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

BASF
The Chemical Company

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Engineering Plastics Europe - KTE

Content

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- **Integrative Simulation?**
  - **Motivation**
  - **Fiber orientation in filling process**
  - **Material modelling**
  - **Influence of fiber orientation tensor**
- **Simulation applications**
  - **Simulation of material tests**
  - **Static loading**
  - **Crash loading**

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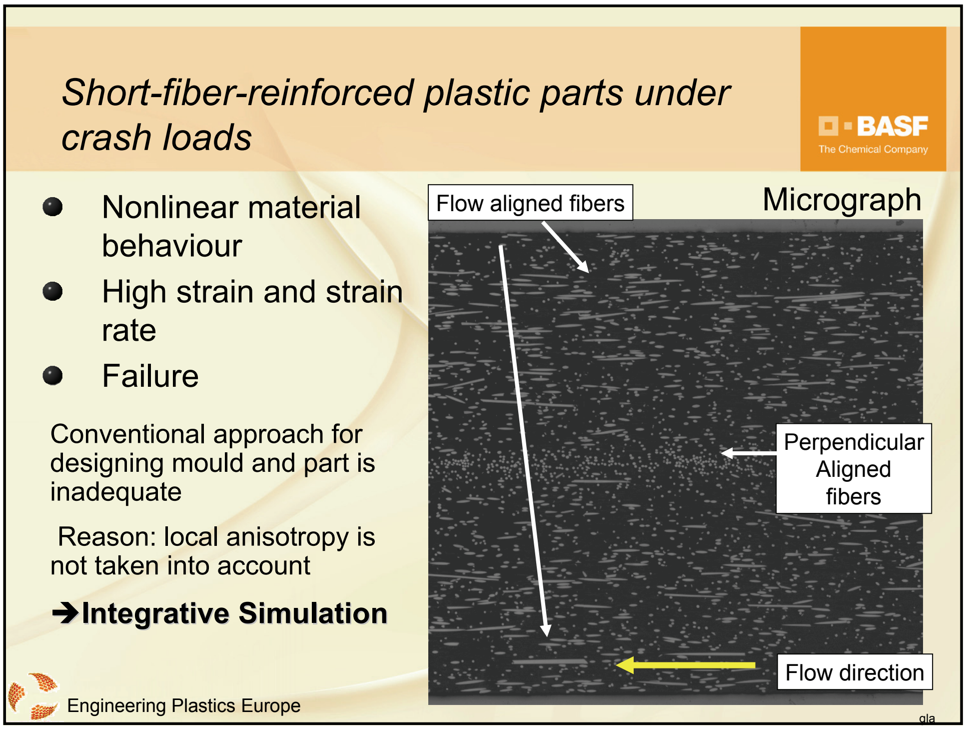
Short-fiber-reinforced plastic parts under crash loads
BASF
The Chemical Company
Nonlinear material behaviour
High strain and strain rate
Failure
Conventional approach for designing mould and part is inadequate
Reason: local anisotropy is not taken into account
➔Integrative Simulation
Flow aligned fibers
Micrograph
Perpendicular Aligned fibers
Flow direction
Engineering Plastics Europe
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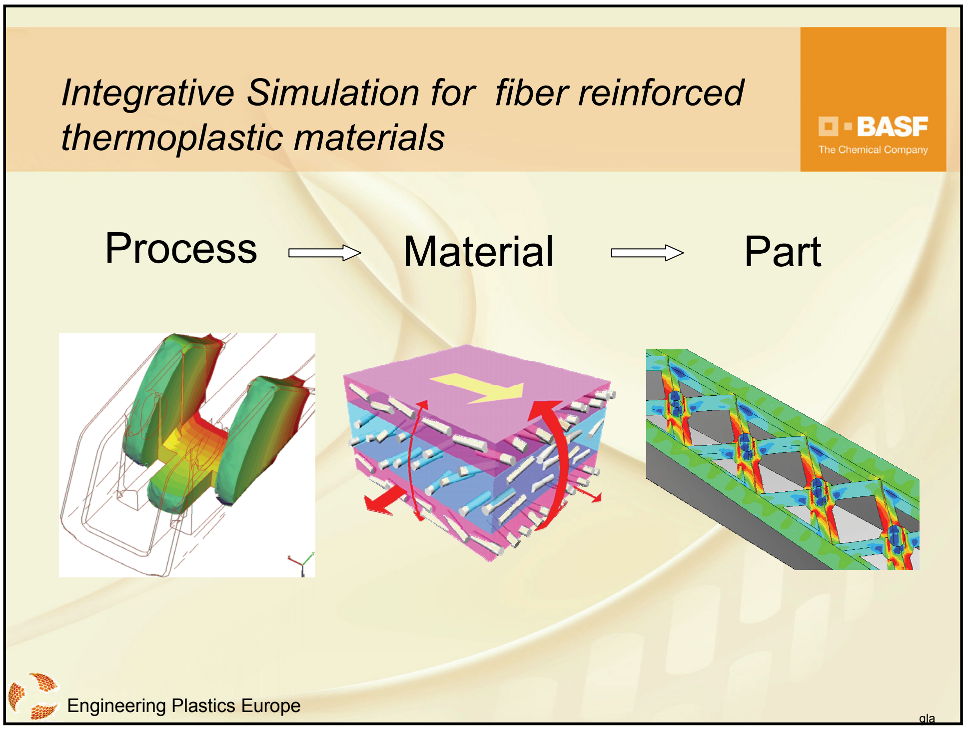
Integrative Simulation for fiber reinforced thermoplastic materials
BASF
The Chemical Company
Process
Material
Part
Engineering Plastics Europe
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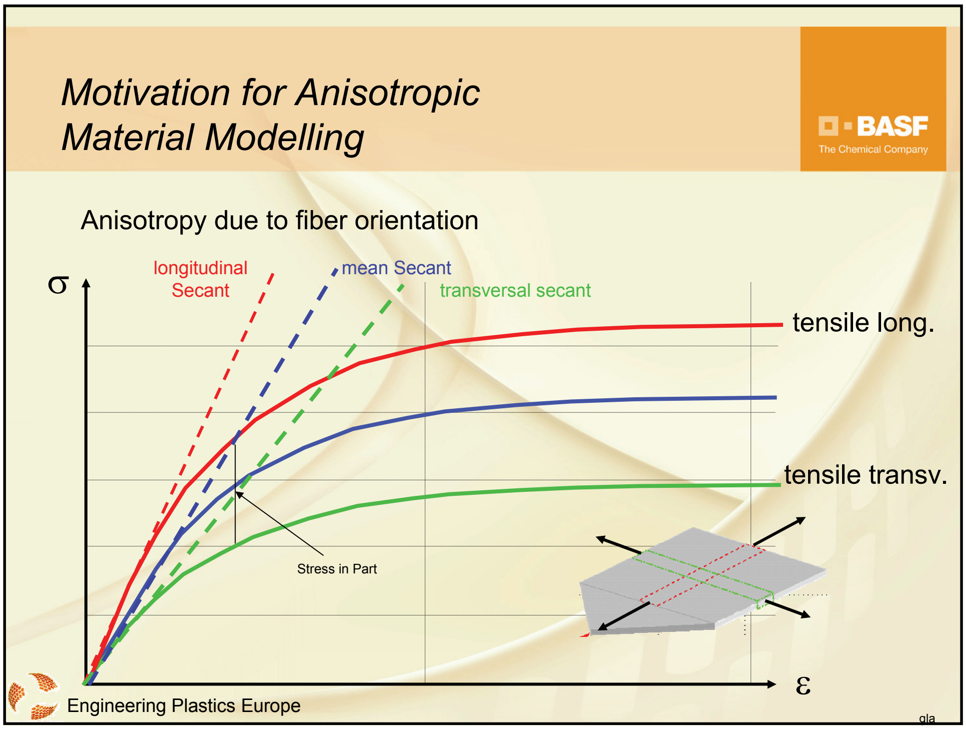
Motivation for Anisotropic
Material Modelling
BASF
The Chemical Company
Anisotropy due to fiber orientation
longitudinal
Secant
mean Secant
transversal secant
σ
tensile long.
tensile transv.
Stress in Part
ε
Engineering Plastics Europe
