Integrative crash simulation of composite structures – the importance of process induced material data

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  - **Static loading**
  - **Crash loading**

Short-fiber-reinforced plastic parts under crash loads

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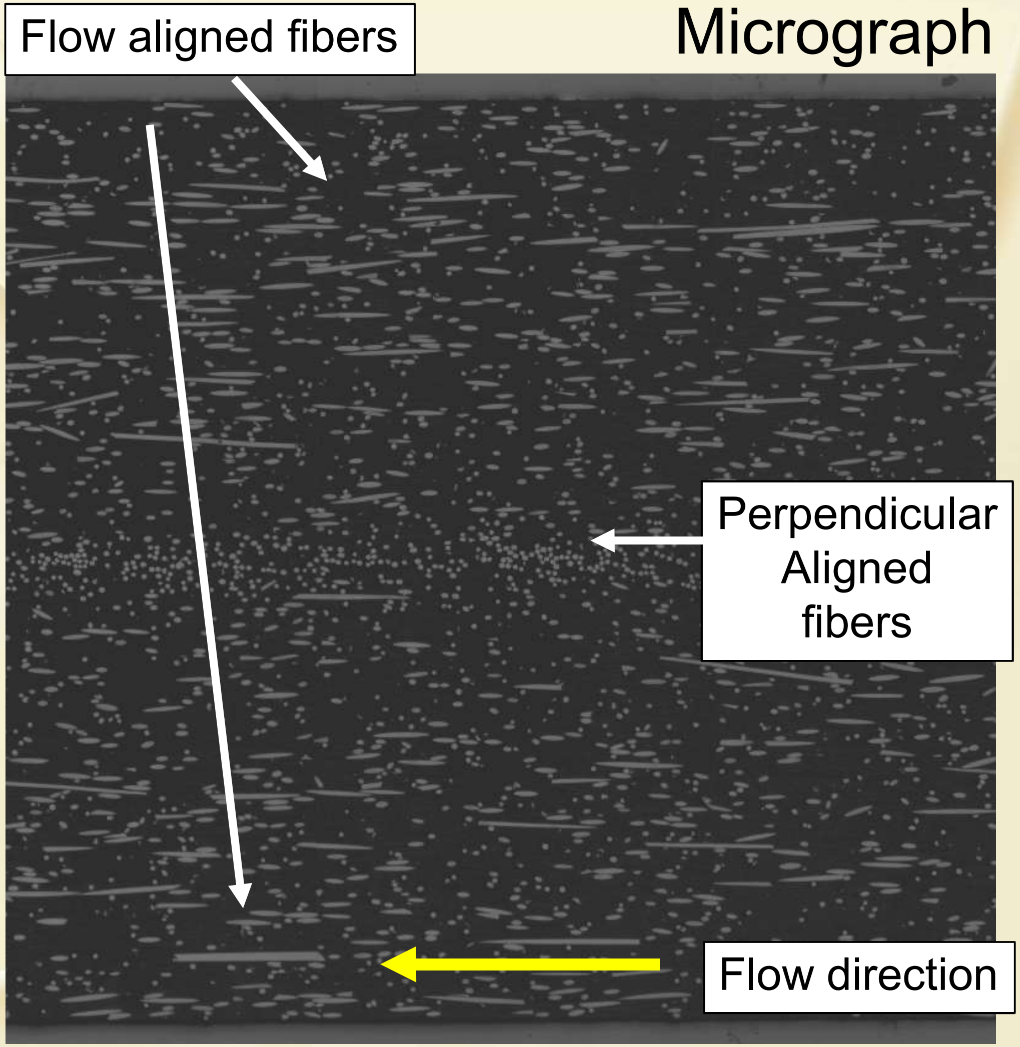
- Nonlinear material behaviour
- High strain and strain rate
- Failure

Conventional approach for designing mould and part is inadequate

Reason: local anisotropy is not taken into account

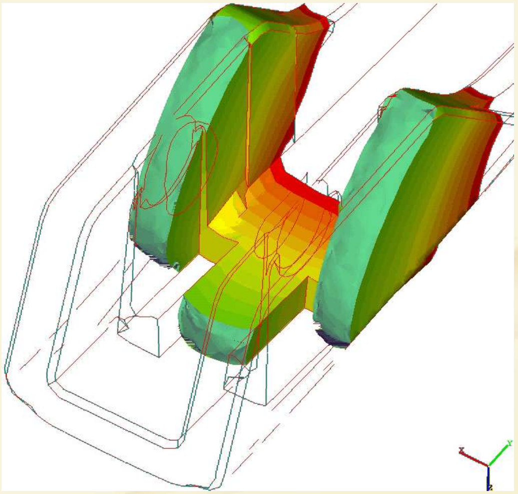
➔**Integrative Simulation**

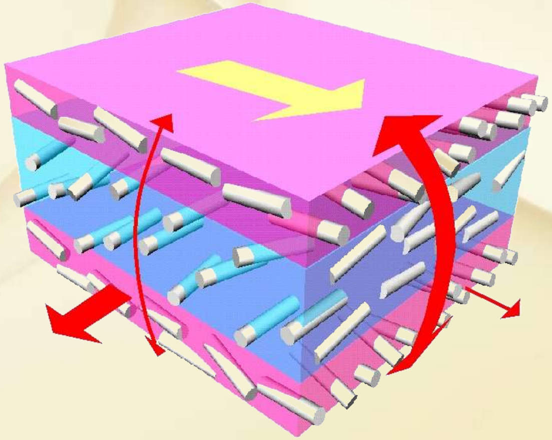
Micrograph

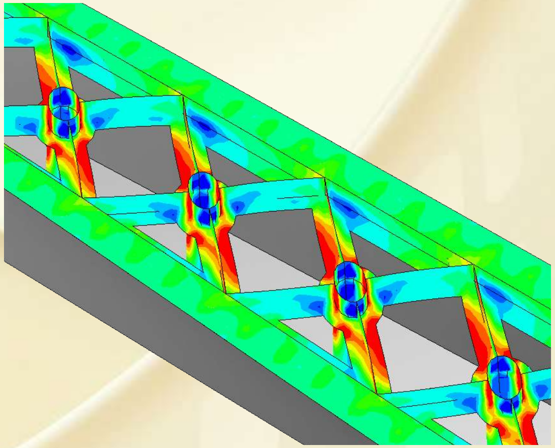


Integrative Simulation for fiber reinforced thermoplastic materials

Process → Material → Part

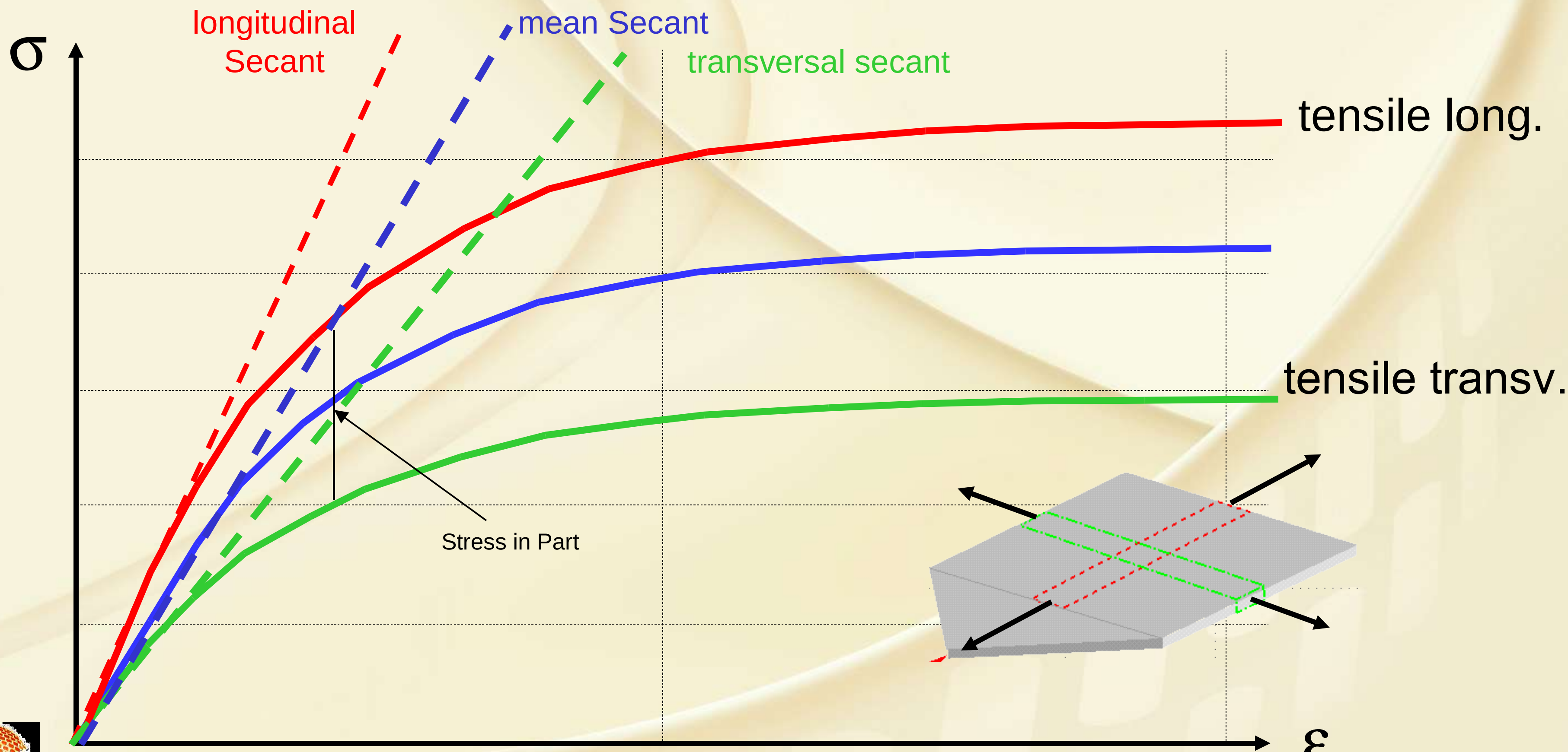






Motivation for Anisotropic Material Modelling

Anisotropy due to fiber orientation



Parts development:
Short-fiber-reinforced thermoplastics

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Geometry

Traditional

Proposed design

?

