Beschreibung von unverstärkten, kurzfaserverstärkten und endlosfaserverstärkten Kunststoffen in der Crashsimulation

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MATFEM Partnerschaft Dr. Gese & Oberhofer, München

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MATFEM

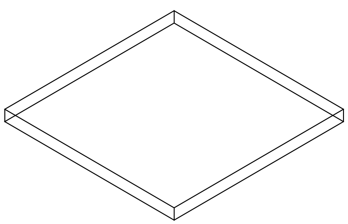
MF GenYld + CrachFEM for polymers

MATFEM

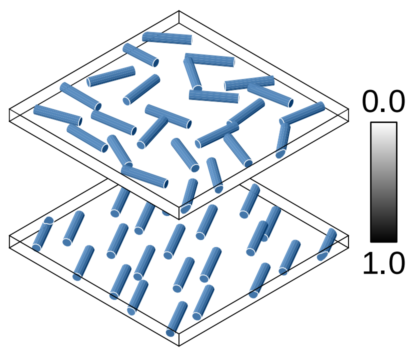
▶ Different classes of polymers

Endless fibre reinforced polymers

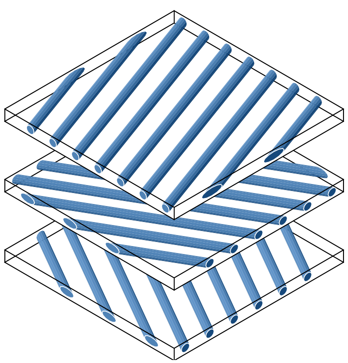
Non-reinforced polymer



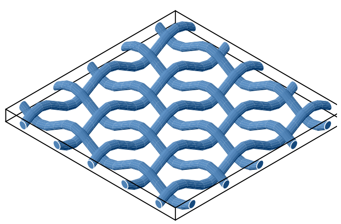
Short-fibre reinforced polymer



Unidirectional layer



Organic fabric



MF GenYld + CrachFEM for polymers

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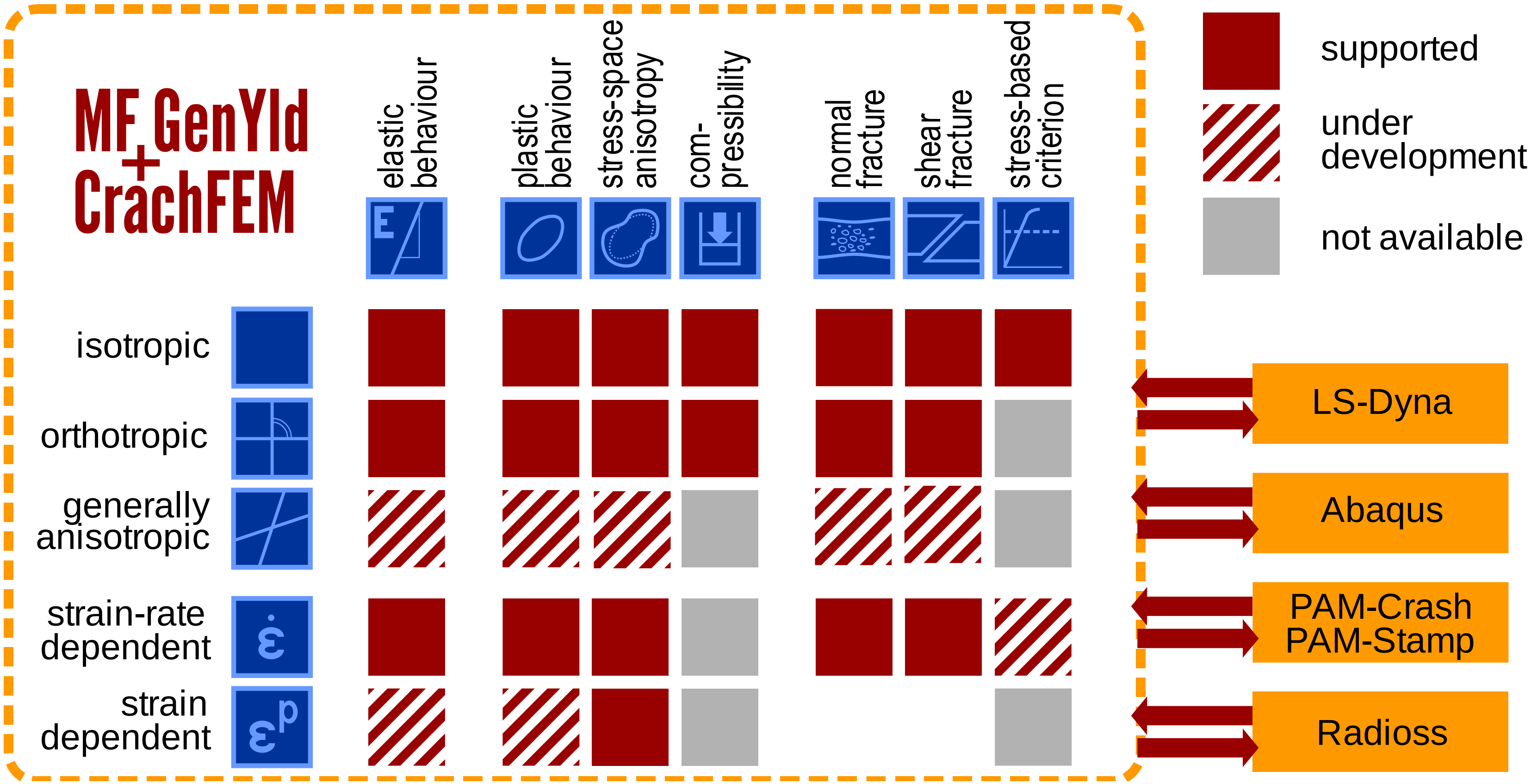
Modules for modelling of non-reinforced and fiber-reinforced polymers



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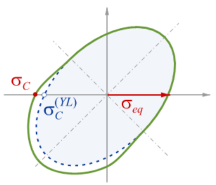
- Introduction: Functionality of material model MF GenYld+CrachFEM for non-reinforced and fiber-reinforced polymers
- Some aspects of modeling unreinforced polymers
- Modeling approach for short fiber reinforced polymers
- New modeling approach: anisotropic yield surface
- Discussion and Outlook

Contents

MATFEM

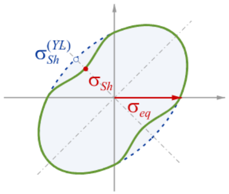
- Uniaxial tensile tests DIN-EN-ISO 8256
  - 0.1 mm/s
  - 10 mm/s
  - 200 mm/s
  - 2000 mm/s
- Uniaxial compression tests:

Asymmetry curve: compression hardening referred to uniax. tension



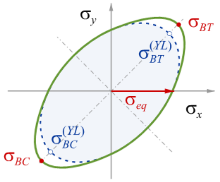
- Shear tests:

Waist curve: shear hardening referred to uniax. tension



- Biaxial tension:

Biax. Scaling curve: biax. tension hardening referred to uniax. tension



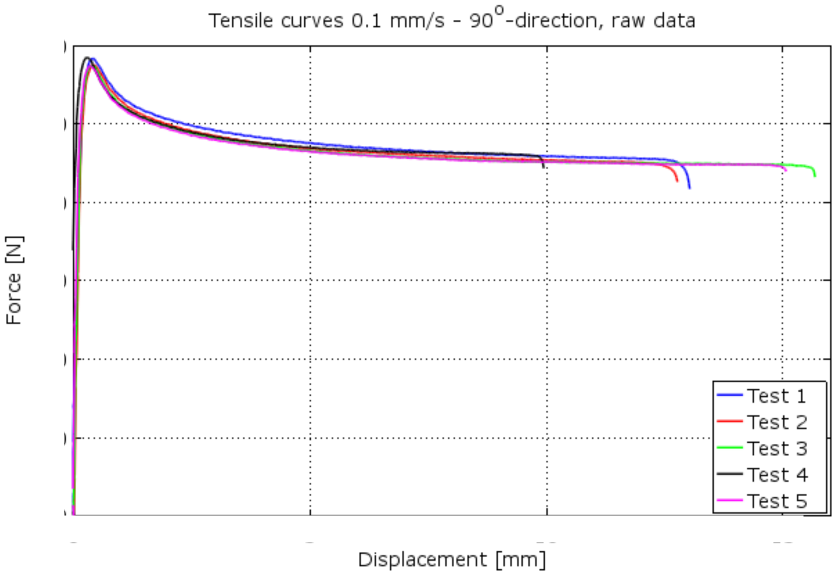
Material data preparation: tensile tests

MATFEM

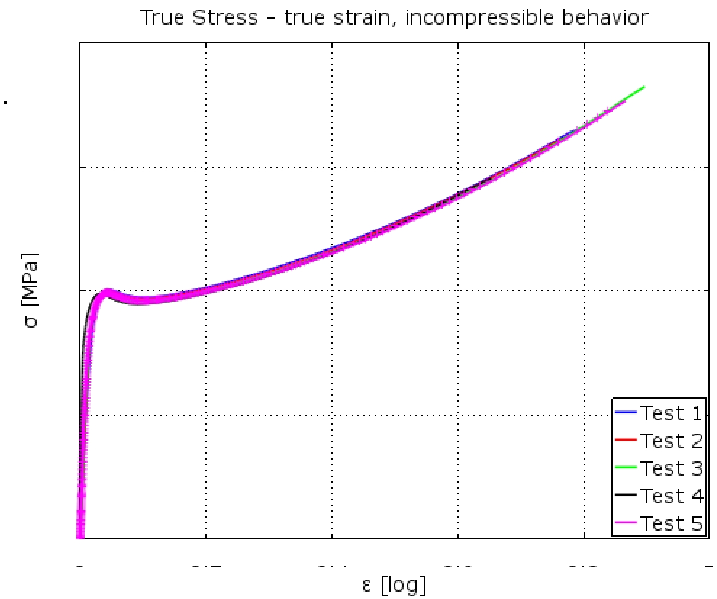
- 0.1 mm/s uniaxial tensile test, 90° direction:
  - Computation of stress – strain curves, **incompressible behavior** assumed

Force – displacement curves

Stress – strain curves



.. convertion ..