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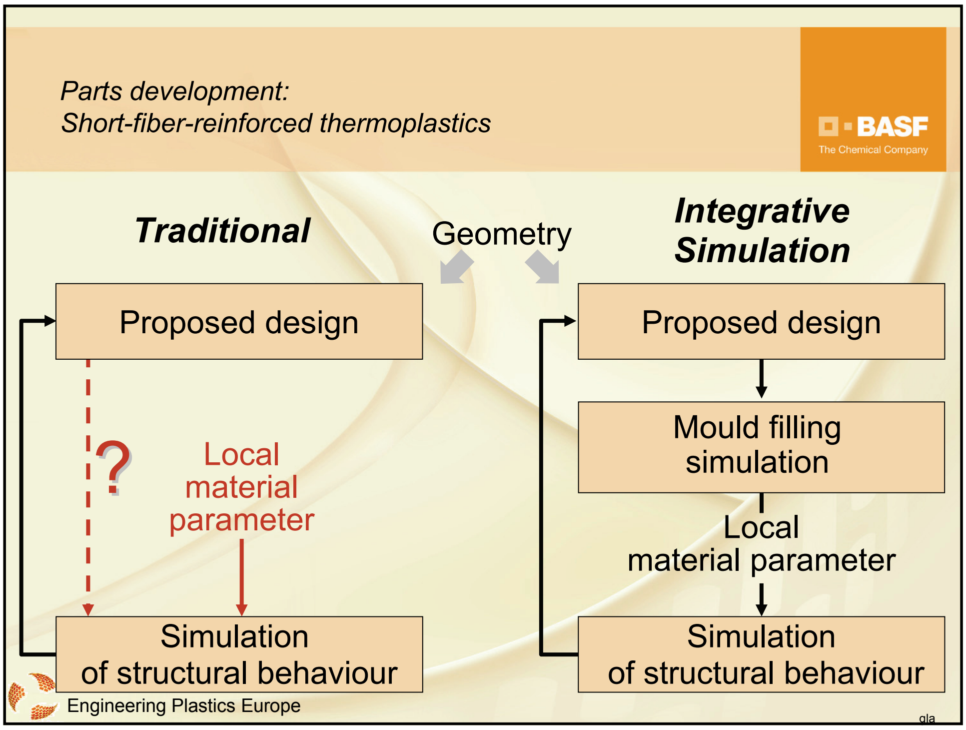
Parts development:
Short-fiber-reinforced thermoplastics
BASF
The Chemical Company
Traditional
Geometry
Integrative
Simulation
Proposed design
Proposed design
?
Local
material
parameter
Mould filling
simulation
Local
material parameter
Simulation
of structural behaviour
Simulation
of structural behaviour
Engineering Plastics Europe
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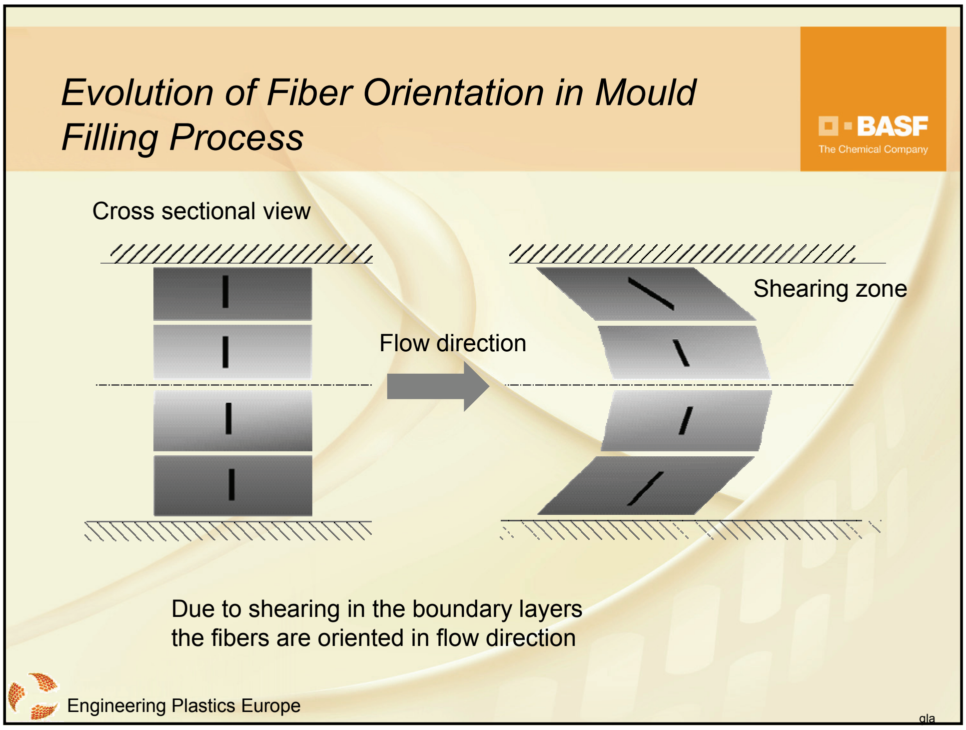
Evolution of Fiber Orientation in Mould Filling Process
BASF
The Chemical Company
Cross sectional view
Flow direction
Shearing zone
Due to shearing in the boundary layers
the fibers are oriented in flow direction
Engineering Plastics Europe
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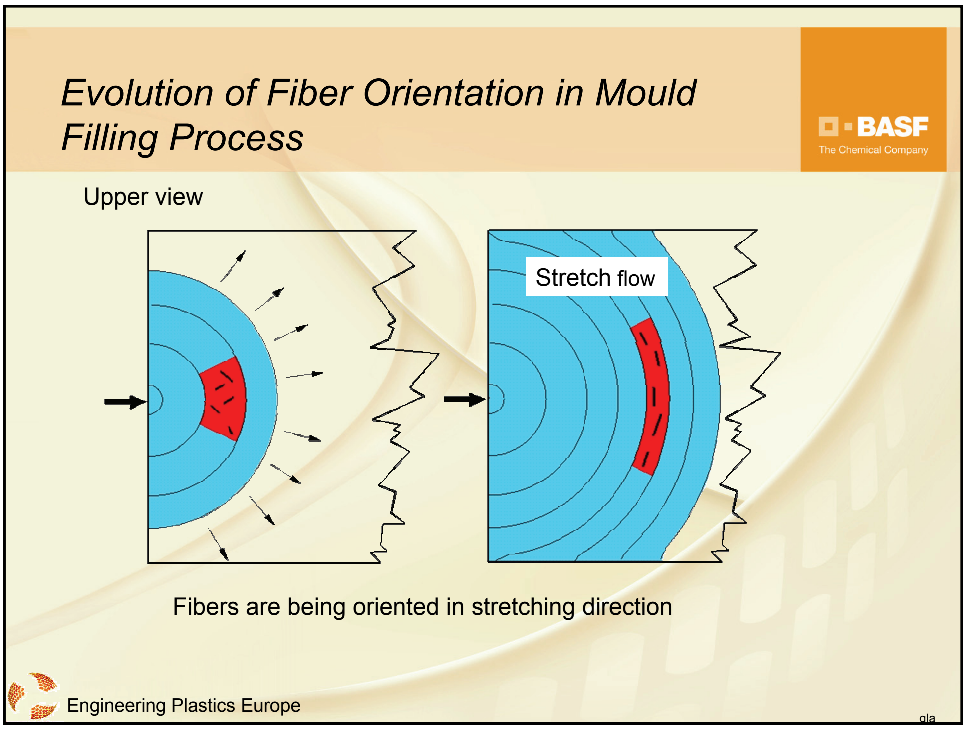
Evolution of Fiber Orientation in Mould Filling Process
BASF
The Chemical Company
Upper view
Stretch flow
Fibers are being oriented in stretching direction
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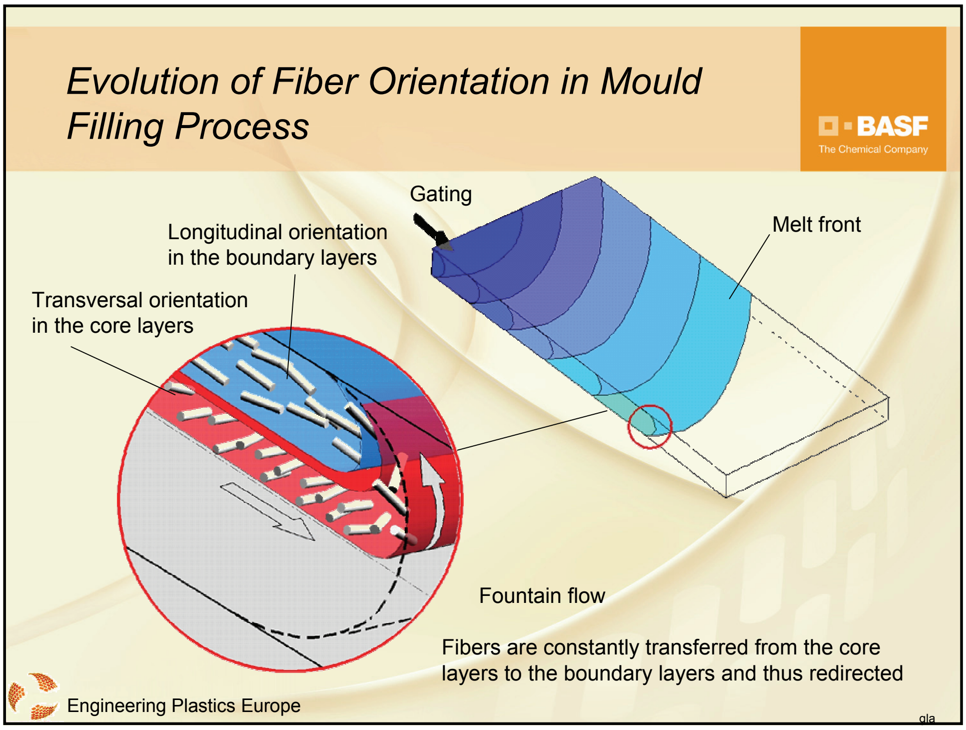
Evolution of Fiber Orientation in Mould Filling Process
BASF
The Chemical Company
Gating
Longitudinal orientation in the boundary layers
Melt front
Transversal orientation in the core layers
Fountain flow
Fibers are constantly transferred from the core layers to the boundary layers and thus redirected
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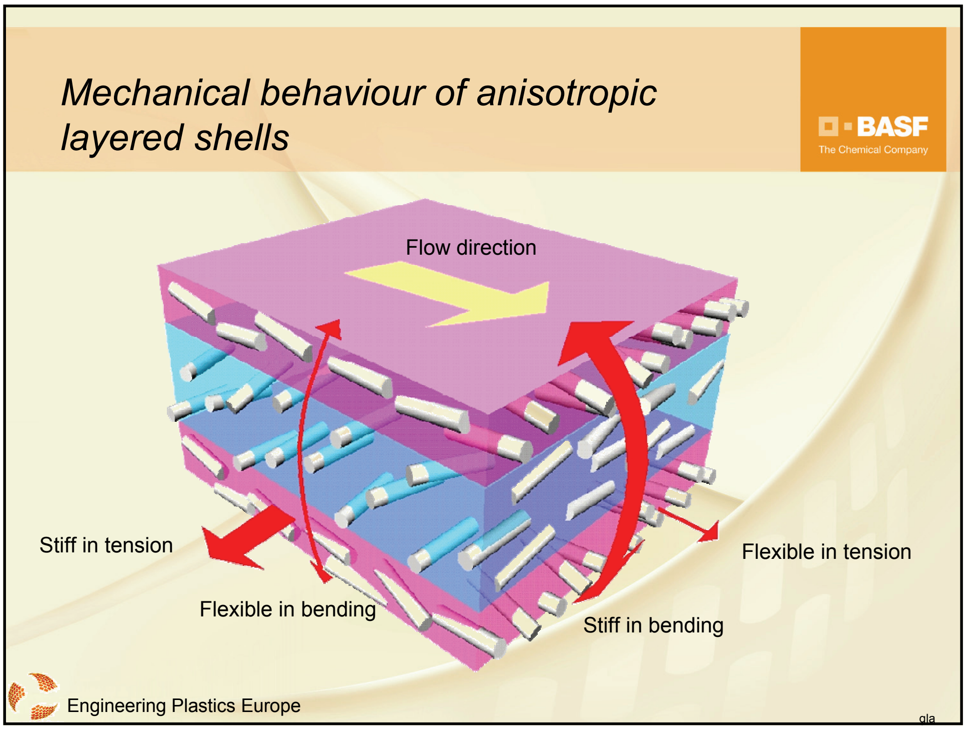
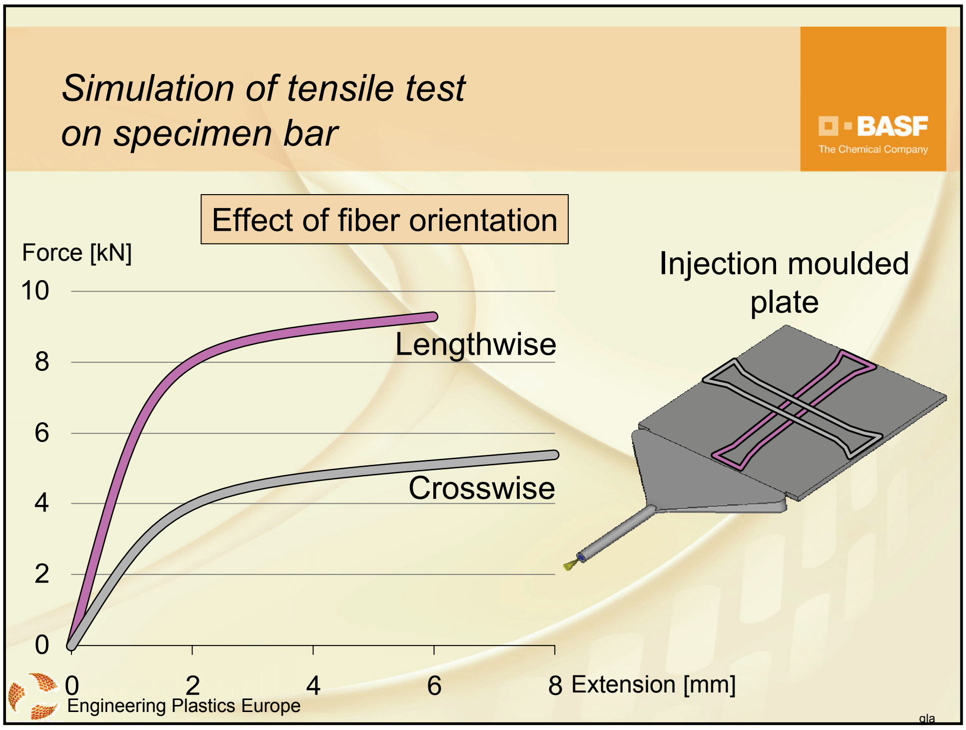
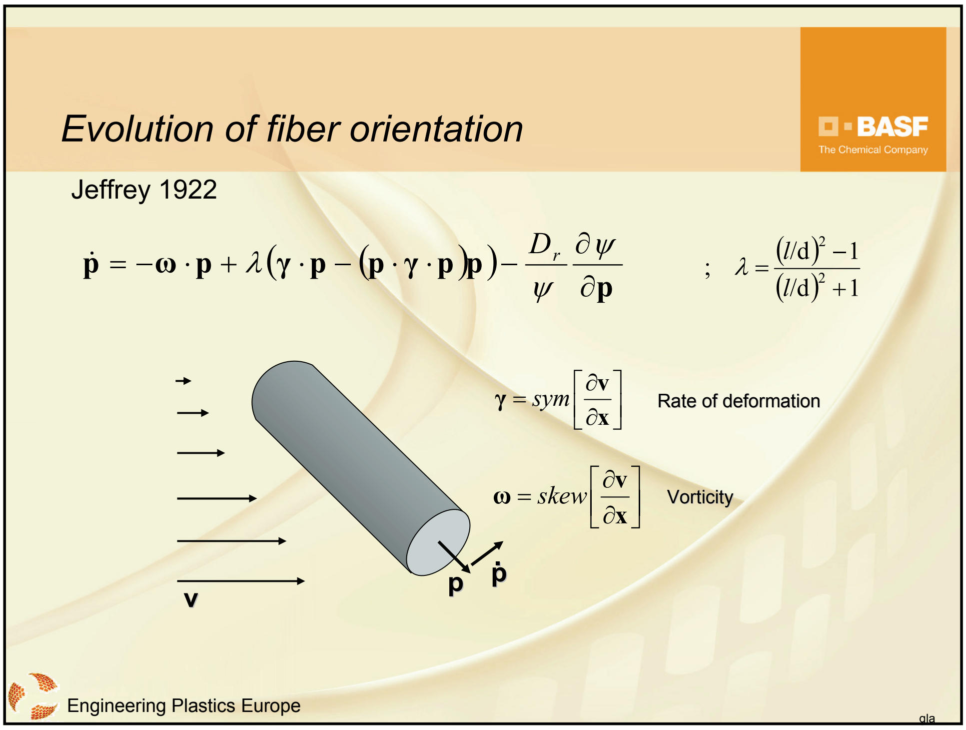

