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INCREASING RUPTURE PREDICTABILITY FOR ALUMINUM

Influence of anisotropy

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CONTENT

- Introduction/motivation
- Isotropic & anisotropic material models
- Rupture criterion
- Conducted tests for characterization
- Validation
- Comparison
- Conclusion

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INTRODUCTION / MOTIVATION

- **Reducing weight + growing safety standards**
  - More ultra high strength materials
  - Ductility and hardening as a safety buffer is diminished
  - Rupture prediction essential for CAE driven product development
- **Rupture prediction is limited**
  - by physical noises like material or geometry deviations
  - by the applied numerical material and rupture model.
- **Will the introduction of Anisotropy push this limitation?**

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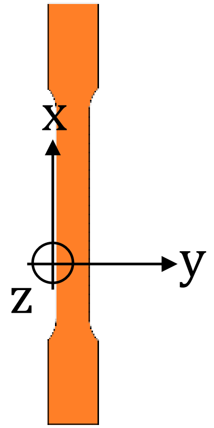
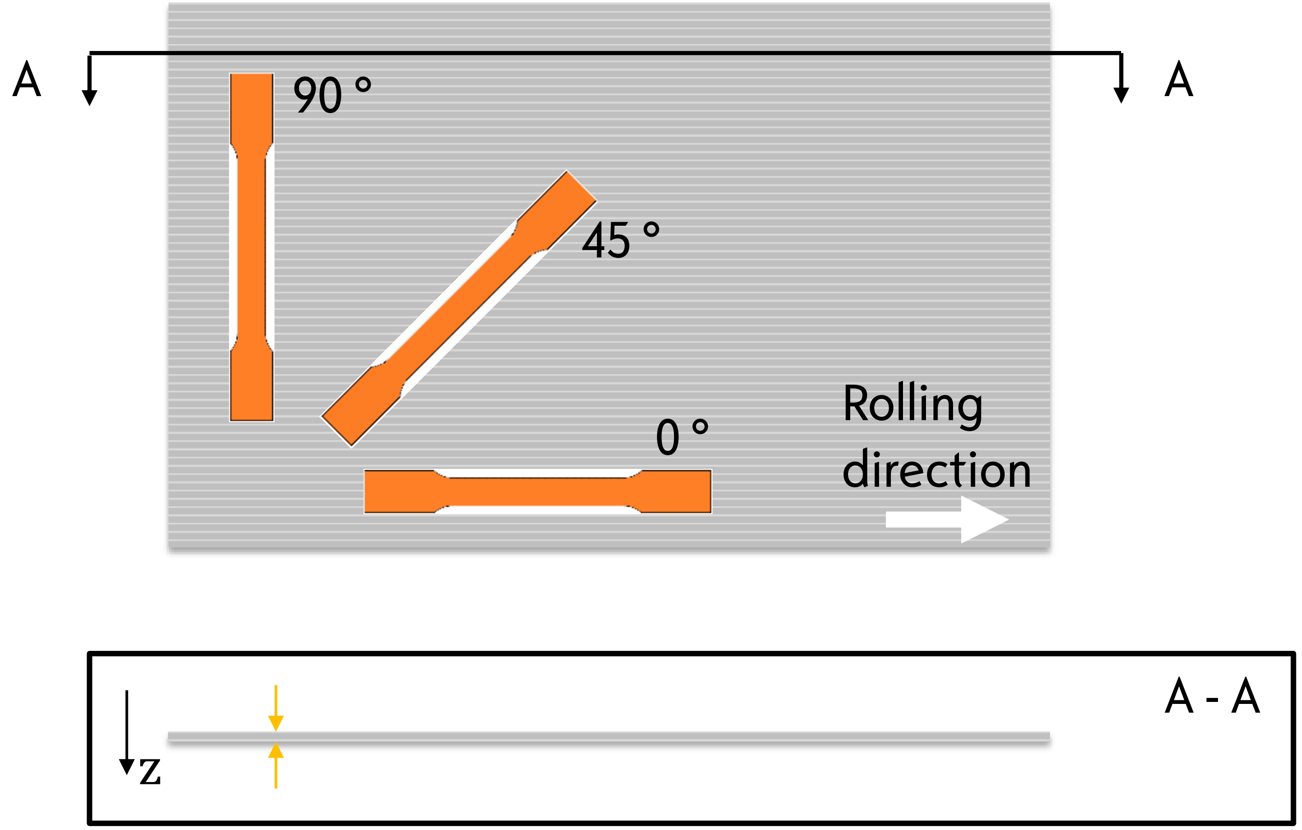
DIRECTION DEPENDENCY

- Young's modulus
- Yield strength
- Hardening
- Flow, necking and rupture
- Lankford coefficient R

$$R = \frac{\varepsilon_{yy}}{\varepsilon_{zz}} = \frac{\varepsilon_{yy}}{\nu * \varepsilon_{xx}} = \frac{\varepsilon_{yy}}{-(\varepsilon_{xx} + \varepsilon_{yy})}$$

Ratio of lateral vs. thickness strain





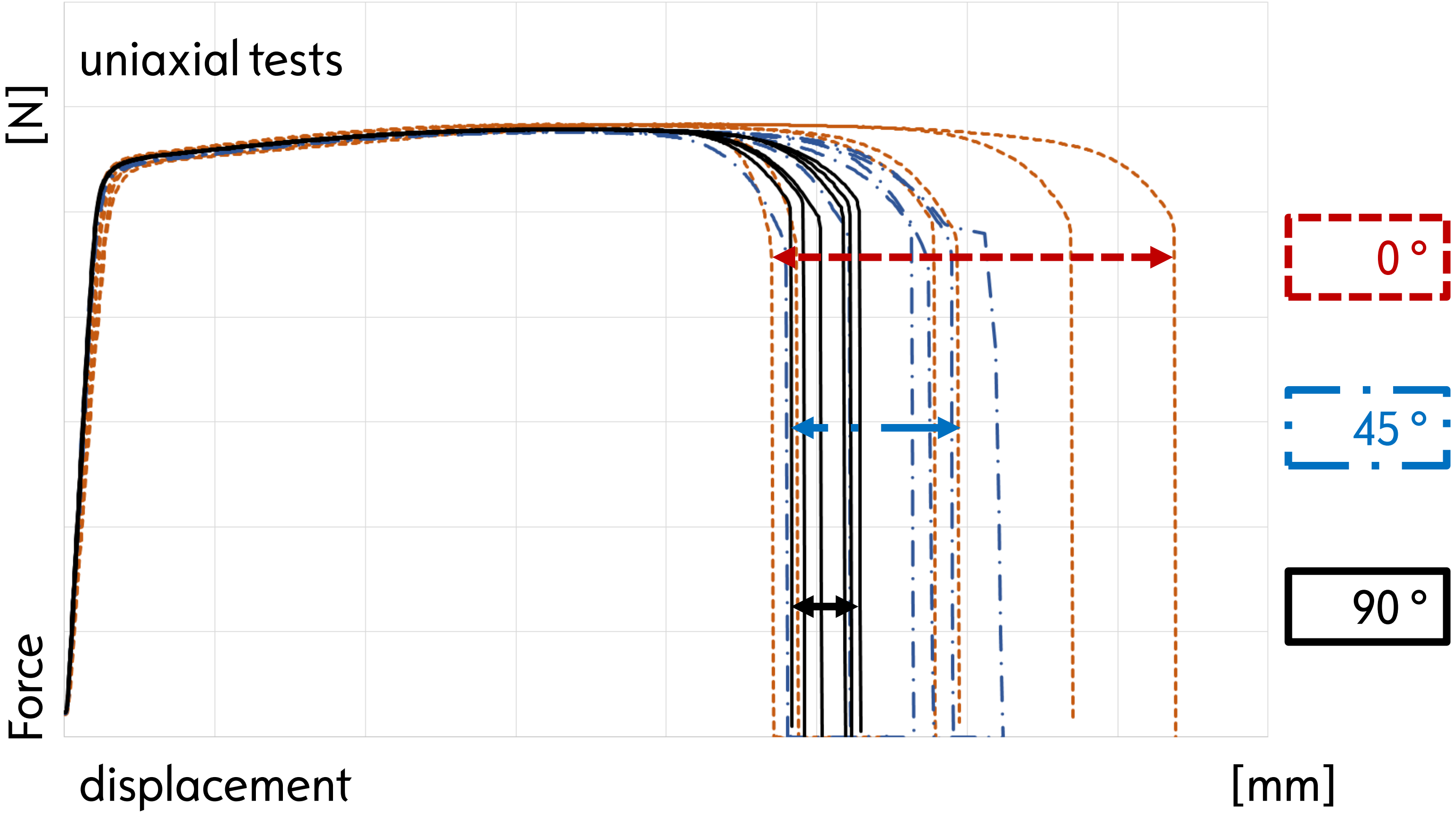
Anisotropy

TESTED ALUMINUM SHEET

- Young's modulus
- Yield strength
- Hardening
- Flow, necking and rupture
- Lankford coefficient

  $R_0 \sim R_{45} \sim R_{90} \sim 0.5$

→ Transversely isotropic



➔ Model handling same as isotropic

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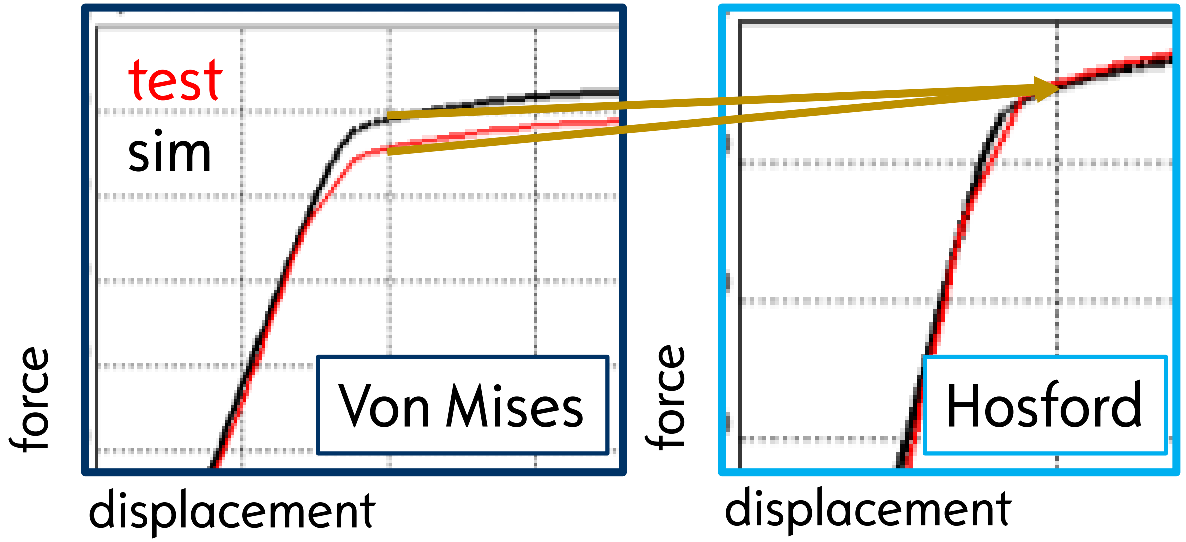
YIELD CRITERION

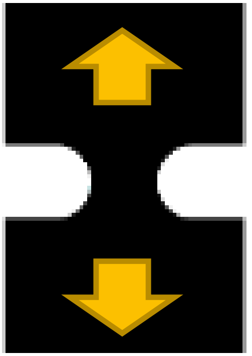
Von Mises (*MAT_024):

$$\sigma_v = \sqrt{\tfrac{1}{2}[(\sigma_1-\sigma_2)^2+(\sigma_1-\sigma_3)^2+(\sigma_2-\sigma_3)^2]}$$

Hosford(isotropic) / Barlat(anisotropic) (*MAT_036):