Conversion from true stresses and strains and vice versa:

$$\varepsilon^{tech} = \frac{\Delta l}{l_0}$$

$$\varepsilon^{true} = \ln\left(\frac{l}{l_0}\right) = \ln(1 + \varepsilon^{tech})$$

$$\sigma^{tech} = \frac{F}{A_0}$$

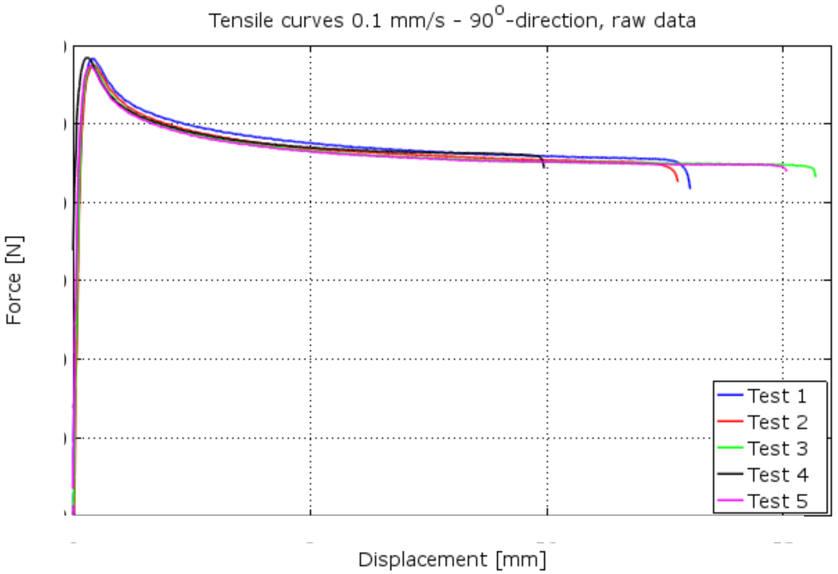
$$\sigma^{true} = \frac{F}{A_0 \cdot e^{(\varepsilon_{width} + \varepsilon_{thcikness})}}$$

If incompressibility is assumed:

$$\sigma^{true} = \frac{F}{A_0 \cdot e^{-\varepsilon_{longitudinal}}}$$

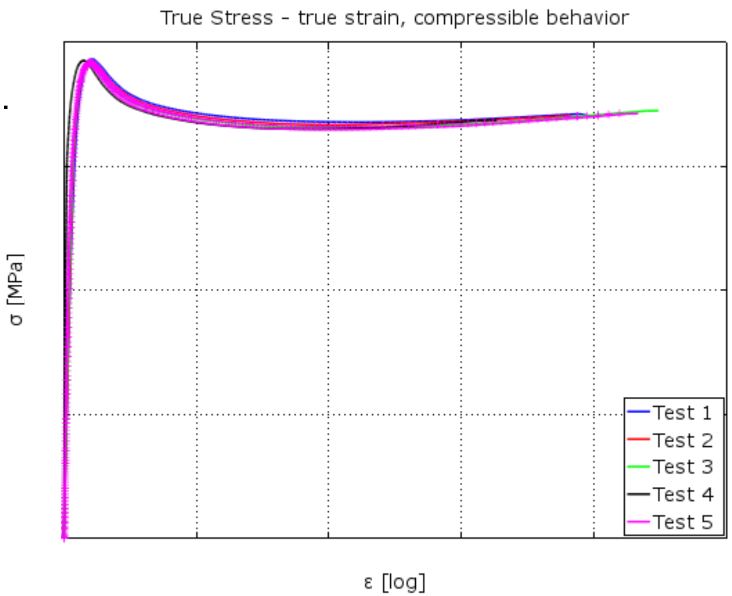
- 0.1 mm/s uniaxial tensile test, 90° direction:
  - Computation of stress – strain curvesm, **compressible behavior** assumed

Force – displacement curves



.. convertion ..

Stress – strain curves



Conversion from true stresses and strains and vice versa:

$$\varepsilon^{tech} = \frac{\Delta l}{l_0} \qquad \varepsilon^{true} = \ln\left(\frac{l}{l_0}\right) = \ln(1 + \varepsilon^{tech})$$

$$\sigma^{tech} = \frac{F}{A_0} \qquad \sigma^{true} = \frac{F}{A_0 \cdot e^{(\varepsilon_{width} + \varepsilon_{thcikness})}}$$

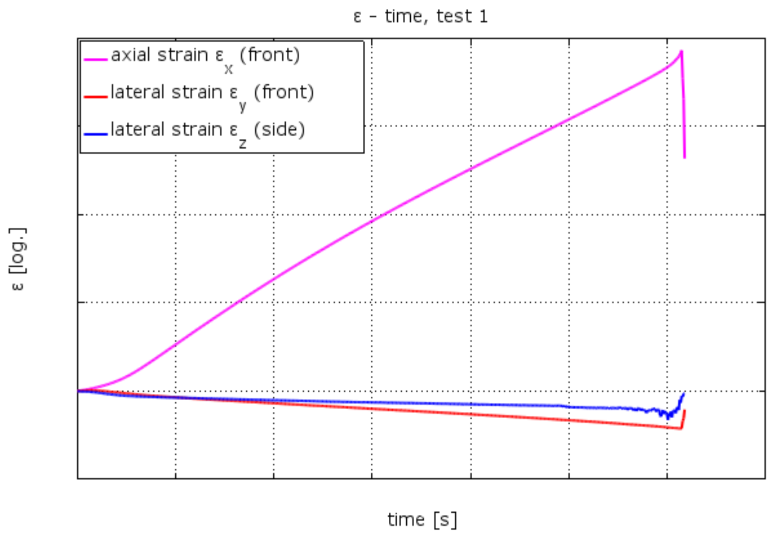
If incompressibility is assumed:

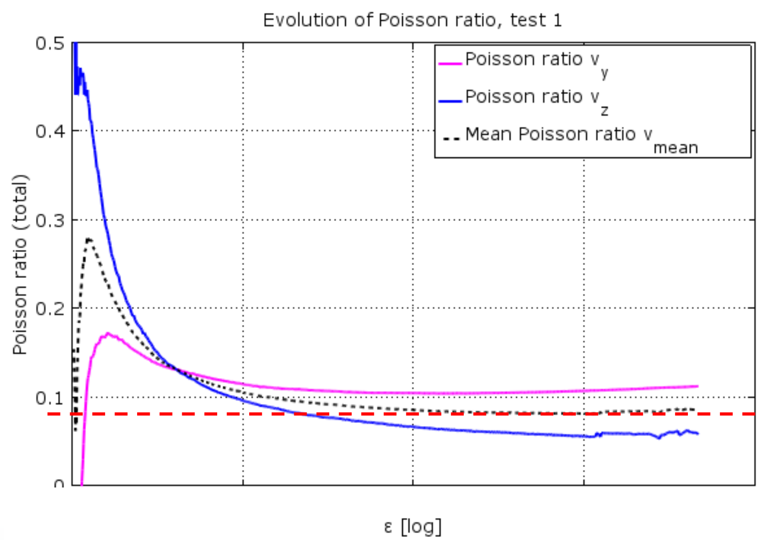
$$\sigma^{true} = \frac{F}{A_0 \cdot e^{-\varepsilon_{longitudinal}}}$$

Non-reinforced polymers

MATFEM

- 1 mm/s uniaxial tensile test, 3D strain measurement → Information about compressibility





- Different lateral strains in thickness and width are observed (although the yielding behavior itself is nearly isotropic!)
  → This can be described with an orthotropic flow potential

- Highly compressible behavior!

$$0 \leq \nu \leq 0.5$$

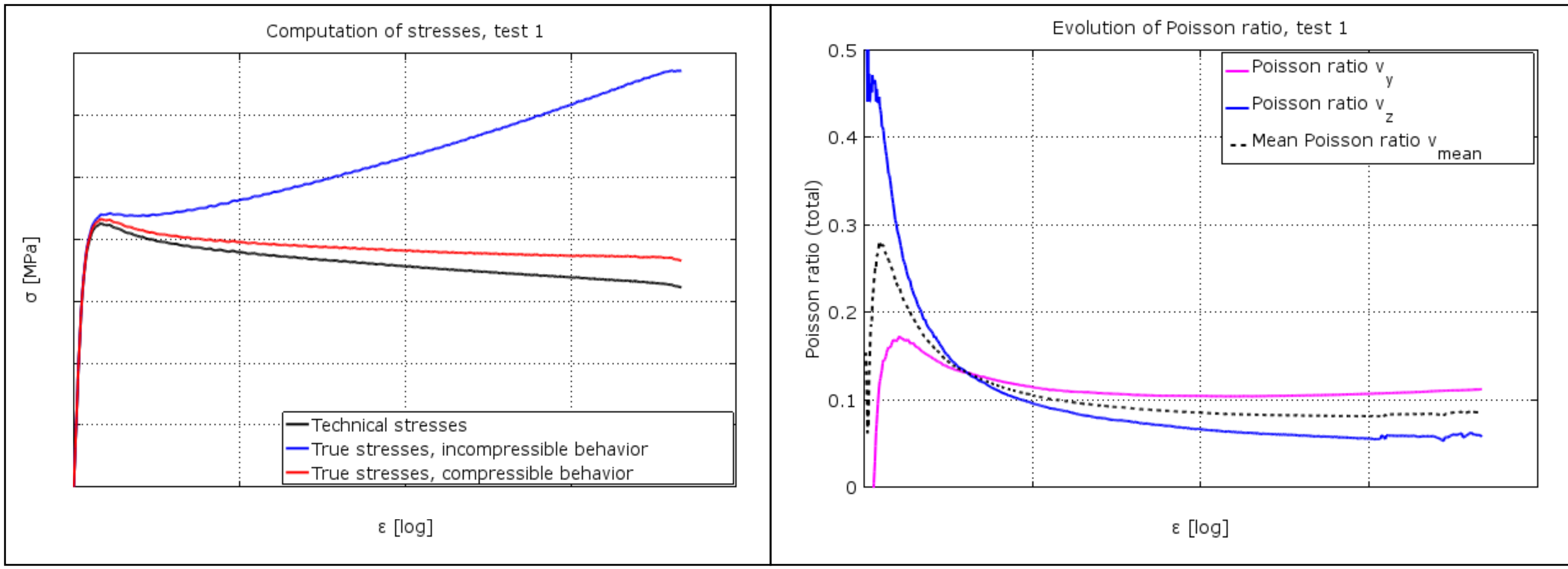
Highly compressible behavior (foam-like)

Incompressible behavior (rubber)

assumed: $\nu_p = 0.85\ (= const.)$ (mean value)