Mechanical behaviour of anisotropic layered shells
BASF
The Chemical Company
Flow direction
Stiff in tension
Flexible in tension
Flexible in bending
Stiff in bending
Engineering Plastics Europe


Simulation of tensile test
on specimen bar
BASF
The Chemical Company
Effect of fiber orientation
Force [kN]
10
8
6
4
2
0
Lengthwise
Crosswise
0
2
4
6
8 Extension [mm]
Injection moulded
plate
Engineering Plastics Europe


Evolution of fiber orientation
BASF
The Chemical Company
Jeffrey 1922
$\dot{\mathbf{p}} = -\boldsymbol{\omega}\cdot\mathbf{p} + \lambda(\boldsymbol{\gamma}\cdot\mathbf{p} - (\mathbf{p}\cdot\boldsymbol{\gamma}\cdot\mathbf{p})\mathbf{p}) - \frac{D_r}{\psi}\frac{\partial\psi}{\partial\mathbf{p}}$; $\lambda = \frac{(l/d)^2 - 1}{(l/d)^2 + 1}$
$\boldsymbol{\gamma} = sym\left[\frac{\partial\mathbf{v}}{\partial\mathbf{x}}\right]$ Rate of deformation
$\boldsymbol{\omega} = skew\left[\frac{\partial\mathbf{v}}{\partial\mathbf{x}}\right]$ Vorticity
v
p
ṗ
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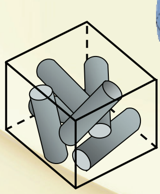
Orientation distribution function

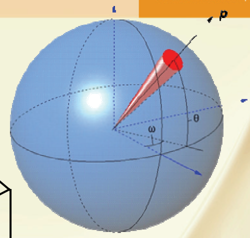
Orientation tensors

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

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

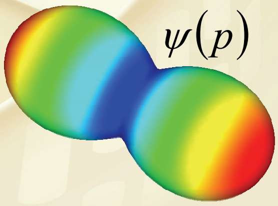
(Tucker 1987)





Taylor expansion of ODF

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



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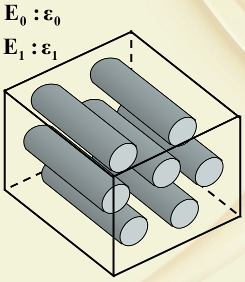
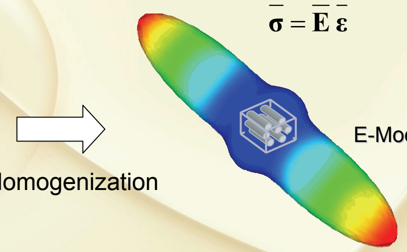
Homogenization of fibers and polymer