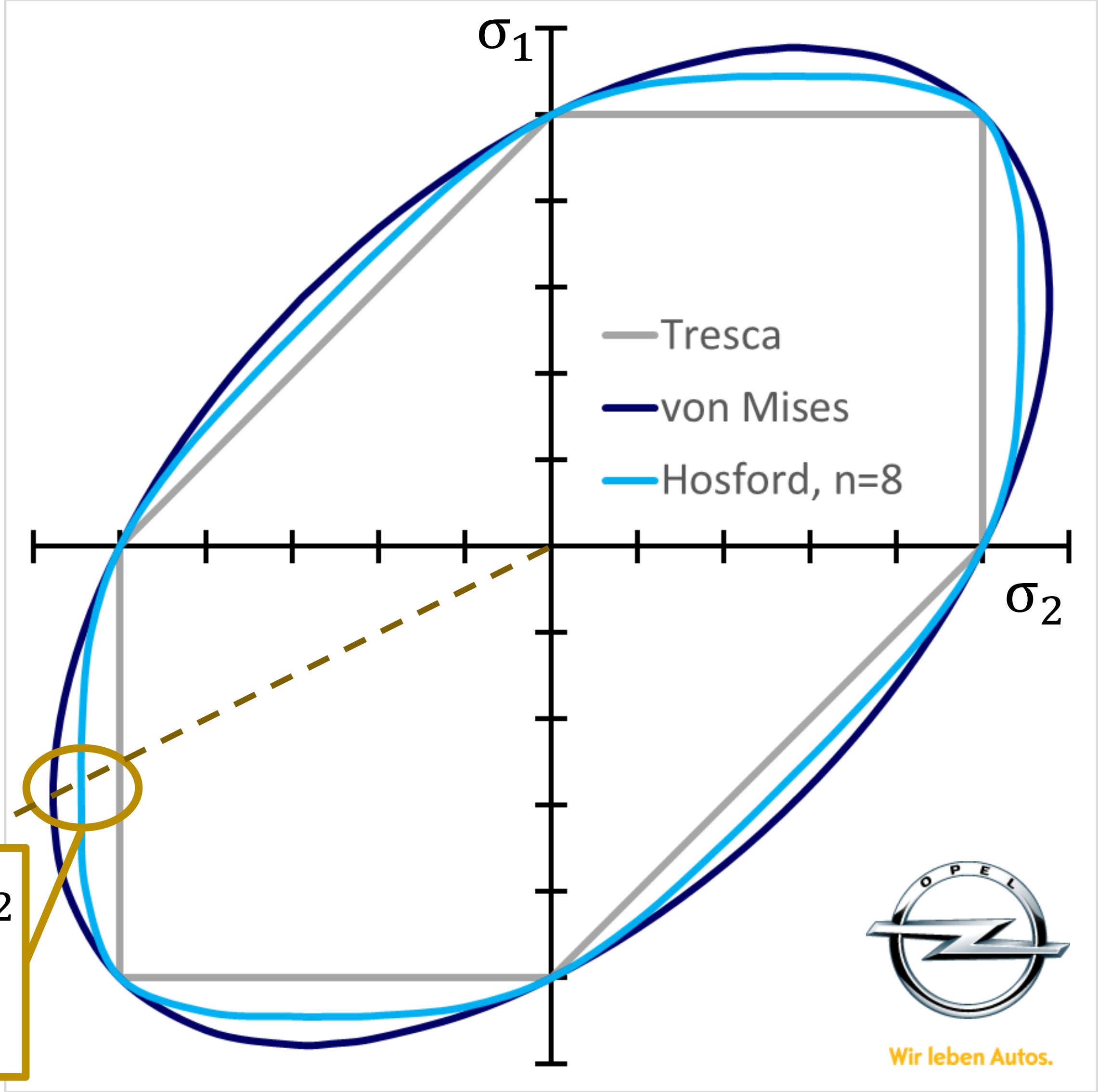
$$\sigma_y = \left(\tfrac{1}{2}|\sigma_2-\sigma_3|^n+\tfrac{1}{2}|\sigma_3-\sigma_1|^n+\tfrac{1}{2}|\sigma_1-\sigma_2|^n\right)^{1/n}$$





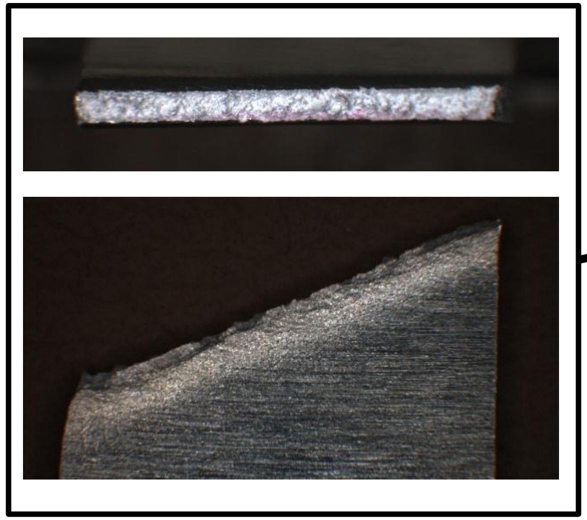
$\sigma_1 = 2\times\sigma_2$

$(\eta = \frac{1}{\sqrt{3}})$

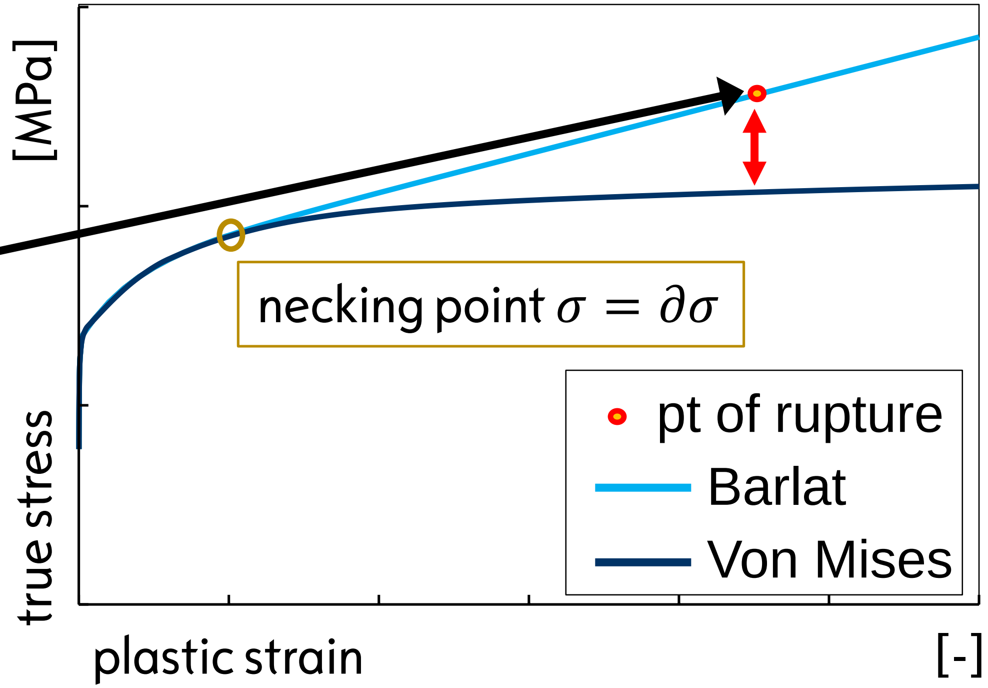


Comparison Von Mises vs Barlat

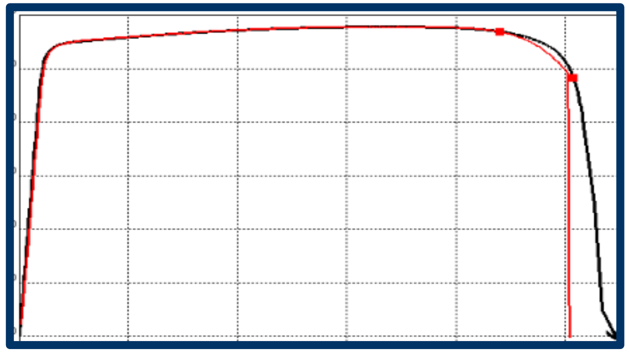
NECKING BEHAVIOR



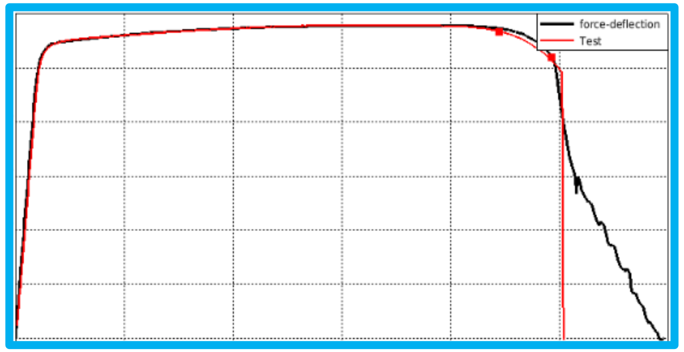
yield curves



- Von Mises curve is reverse engineered



- Barlat curve is purely test based



— test

— simulation (0.5 mm)

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Rupture criterion

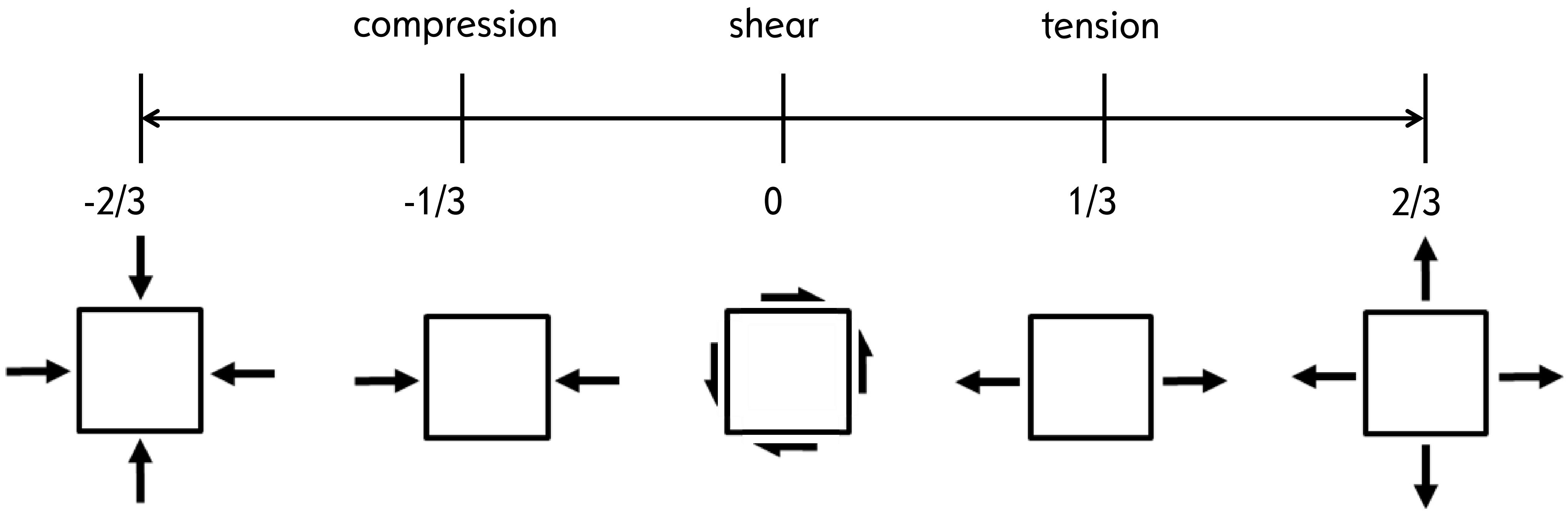
TRIAXIALITY

- Capture stress state in one value
- (The Lode angle parameter is not needed for elements following plane stress)

Definition :

$$\eta = \frac{\text{hydrostatic stress}}{\text{deviatoric stress}}$$

For plane stress(σ_{ZZ}=0, τ_{XZ}=0, τ_{YZ}=0) follows :