Local
material
parameter

Simulation
of structural behaviour

Integrative Simulation

Proposed design

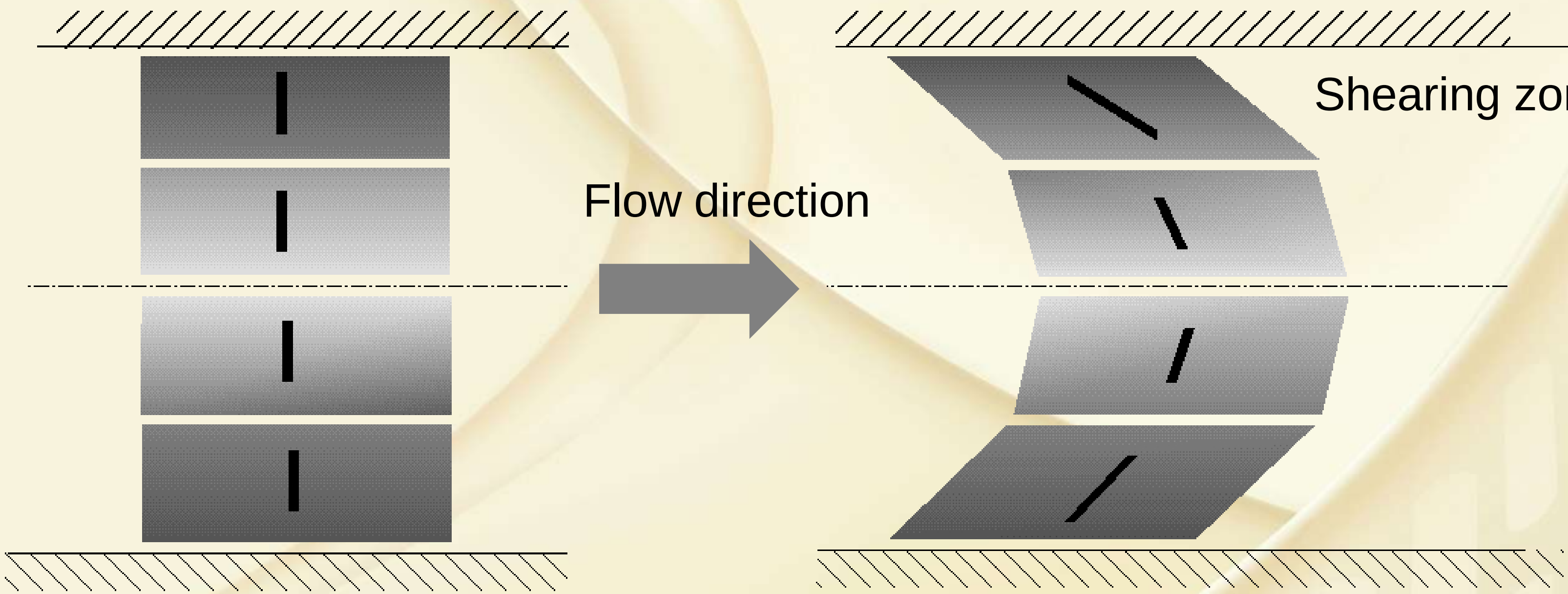
Mould filling
simulation

Local
material parameter

Simulation
of structural behaviour

Evolution of Fiber Orientation in Mould Filling Process

Cross sectional view



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

Evolution of Fiber Orientation in Mould Filling Process

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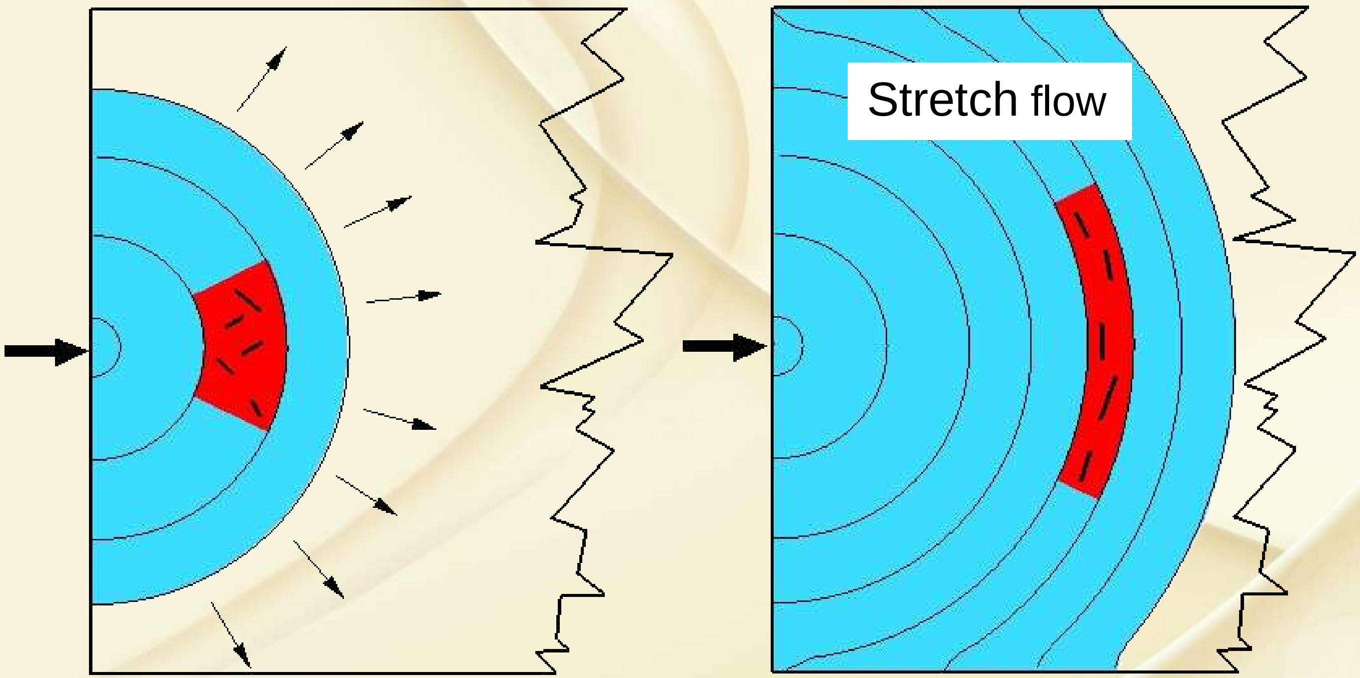
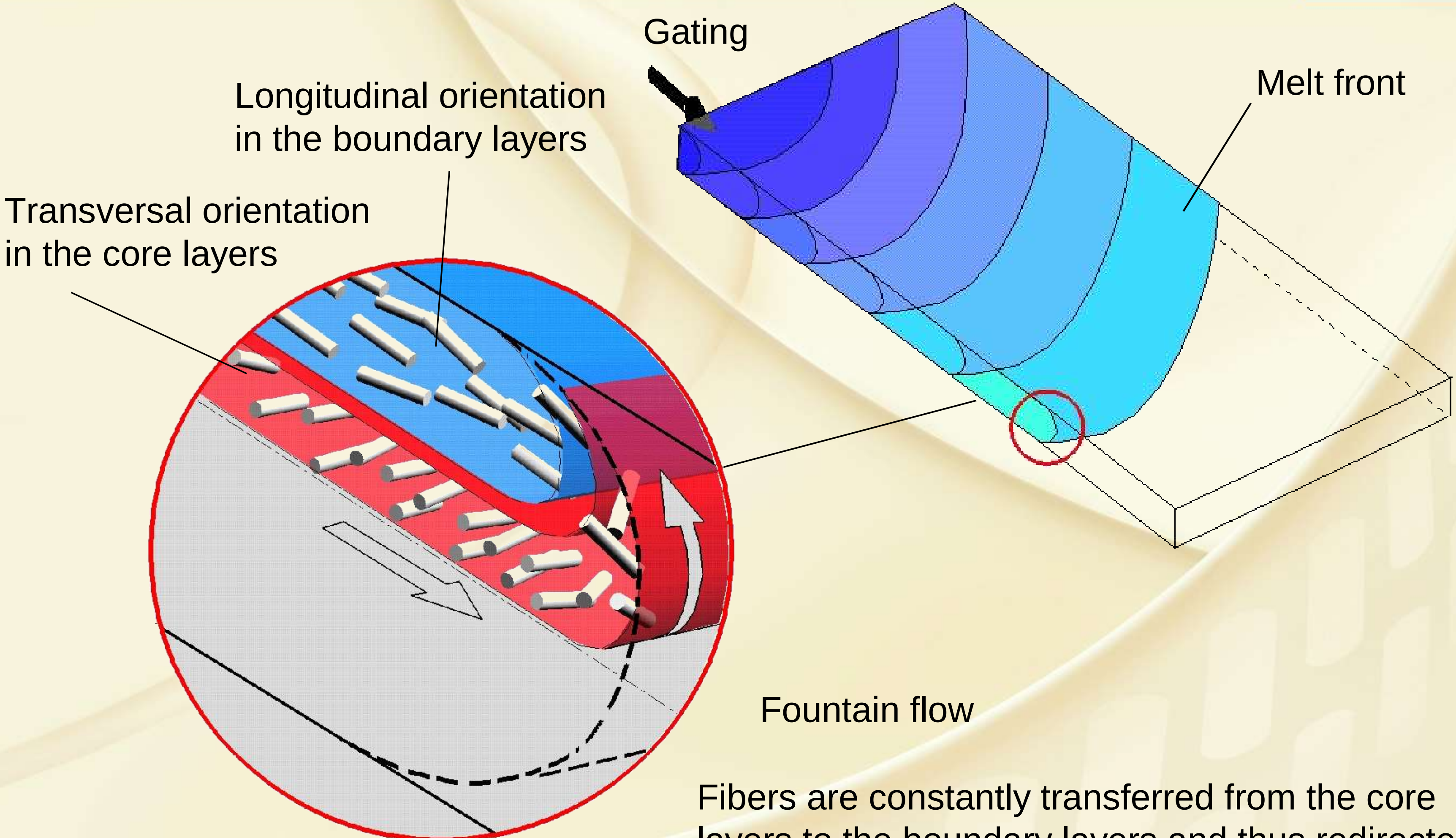
Upper view



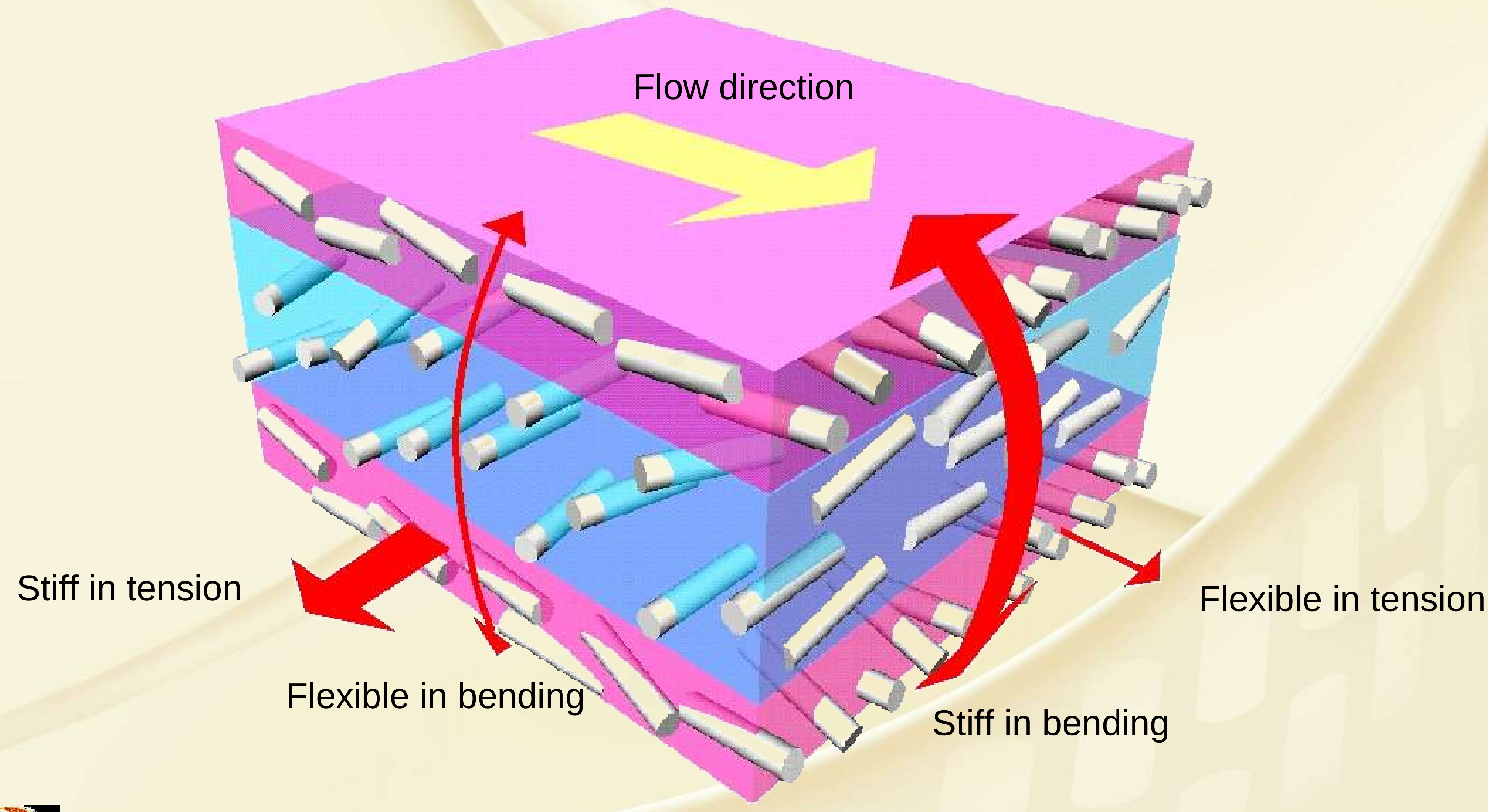
Fibers are being oriented in stretching direction

Evolution of Fiber Orientation in Mould Filling Process



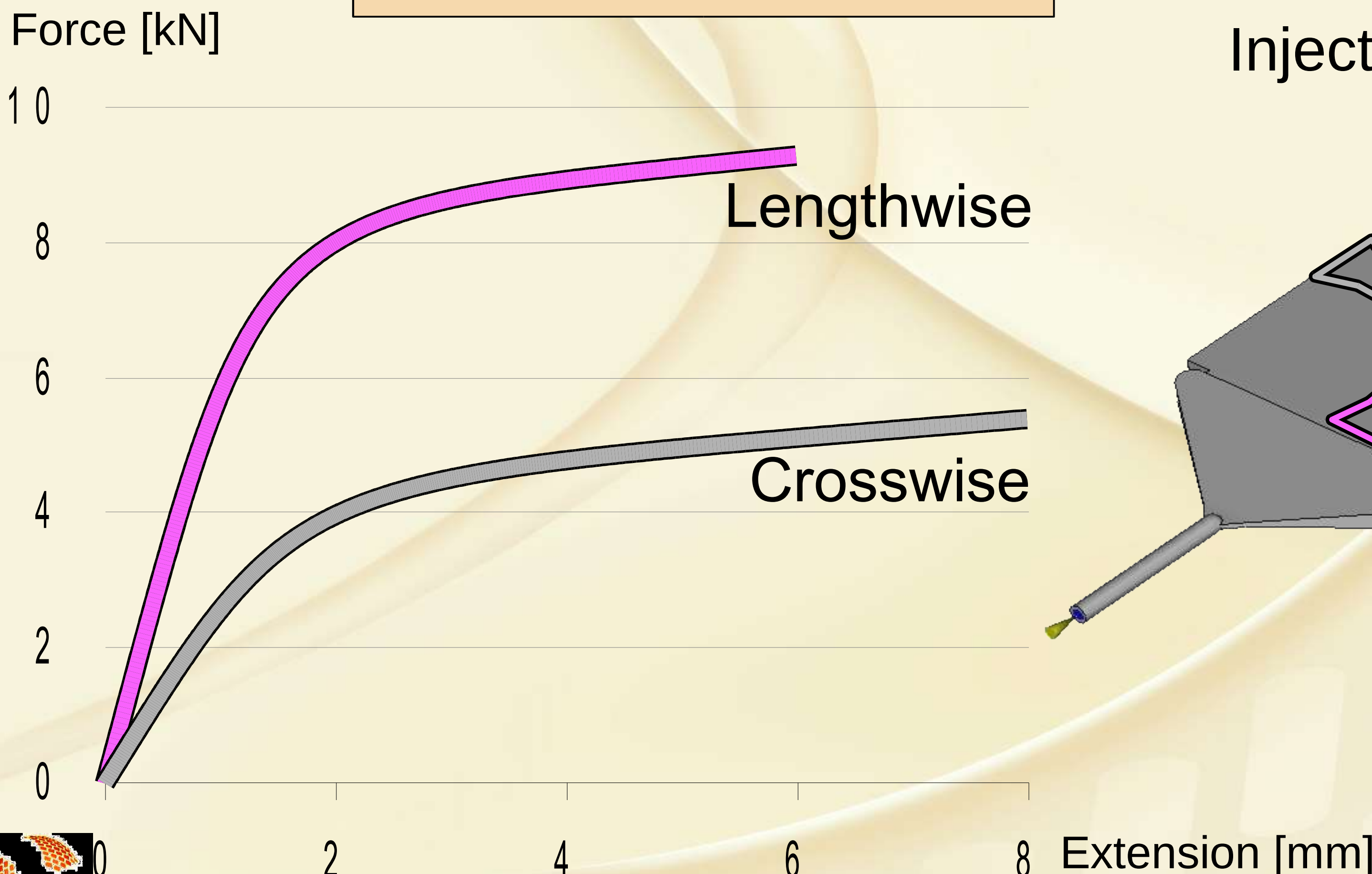
Fibers are constantly transferred from the core layers to the boundary layers and thus redirected