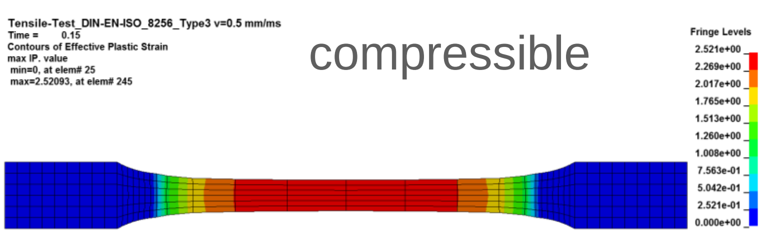
► Approximation of hardening behavior: compressibility check

Compressible vs. incompressible behavior in 1 mm/s uniaxial tensile test

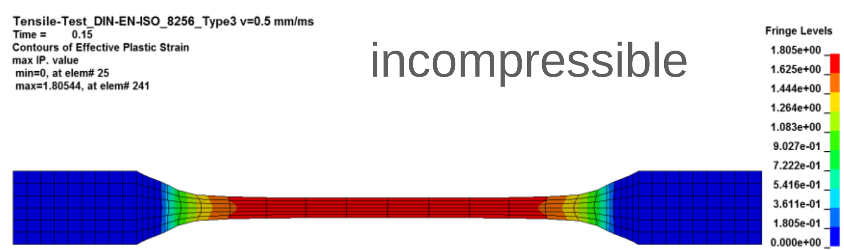


- Highly compressible behavior in uniax. tension: $\nu_p = 0.85$

compressible



incompressible



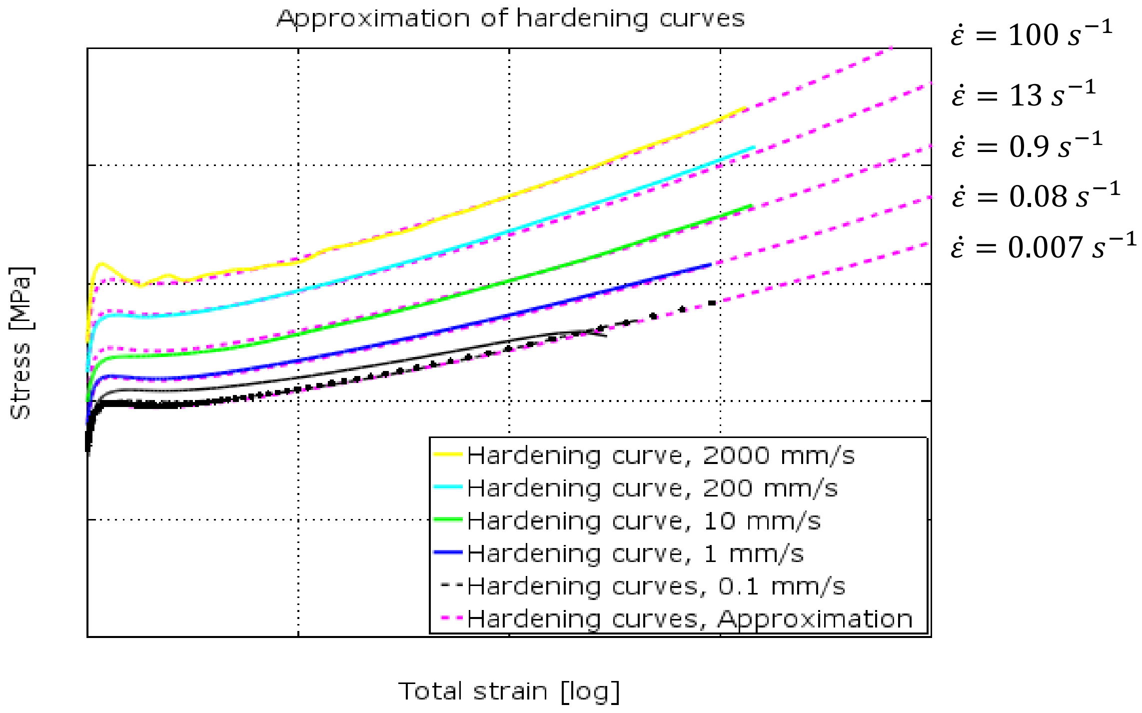
► Approximation of viscoplastic behavior

$$\sigma_{eq} = \sigma_{ref} \left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_{ref}} \right)^m$$

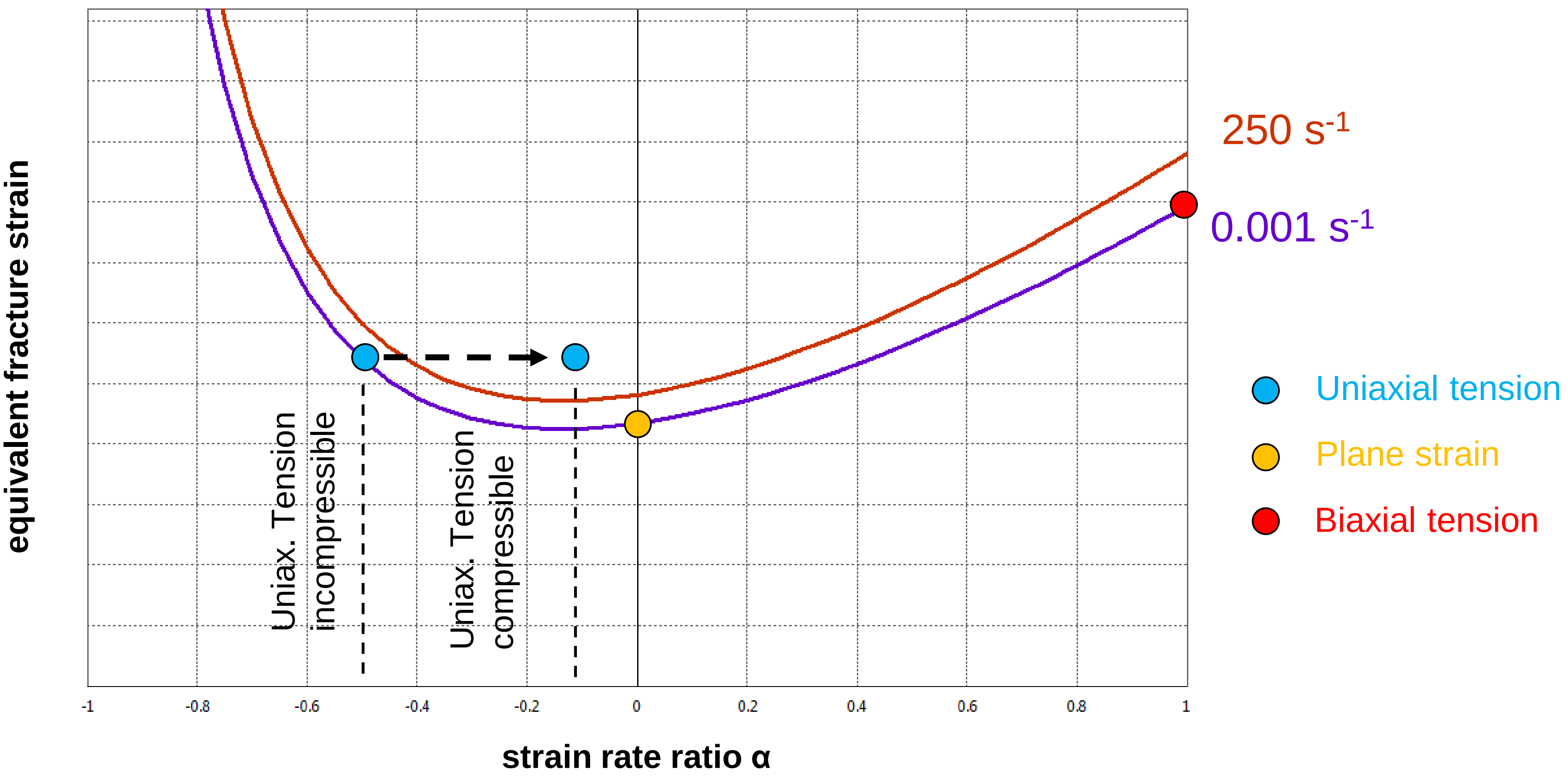
$\dot{\varepsilon}_{ref} = 0.00$ - reference strain rate (1 mm/s uniax. tensile test)

σ_{ref} - reference stress (from 1 mm/s uniax. tensile hardening curve)

m - viscoplastic paramter (dimensionless, from optimization)