Damage accumulation

GISSMO

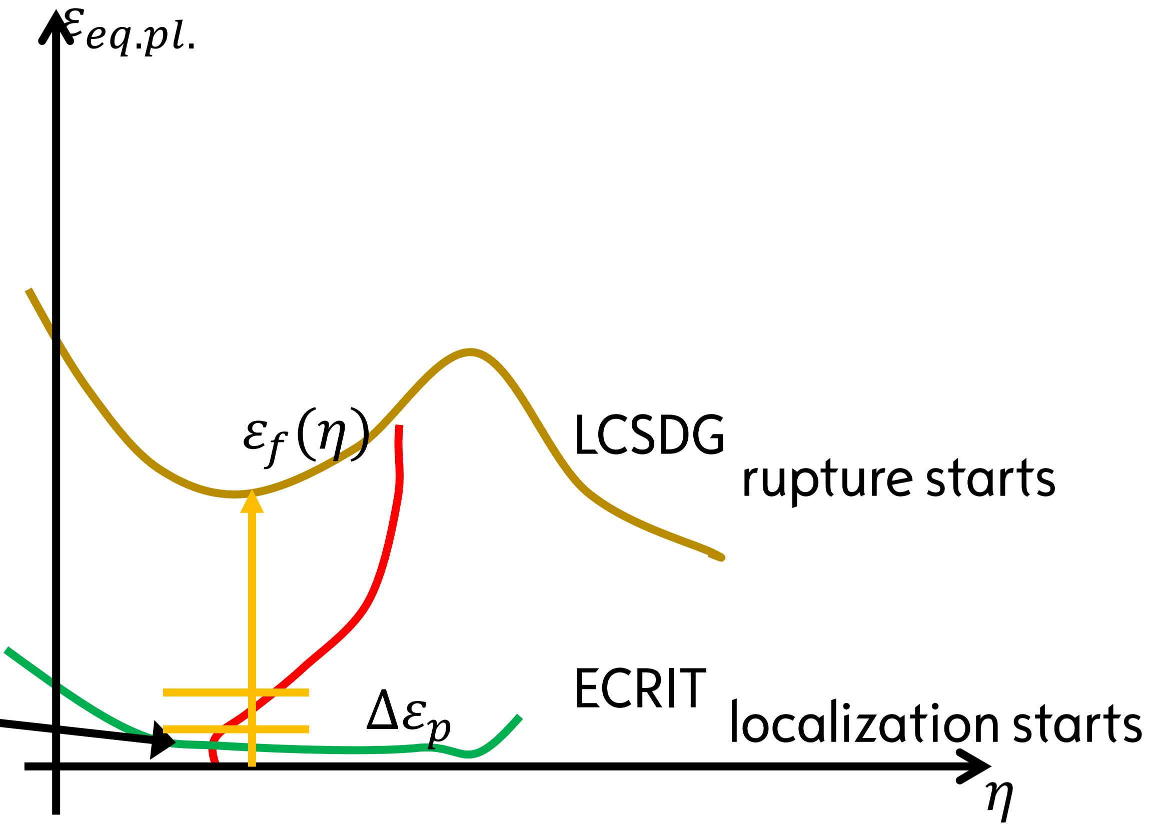
$$D = \sum \Delta D$$

$\hookrightarrow D = 1 \longrightarrow$ IP deleted

$$\Delta D = \frac{DMGEXP}{\varepsilon_f} D^{\left(1-\frac{1}{DMGEXP}\right)} \Delta\varepsilon_p$$

D_0=1E-12

$$D_{crit} = D(\varepsilon_{crit}(\eta))$$



$$\sigma = \tilde{\sigma}\left(1-\left(\frac{D-DCRIT}{1-DCRIT}\right)^{FADEXP}\right)$$

$D = D_{crit} \rightarrow \sigma = \breve{\sigma}$

$D = 1 \rightarrow \sigma = 0$

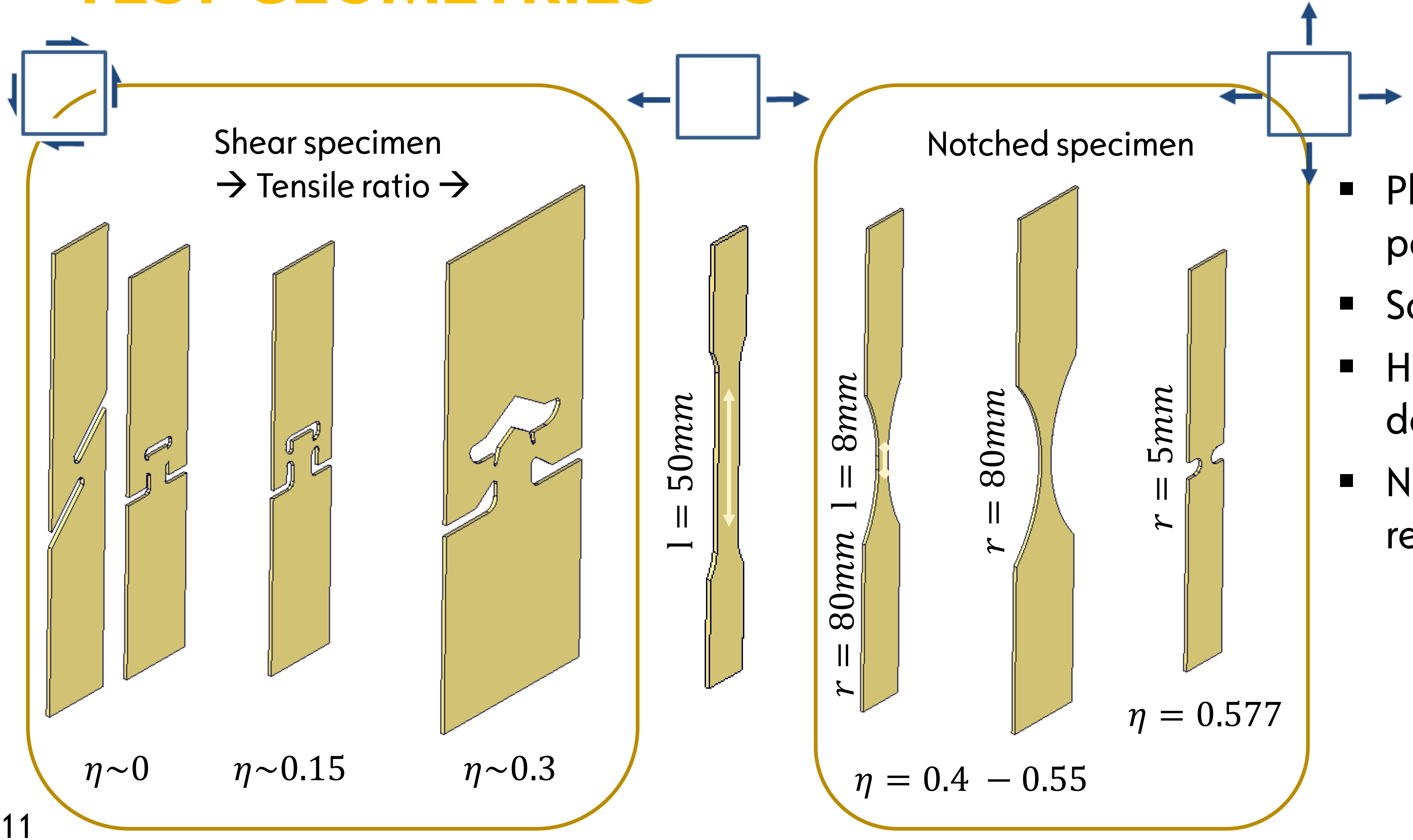
→ Eq. plastic strain at rupture is not equal to $\varepsilon_f(\eta)$

→ Coupling reduces the strength of the element prior to element deletion

➔ ductile fracture

Triaxality tests

TEST GEOMETRIES

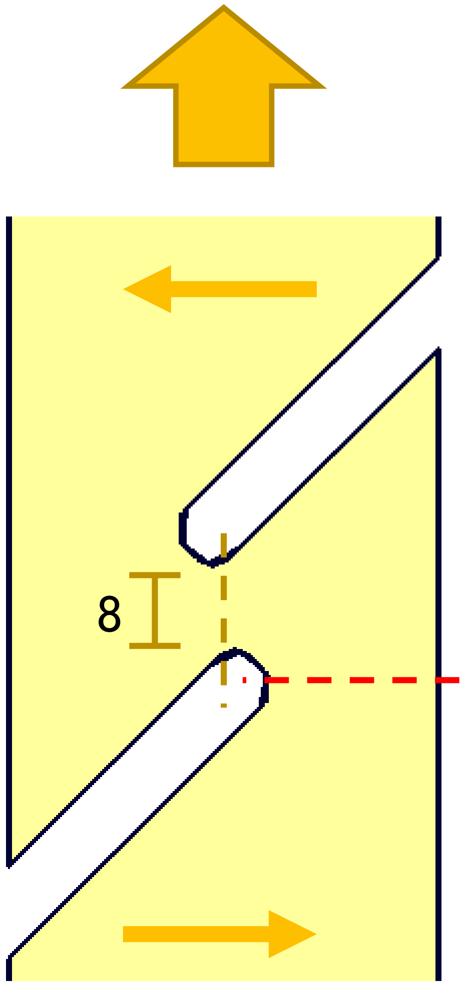


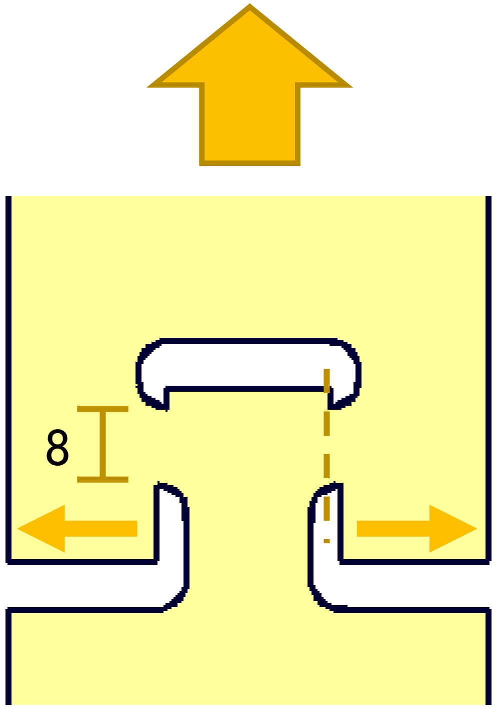
Principles:

- Plane stress as long as possible (b/t>4)
- Scalability of element size
- Homogenous triaxiality in deformed area
- No local thickness reduction

Triaxality tests

TEST GEOMETRIES - SHEAR





- Optimized radii and offsets to focus the load onto the center
- Symmetrical specimen : lateral deformation does not effect the test equipment
- Asymmetrical specimen : lateral deformation is test equipment dependent

