Berlin, December 1st, 2022

GISSMO for Damage and Failure Prediction

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The Material Competence Center

Who we are and what we offer

The Material Competence Center

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- **Testing services**
  - Tensile, compression, puncture, bending testing
  - Static, dynamic, cyclic testing
  - Component testing
  - Sample processing and conditioning
  - 3D-DIC measurement of the strain field
- **Benefits**
  - Parameter identification from a single source
  - Minimize time and costs
  - The LS-DYNA developer team is always available

- **Material Characterization**
  - LS-DYNA material model calibration for: **Metals**, **polymers**, **glass**, **foams**, and more
  - Deformation behavior
    - Viscoelastic and visco-plastic
    - Isotropic and anisotropic
    - Tensile and compressive- asymmetry
  - Damage and failure modelling
    - GISSMO (General Incremental Stress State dependent damage Model)
    - DIEM (Damage Initiation and Evolution Model)

The Material Competence Center

A selection of our machinery

Water jet cutter

3D ARAMIS-DIC (5M and 12M)

UV LED Printer

Climate chamber

Conditioning of specimen before the tests at constant
- Temperature
- Humidity

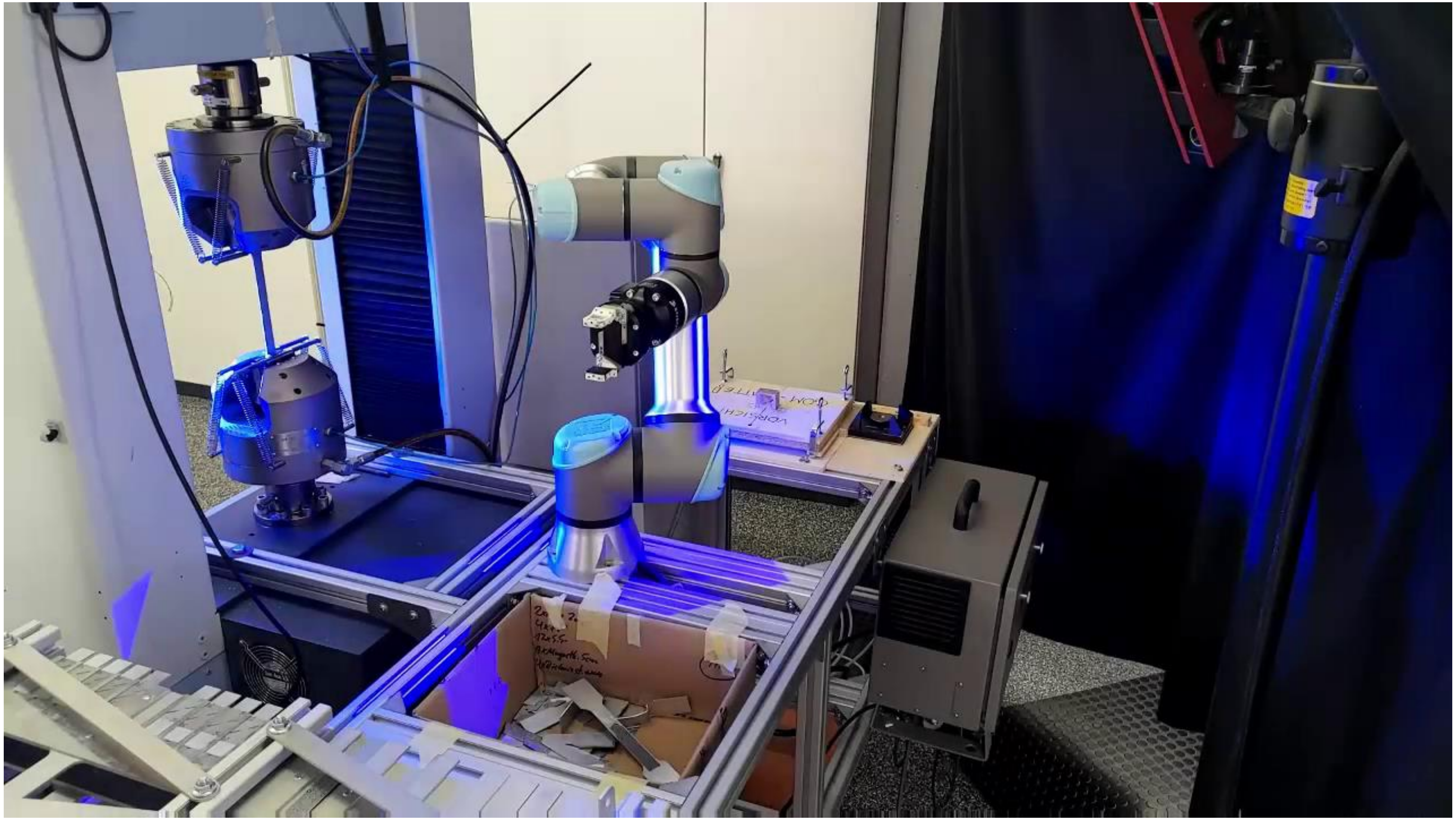
10 kN and 100kN tension test rigs

- Tension tests (QS)
  - Uniaxial
  - Shear
  - Notched
- Compression tests (QS)
- Bending tests (QS)
- Punch tests (QS)