Mechanical behaviour of anisotropic layered shells

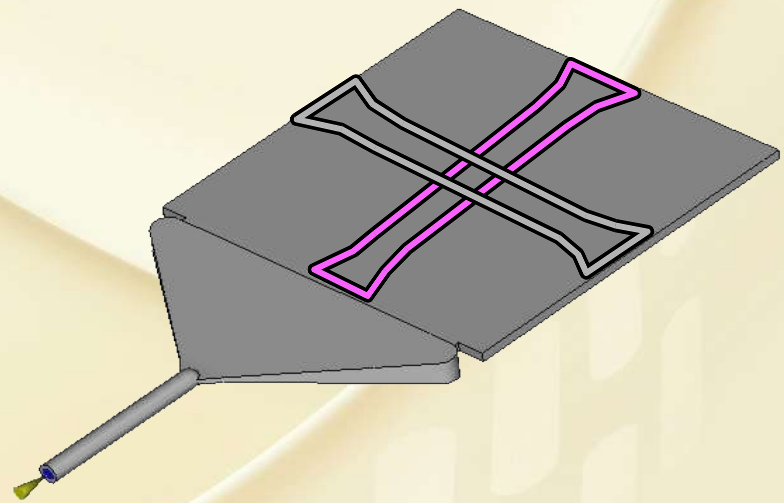


Simulation of tensile test on specimen bar

Effect of fiber orientation



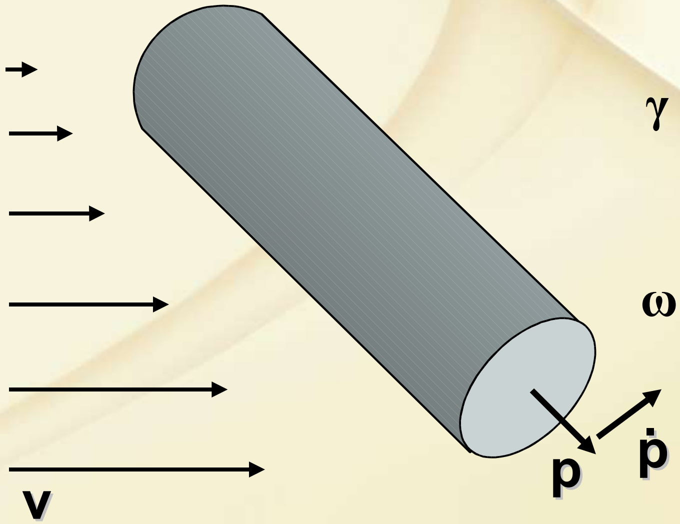
Injection moulded plate



Evolution of fiber orientation

Jeffrey 1922

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



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

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

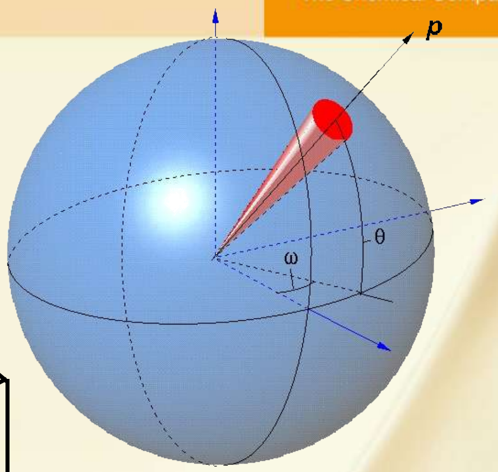
Orientation distribution function

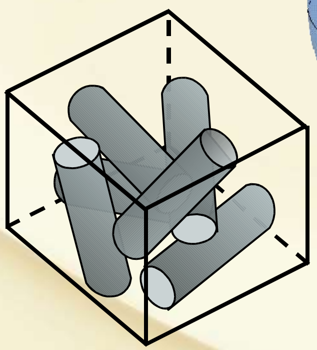
Orientation tensors

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

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

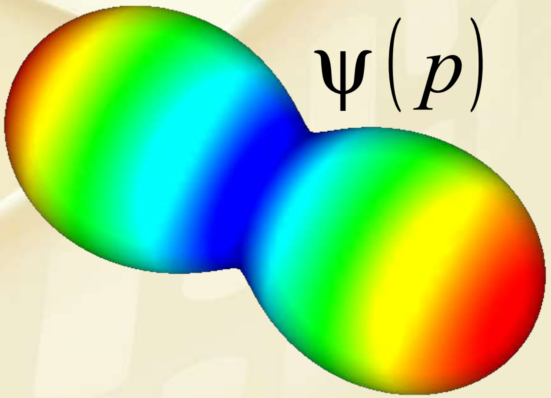
(Tucker 1987)





Taylor expansion of ODF

$$\psi(\mathbf{p}) = \frac{1}{4\pi} + \frac{15}{8\pi} + dev(\mathbf{a}) : dev(\mathbf{p} \otimes \mathbf{p})$$
$$+ \frac{315}{32\pi} dev(\mathbf{a}^4) :: dev(\mathbf{p} \otimes \mathbf{p} \otimes \mathbf{p} \otimes \mathbf{p}) + \ldots$$



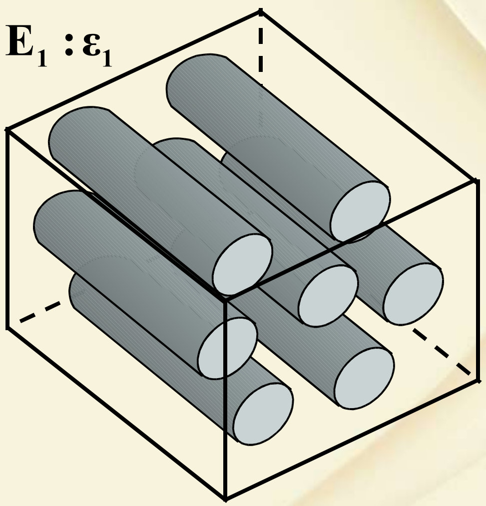
$\psi(p)$

Homogenization of fibers and polymer

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

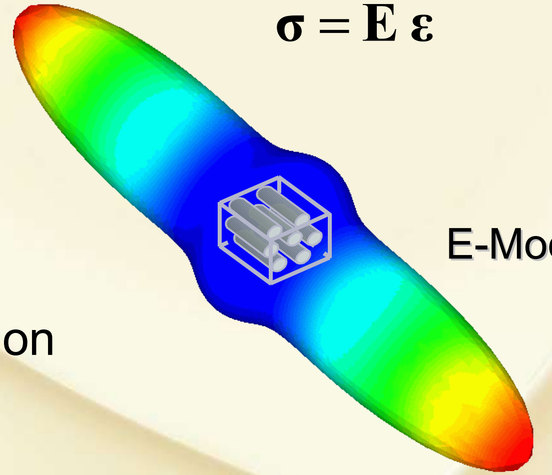
$$\boldsymbol{\sigma}_0 = \mathbf{E}_0 : \boldsymbol{\varepsilon}_0$$

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



Homogenization

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



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

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

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

Homogenization of orientation

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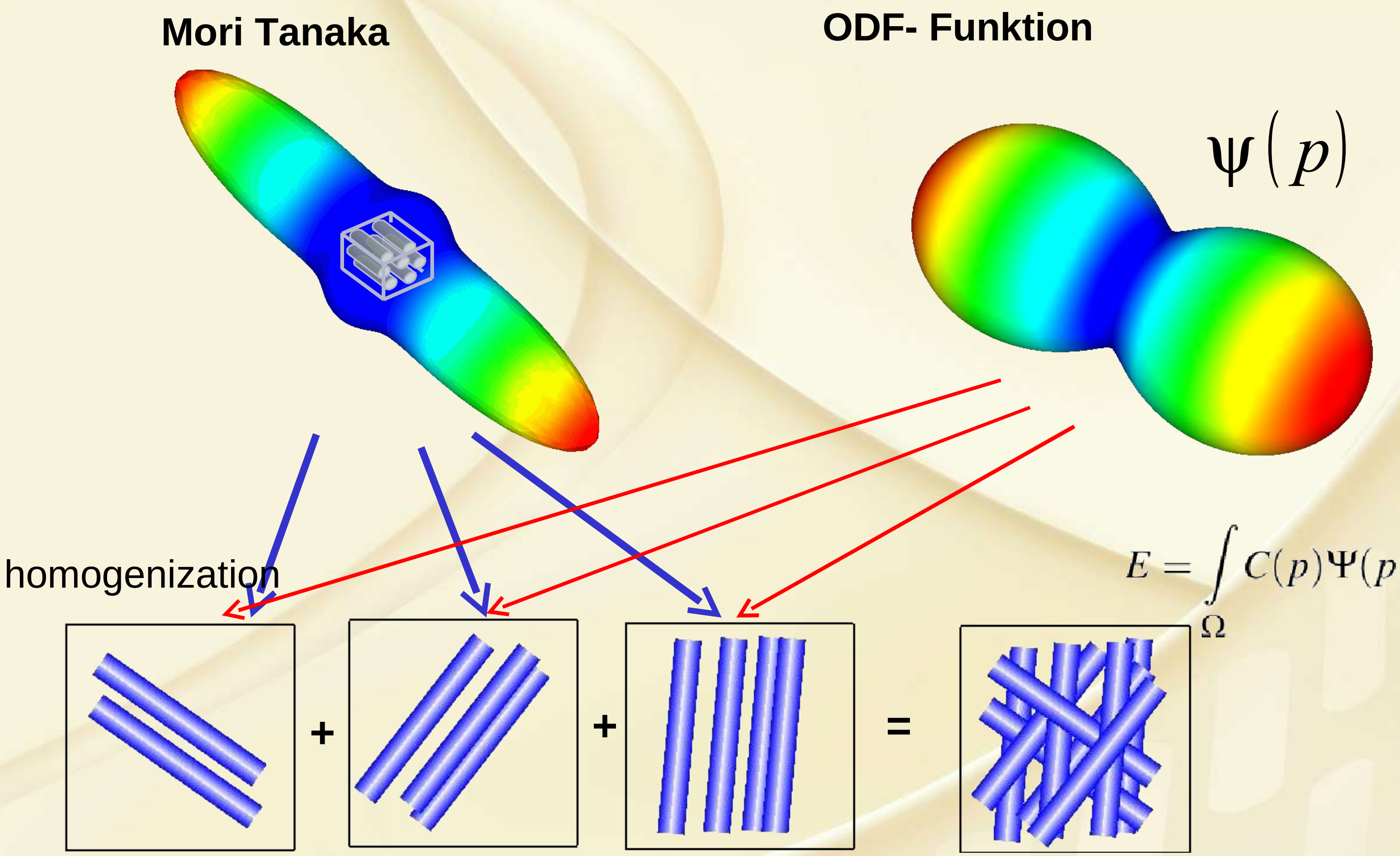
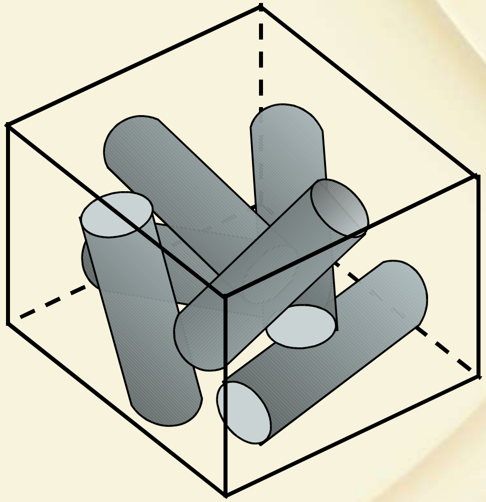


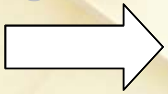
$$E = \int_{\Omega} C(p)\Psi(p)\, d\Omega$$

Material modelling for composite materials

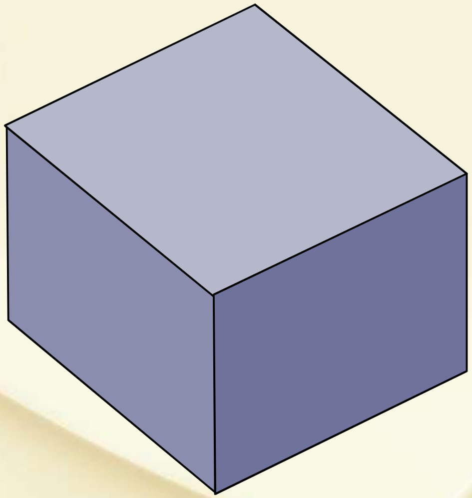
Micro Scale



Homogenization:

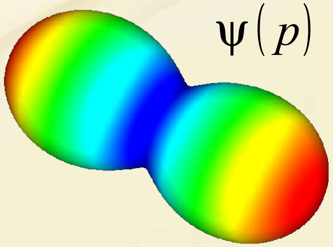


Macro Scale

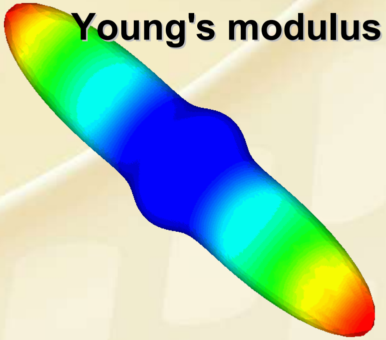


Orientation distribution function

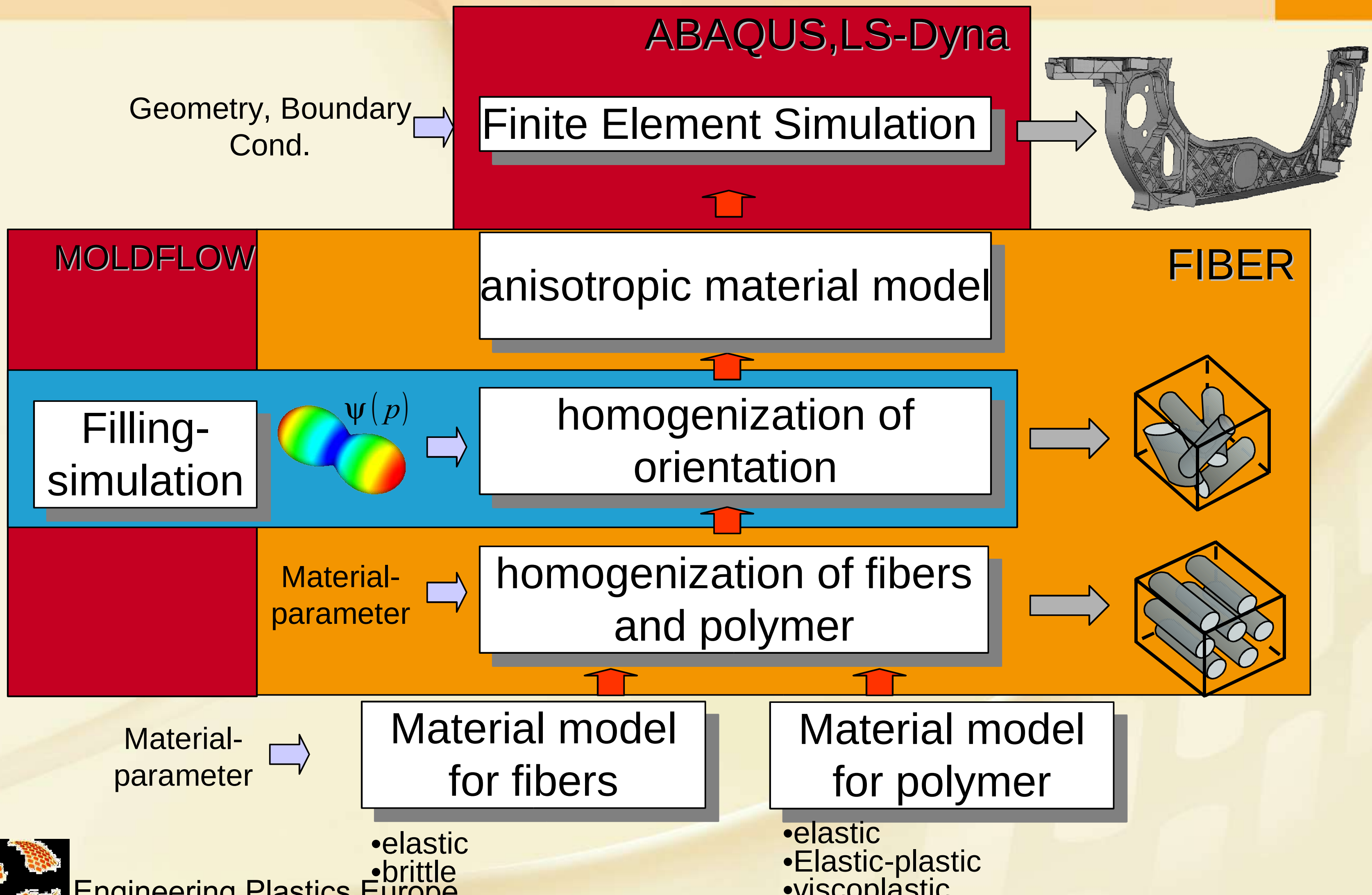
$$\psi\left(p\right)$$



Young's modulus



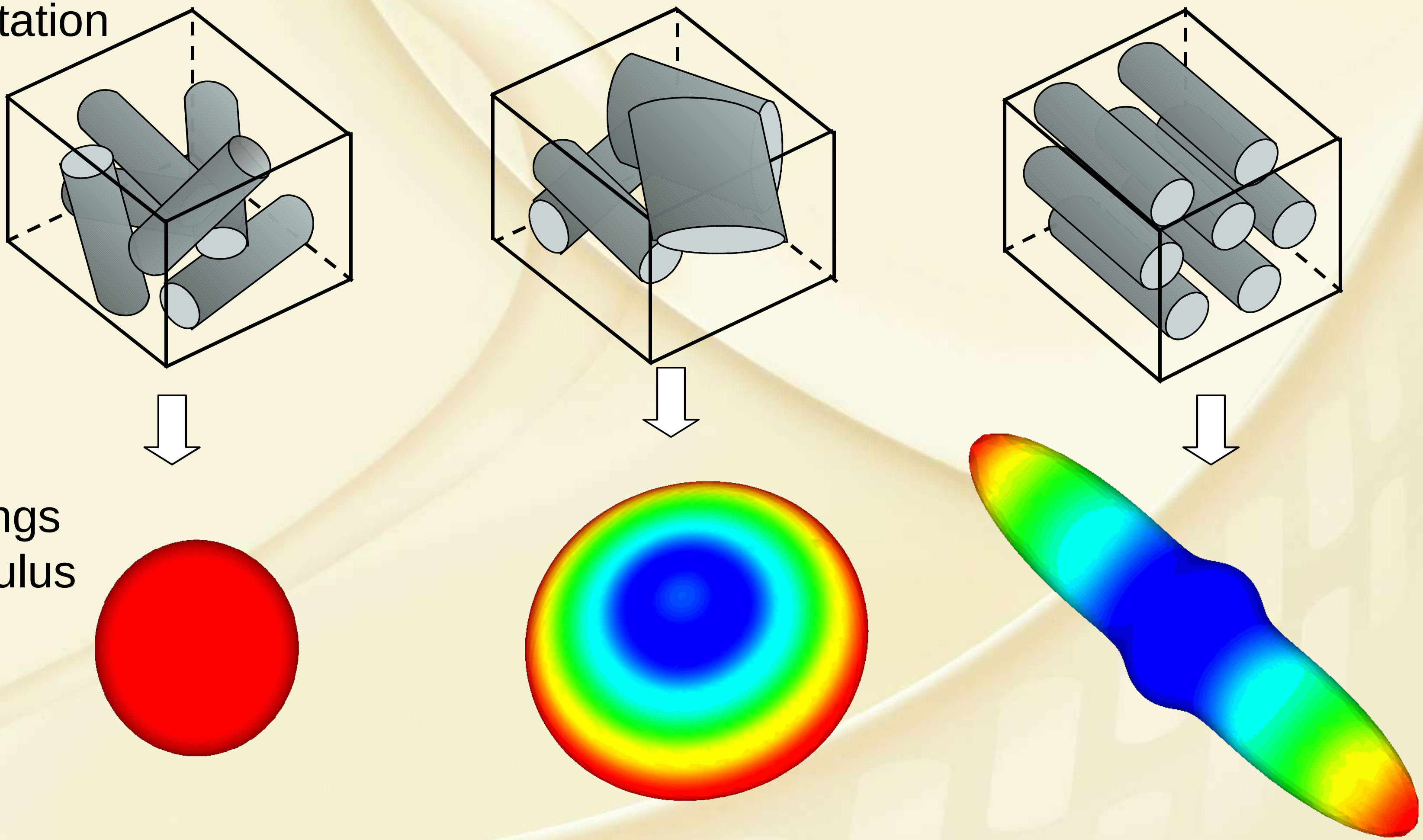
Integrative Simulation



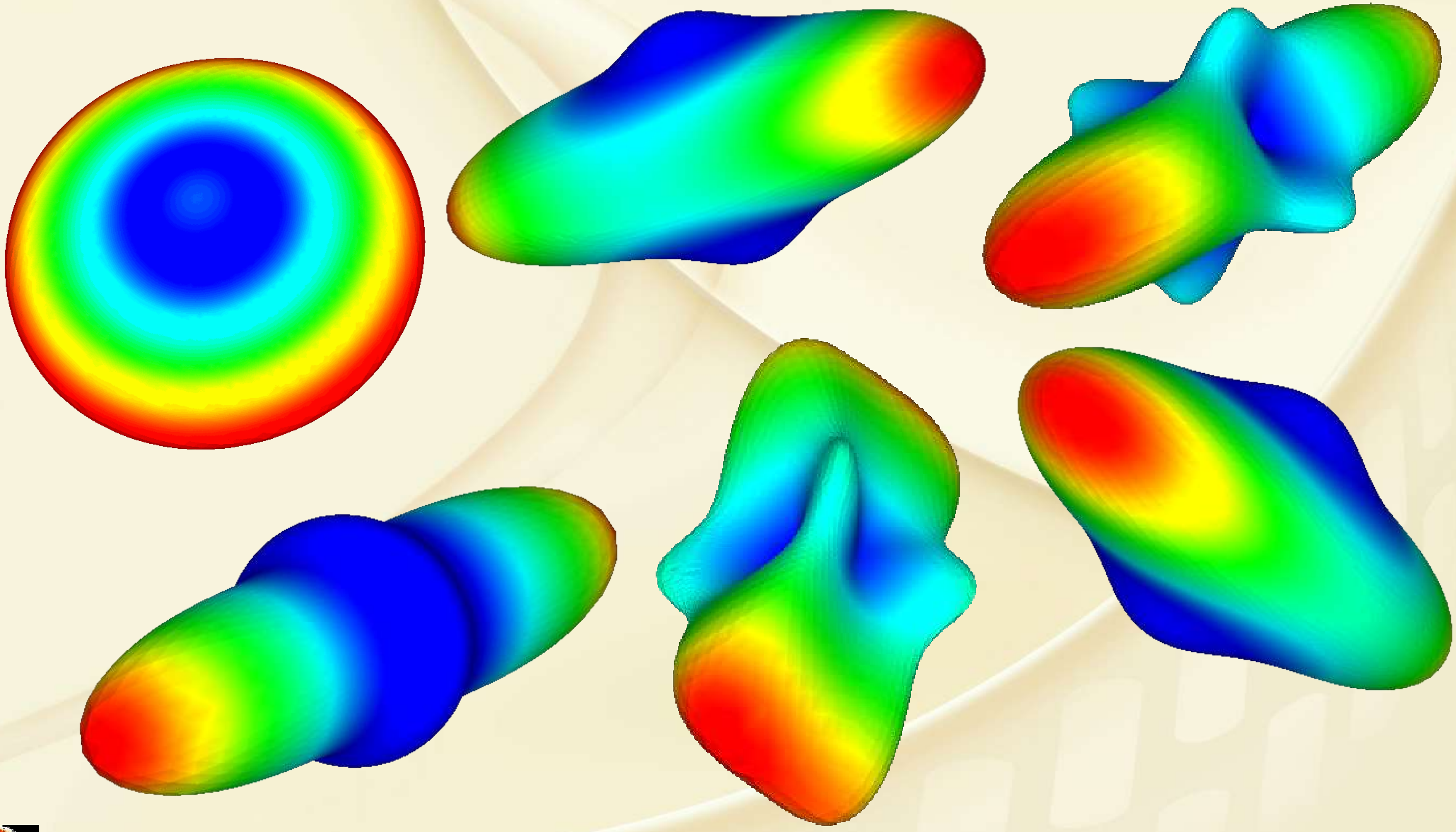
Anisotropic stiffness

Orientation

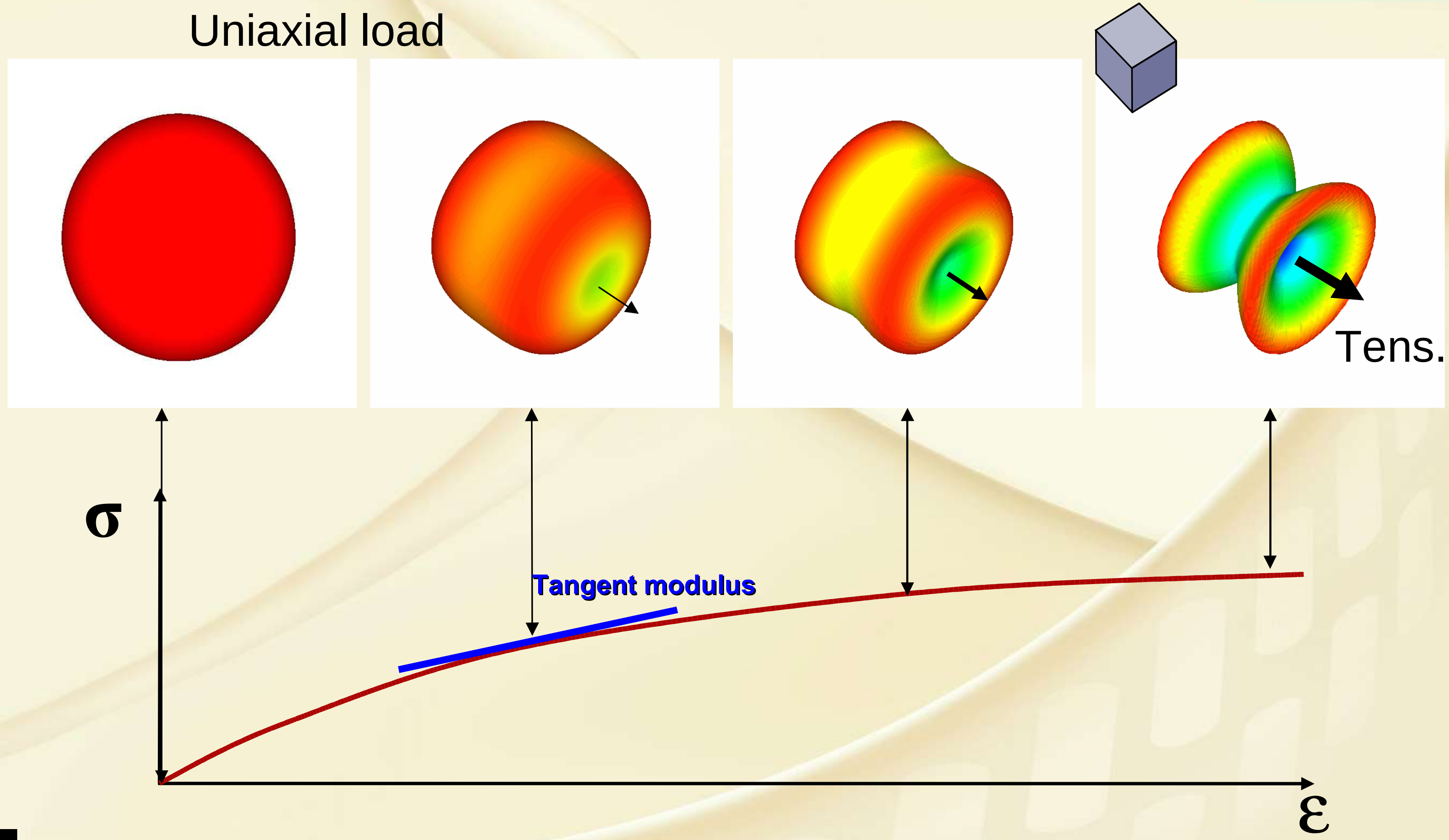
Youngs modulus



Anisotropic stiffness for SFRP-material

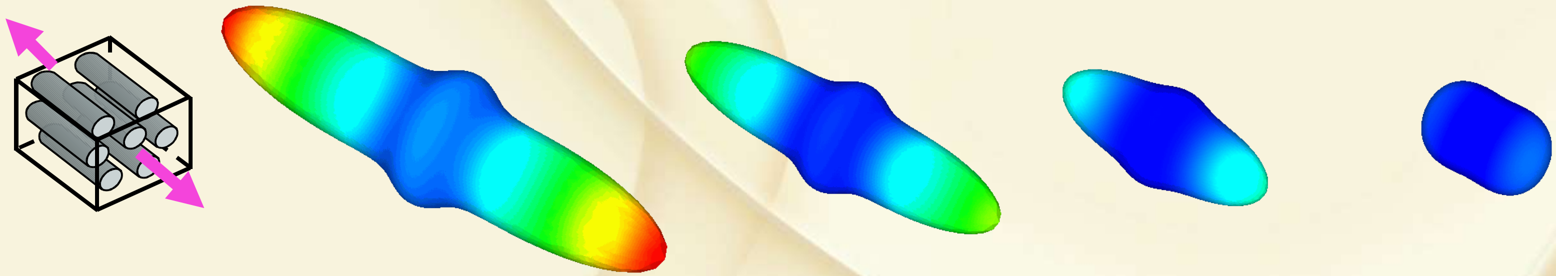


Tangent modulus for polymers

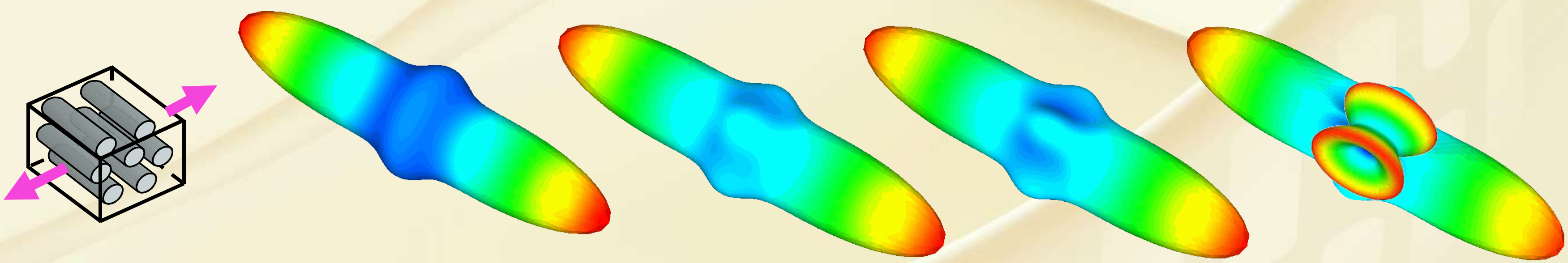


Tangent modulus for SFRP material

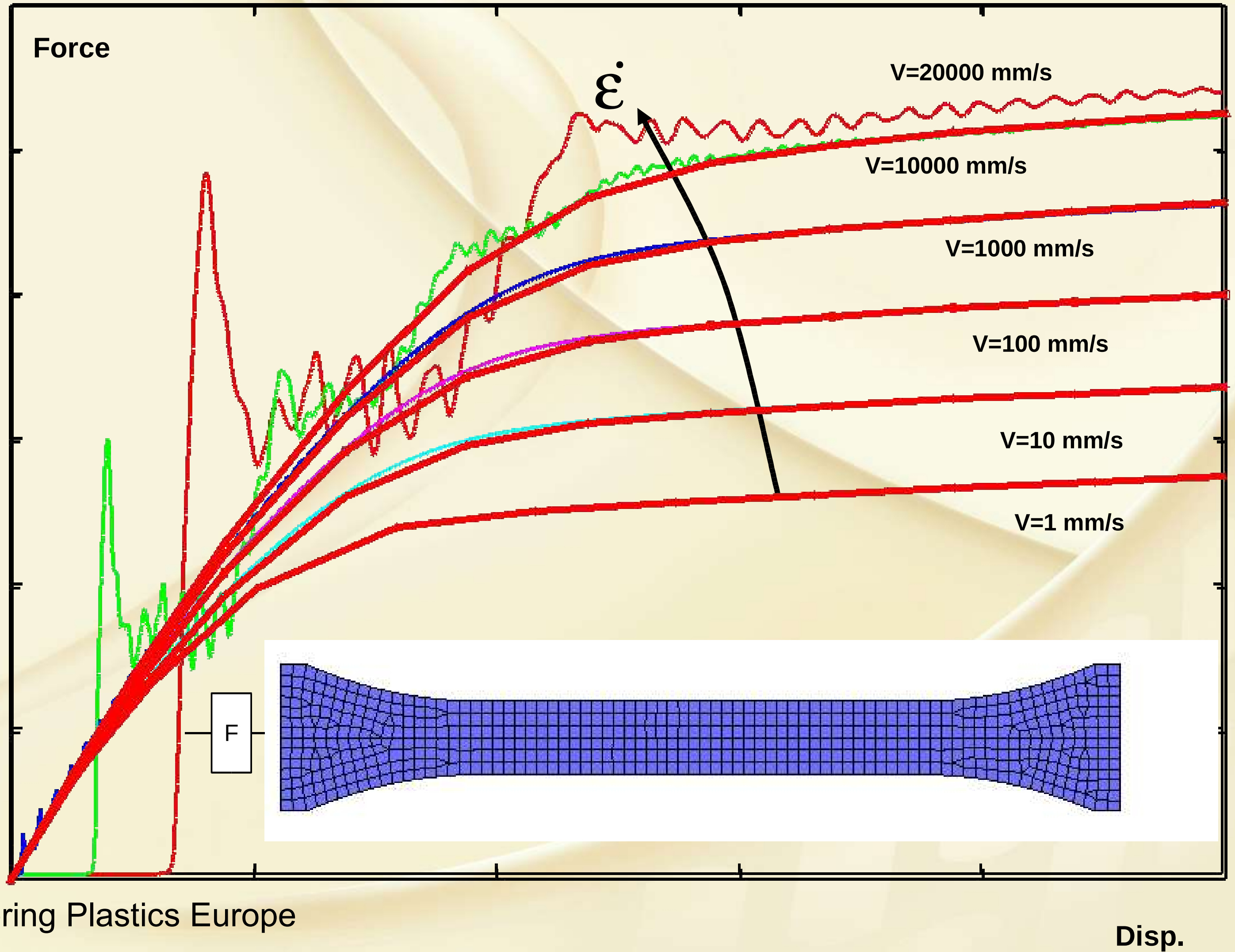
Uniaxial loading longitudinal



Uniaxial loading transversal

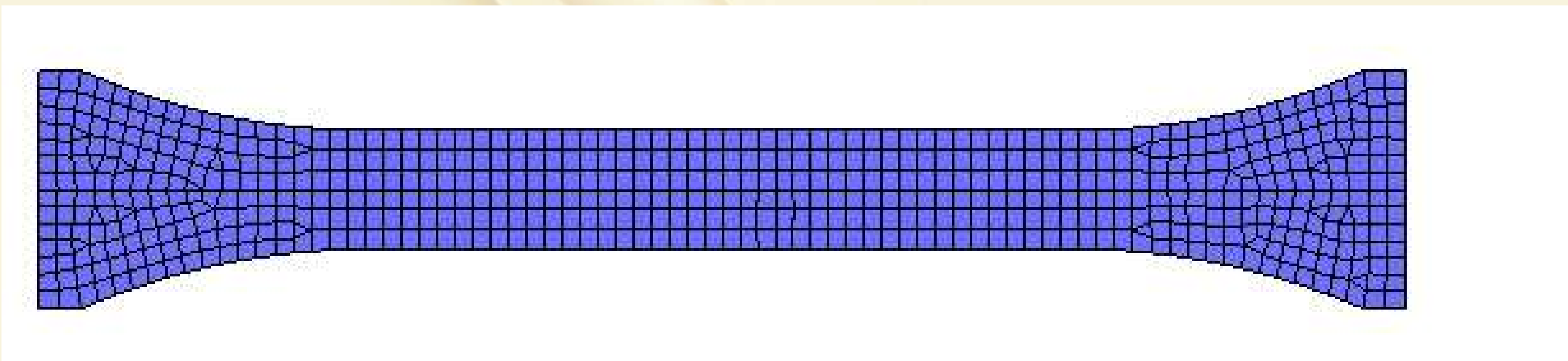