  → Different rupture modes can be triggered for the same material

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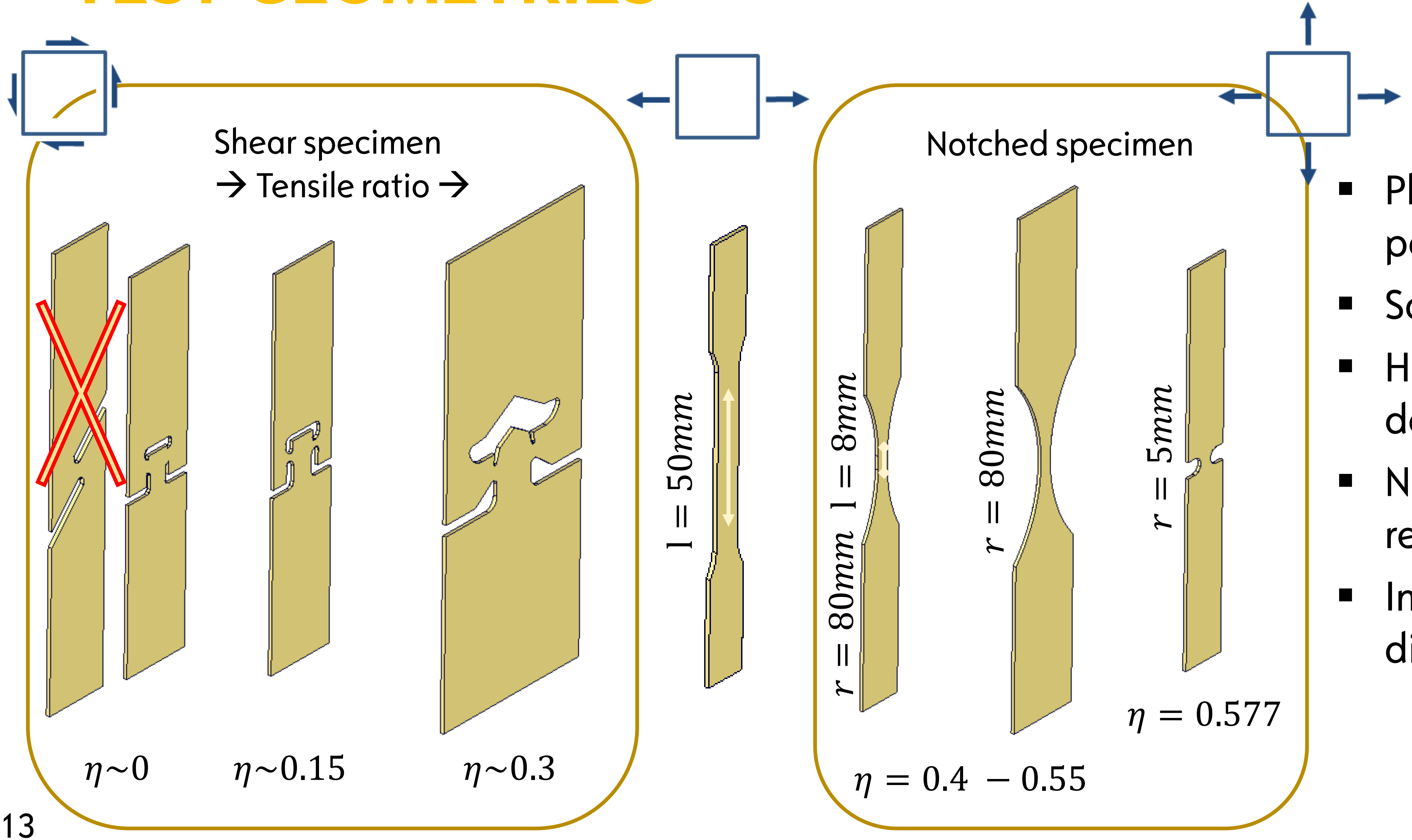
TEST GEOMETRIES



Principles:

- Plane stress as long as possible (b/t>4)
- Scalability of element size
- Homogenous triaxiality in deformed area
- No local thickness reduction
- Internal moment dissipation

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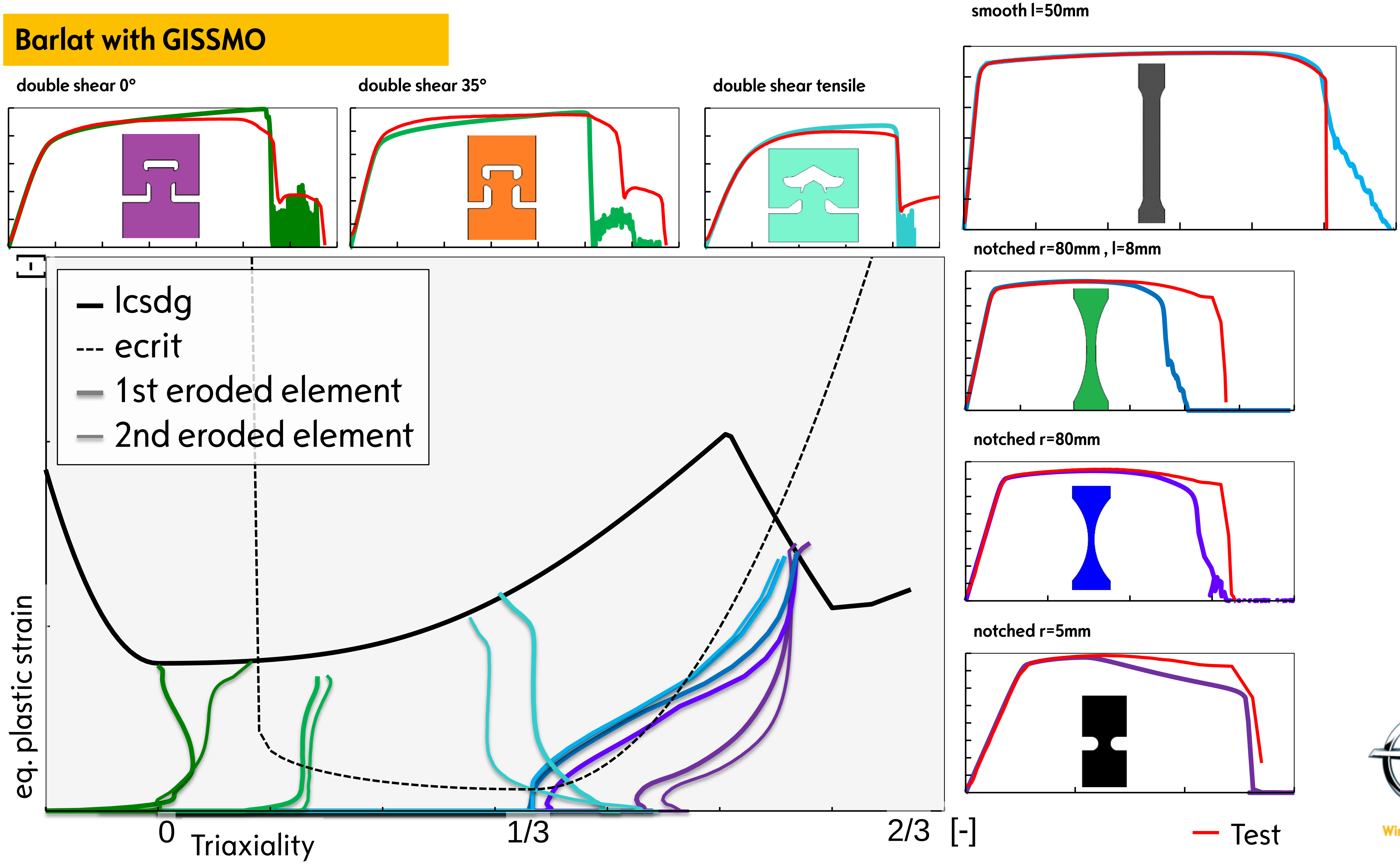
Barlat with GISSMO



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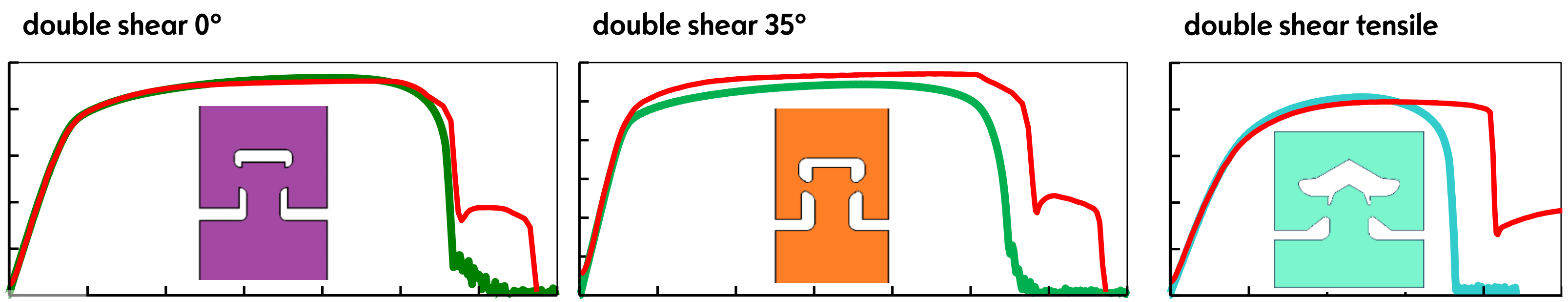
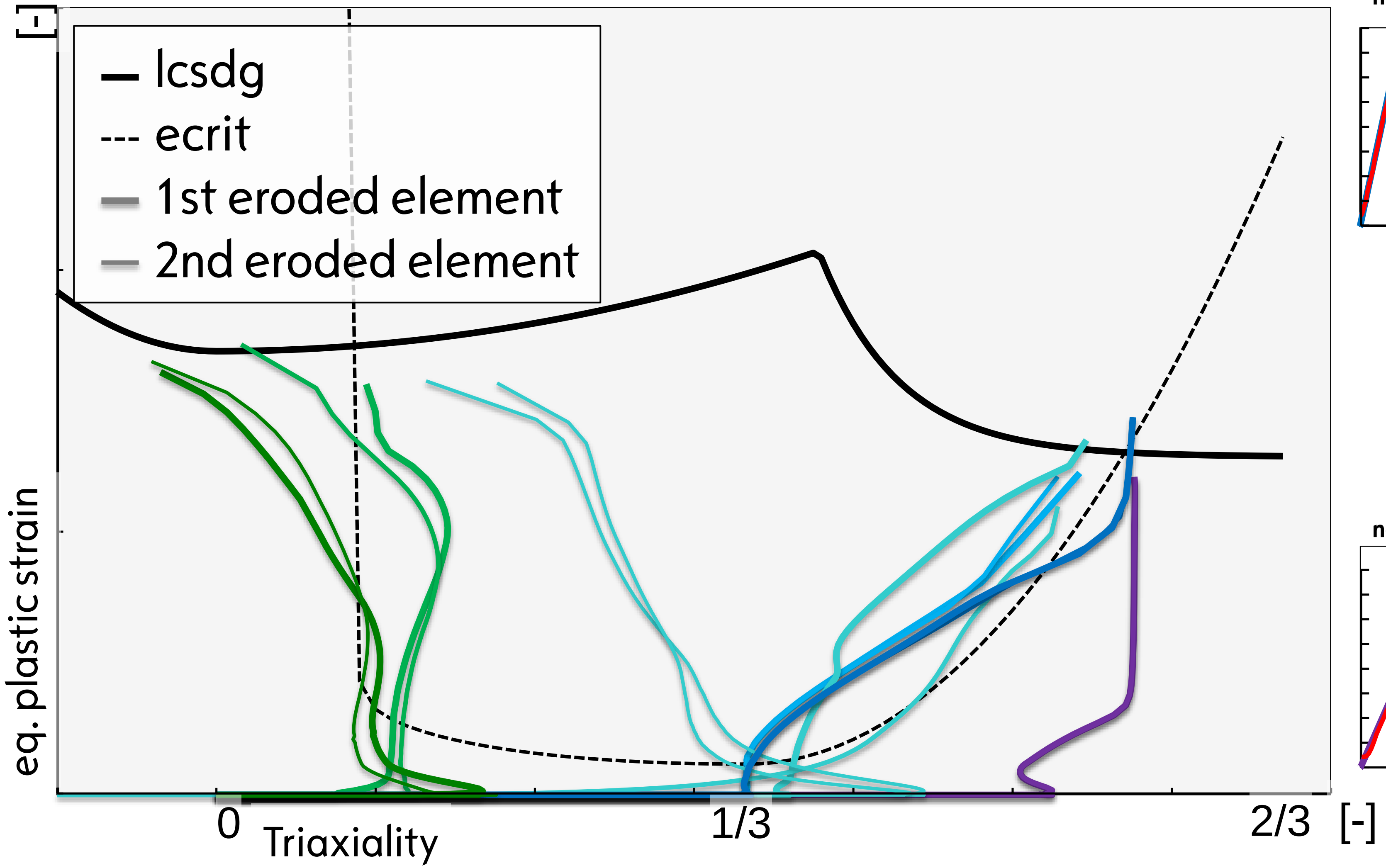
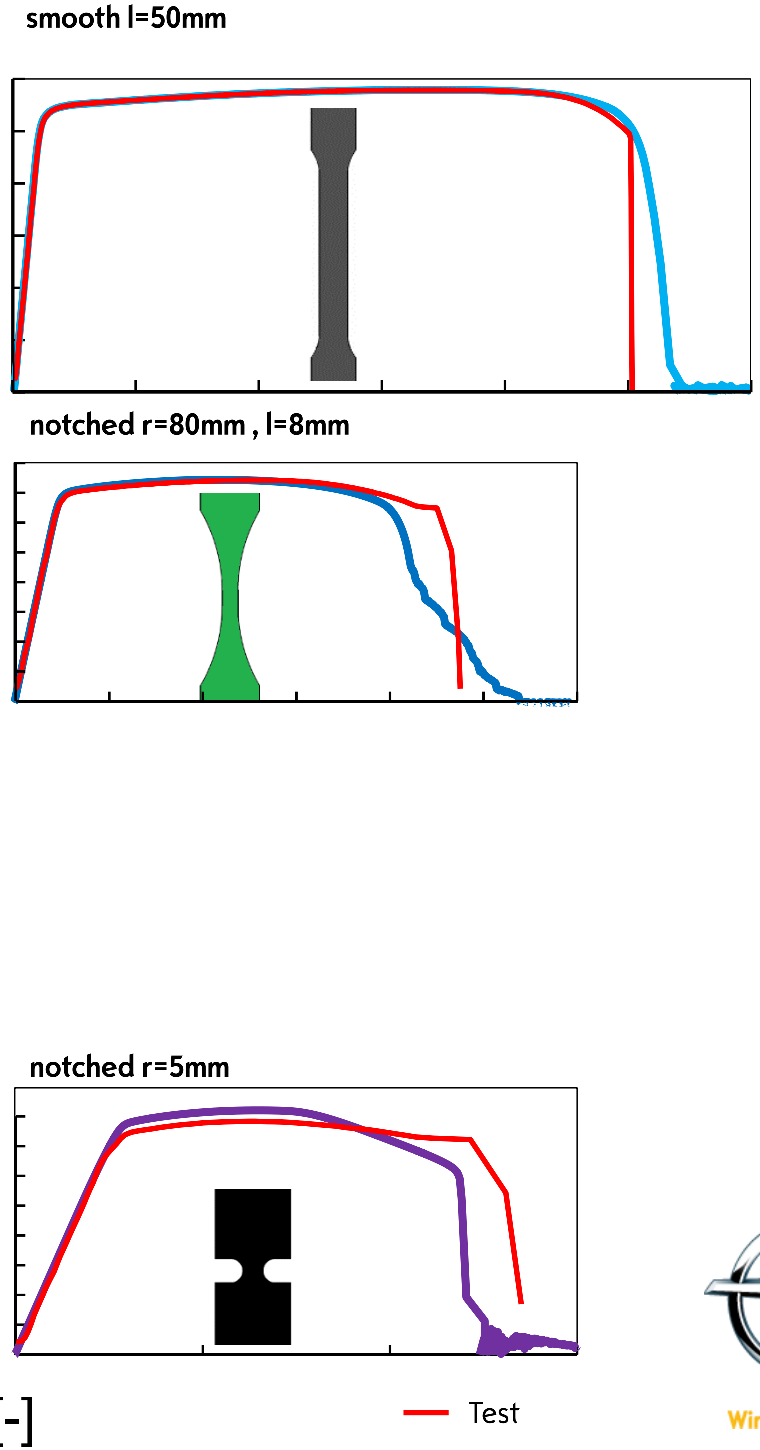
Von Mises with GISSMO