► Approximation of fracture: Dutctile normal fracture in CrachFEM



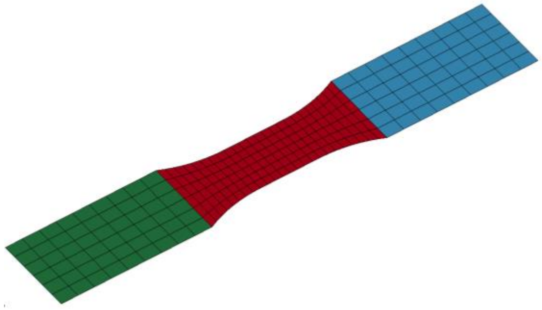
Non-reinforced polymers

MATFEM

- Plastic compressibility of polymers: simulation of basic load cases

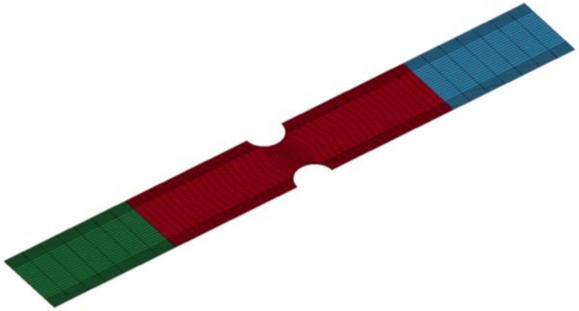
Tensile-Test_DIN-EN-ISO_8256_Type3

Test Speed: 0.1mm/s



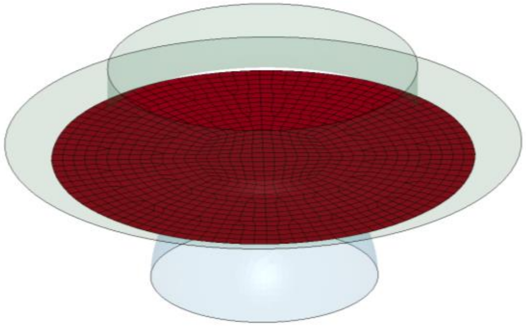
Waisted-Tensile-Test

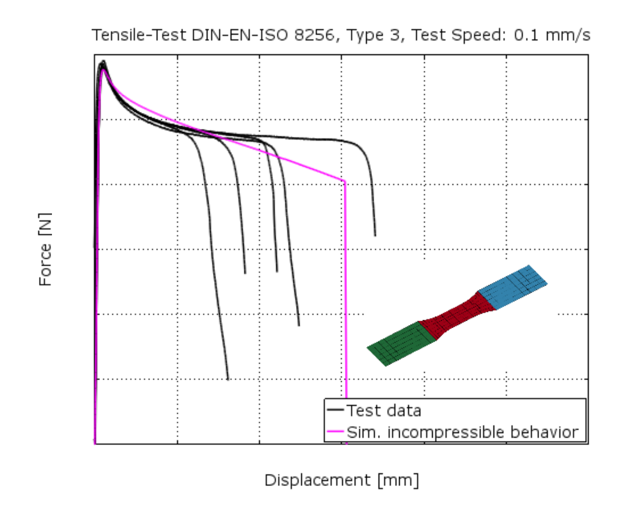
Test Speed: 0.05 mm/s

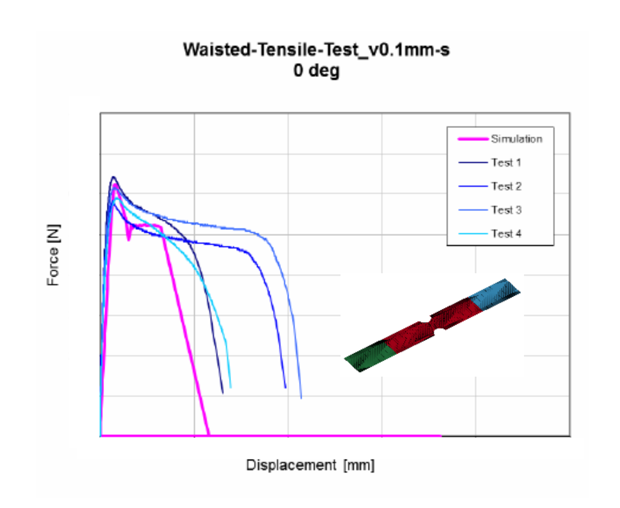


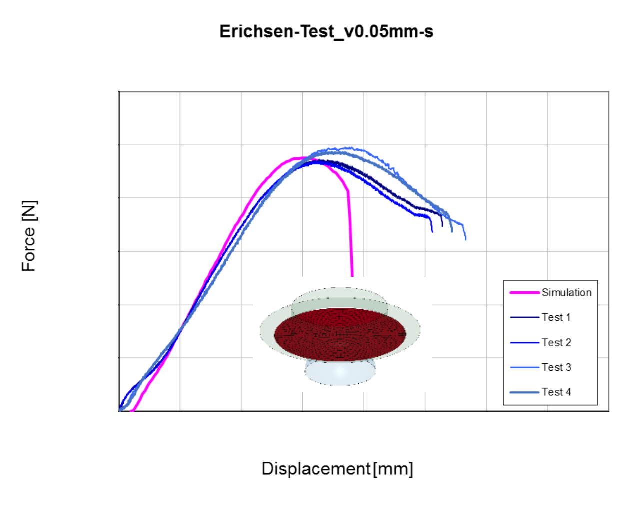
Erichsen-Test

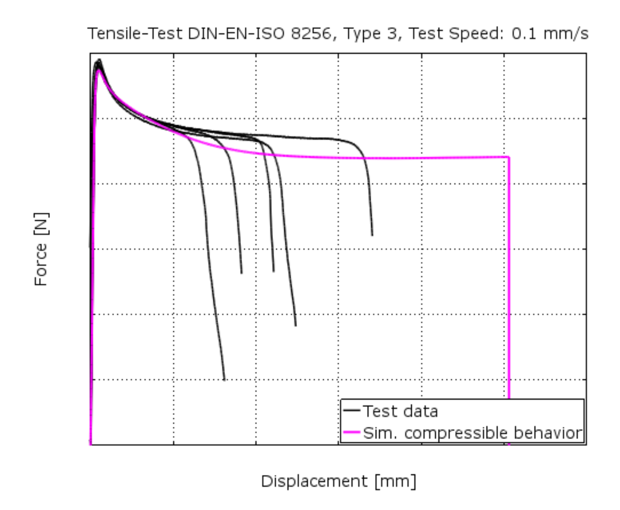
Test Speed: 0.5 mm/s

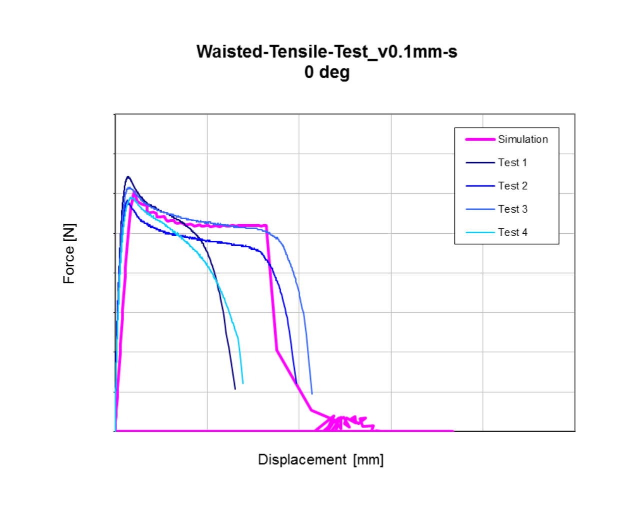


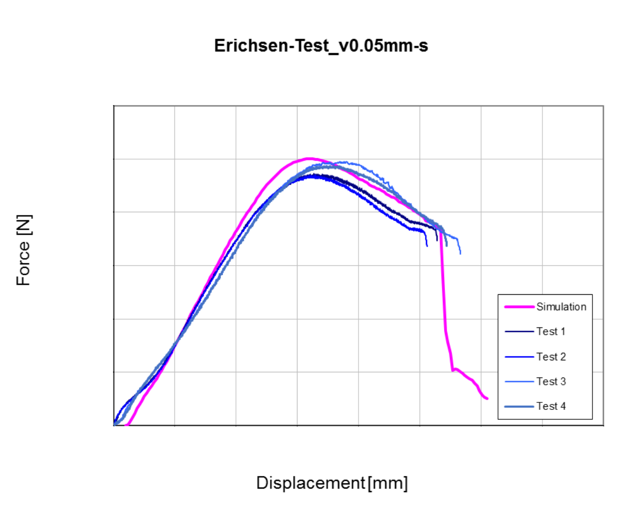

Tensile-Test DIN-EN-ISO 8256, Type 3, Test Speed: 0.1 mm/s
Force [N]
Displacement [mm]
Test data
Sim. incompressible behavior


Waisted-Tensile-Test_v0.1mm-s
0 deg
Force [N]
Displacement [mm]
Simulation
Test 1
Test 2
Test 3
Test 4


Erichsen-Test_v0.05mm-s
Force [N]
Displacement [mm]
Simulation
Test 1
Test 2
Test 3
Test 4


Tensile-Test DIN-EN-ISO 8256, Type 3, Test Speed: 0.1 mm/s
Force [N]
Displacement [mm]
Test data
Sim. compressible behavior

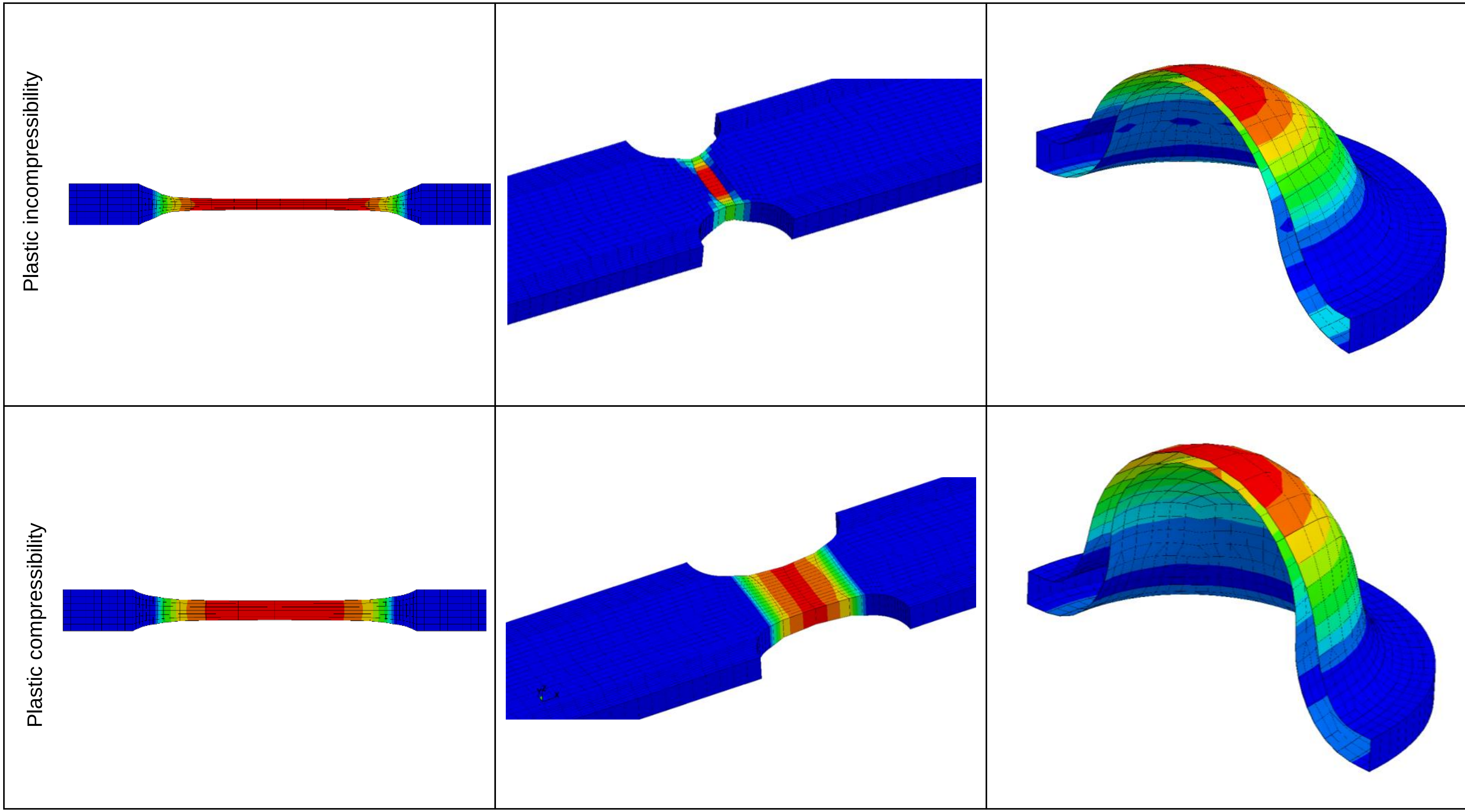

Waisted-Tensile-Test_v0.1mm-s
0 deg
Force [N]
Displacement [mm]
Simulation
Test 1
Test 2
Test 3
Test 4