Dynamic tensile test, simulation



Tensile test at 10 m/s velocity
Wave propagation

Simulation



Experiment

Material behaviour at crash loading

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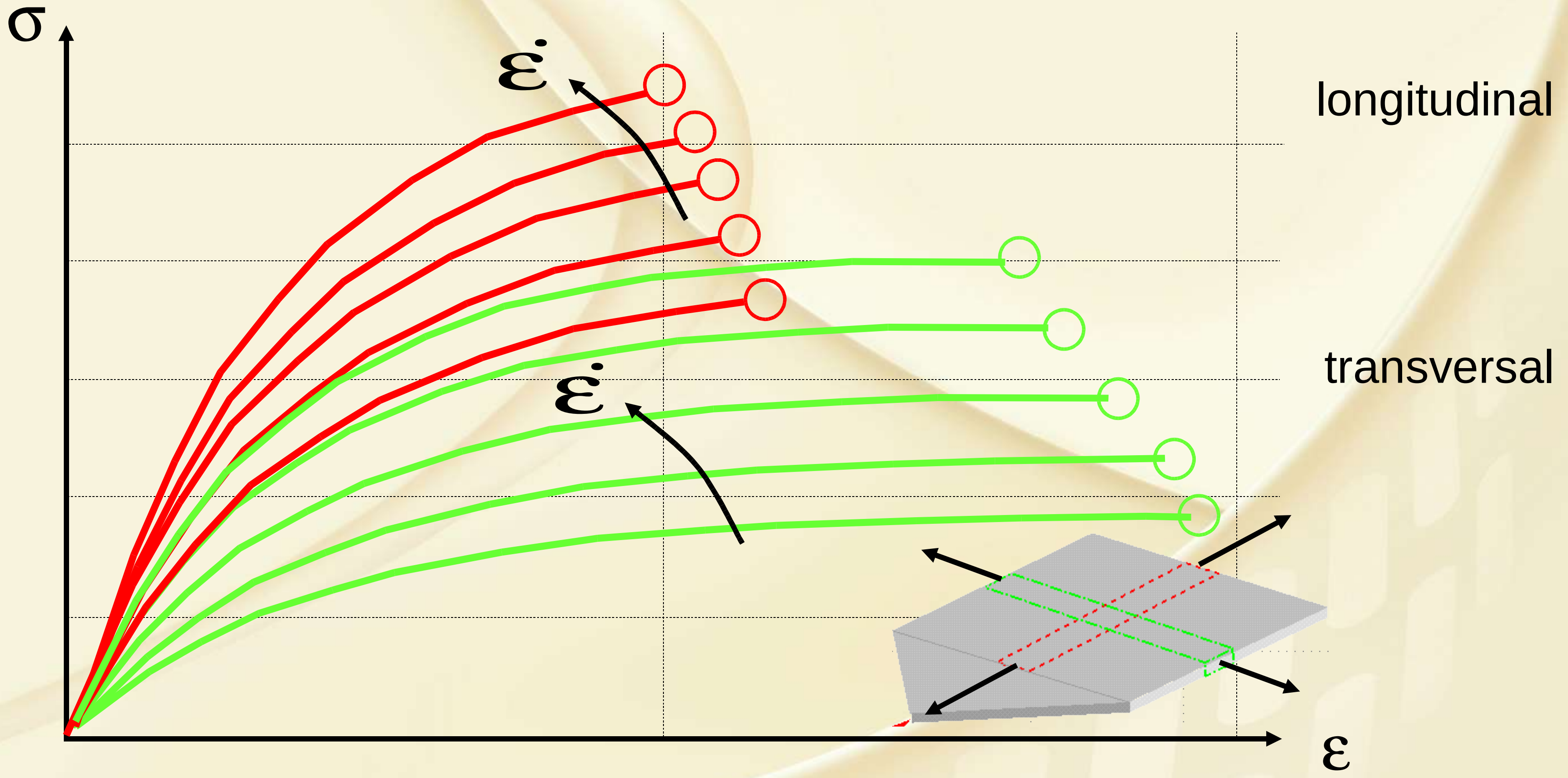
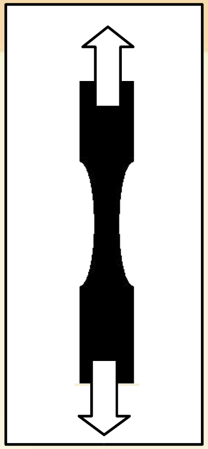
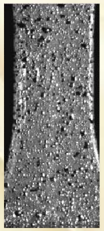
Anisotropic, Strain-rate sensitive, Failure



Material Measurements

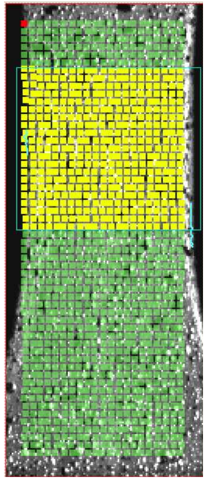




GOM - ARAMIS

Deformationgradient $\mathbf{F} = \frac{\partial \mathbf{x}}{\partial \mathbf{X}}$

Force(t)



BASF Software

$$\mathbf{F} = \frac{\partial \mathbf{x}}{\partial \mathbf{X}} \longrightarrow$$

Strain:

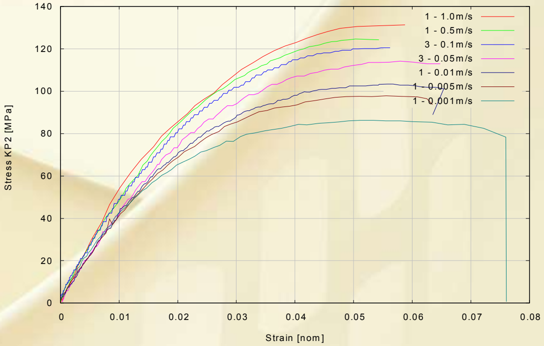
$$\mathbf{E} = \tfrac{1}{2}(\mathbf{F}^{\mathrm{T}}\mathbf{F} - \mathbf{G})$$

