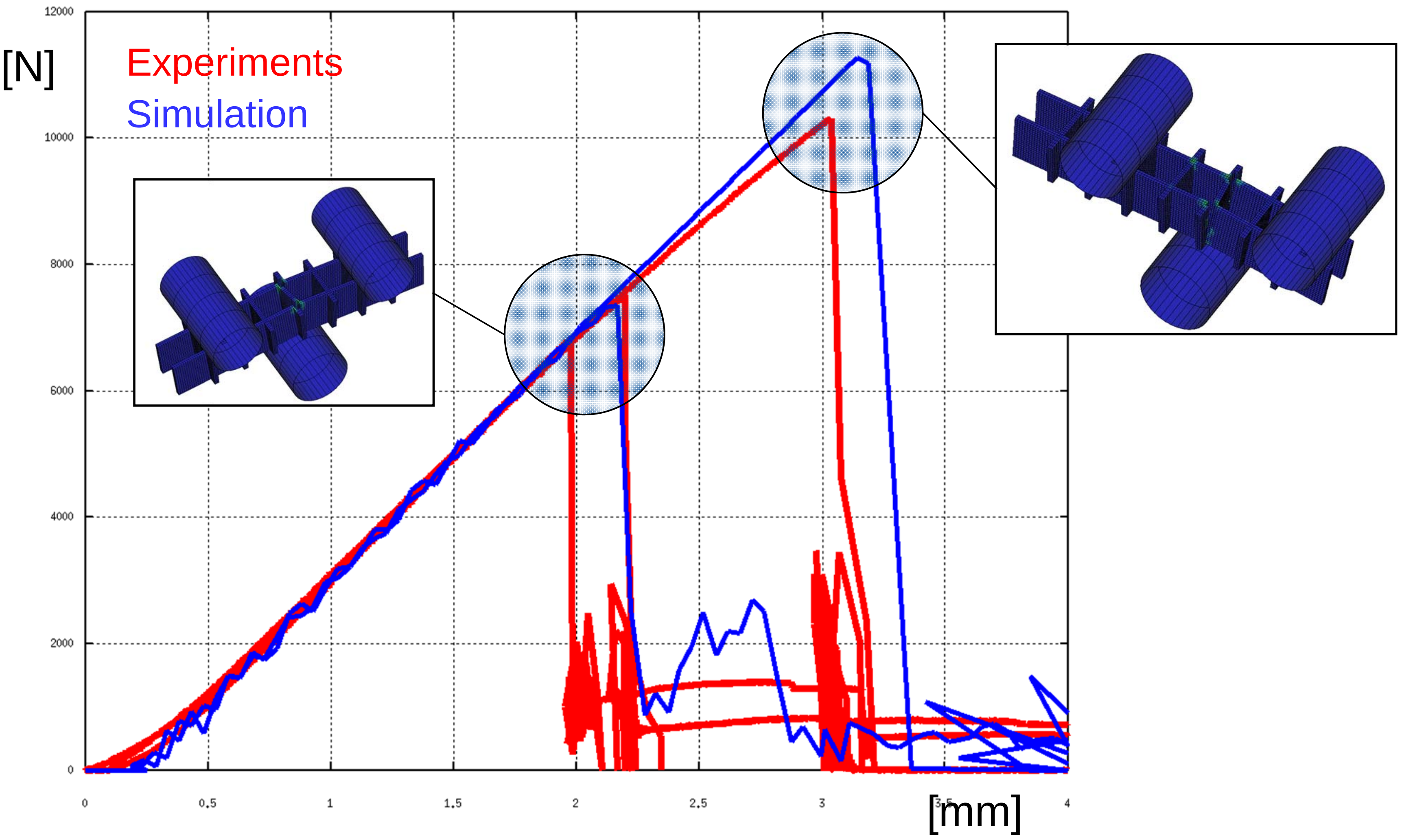
Complex Material behaviour







Force versus Displacement - Curve



Zusammenfassung

- Simulation von Falltests stellt neue Herausforderungen
  - Kinematik → Kontakt
  - Abbildung von Verbindungen → Beispiel Schraube
  - Materialverhalten → ULTRASIM
  - Versagen → ULTRASIM
- Materialmodellierung mit BASF ULTRASIM™
- Bindenahteinfluss bei faserverstärkten Kunststoffen
- Beispiele

Vielen Dank für Ihre Aufmerksamkeit!