Erichsen-Test_v0.05mm-s
Force [N]
Displacement [mm]
Simulation
Test 1
Test 2
Test 3
Test 4

Non-reinforced polymers

MATFEM

- Plastic compressibility vs. incompressibillity: equivalent platic strain



► Approximation of viscoplastic behavior

$$\sigma_{eq} = \sigma_{ref} \left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_{ref}} \right)^{m}$$

$\dot{\varepsilon}_{ref} = 0.00$ - reference strain rate (1 mm/s uniax. tensile test)

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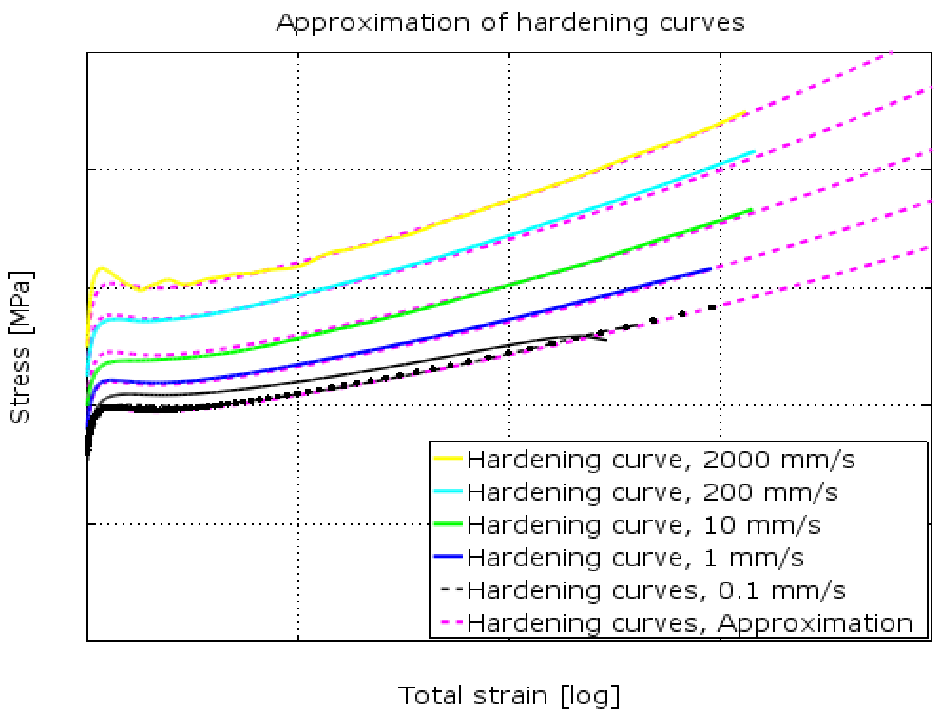


$\dot{\varepsilon} = 100\ s^{-1}$

$\dot{\varepsilon} = 13\ s^{-1}$

$\dot{\varepsilon} = 0.9\ s^{-1}$

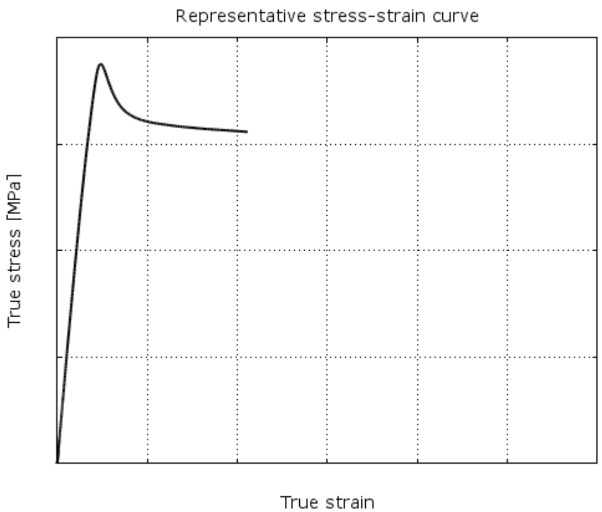
$\dot{\varepsilon} = 0.08\ s^{-1}$

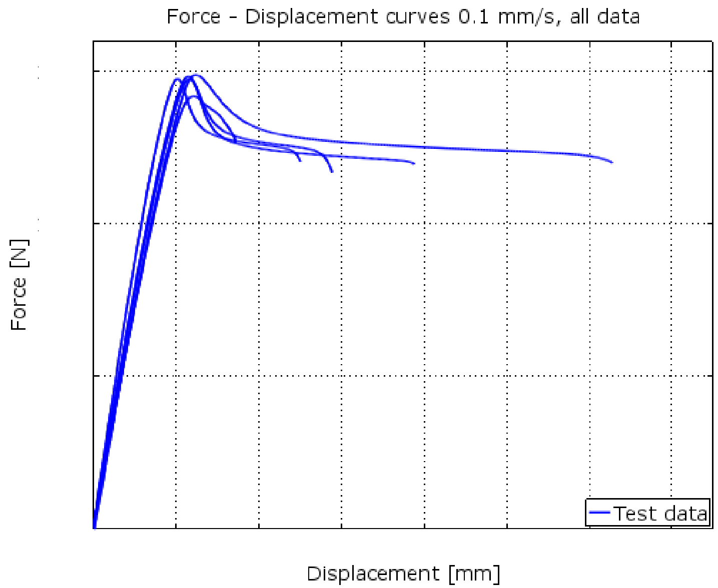
$\dot{\varepsilon} = 0.007\ s^{-1}$

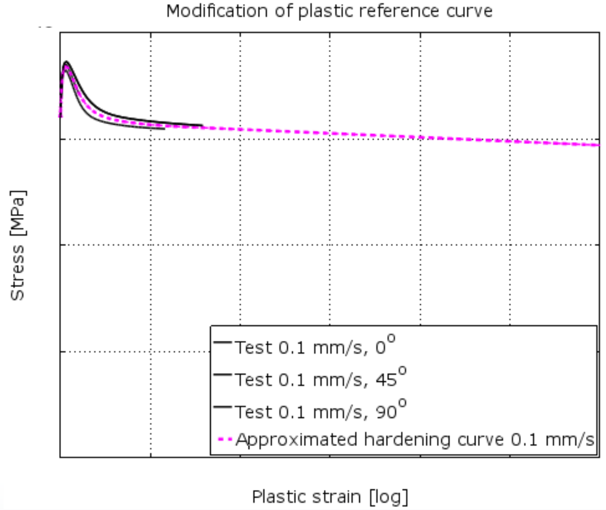
MATFEM

Acrylnitril-Butadien-Styrol – ABS

- Very strong tendency to localization
- Fracture in uniaxial tension?
- Determination of hardening behavior?