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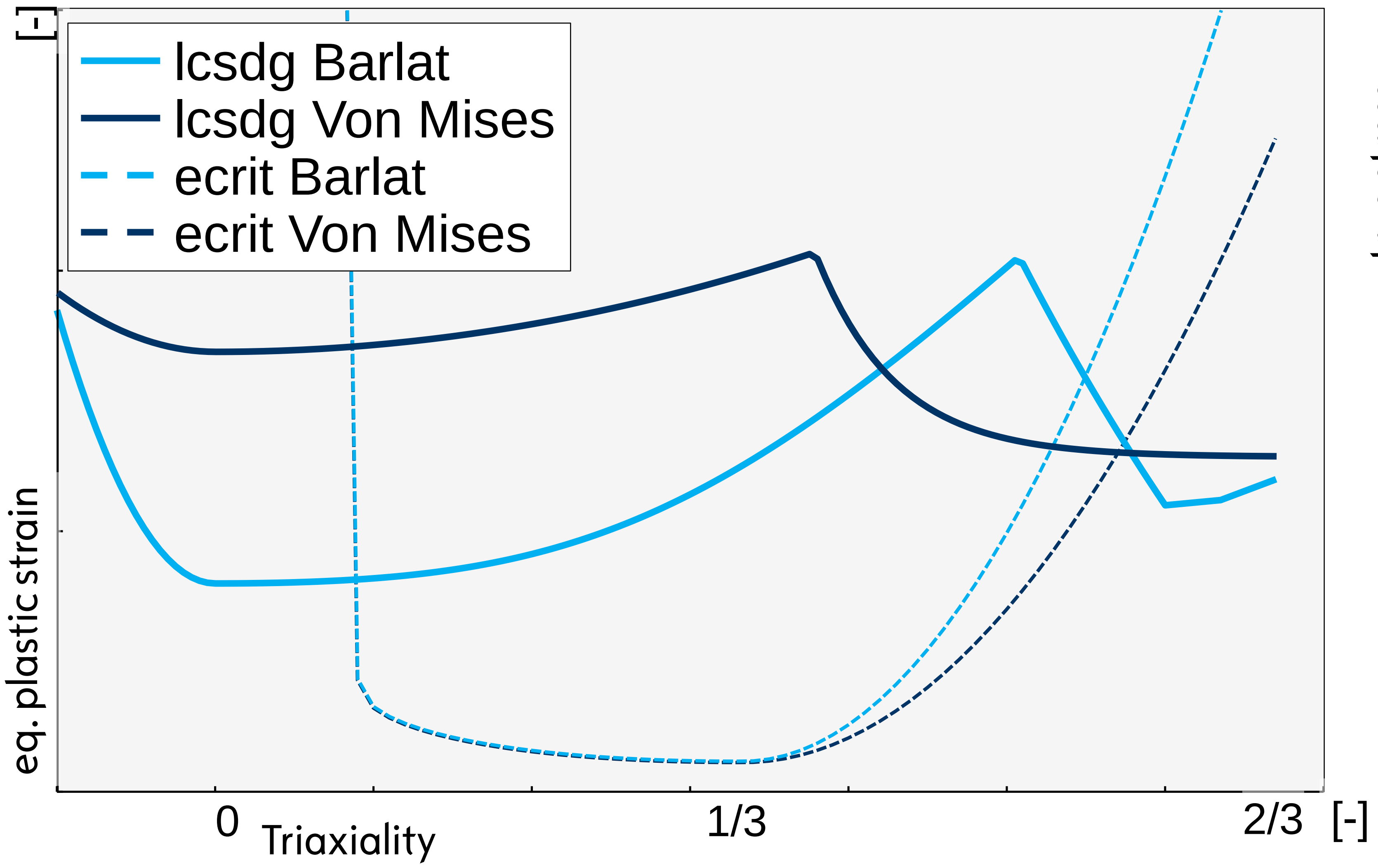
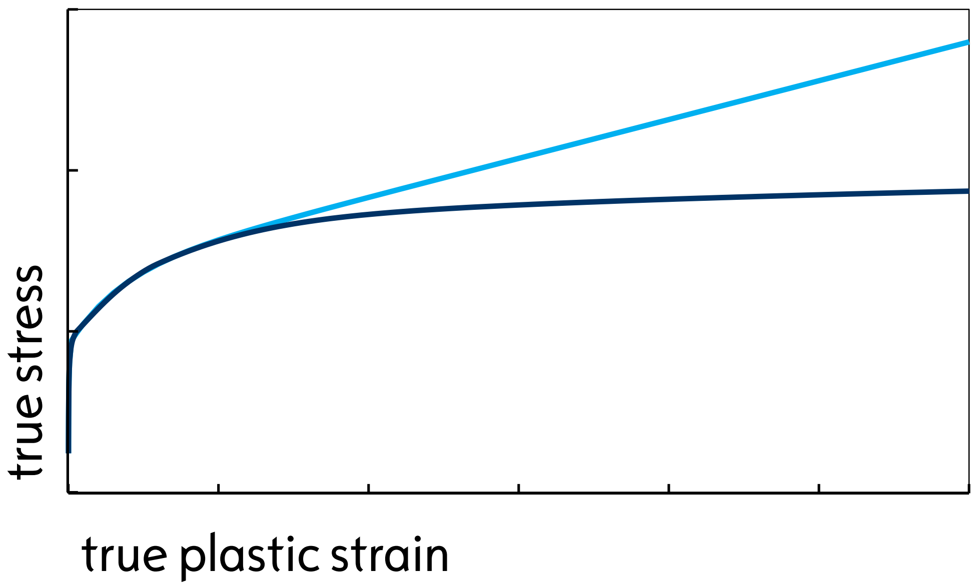
VON MISES VS BARLAT

Damage curves



Yield curves



Lankford coefficient R

(1)

0.5

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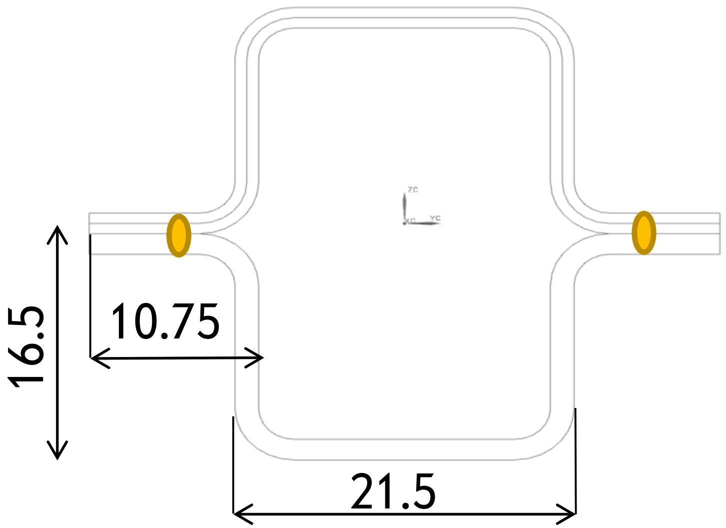
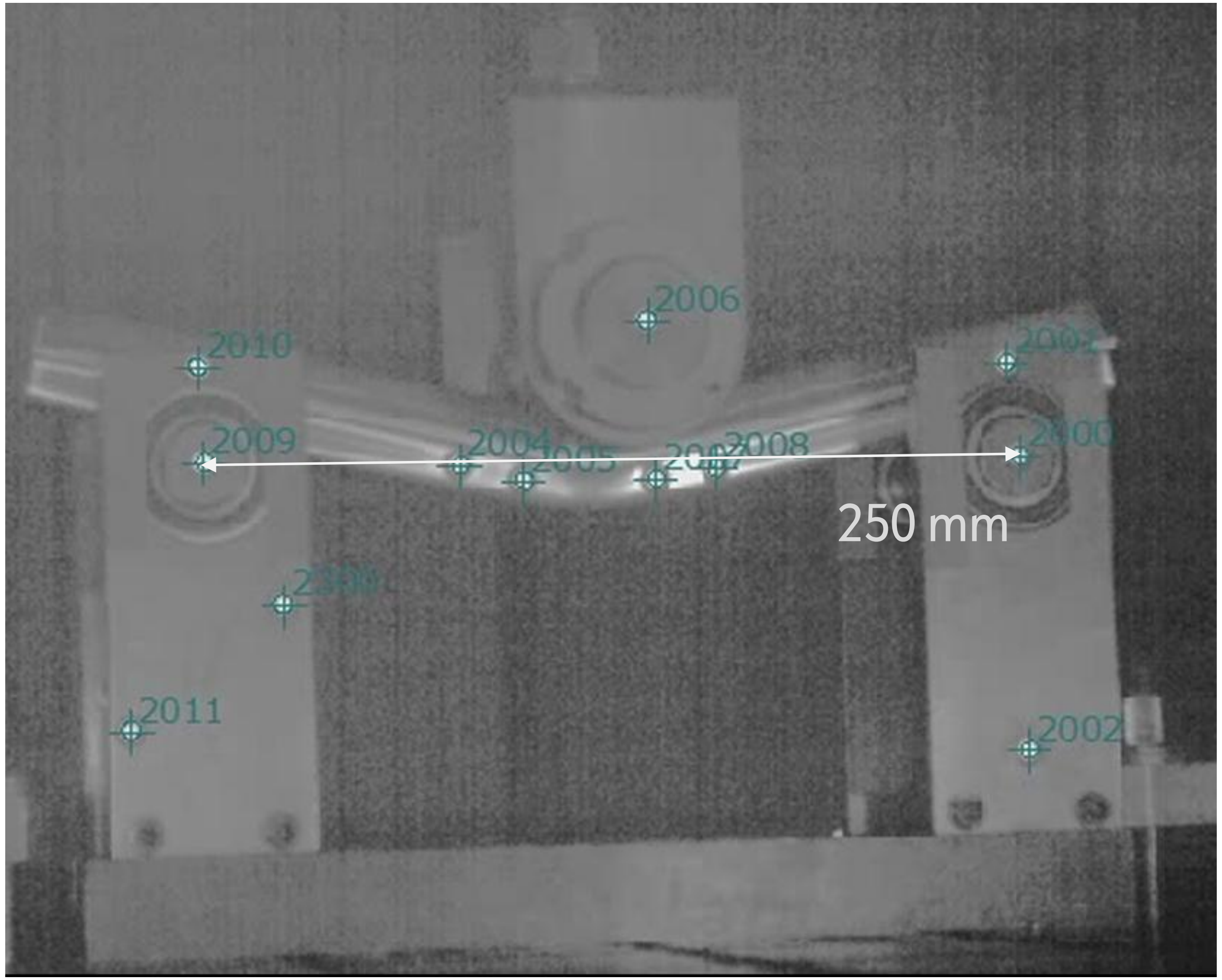
SETUP, TEST