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

$$S^{11} = \frac{Kraft}{A_0}$$

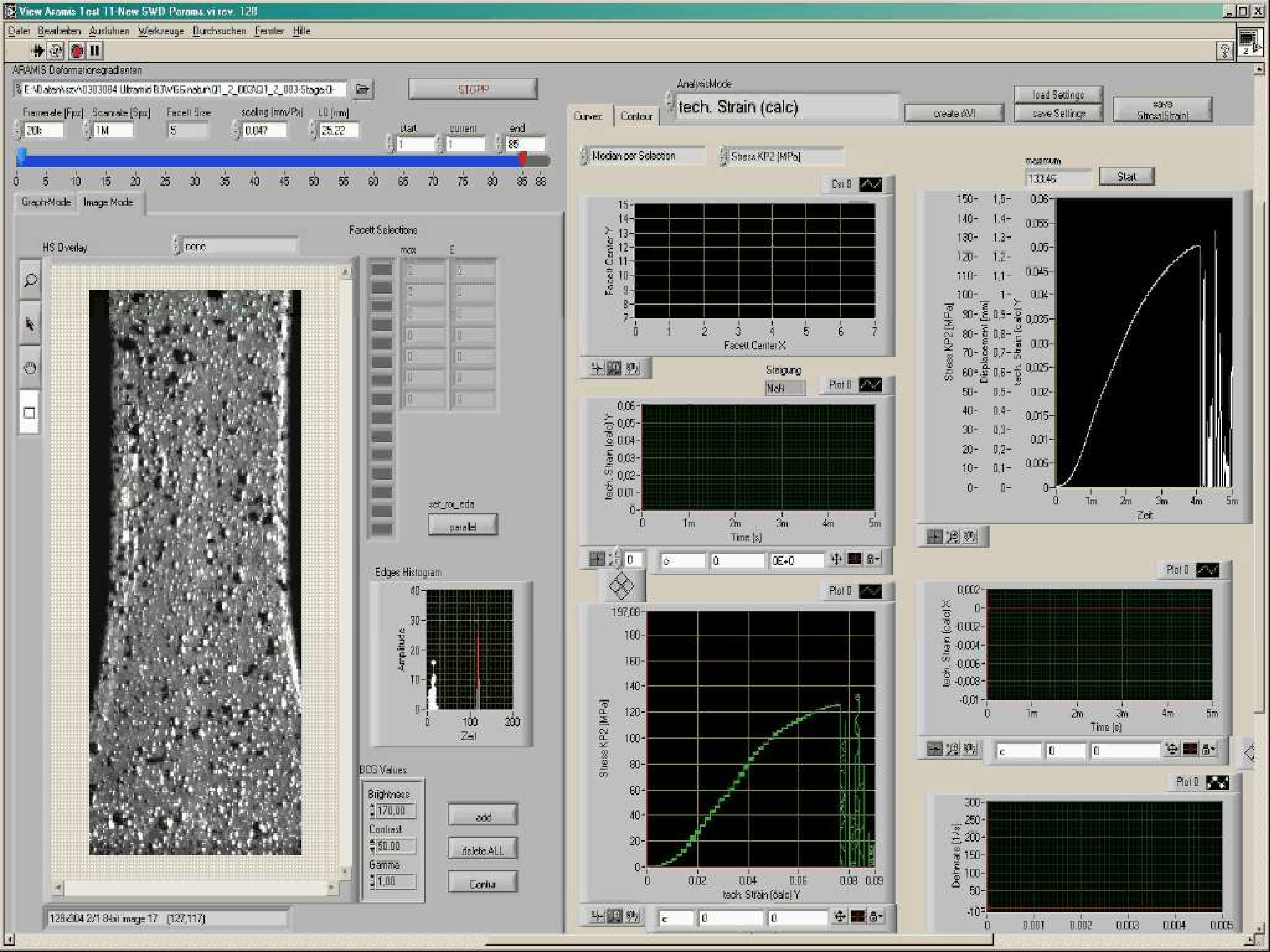
Stress:

$$\boldsymbol{\sigma} = \frac{1}{J}\mathbf{F}\mathbf{S}\mathbf{F}^{T}$$

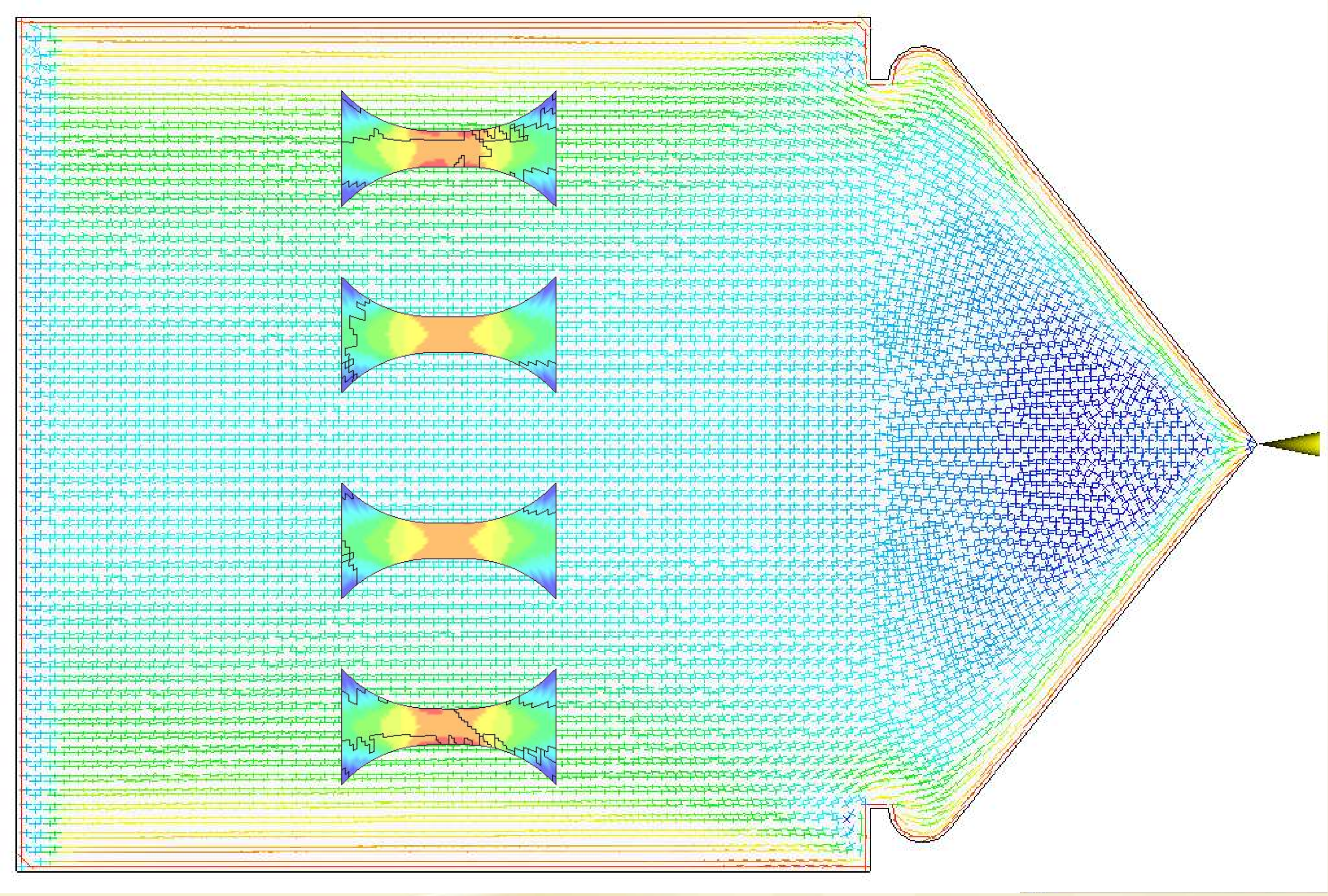


BASF Material Modell

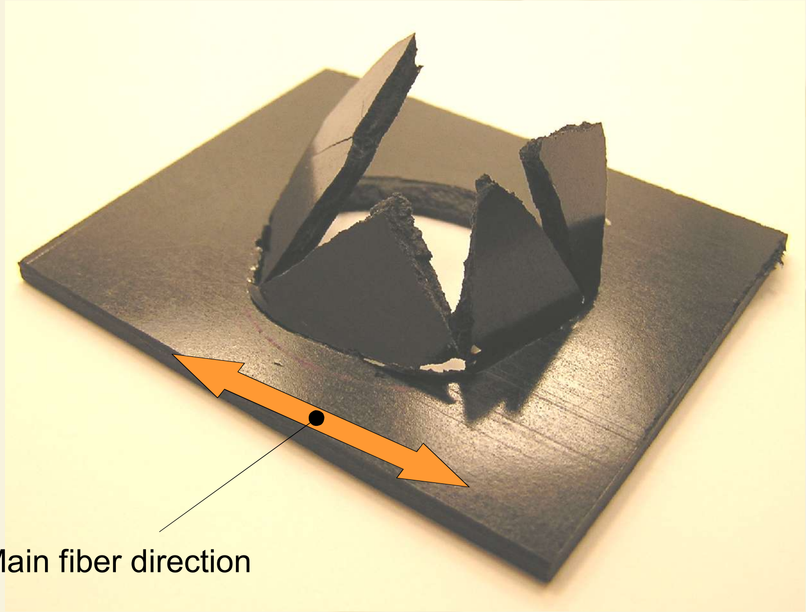
LS-Dyna - UMAT


View Aramis Test 11-New SWD Parama.vi rev. 128
ARAMIS Deformationsgradienten
STOPP
AnalysisMode
tech. Strain (calc)
load Settings
save Settings
create AVI
save Stress(Strain)
Curves
Contour
Median per Selection
Stress KP2 [MPa]
Graph Mode
Image Mode
HS Overlay
Facett Selections
Facett Center Y
Facett Center X
Steigung
tech. Strain (calc) Y
Time [s]
Stress KP2 [MPa]
Displacement [mm]
Zeit
Edges Histogram
Amplitude
BCG Values
Brightness
Contrast
Gamma
add
delete ALL
tech. Strain (calc) X
tech. Strain (calc) Y
Dehnrate [1/s]