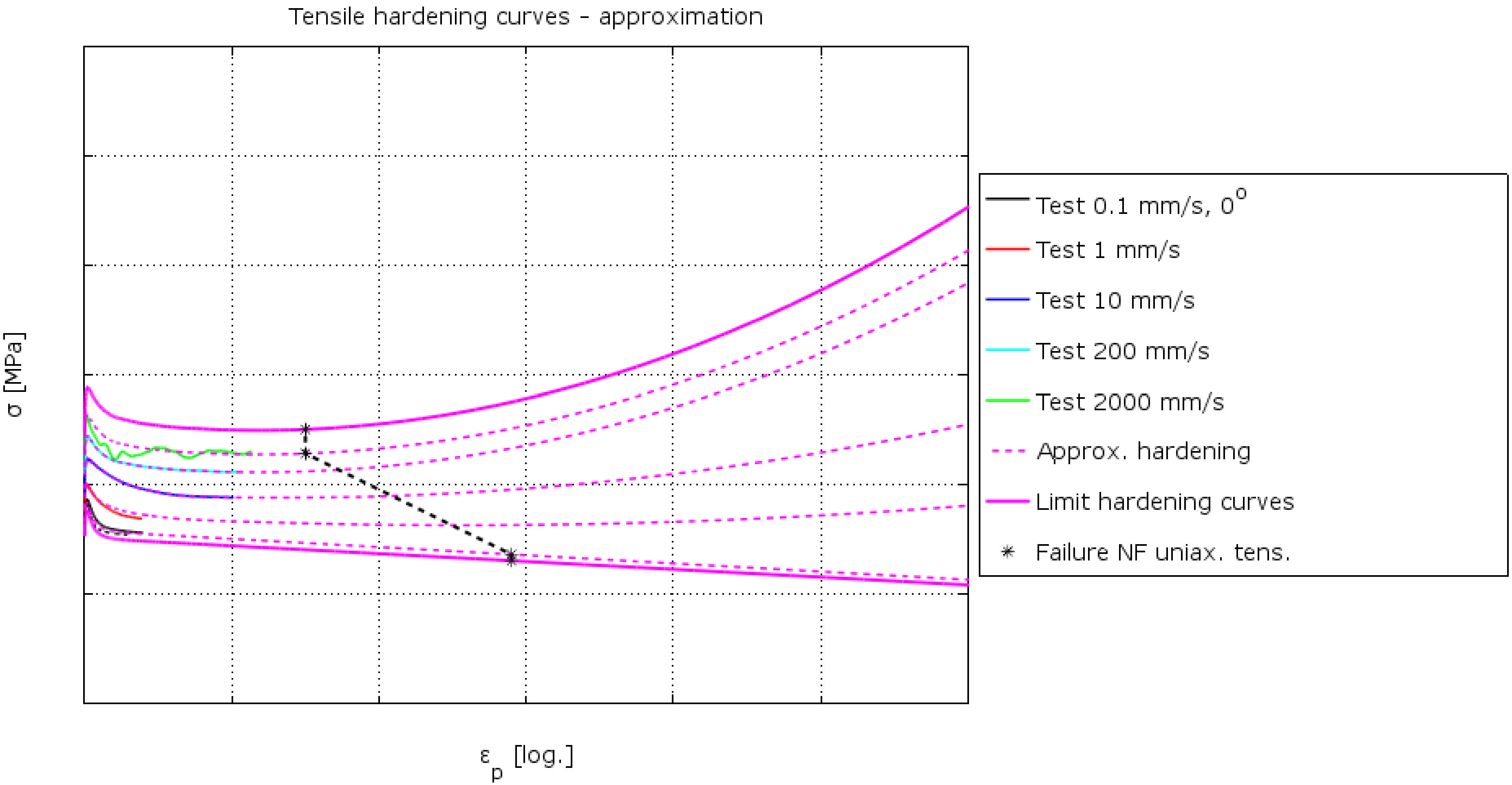






Acrylnitril-Butadien-Styrol – ABS

- Extrapolation of hardening behavior



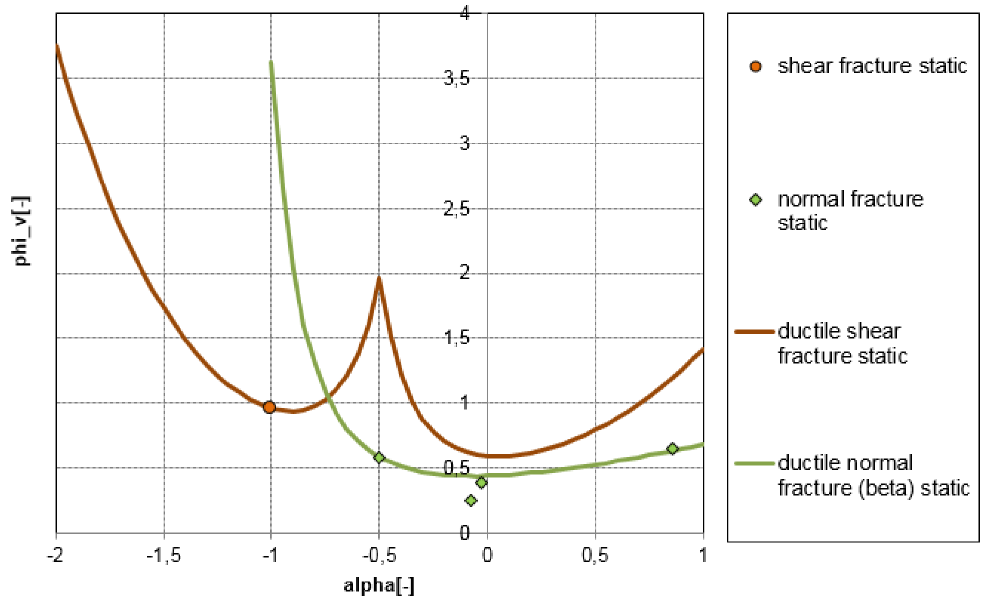
Non-reinforced polymers: ABS

MATFEM

Approximation of ductile shear fracture and ductile normal fracture

- Consideration of multiaxial loading conditions (plane strain, biaxial strain)

Fracture curves at 0.01 s^{-1}



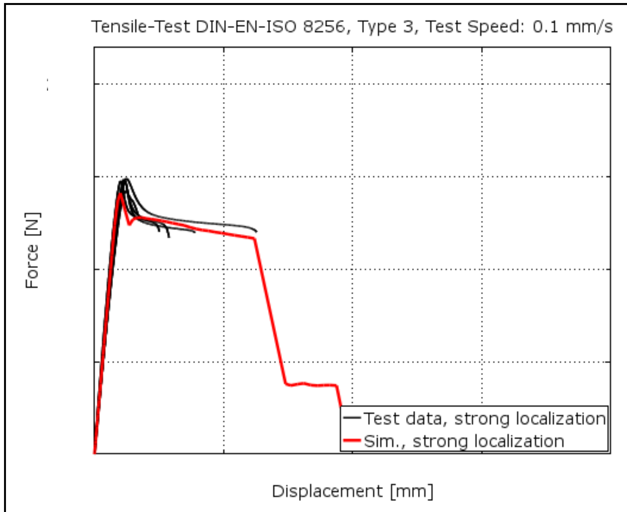
$$\alpha = \frac{\varepsilon_{11}}{\varepsilon_{22}}$$

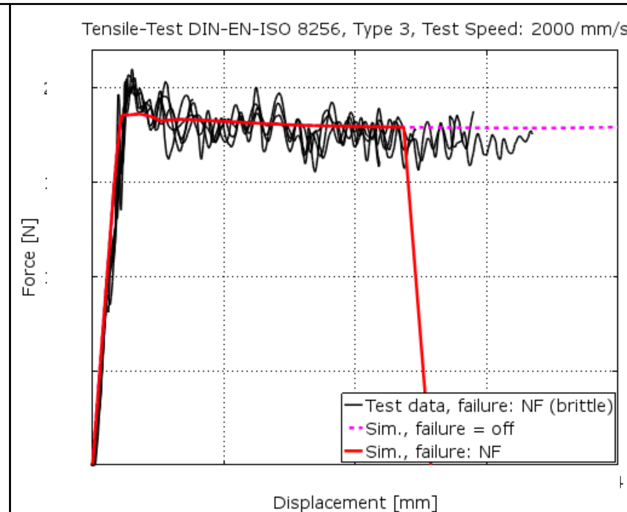
- Uniaxial failure strain hard to determine:
  - Refinement of evaluation range
  - Aramis not always useful
  - Plane strain failure as lower bound for uniaxial tension