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



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

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

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

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

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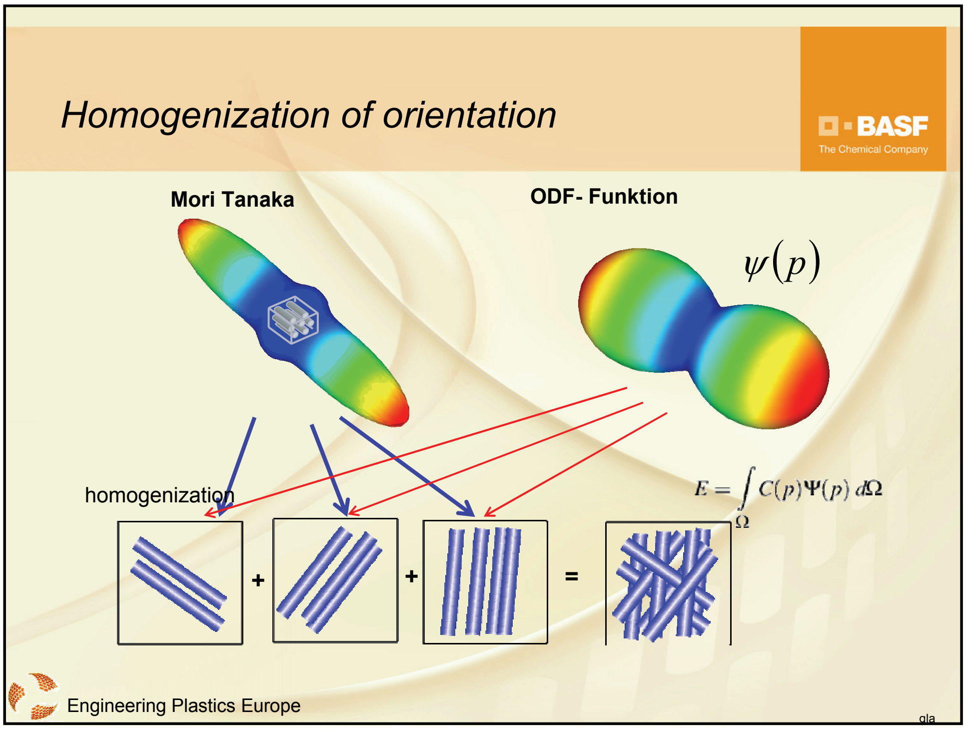
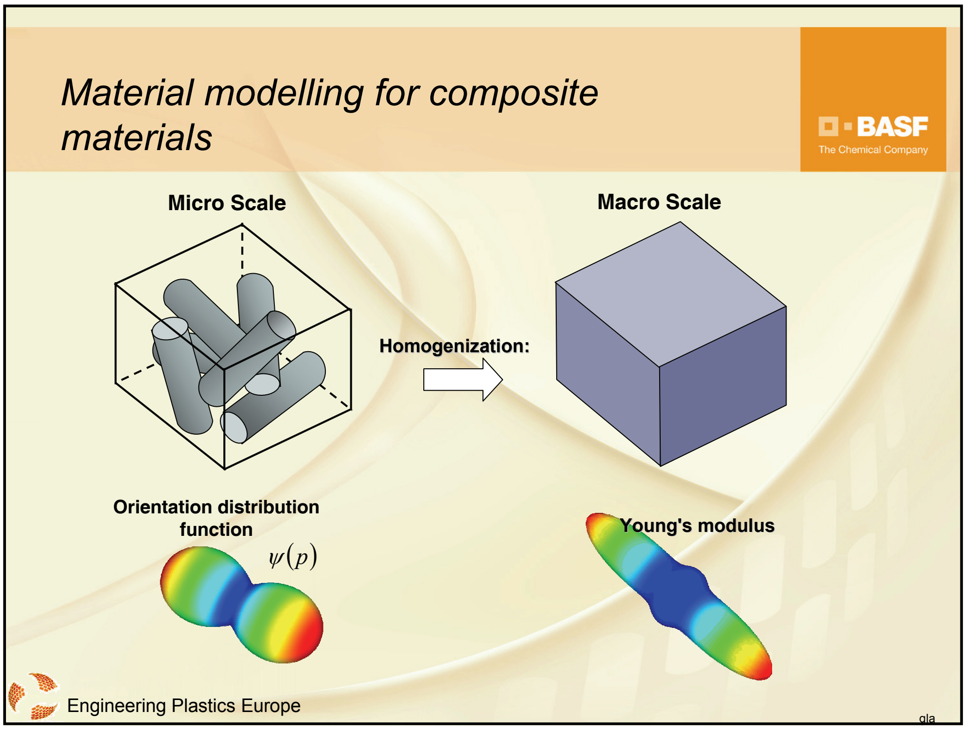
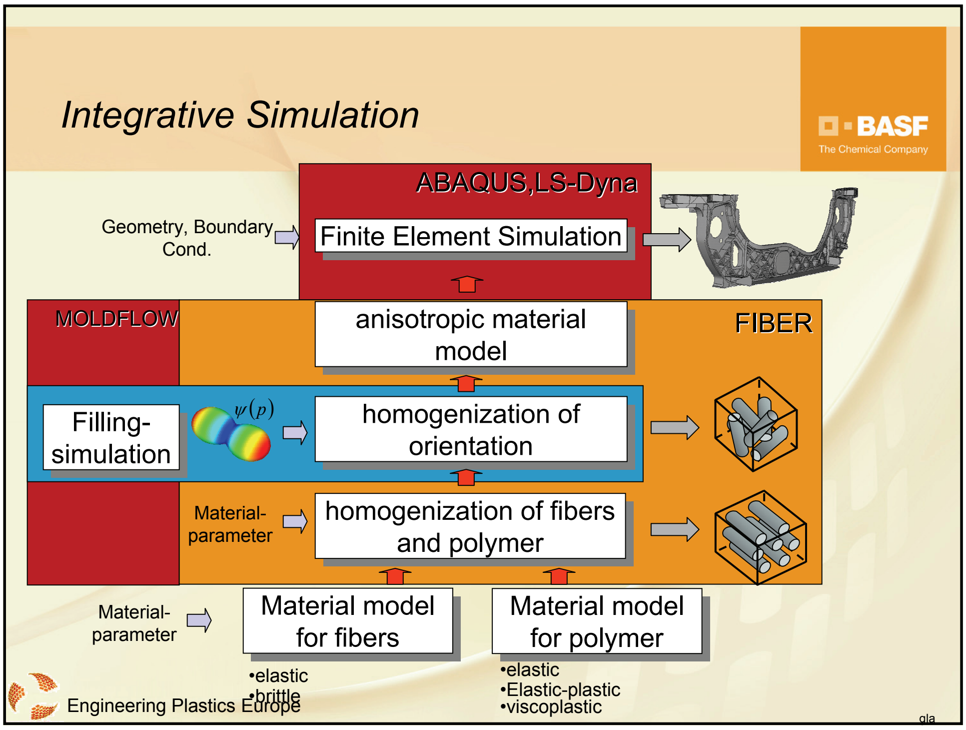
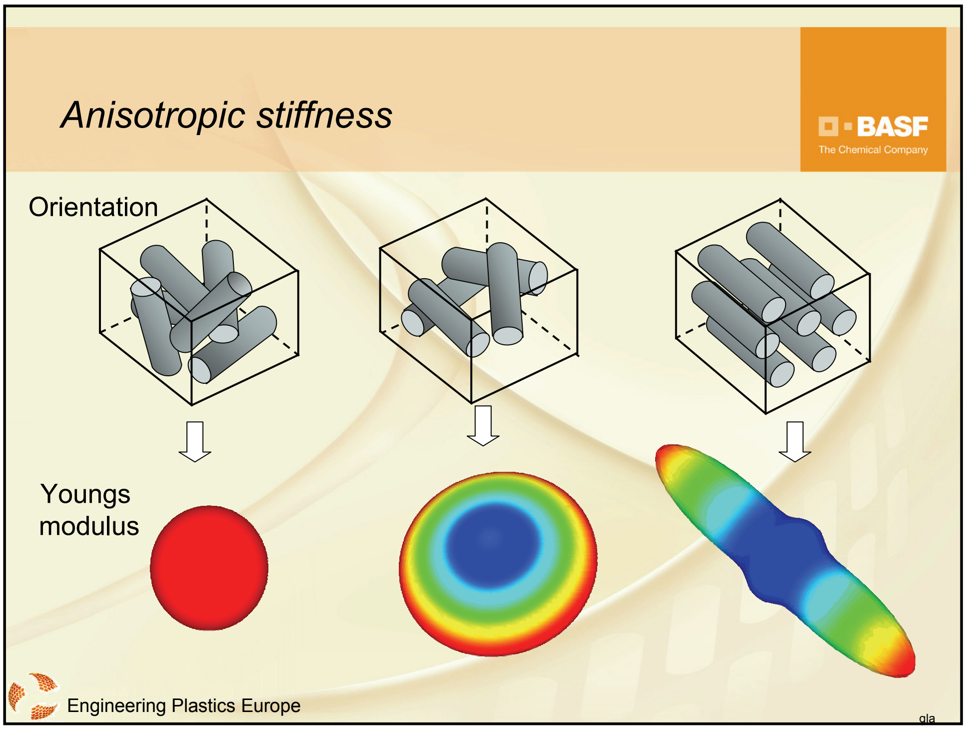


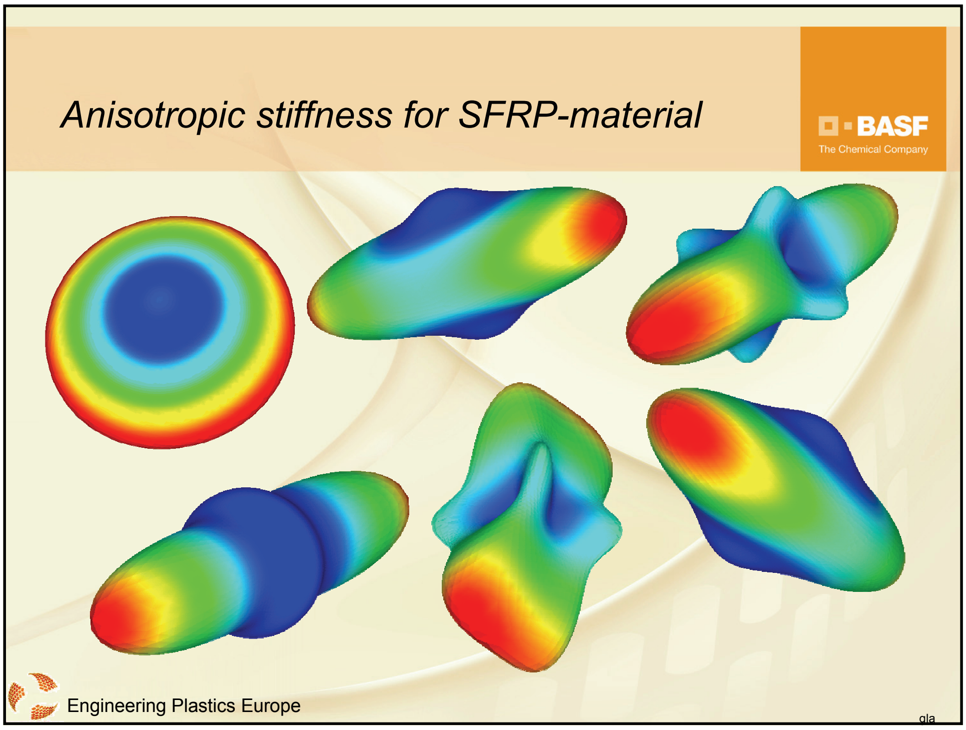
Homogenization of orientation
BASF
The Chemical Company
Mori Tanaka
ODF- Funktion
$\psi(p)$
homogenization
$E = \int_\Omega C(p)\Psi(p)\, d\Omega$
+
+
=
Engineering Plastics Europe
gla

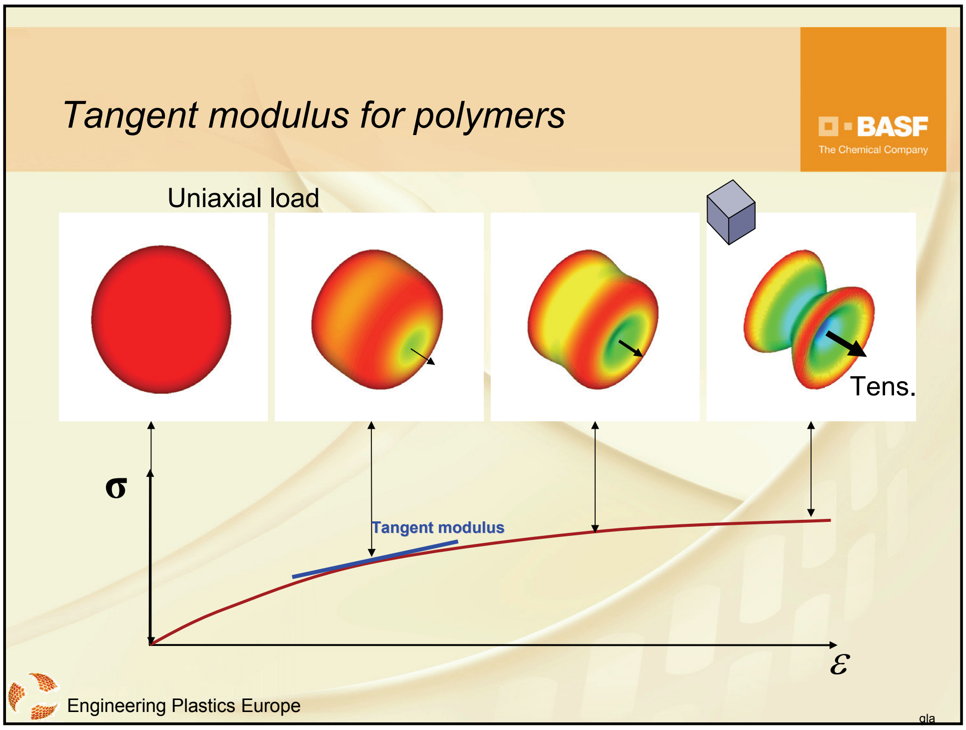


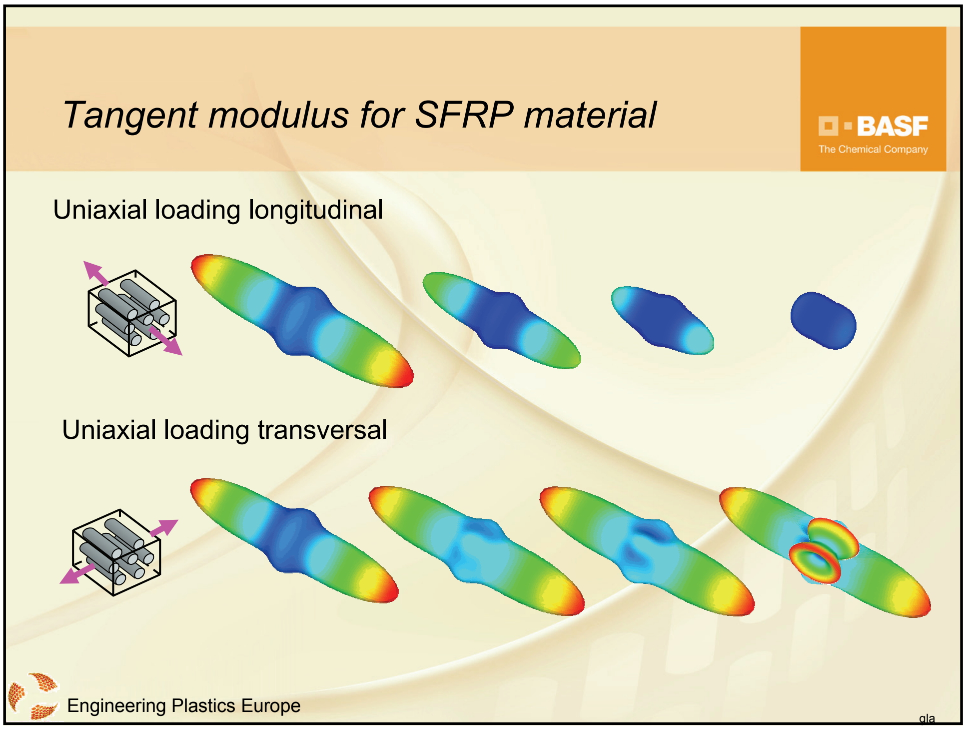
Material modelling for composite materials
BASF
The Chemical Company
Micro Scale
Macro Scale
Homogenization:
Orientation distribution function
$\psi(p)$
Young's modulus
Engineering Plastics Europe
gla