- Small roll formed beam

  with continuous laser welds



- Rotational free cylindrical rests
- Cylindrical impactor



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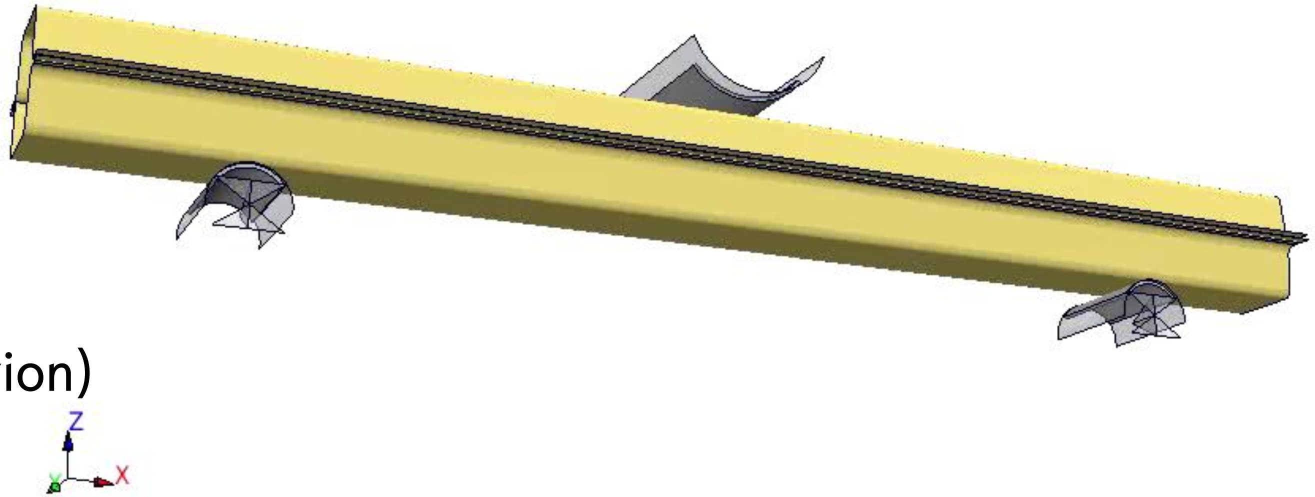
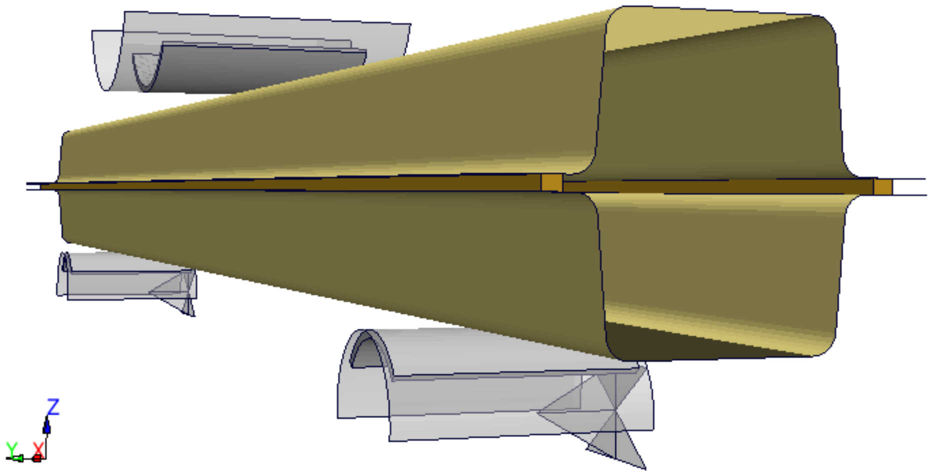
SETUP, SIMULATION

- Beam :
  - Discretization [mm]: 0.5

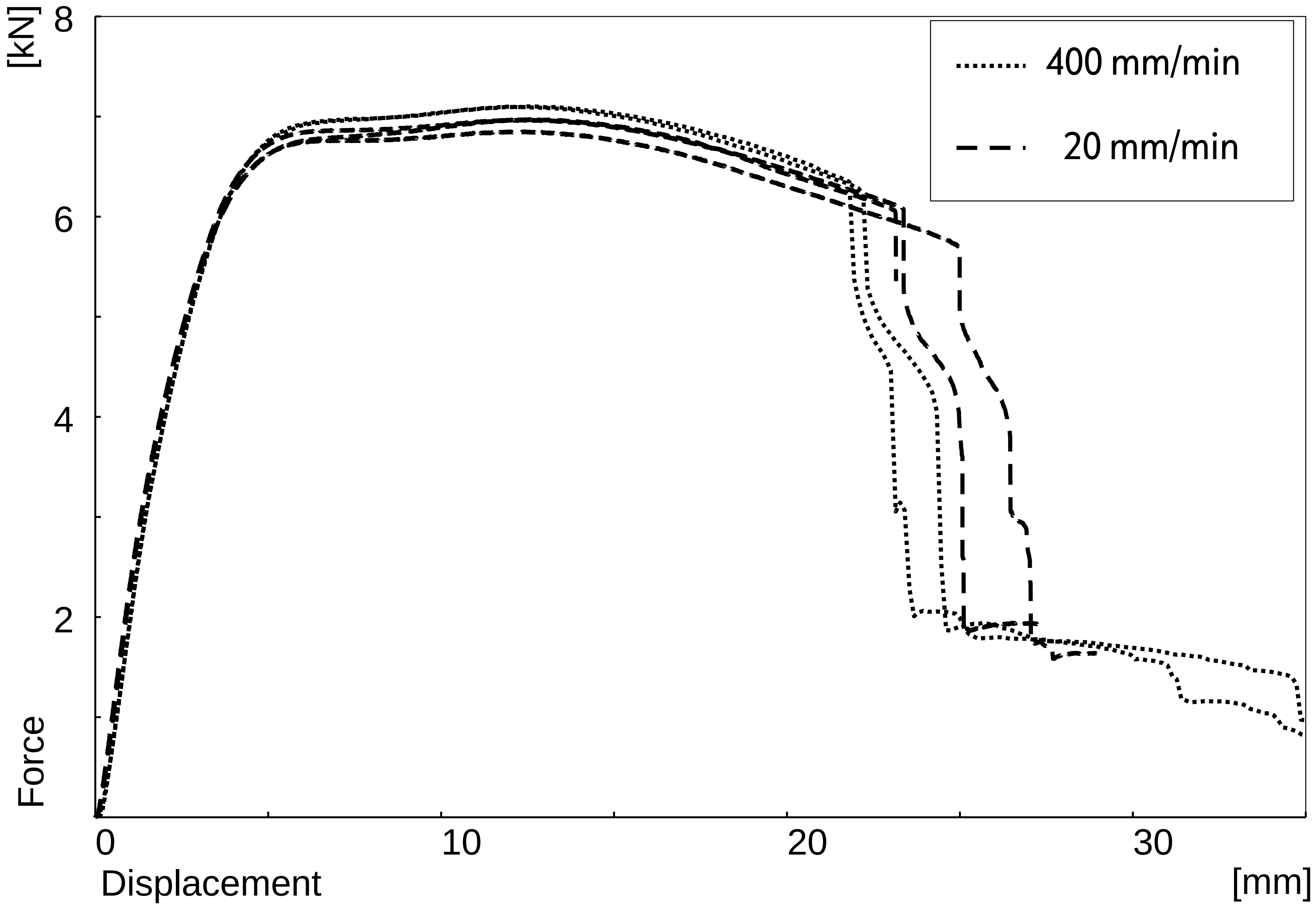
    (also 1.0 , 1.5 , 2.25 , 4.5 not part of this presentation)
  - Fully integrated shell elements (type 16)
  - Laser weld as solid w/ constrained contact
- Rests :
  - Rotational free
- Double precision





Three point bending test

TEST RESULTS



- 5 tests / 2 velocities
  - Good reproducibility
  - Only little strain rate dependency
  - Variation in rupture deflection

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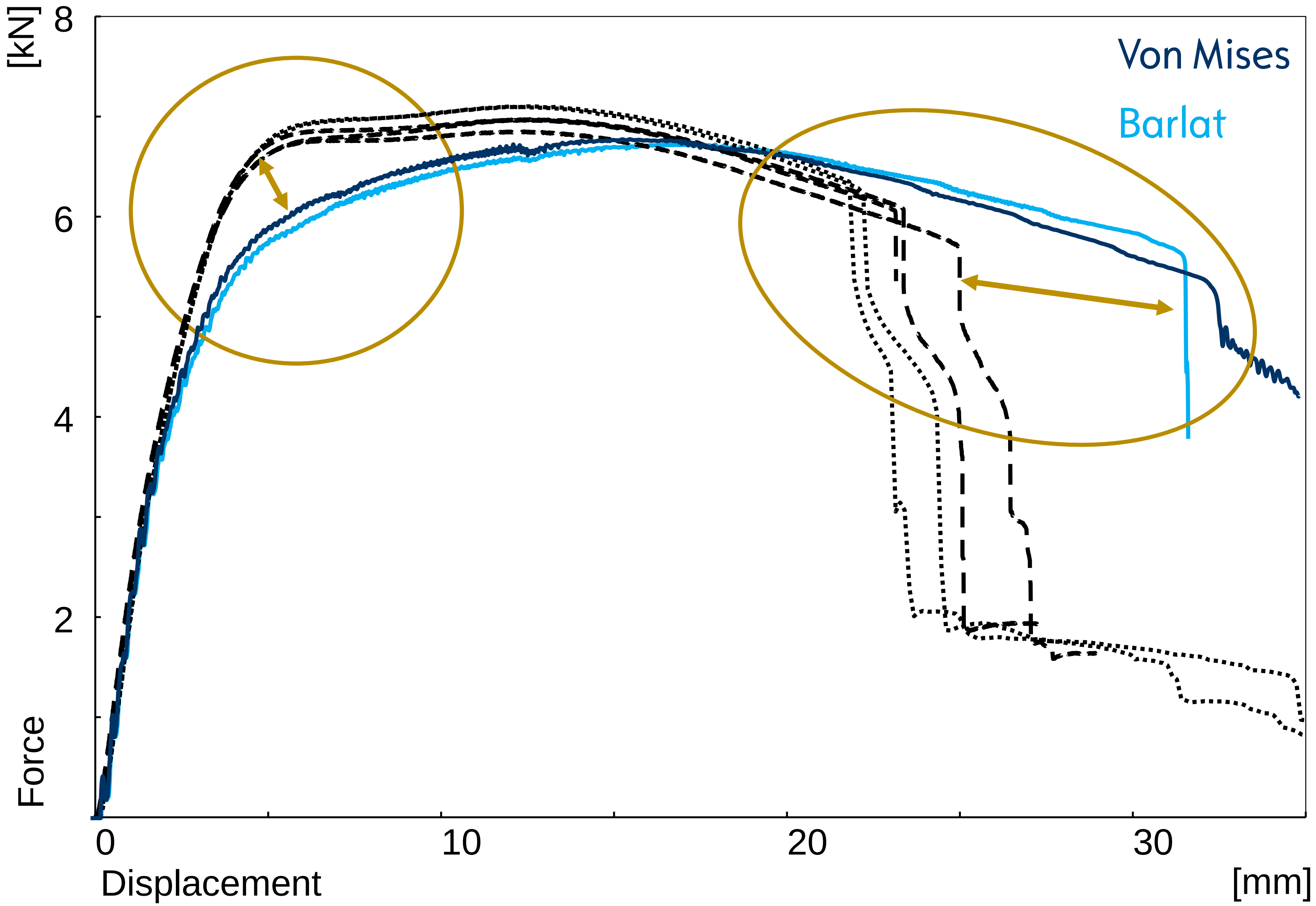
Three point bending test