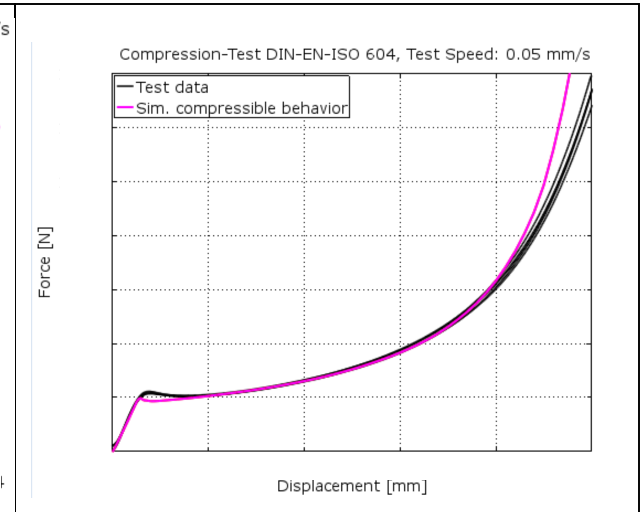
Non-reinforced polymers: ABS

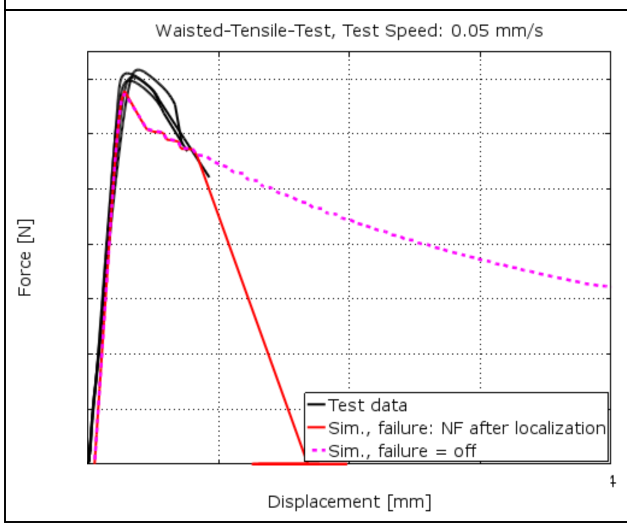
MATFEM

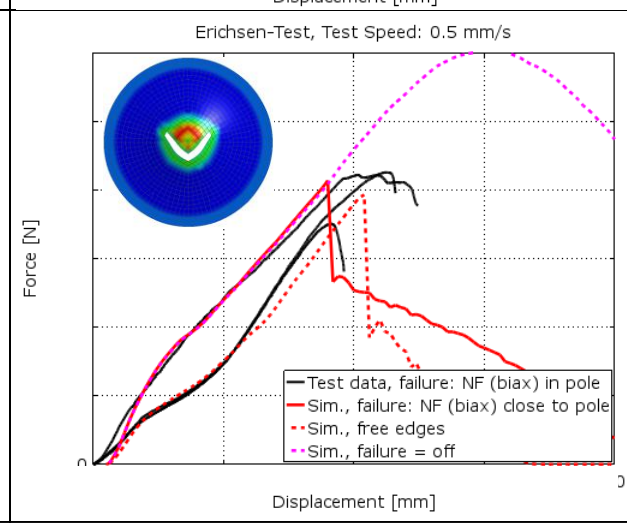
Simulation of basic load cases

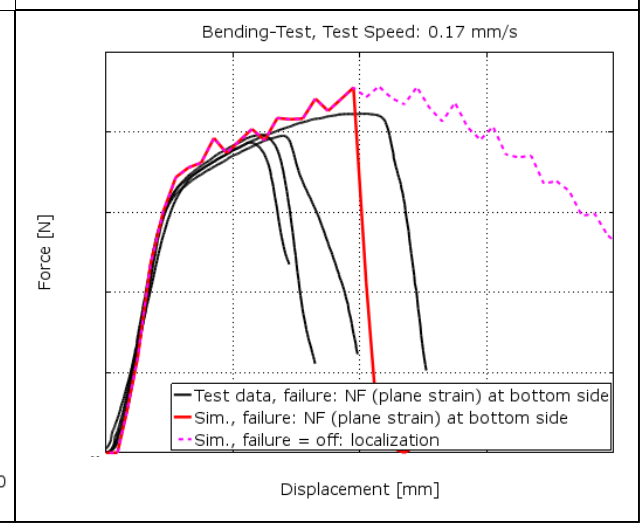












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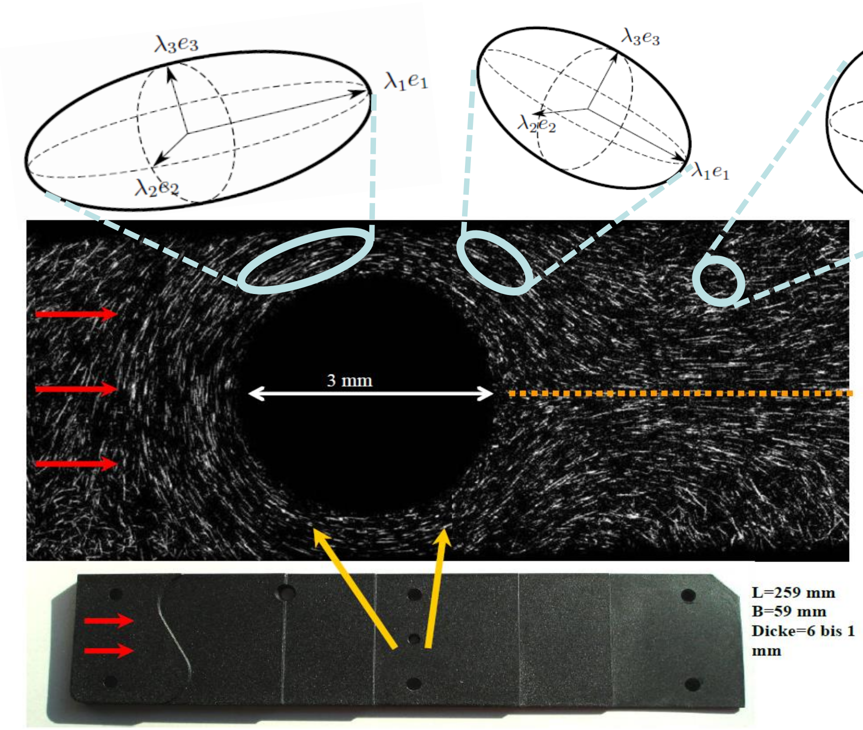
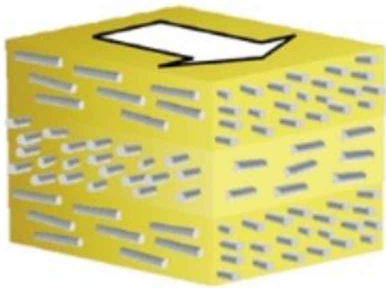
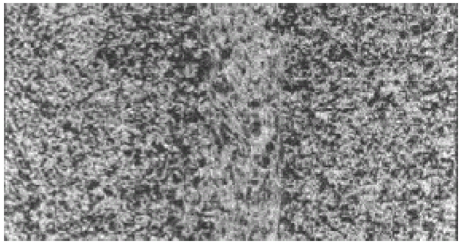


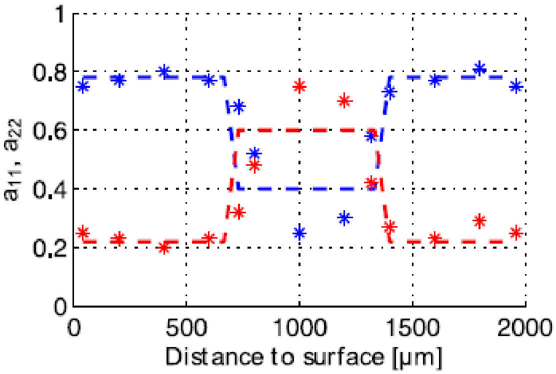
Process chain :

Injection molding simulation → Crash Simulation

MATFEM



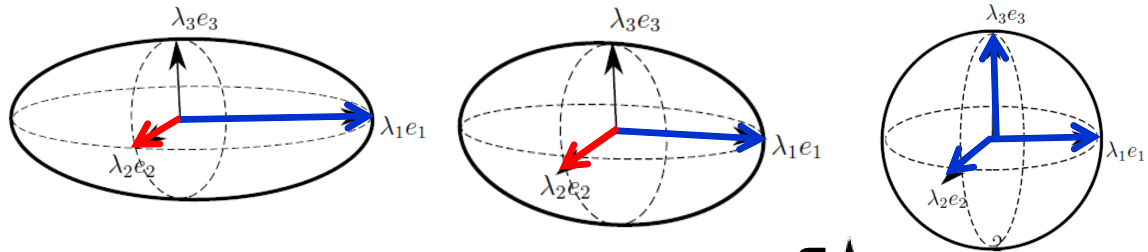


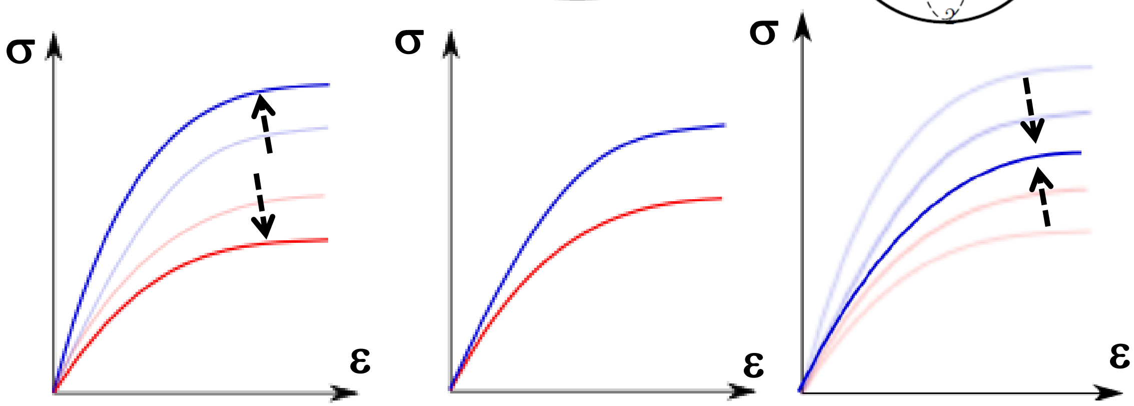


$a_{11} = 0.80$
$a_{22} = 0.20$
$a_{33} = 0.00$

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

$a_{11} = 0.33$
$a_{22} = 0.33$
$a_{33} = 0.33$

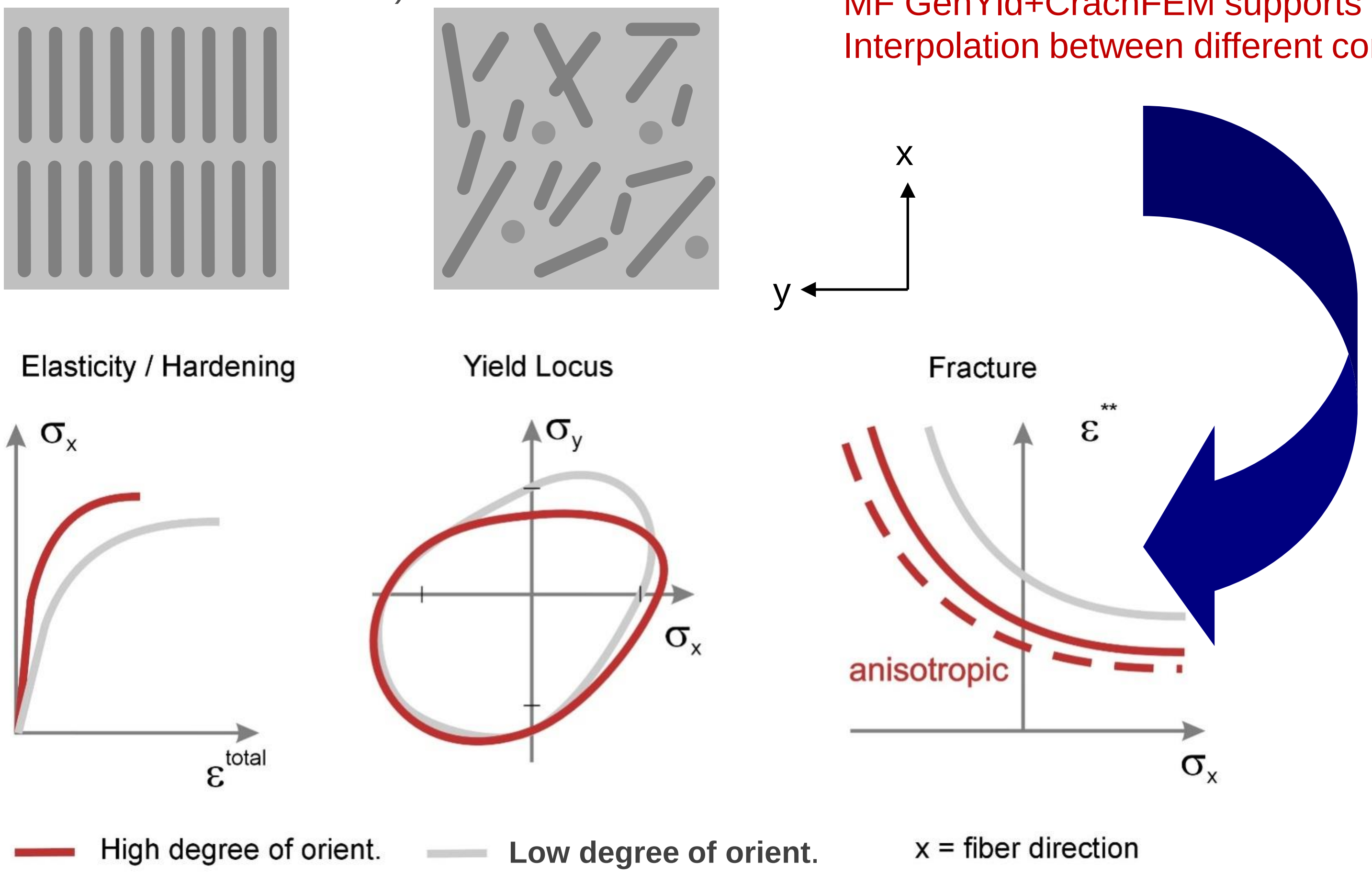




- Degree of fiber orientation
  - Extremal conditions for one fiber density: a) Highly oriented fibers (maximum degree of anisotropy) / b) Randomly distributed fibers (isotropic)

a) b)