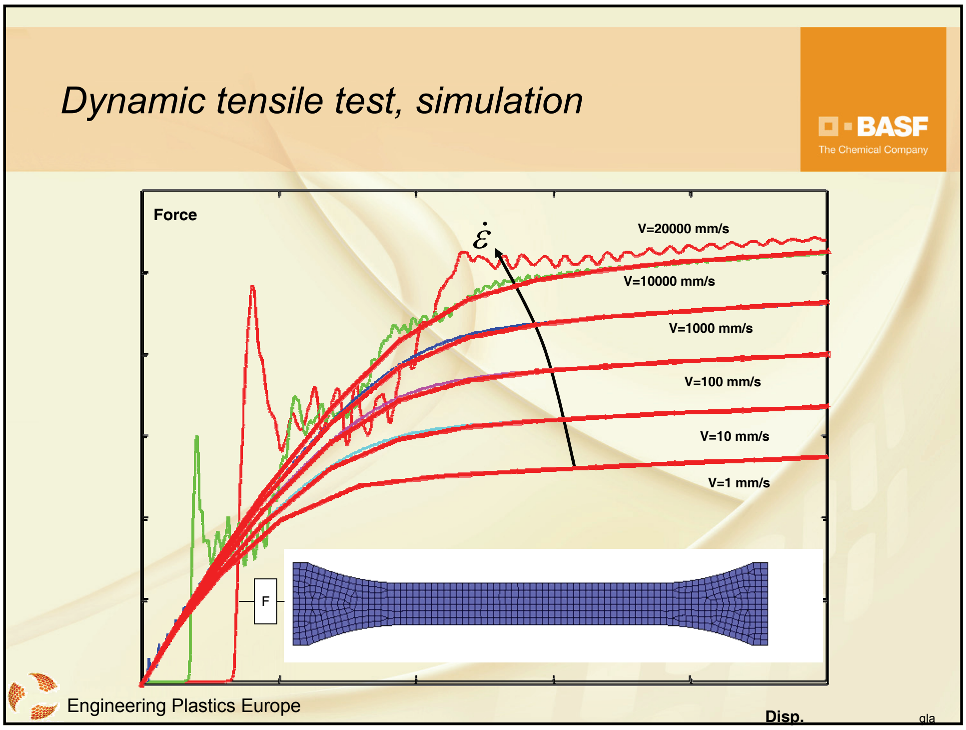

Integrative Simulation
BASF
The Chemical Company
ABAQUS,LS-Dyna
Geometry, Boundary Cond.
Finite Element Simulation
MOLDFLOW
anisotropic material model
FIBER
Filling-simulation
ψ(p)
homogenization of orientation
Material-parameter
homogenization of fibers and polymer
Material-parameter
Material model for fibers
Material model for polymer
•elastic
•brittle
•elastic
•Elastic-plastic
•viscoplastic
Engineering Plastics Europe

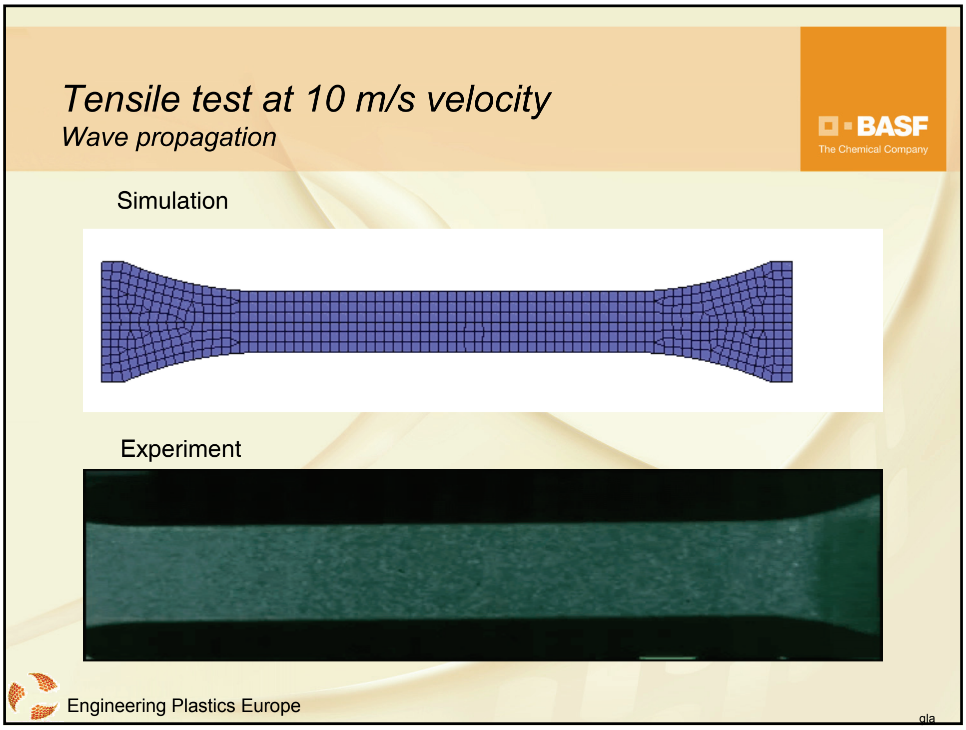

Anisotropic stiffness
BASF
The Chemical Company
Orientation
Youngs modulus
Engineering Plastics Europe

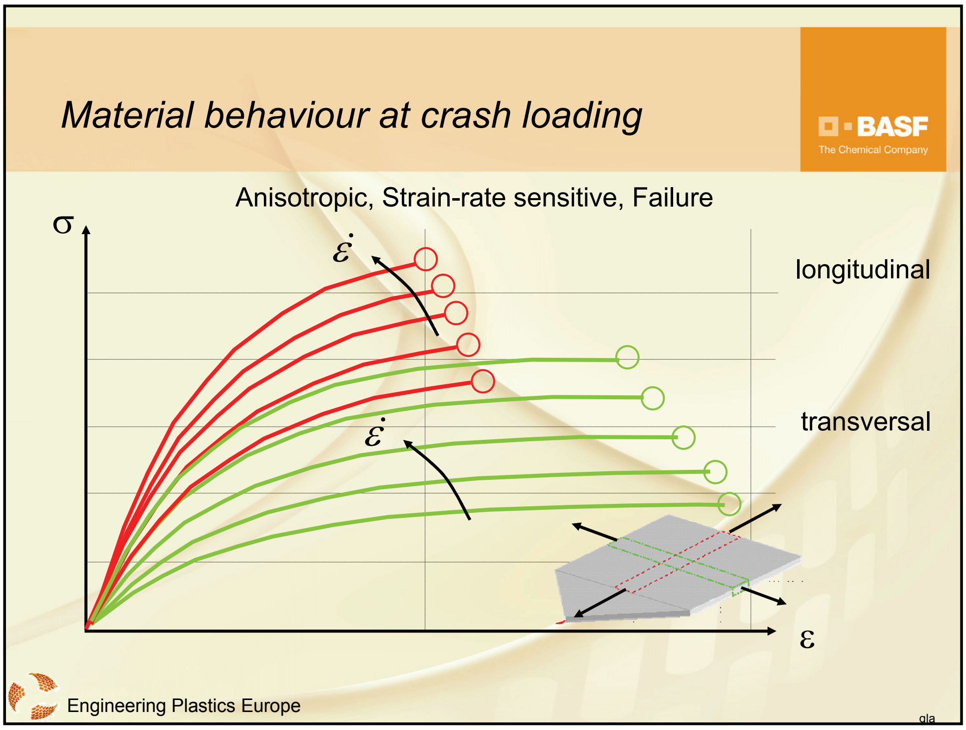

Anisotropic stiffness for SFRP-material
BASF
The Chemical Company
Engineering Plastics Europe
gla

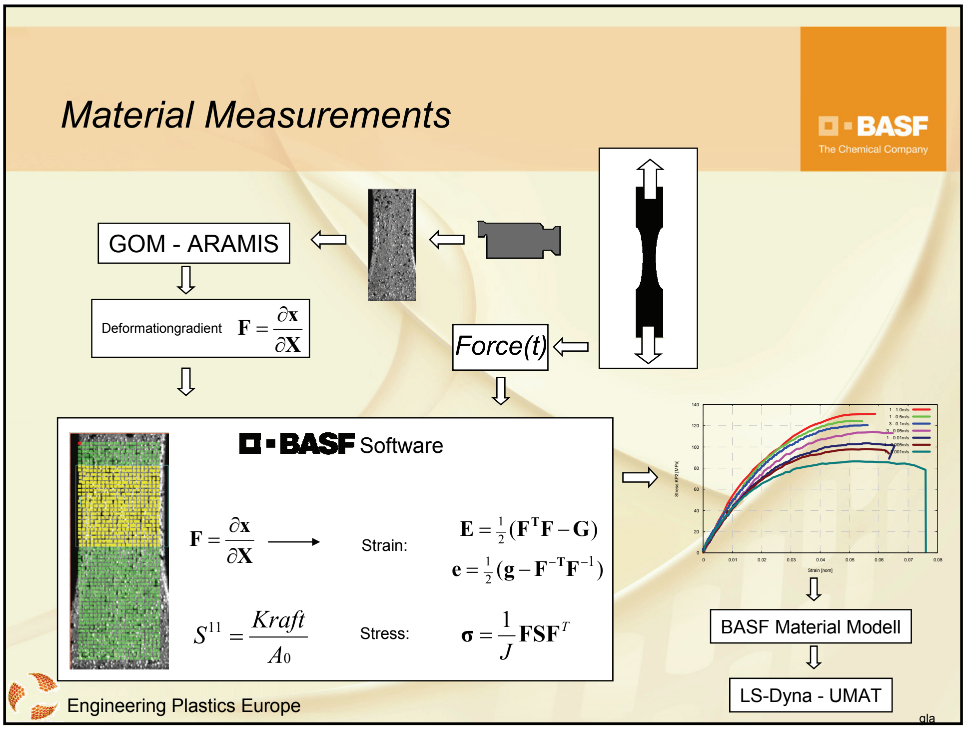

Tangent modulus for polymers
BASF
The Chemical Company
Uniaxial load
Tens.
σ
Tangent modulus
ε
Engineering Plastics Europe
gla