TEST RESULTS VS SIMULATION



- Yielding is too soft
- Rupture too late
- Barlat and Von Mises similar

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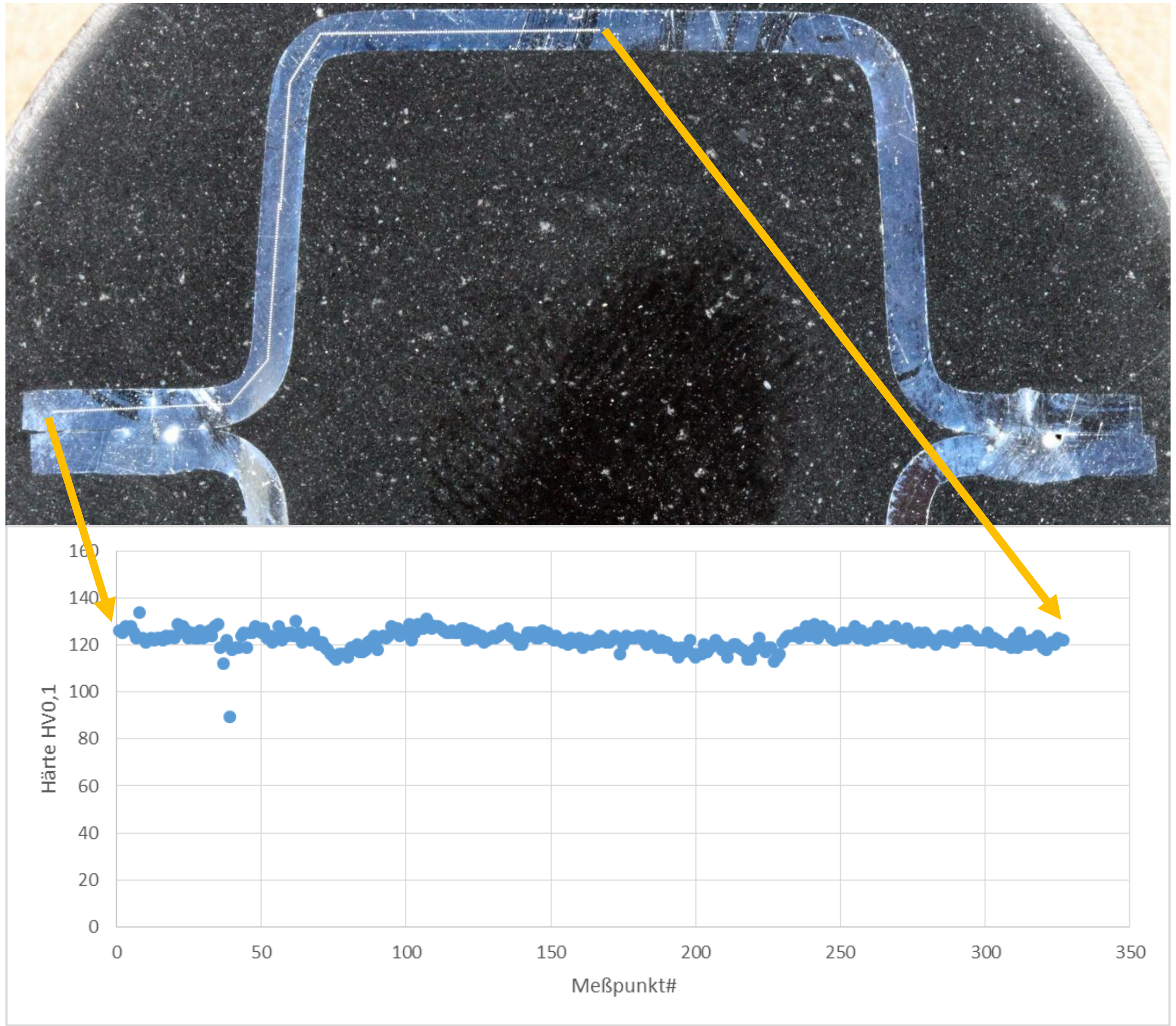
Three point bending test

ADDITIONAL TEST EVALUATION



- HV hardness
  - Uniform, but for weld line
- Inner and outer radius
  - Smaller than intended (1.5 mm < 2.3 mm)
- Overall geometry
  - Angles and lengths deviate

→ Geometry has to be adjusted

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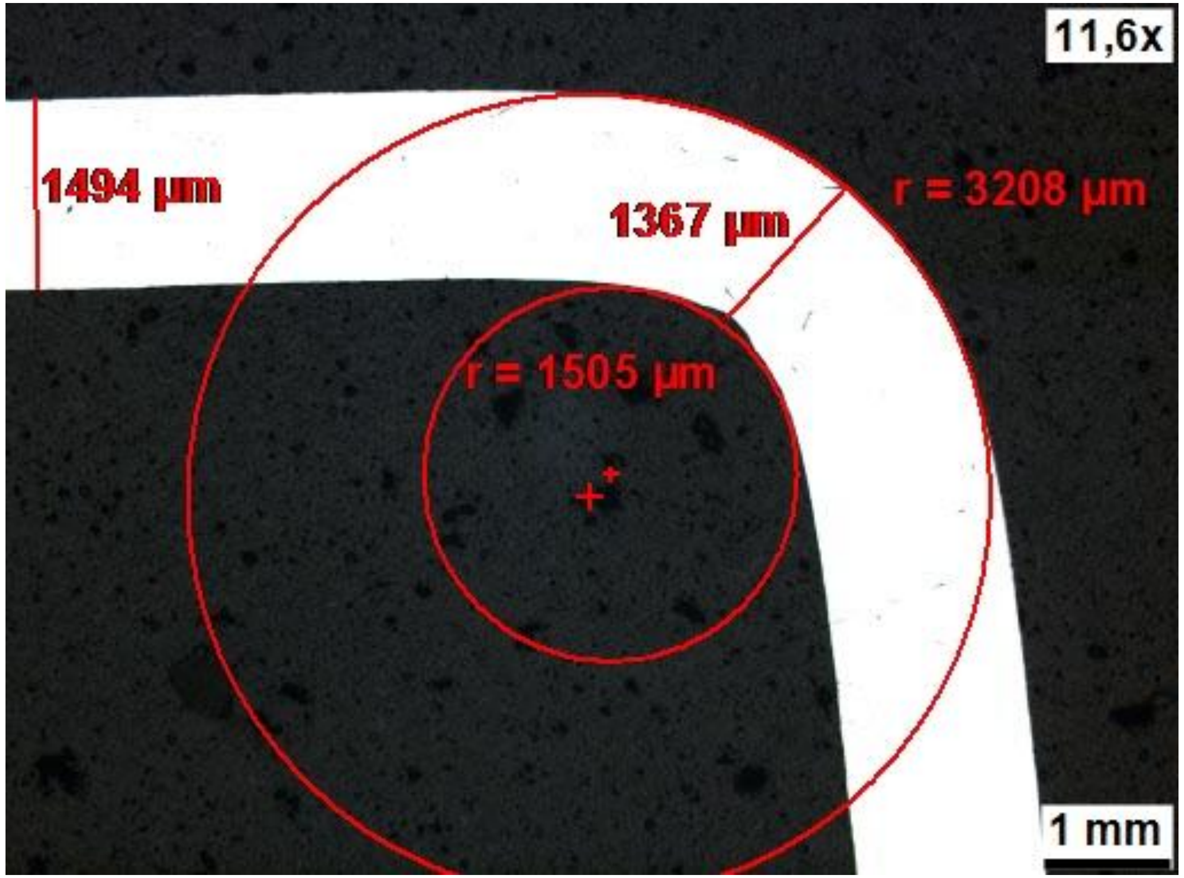
Three point bending test

ADDITIONAL TEST EVALUATION



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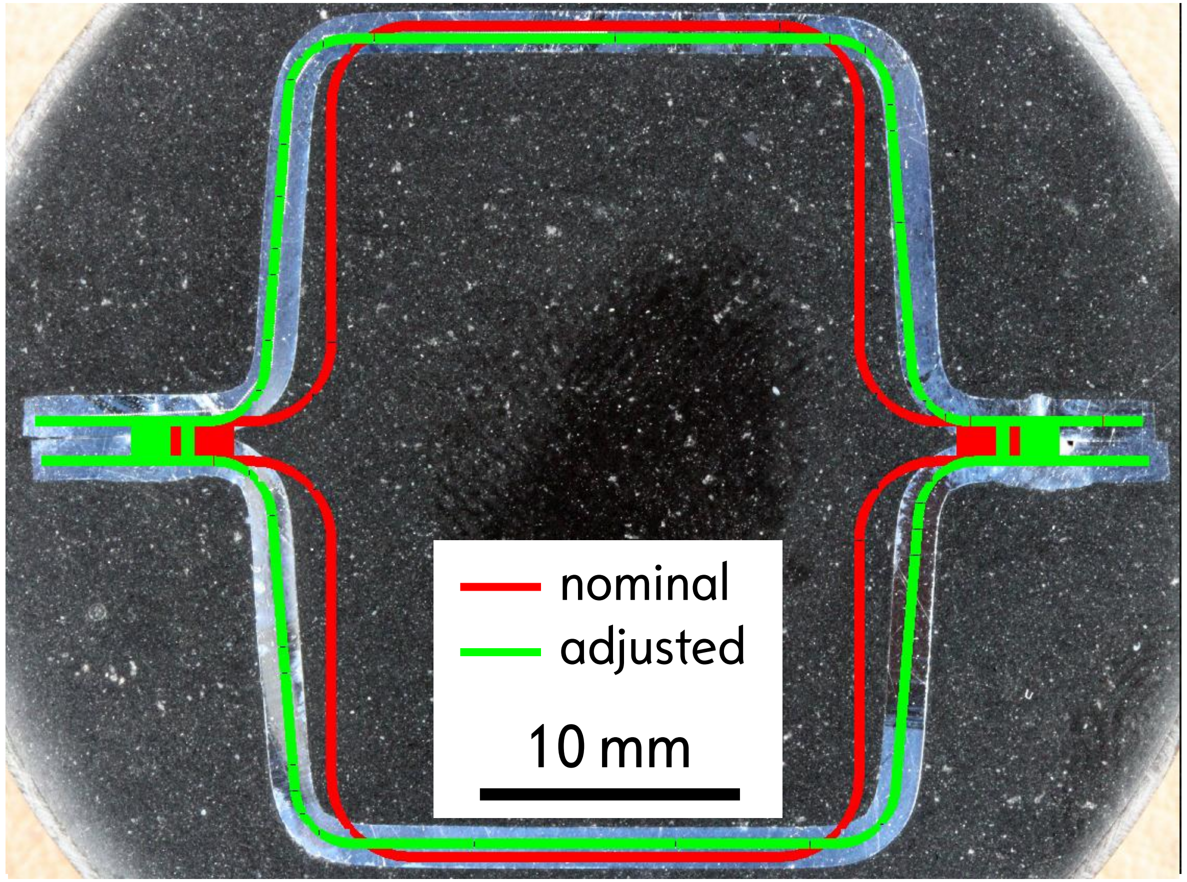