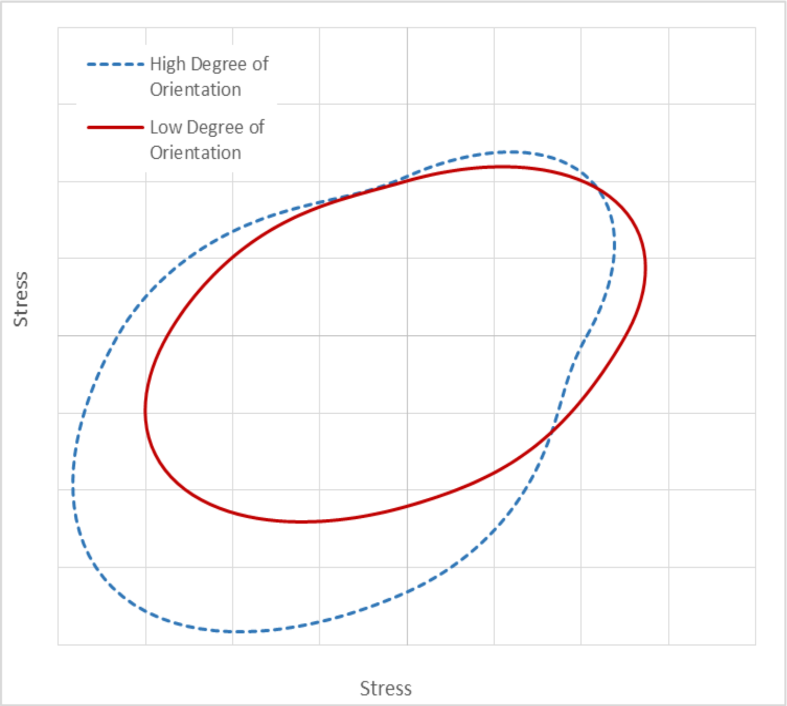
MF GenYld+CrachFEM supports automatic Interpolation between different conditions



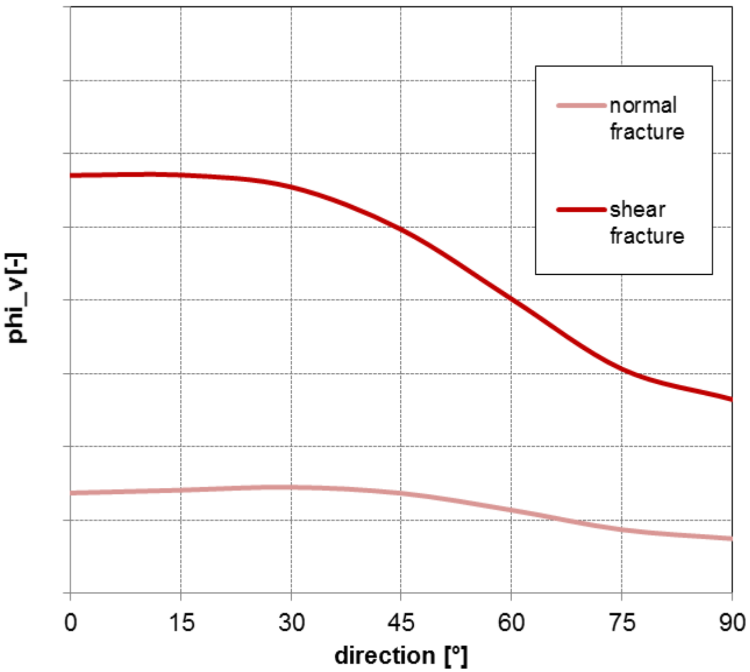
Mechanical Properties (schematic repre-sentation)

- Degree of fiber orientation
  - Example

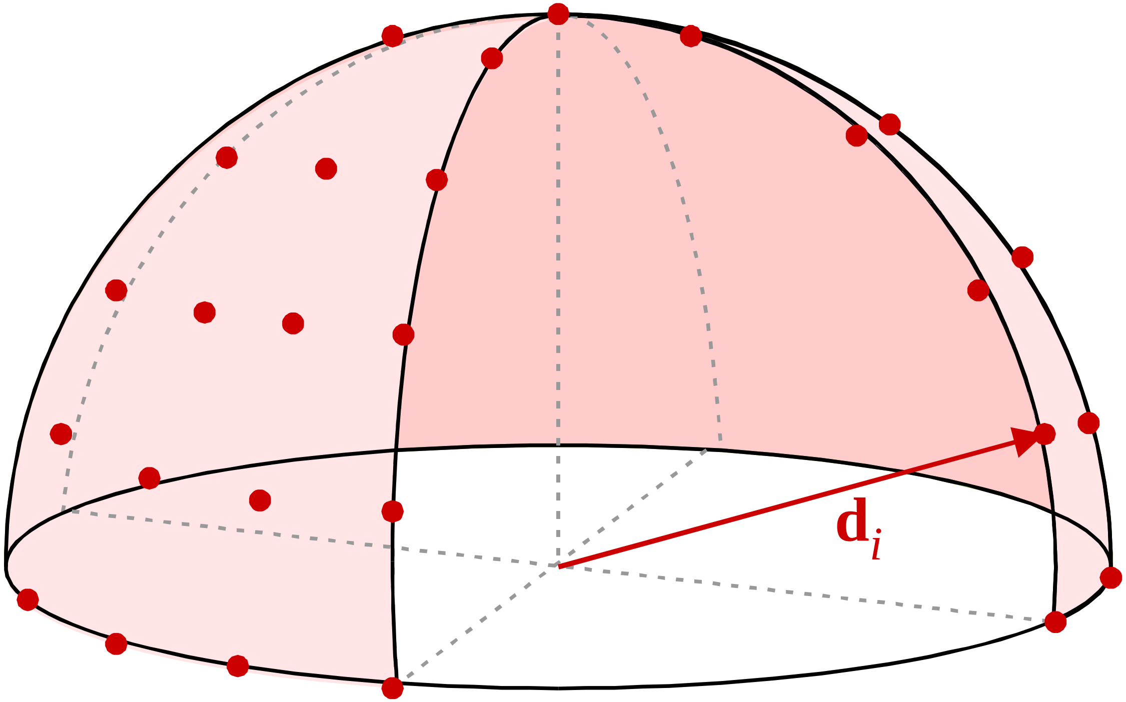
Yield locus



Anisotropy of fracture



- Anisotropy of fracture



New approach to fracture:

Various discrete directions are probed for the maximum fracture risk:

$$\varepsilon^{**} = \min_{i=1}^{n} \varepsilon^{**}(\mathbf{d}_i)$$

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- Some aspects of modeling unreinforced polymers
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- Discussion and Outlook

New modeling approach:

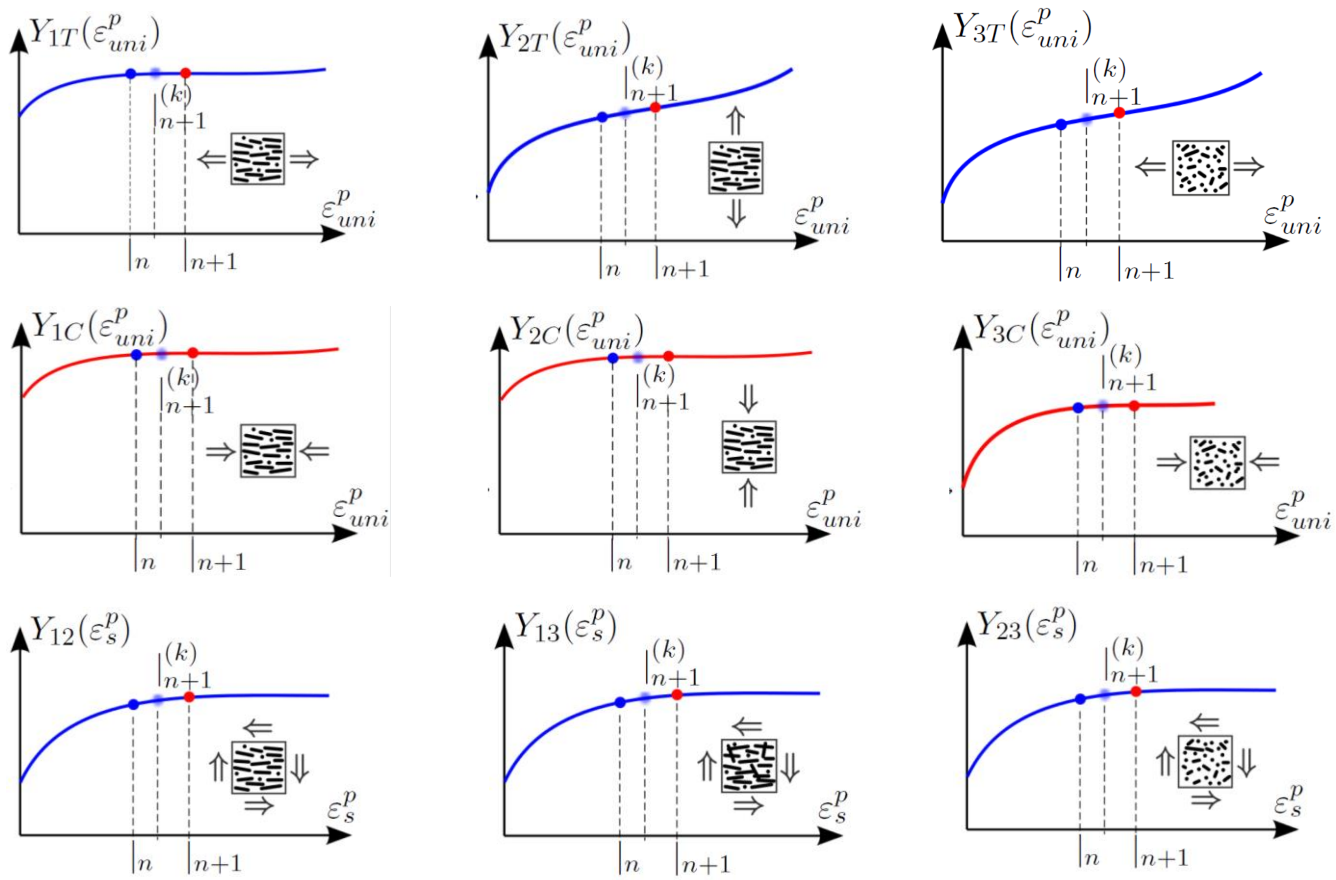
MATFEM

Different yielding in:

..tension:

..compression:

..shear:



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

MATFEM

- **General anisotropic material behavior:**
  - extension of the modular material model MF GenYld+CrachFEM to non-orthotropic behavior (organic sheets)
- **Tracking of fiber directions during the deformation process:** very important for organic sheets but also for short fiber reinforced polymers and UD carbon composites
- **Viscoelastic – viscoplastic coupling**

Acknowledgement

Thank you to ELIX Polymers for providing the test data for the ABS polymer!