Tangent modulus for SFRP material
BASF
The Chemical Company
Uniaxial loading longitudinal
Uniaxial loading transversal
Engineering Plastics Europe
gla


Dynamic tensile test, simulation
BASF
The Chemical Company
Force
V=20000 mm/s
V=10000 mm/s
V=1000 mm/s
V=100 mm/s
V=10 mm/s
V=1 mm/s
F
Disp.
Engineering Plastics Europe
gla


Tensile test at 10 m/s velocity
Wave propagation
BASF
The Chemical Company
Simulation
Experiment
Engineering Plastics Europe
gla


Material behaviour at crash loading
BASF
The Chemical Company
Anisotropic, Strain-rate sensitive, Failure
σ
$\dot{\varepsilon}$
longitudinal
$\dot{\varepsilon}$
transversal
ε
Engineering Plastics Europe
gla


Material Measurements
BASF
The Chemical Company
GOM - ARAMIS
Deformationgradient $\mathbf{F} = \frac{\partial \mathbf{x}}{\partial \mathbf{X}}$
Force(t)
BASF Software
$\mathbf{F} = \frac{\partial \mathbf{x}}{\partial \mathbf{X}}$
Strain:
$\mathbf{E} = \frac{1}{2}(\mathbf{F}^T\mathbf{F} - \mathbf{G})$
$\mathbf{e} = \frac{1}{2}(\mathbf{g} - \mathbf{F}^{-T}\mathbf{F}^{-1})$
$S^{11} = \frac{Kraft}{A_0}$
Stress:
$\boldsymbol{\sigma} = \frac{1}{J}\mathbf{FSF}^T$
BASF Material Modell
LS-Dyna - UMAT
Engineering Plastics Europe
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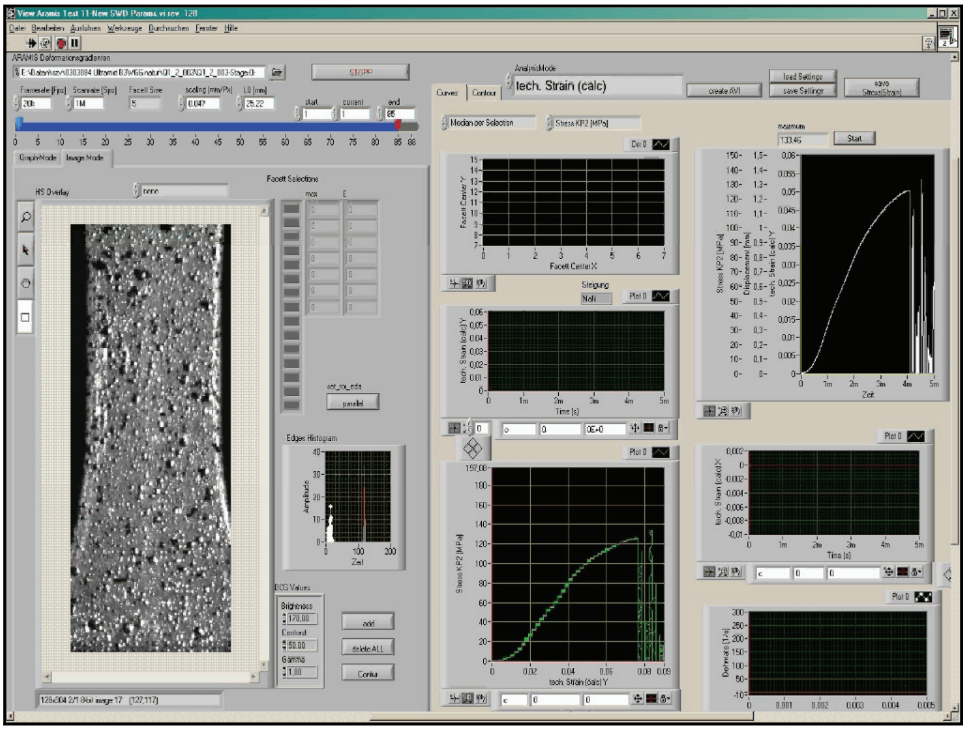