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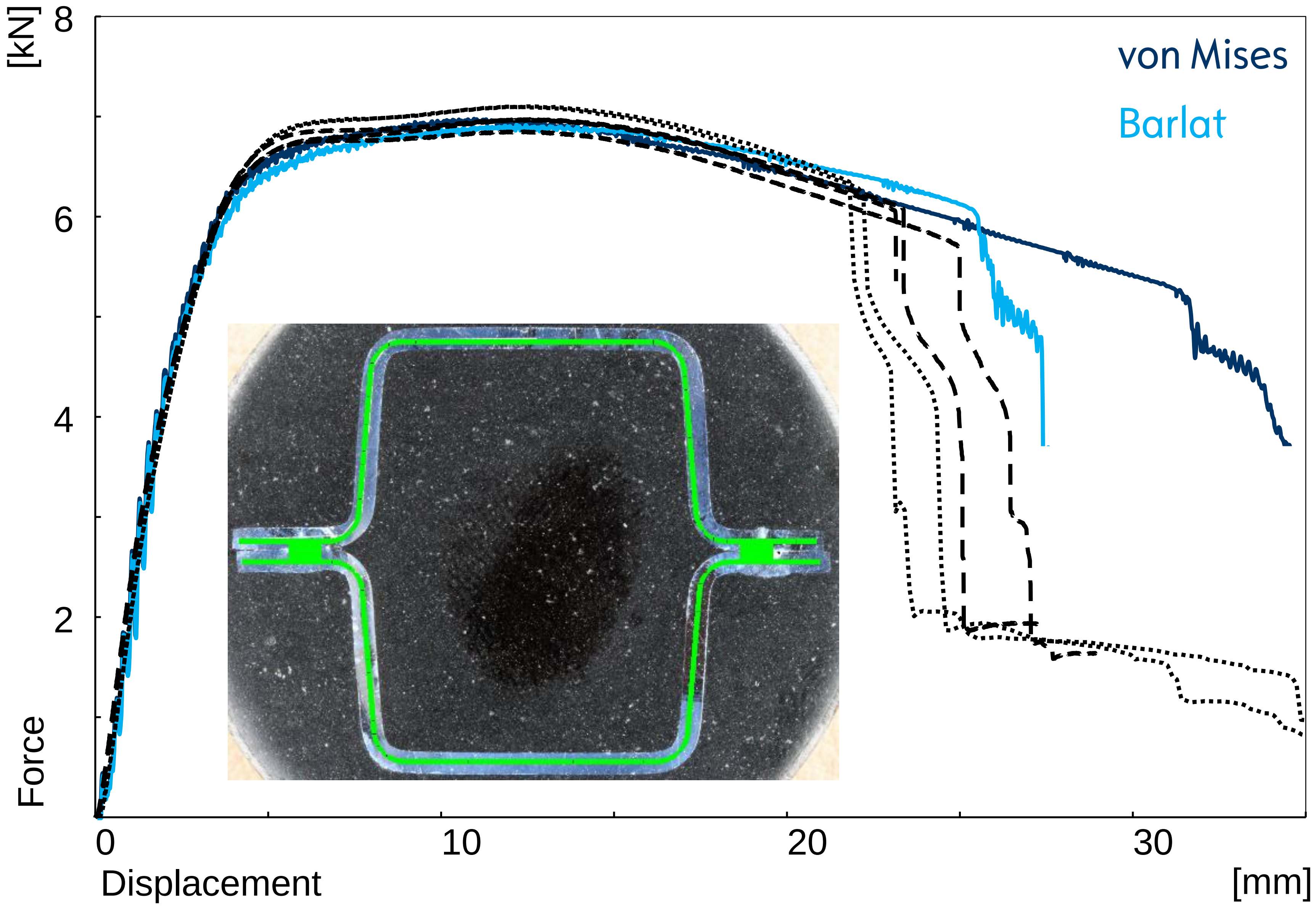
Three point bending test

TEST RESULTS VS SIMULATION



- Model geometry adjusted to test
- Process simulation mapped
- Friction set to μ=0.1 from 0.2

Best rupture prediction

Von Mises

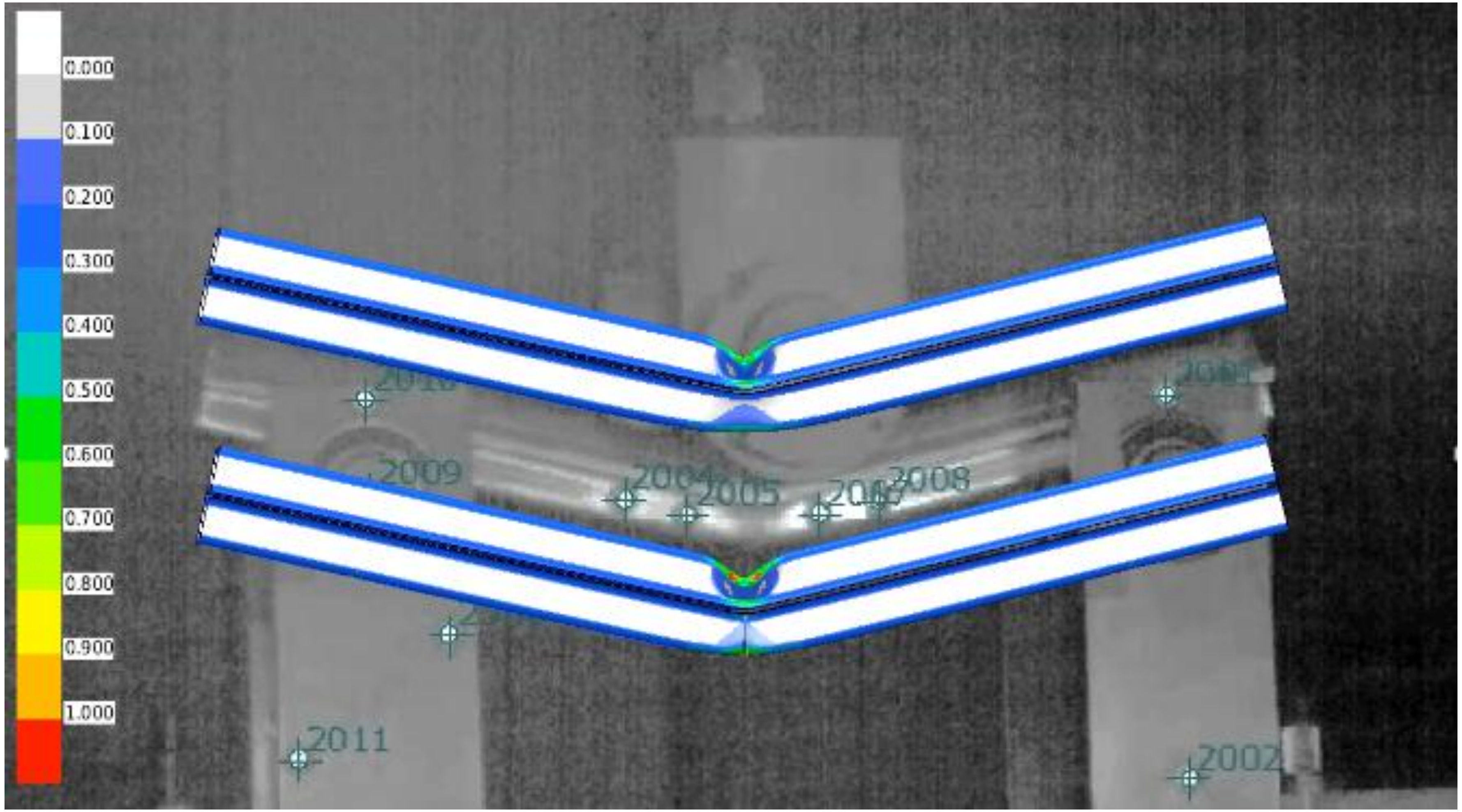
→ Too optimistic

Barlat

→ Still optimistic but close to test

Three point bending test

TEST RESULTS VS SIMULATION



Von Mises

Test

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Three point bending test

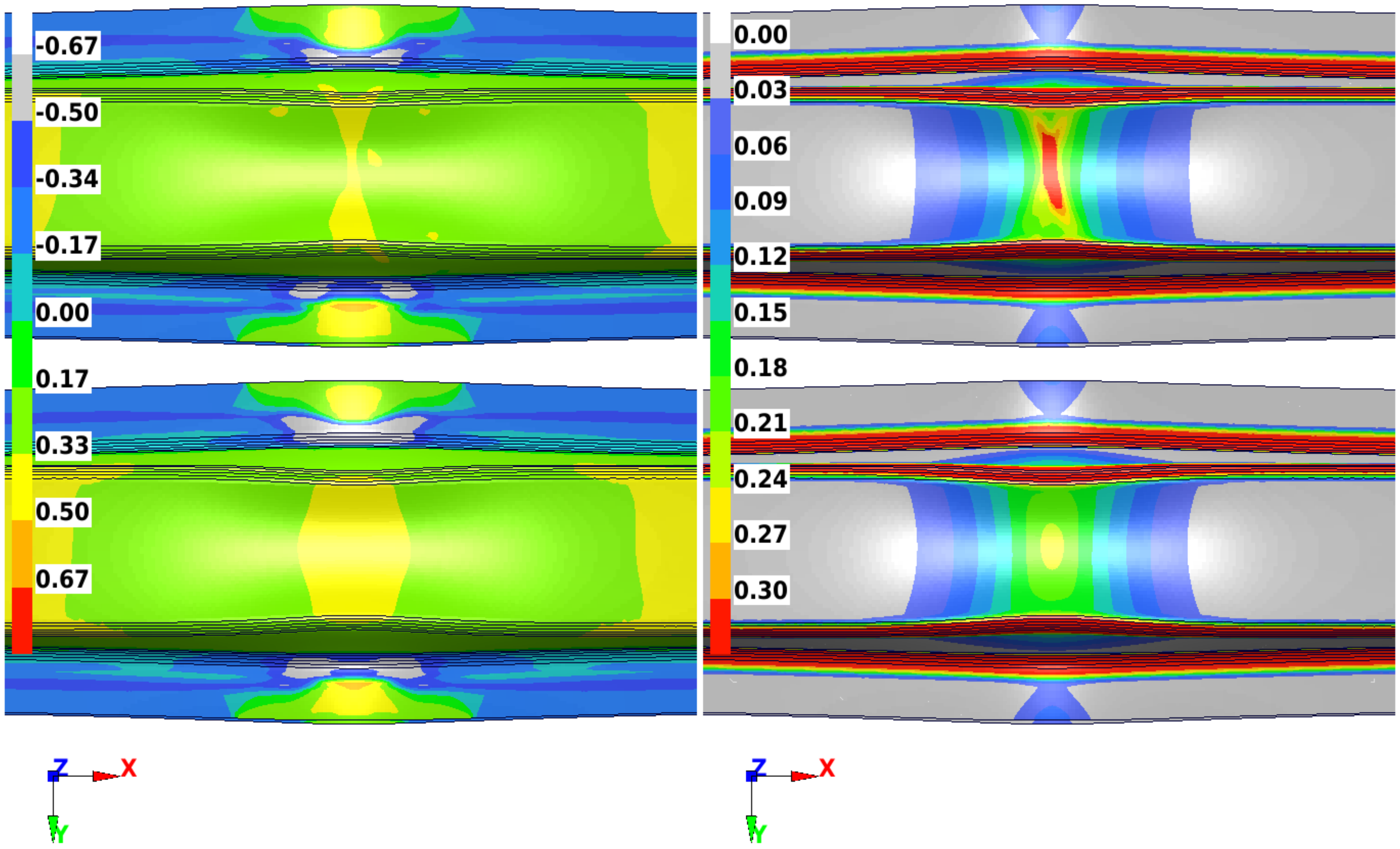
TEST RESULTS VS SIMULATION

Bottom view

Rupture
imminent

Triaxiality

Plastic strain



Barlat

Von Mises

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CONCLUSION

- An accurate yield criterion and flow law are fundamental, Von Mises law is not sufficient in this study
- Introduction of out of plain anisotropy has improved results significantly without increasing the model complexity
- Geometrical detail and process data have an immense impact on validation

➔ We need every piece of the puzzle

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Daniel Riemensperger

THANK YOU.