Average Fiber orientation, and Failure variable



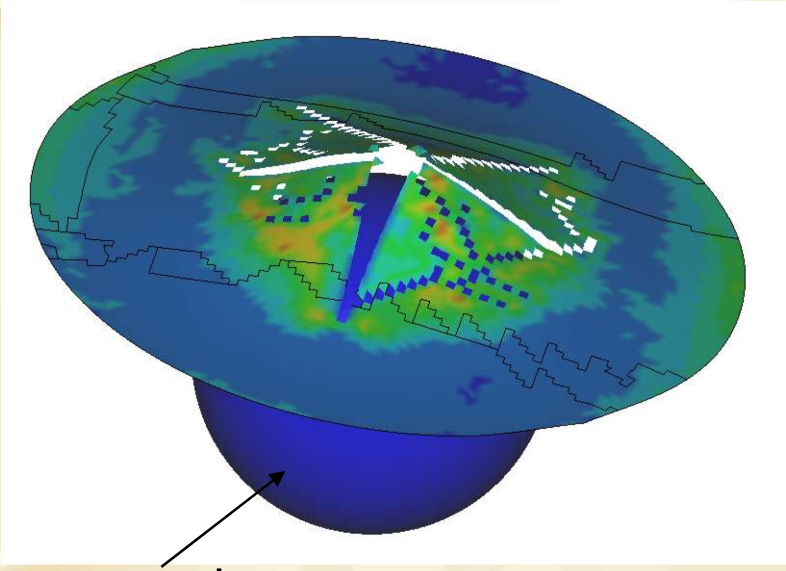
Penetration Experiment



Main fiber direction

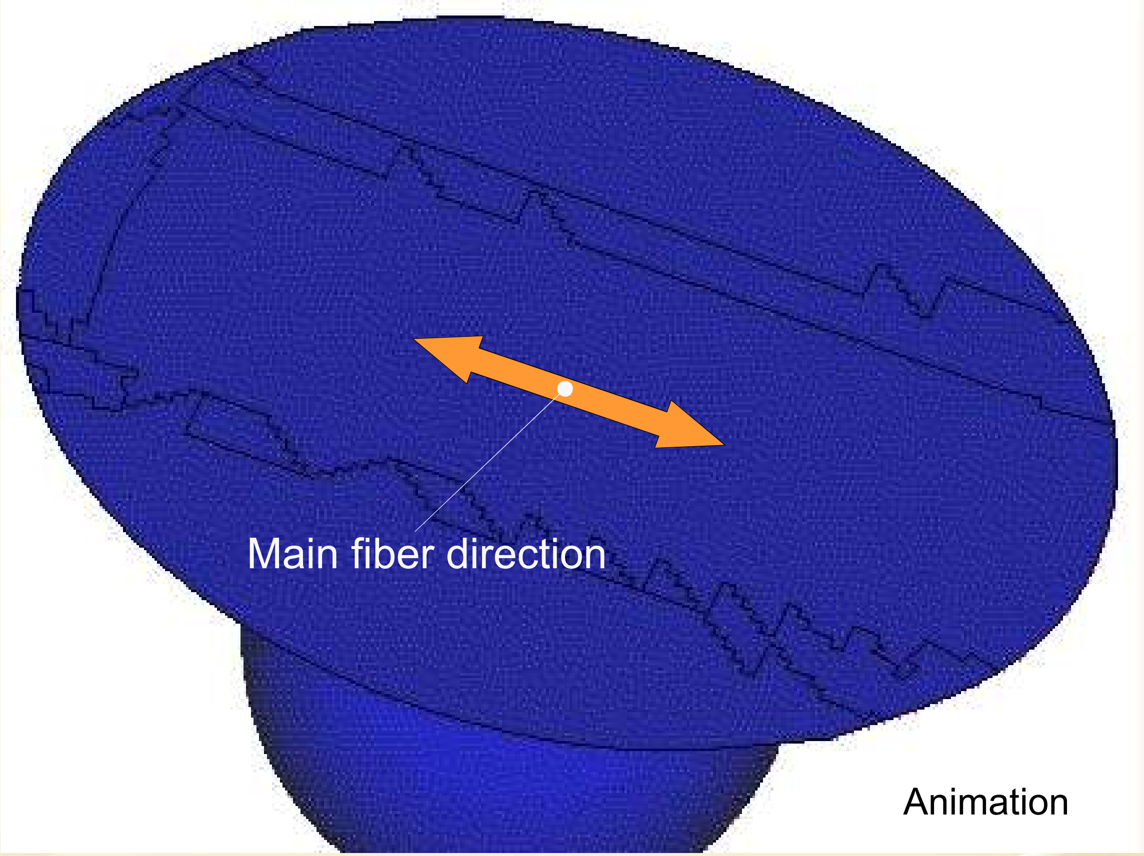
Biaxial Stress

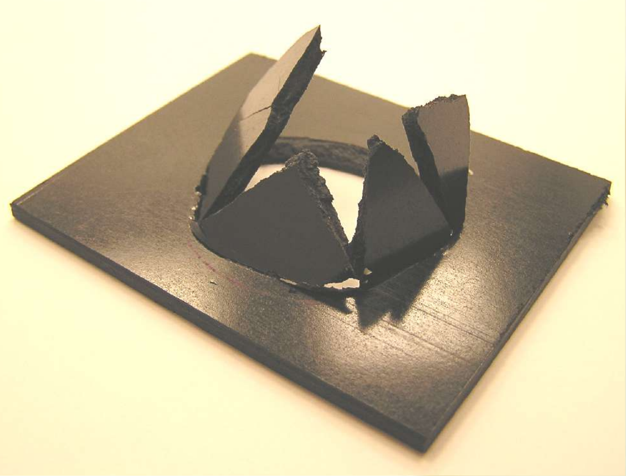
Fixed by axisymmetric die

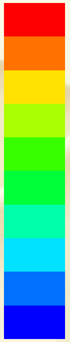


punch

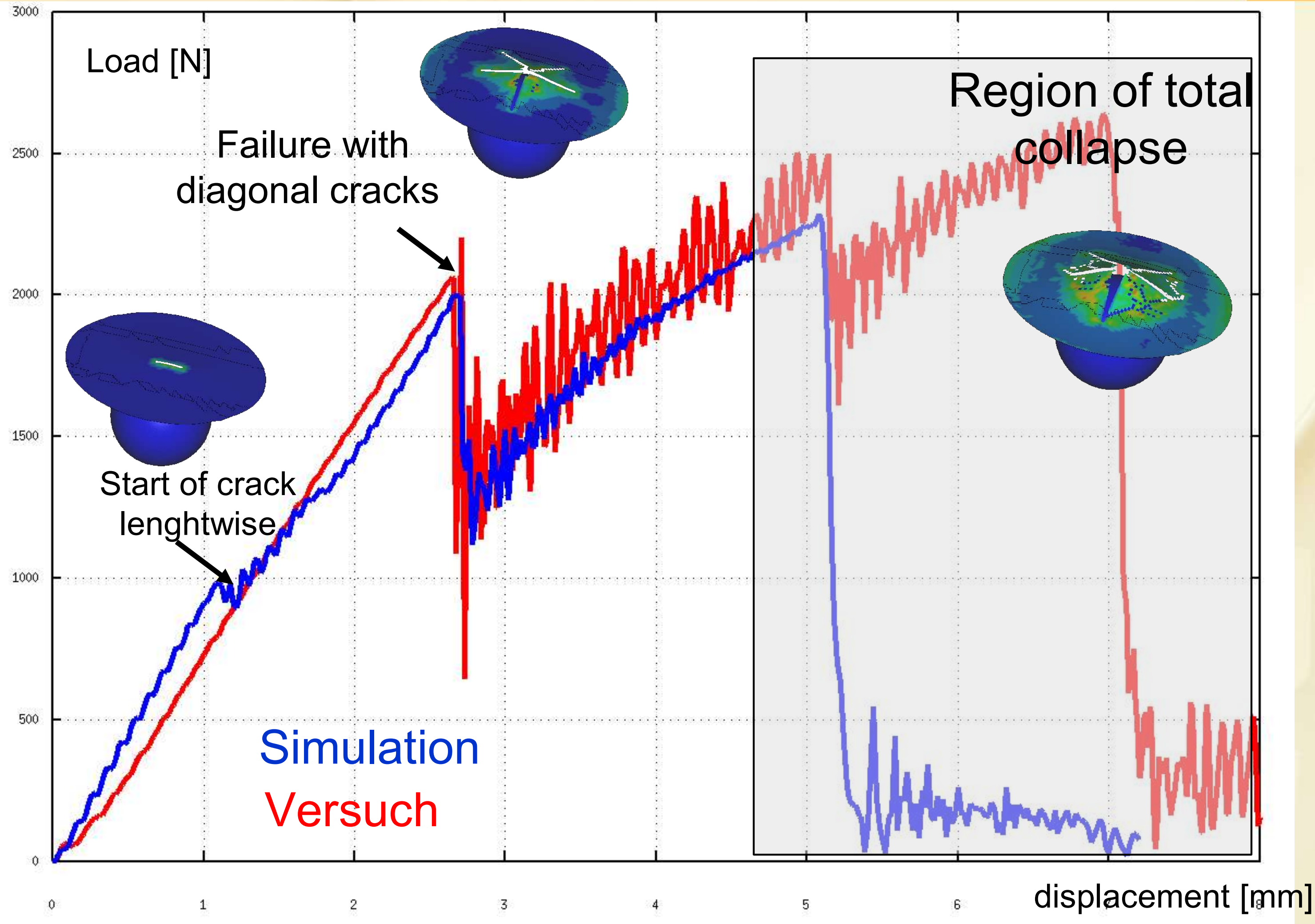
Simulation of penetration experiment



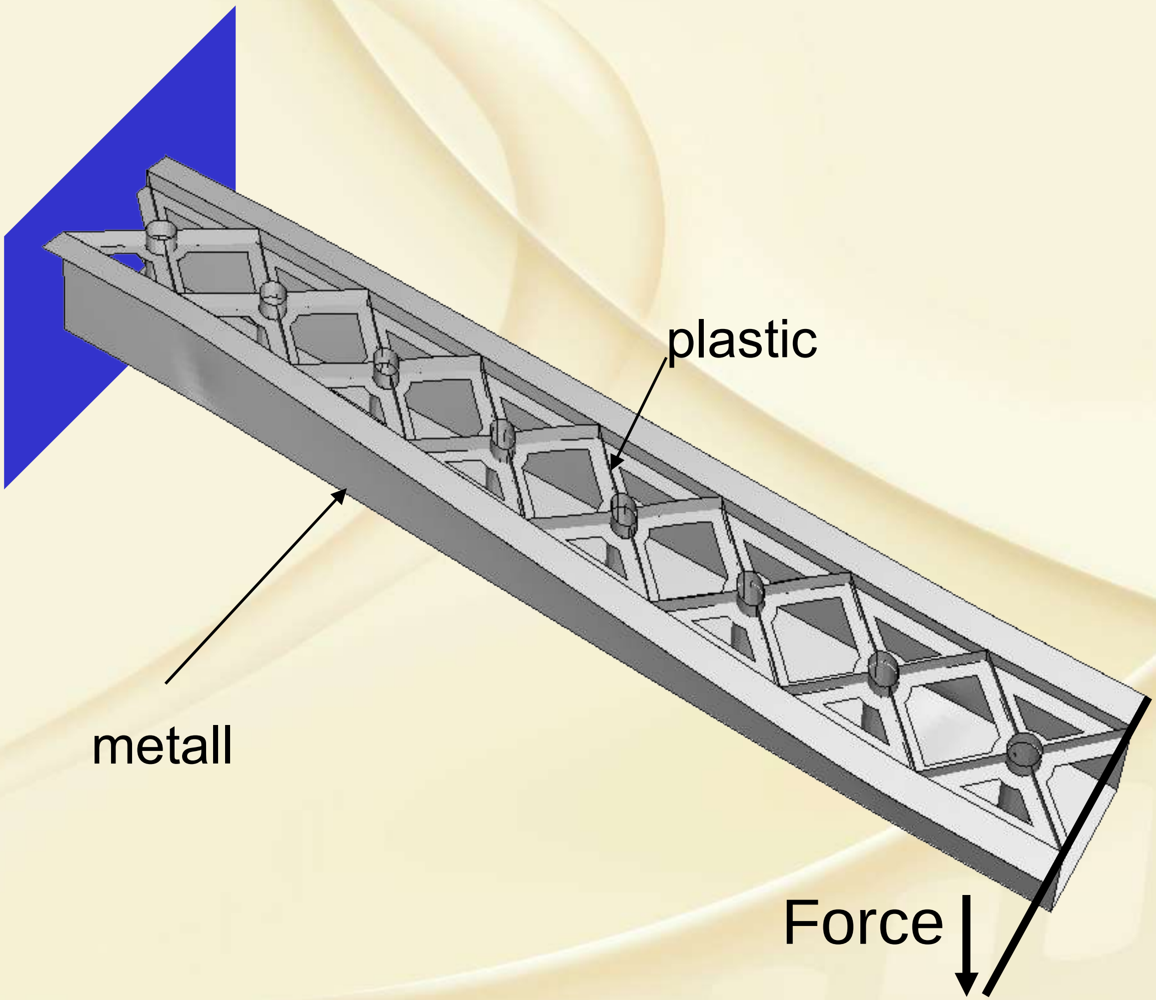




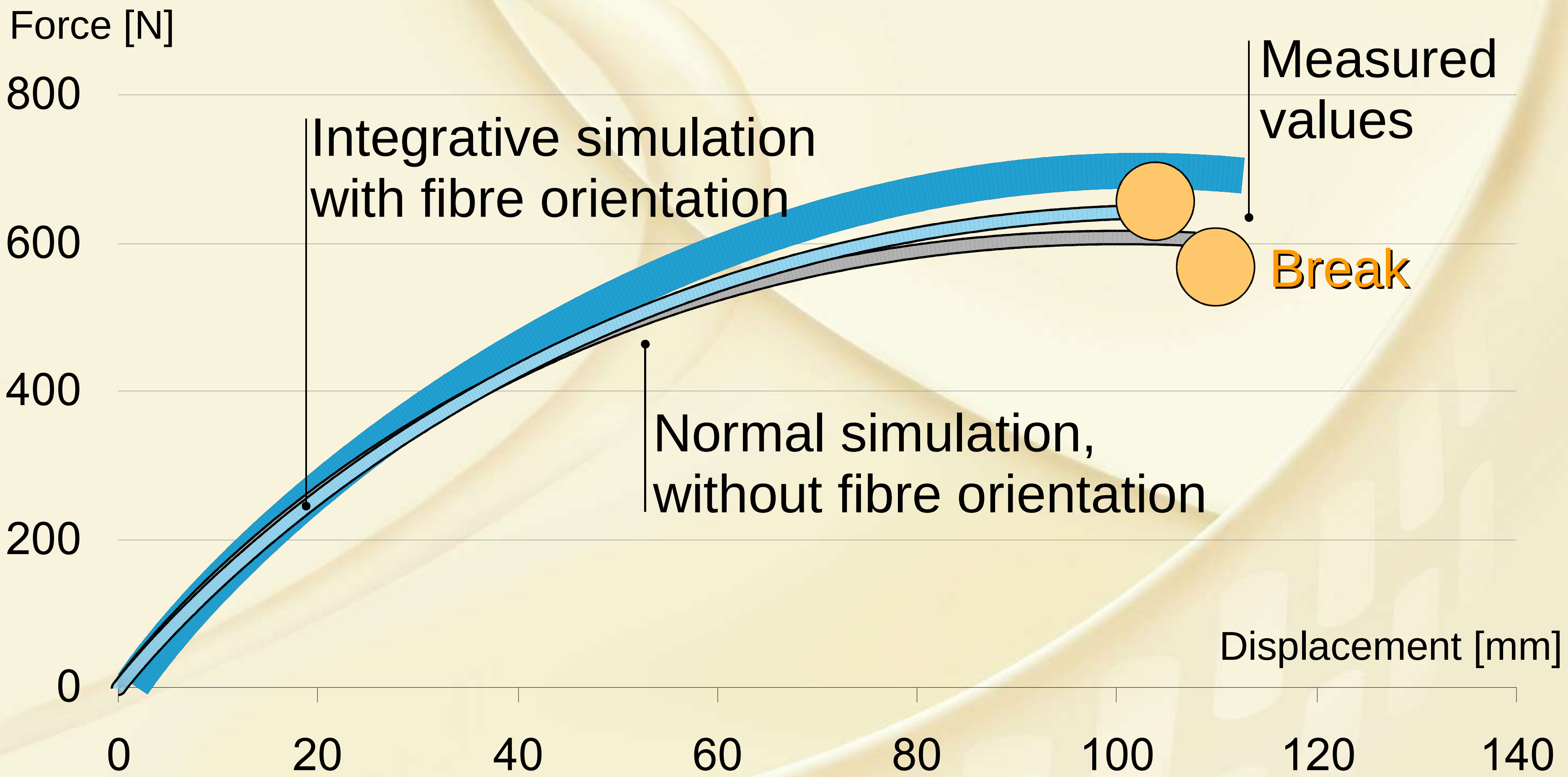
Simulation of penetration experiment



Beam (LU carrier) under torsional load

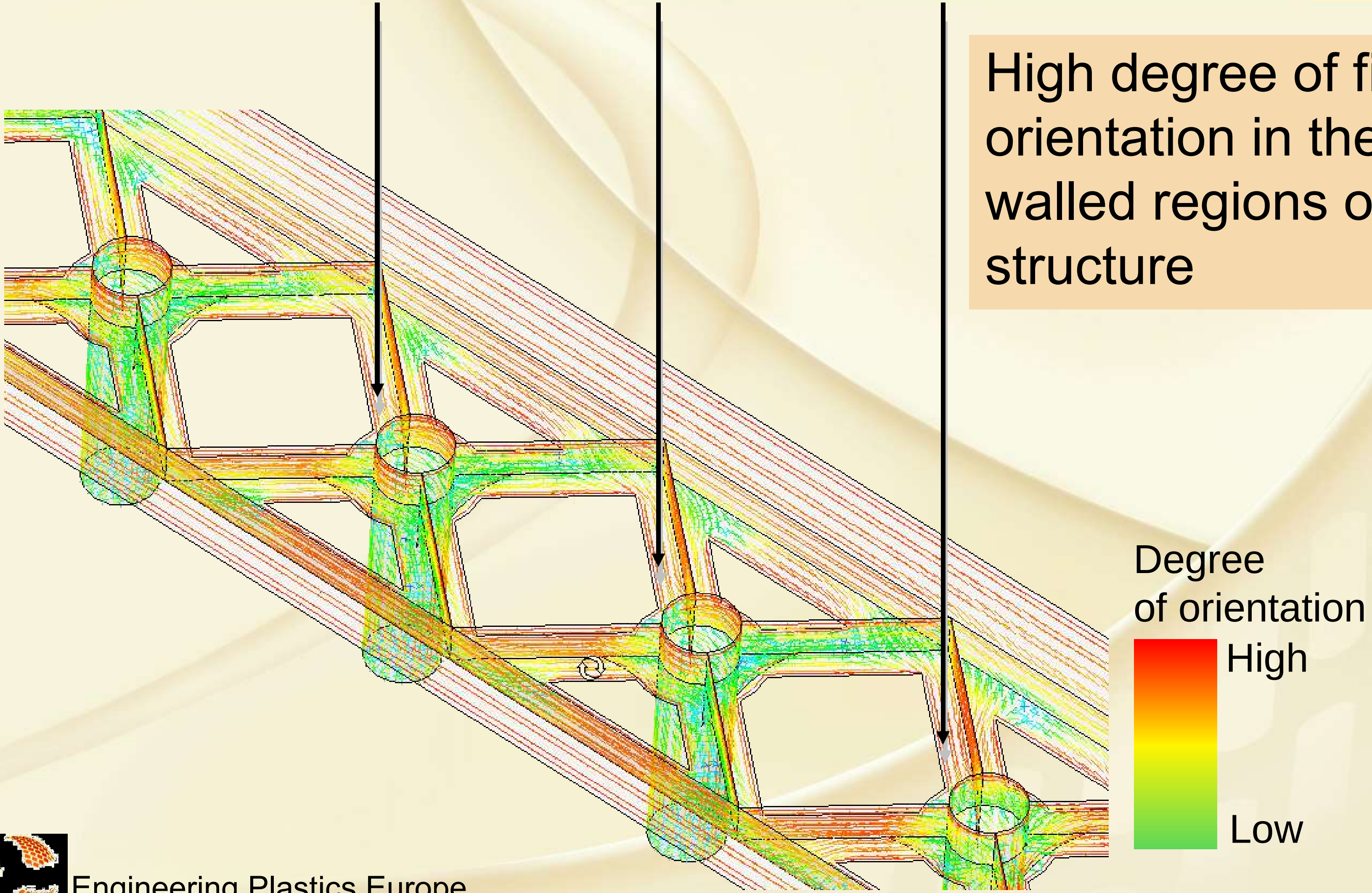


Torsional test on LU carrier



Degree of fibre orientation in the structure

High degree of fibre orientation in the thin-walled regions of the structure