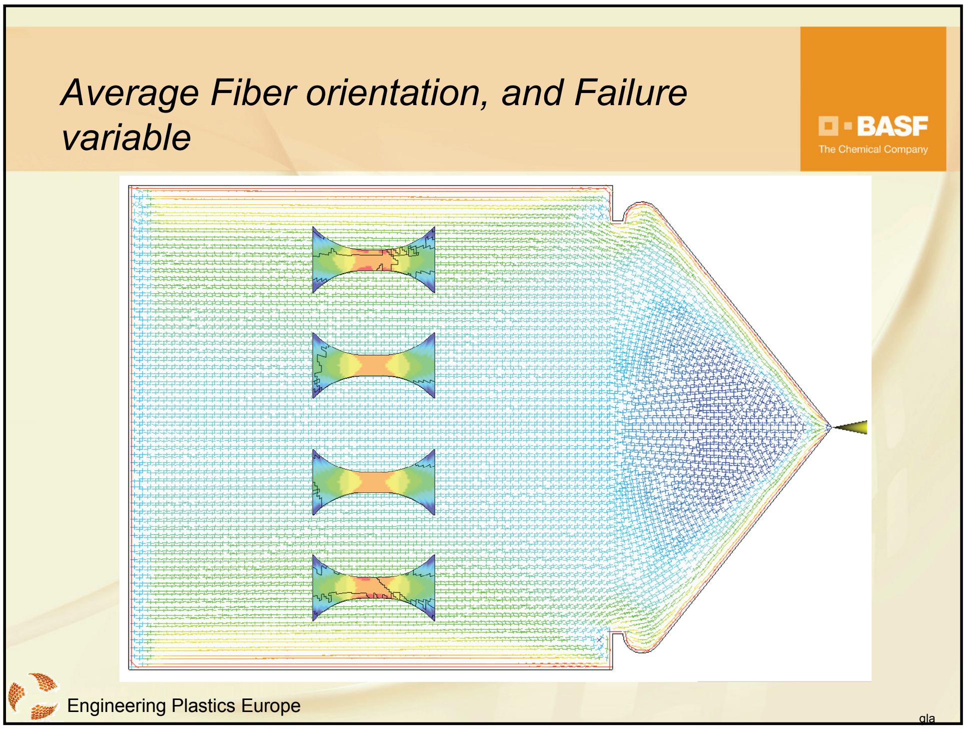
Average Fiber orientation, and Failure variable
BASF
The Chemical Company
Engineering Plastics Europe
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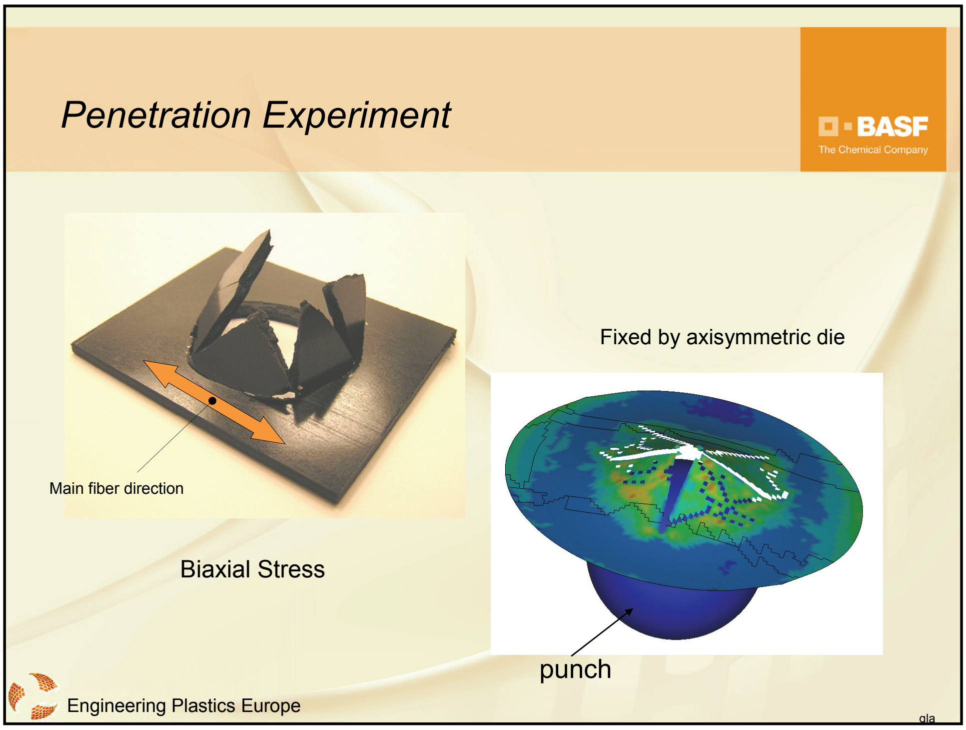
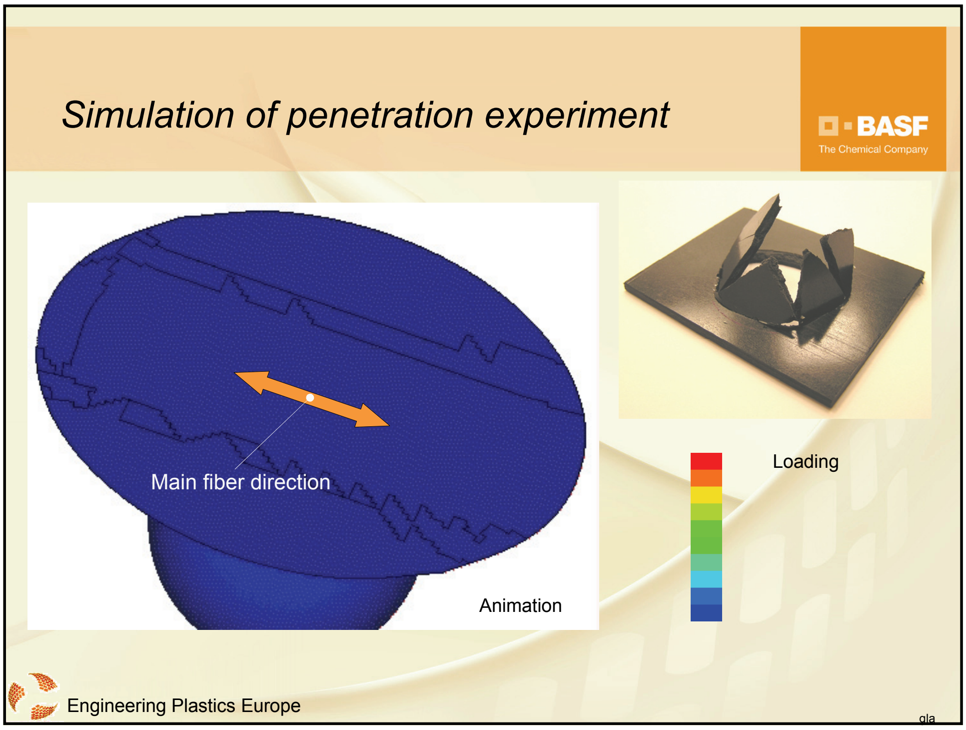
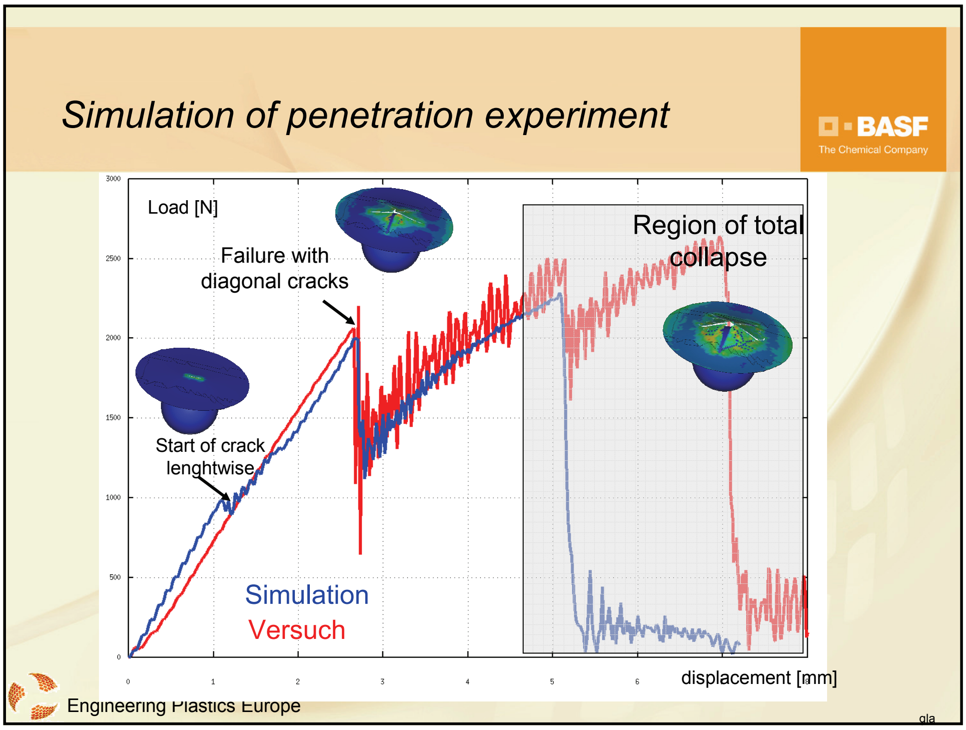
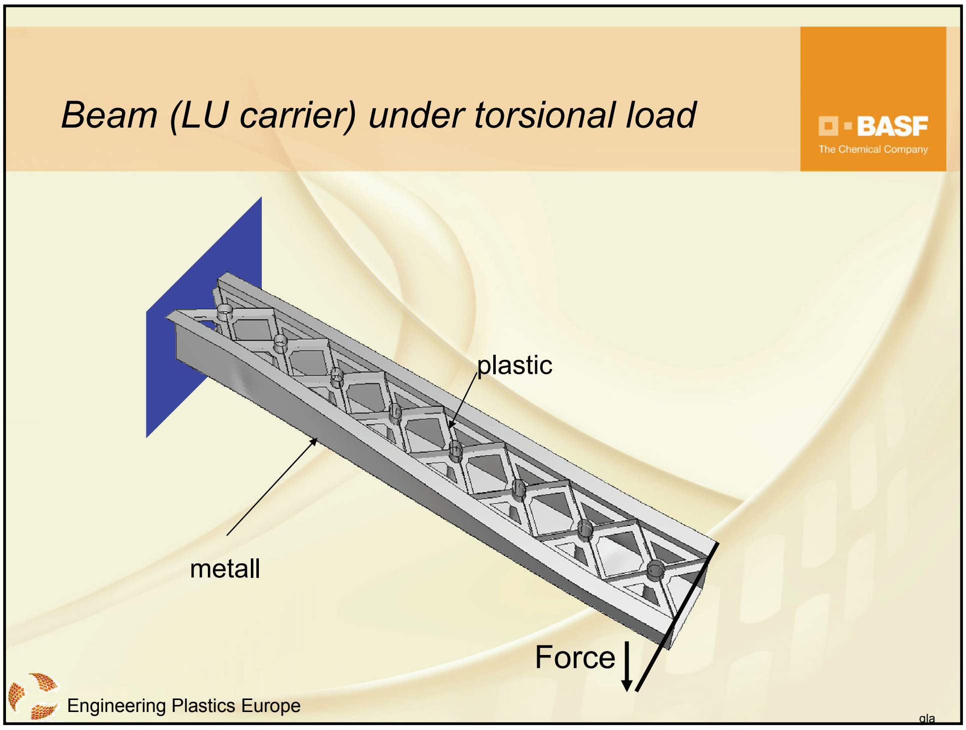
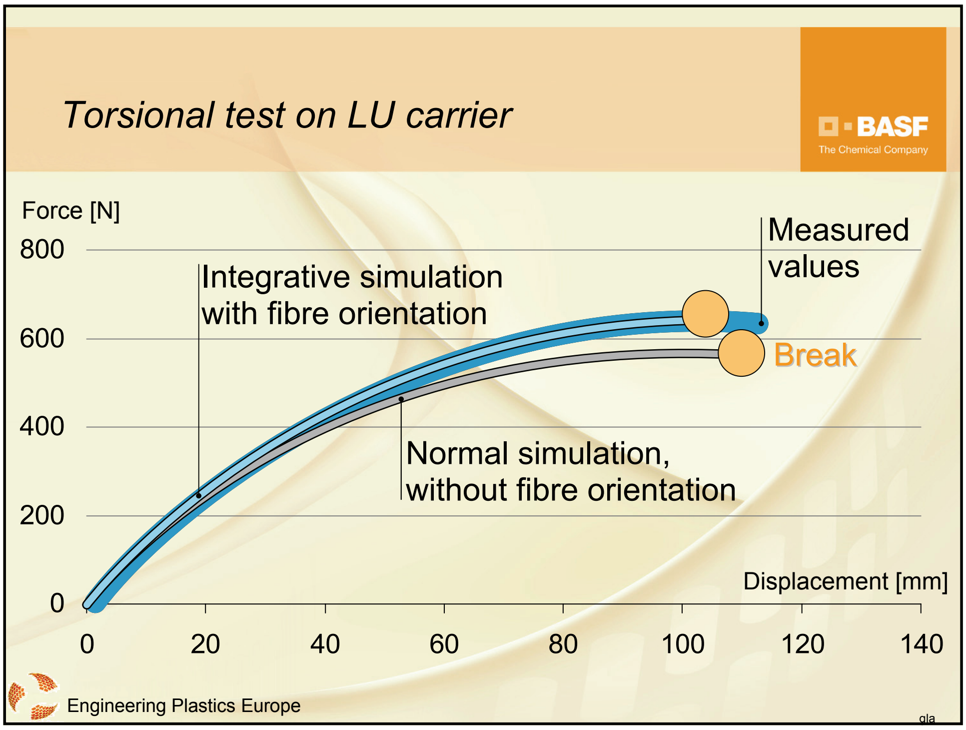
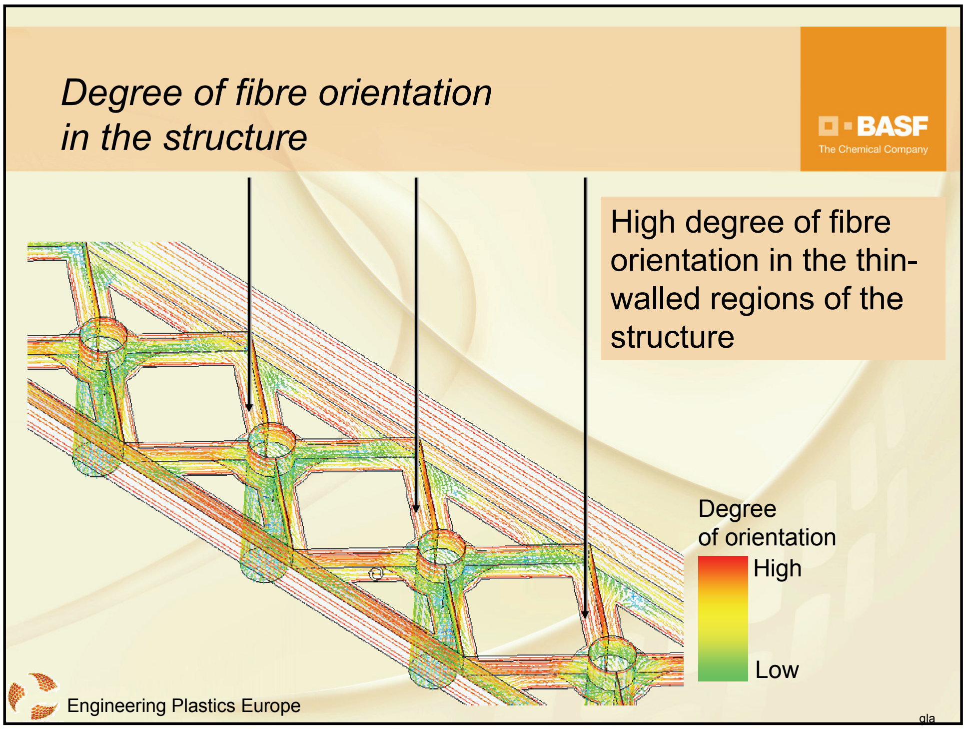

Penetration Experiment
BASF
The Chemical Company
Main fiber direction
Biaxial Stress
Fixed by axisymmetric die
punch
Engineering Plastics Europe
gla


Simulation of penetration experiment
BASF
The Chemical Company
Main fiber direction
Animation
Loading
Engineering Plastics Europe
gla


Simulation of penetration experiment
BASF
The Chemical Company
Load [N]
Failure with
diagonal cracks
Region of total
collapse
Start of crack
lenghtwise
Simulation
Versuch
displacement [mm]
Engineering Plastics Europe
gla


Beam (LU carrier) under torsional load
BASF
The Chemical Company
plastic
metall
Force
Engineering Plastics Europe
gla


Torsional test on LU carrier
BASF
The Chemical Company
Force [N]
800
600
400
200
0
Integrative simulation
with fibre orientation
Measured
values
Break
Normal simulation,
without fibre orientation
Displacement [mm]
0
20
40
60
80
100
120
140
Engineering Plastics Europe
gla


Degree of fibre orientation
in the structure
BASF
The Chemical Company
High degree of fibre orientation in the thin-walled regions of the structure
Degree
of orientation
High
Low
Engineering Plastics Europe
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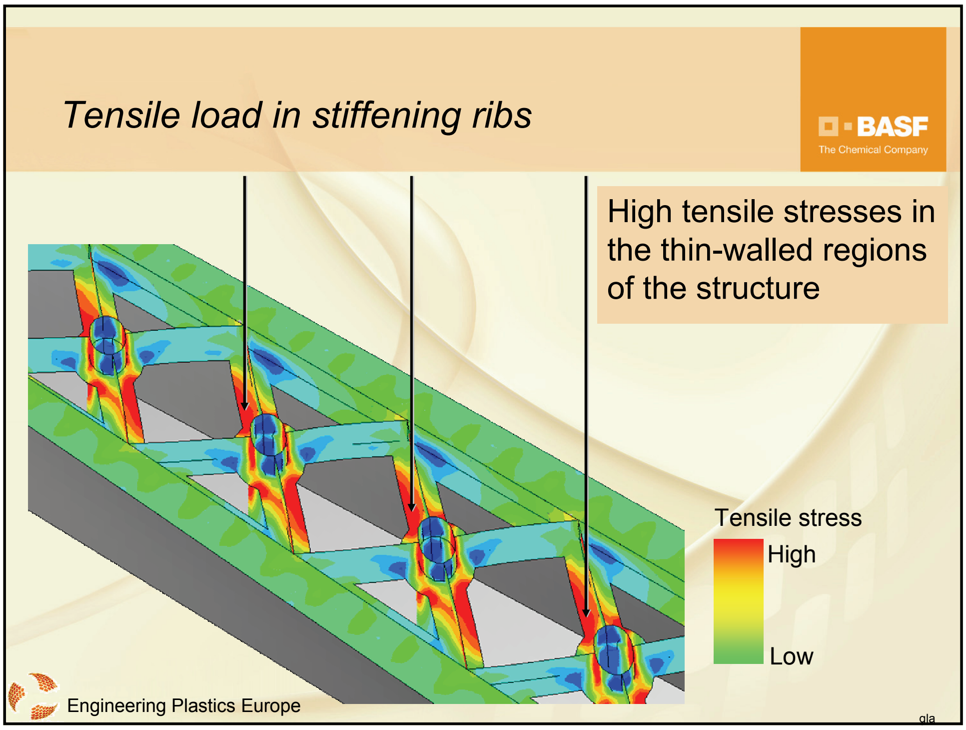
Tensile load in stiffening ribs
BASF
The Chemical Company
High tensile stresses in the thin-walled regions of the structure
Tensile stress
High
Low
Engineering Plastics Europe
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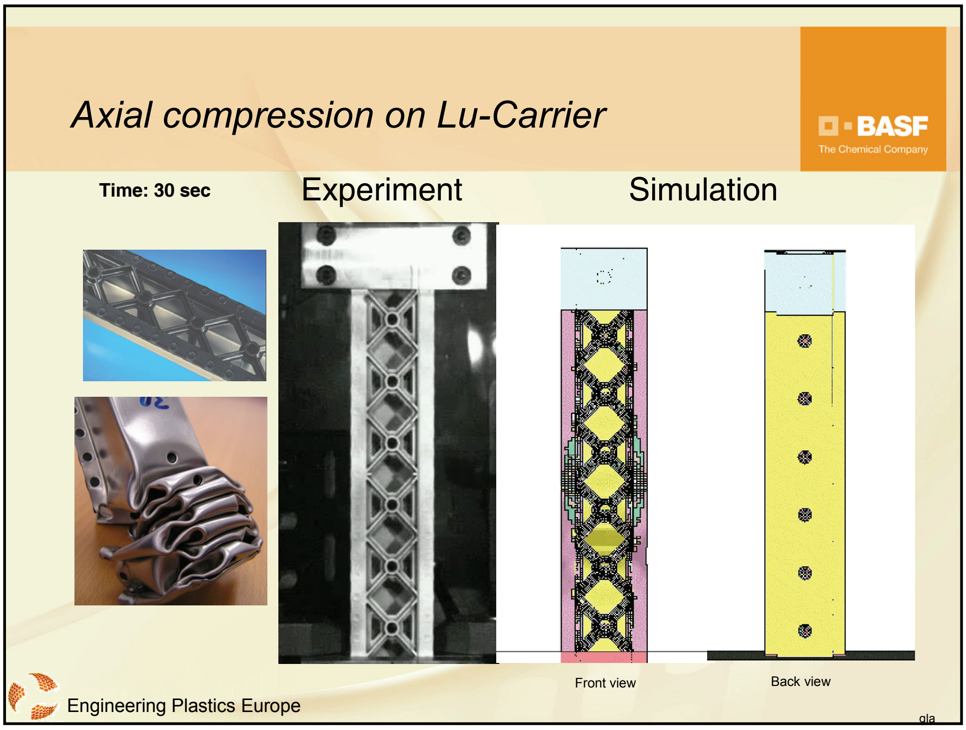
Axial compression on Lu-Carrier
BASF
The Chemical Company
Time: 30 sec
Experiment
Simulation
Front view
Back view
Engineering Plastics Europe
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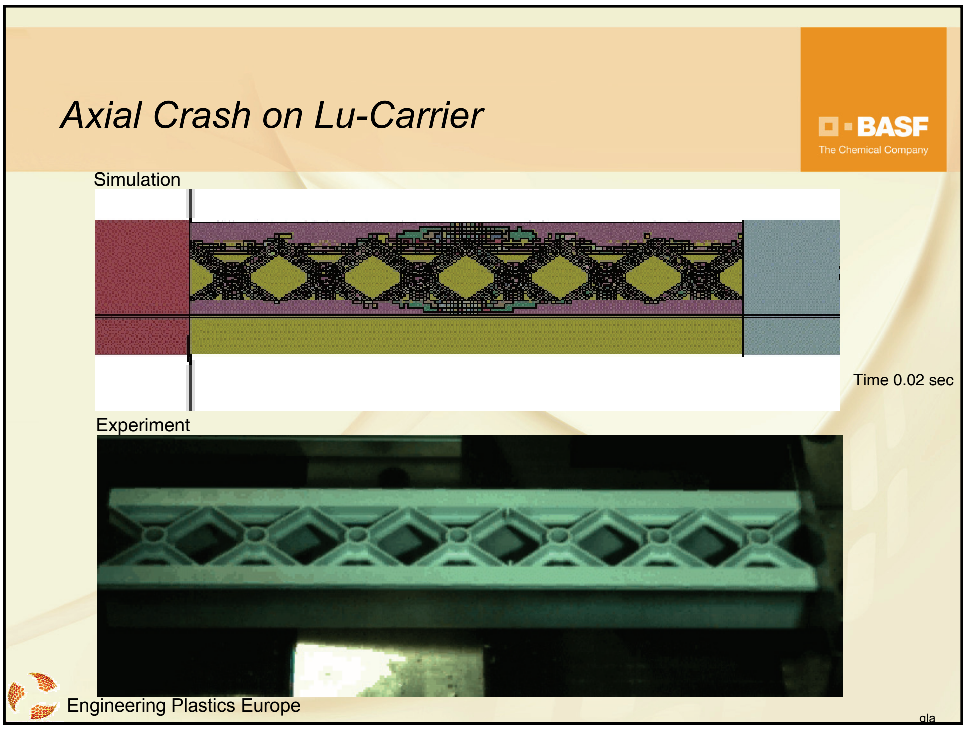
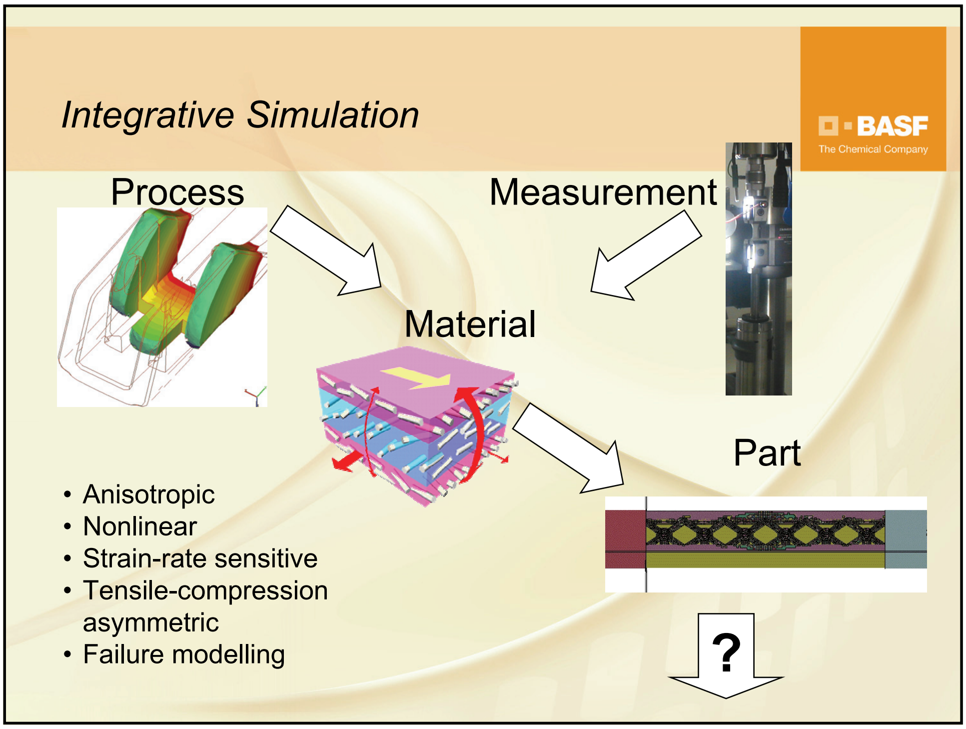

Axial Crash on Lu-Carrier
BASF
The Chemical Company
Simulation
Time 0.02 sec
Experiment
Engineering Plastics Europe
gla


Integrative Simulation
BASF
The Chemical Company
Process
Measurement
Material
Part
• Anisotropic
• Nonlinear
• Strain-rate sensitive
• Tensile-compression asymmetric
• Failure modelling
?