Tensile load in stiffening ribs

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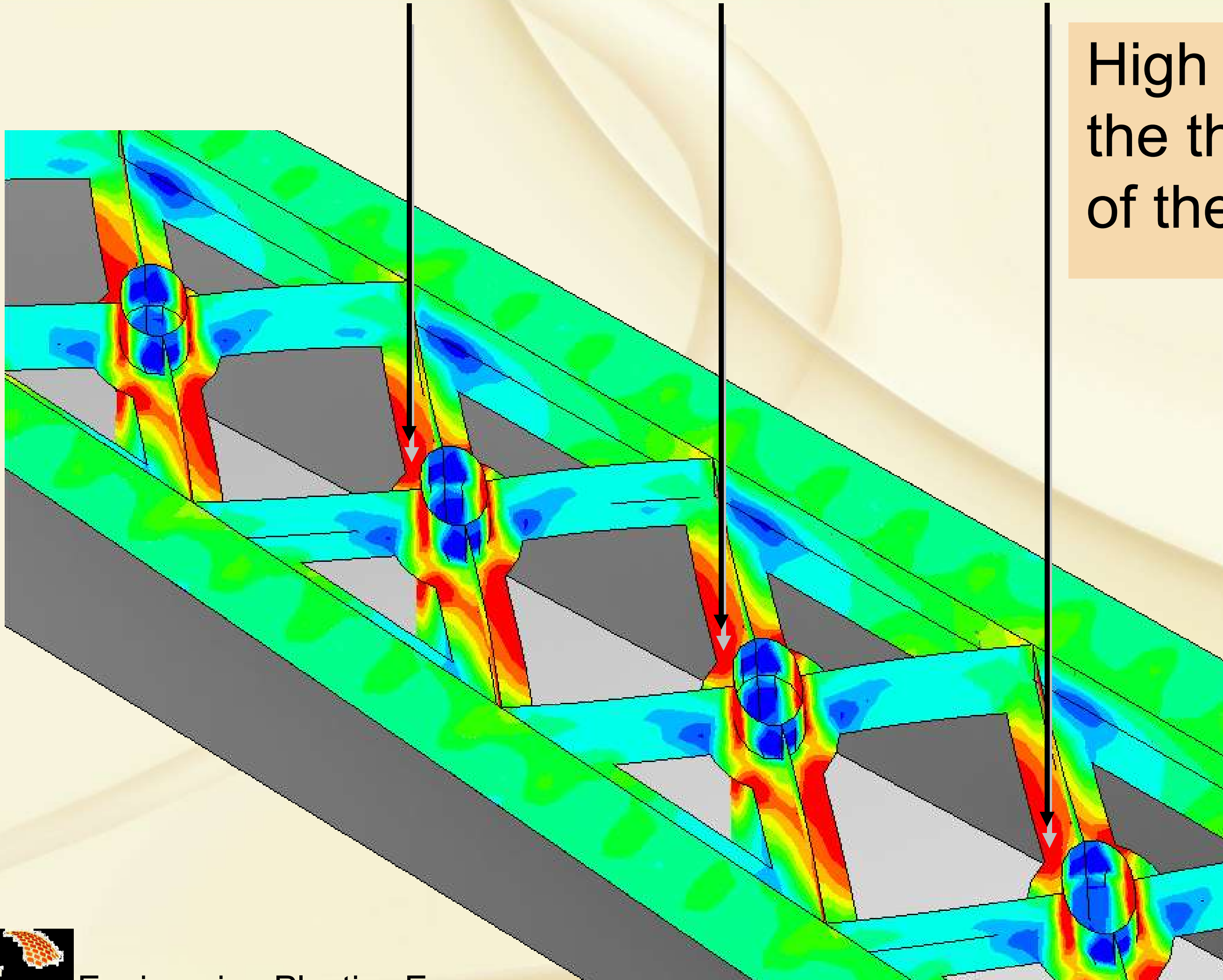
High tensile stresses in the thin-walled regions of the structure



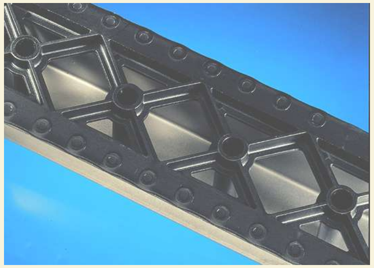
Tensile stress

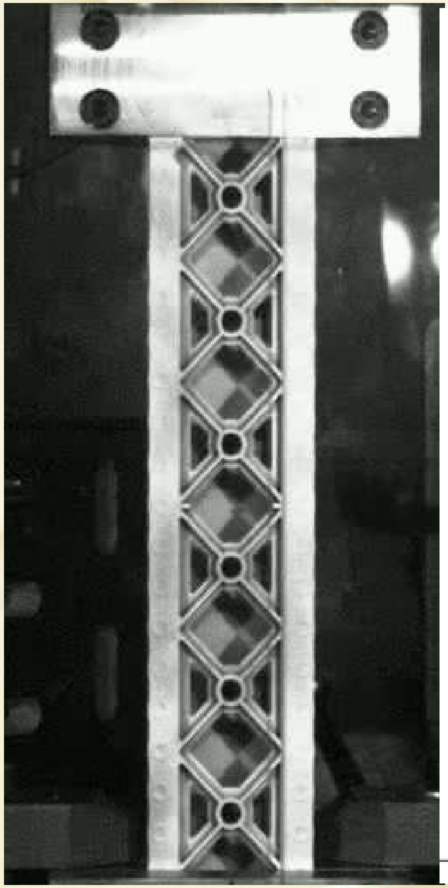
Axial compression on Lu-Carrier

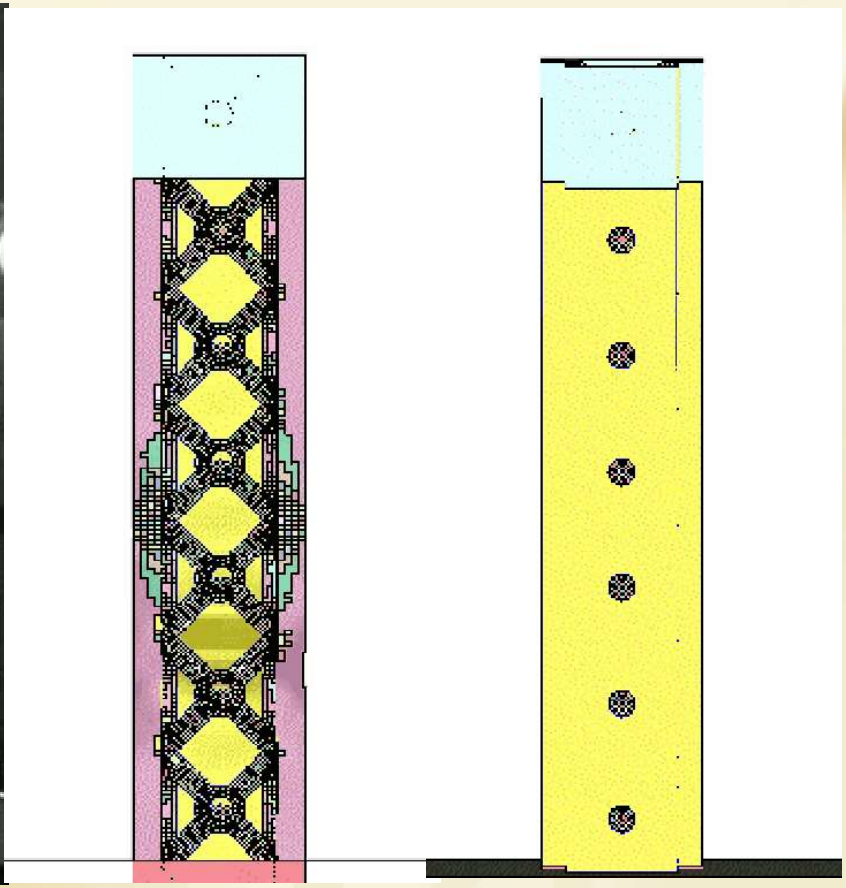
Time: 30 sec

Experiment

Simulation





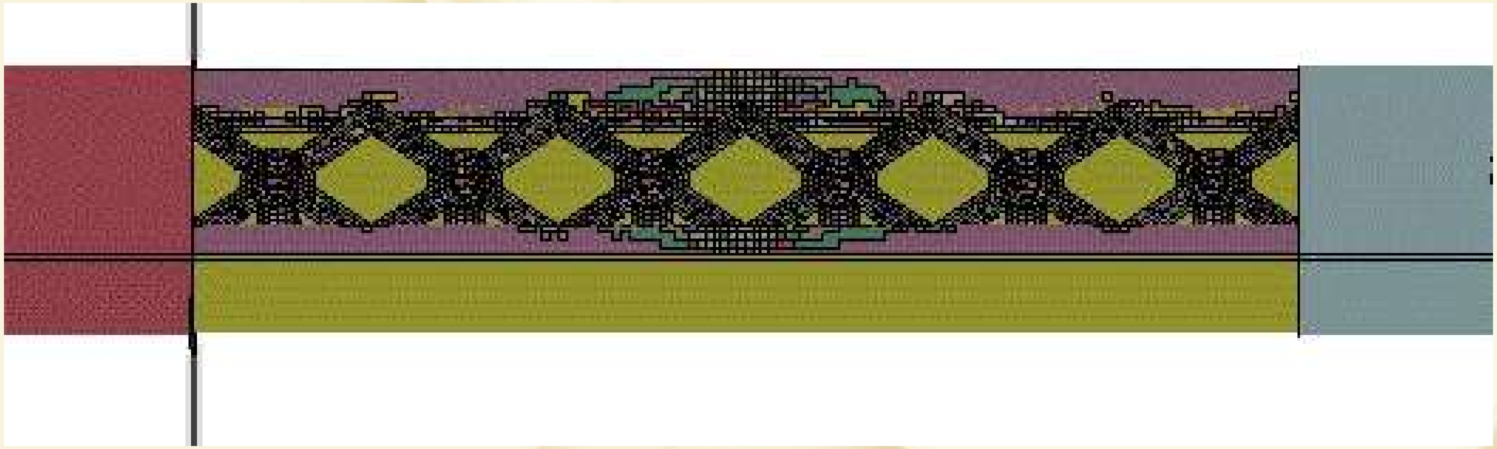


Front view

Back view

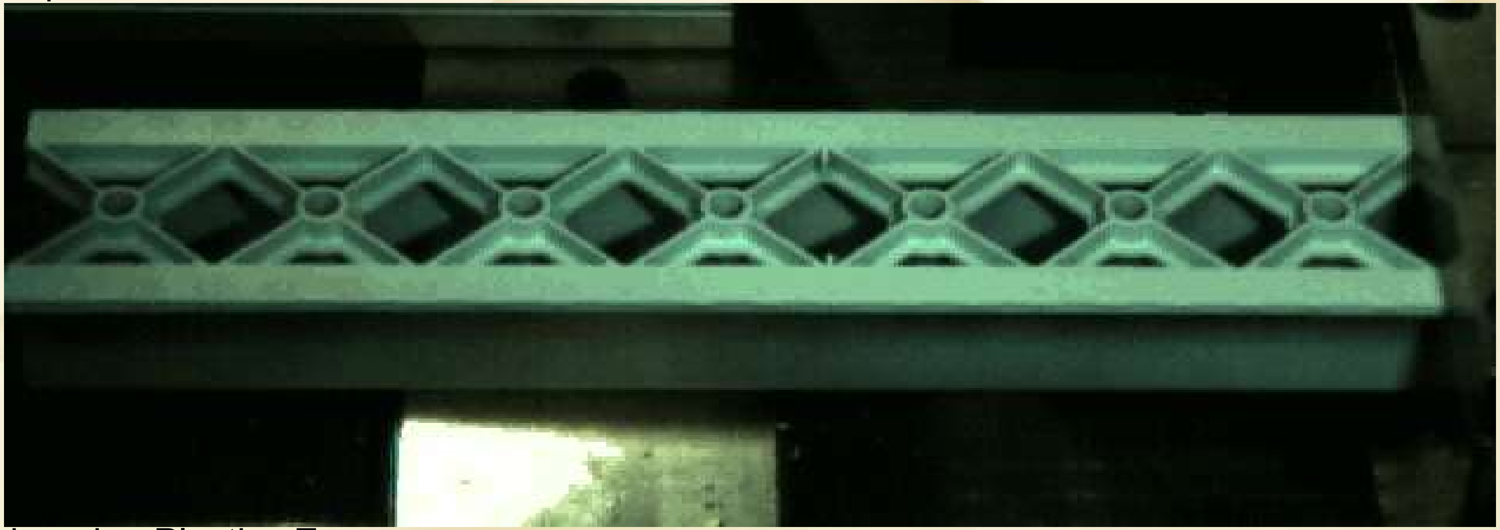
Axial Crash on Lu-Carrier

Simulation



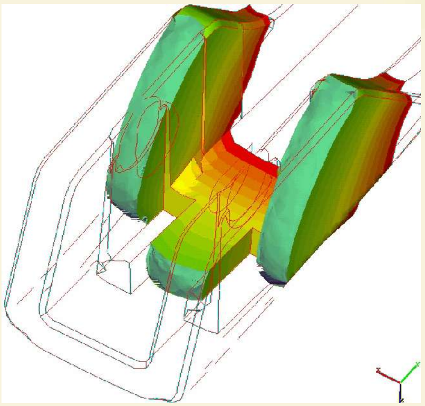
Time 0.02 sec

Experiment



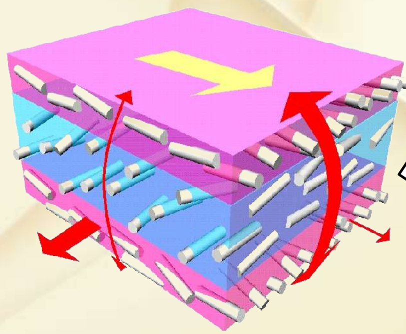
Integrative Simulation

Process



Measurement

Material



Part

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

?