4a Impetus pendulum

- Dynamic bending
- Dynamic compression

The Material Competence Center



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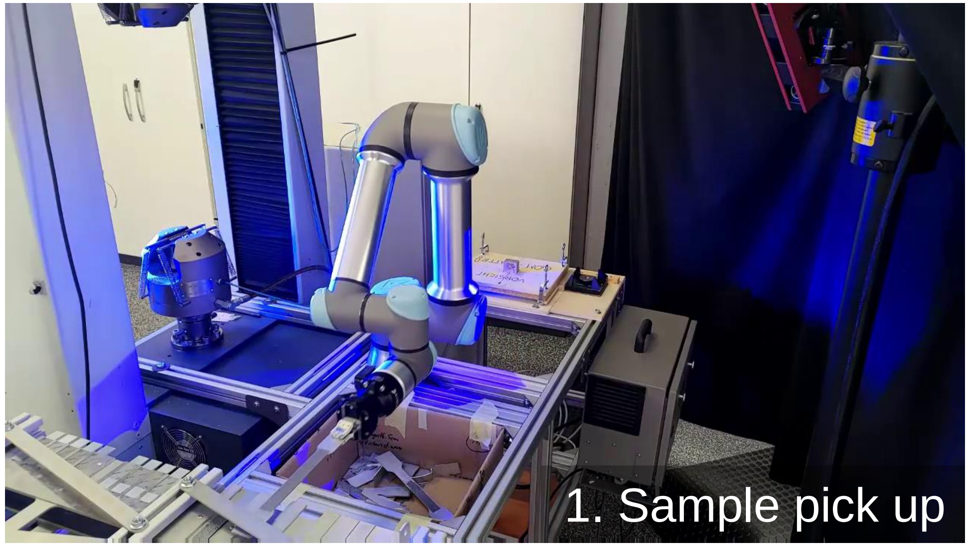
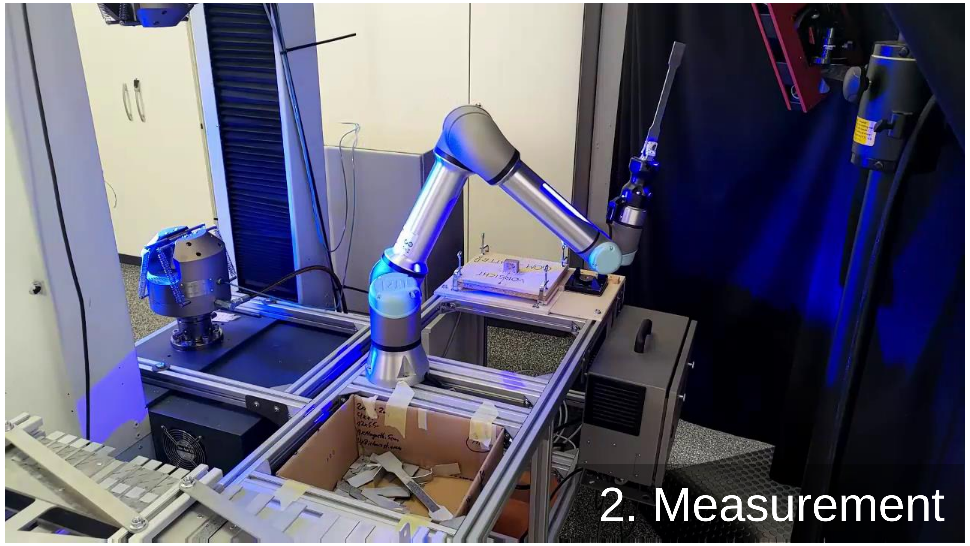
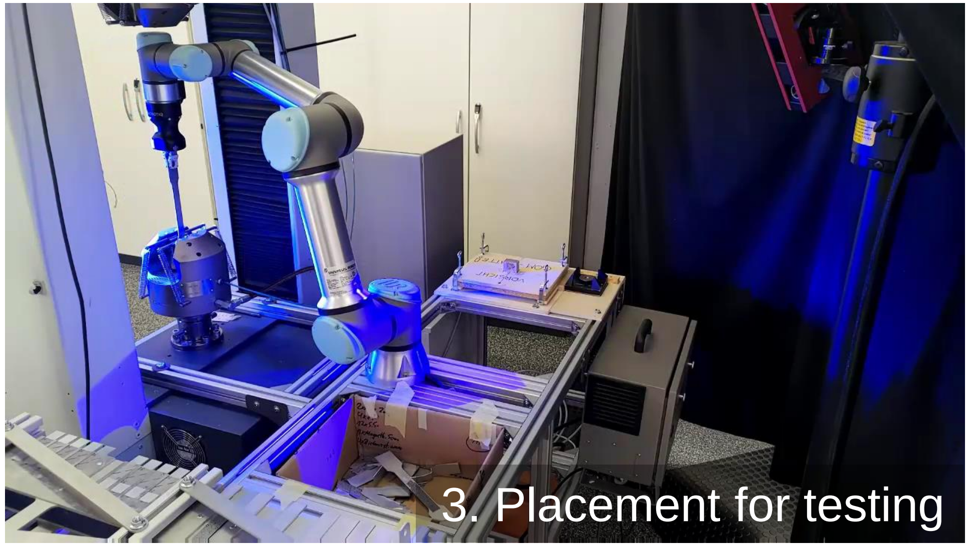
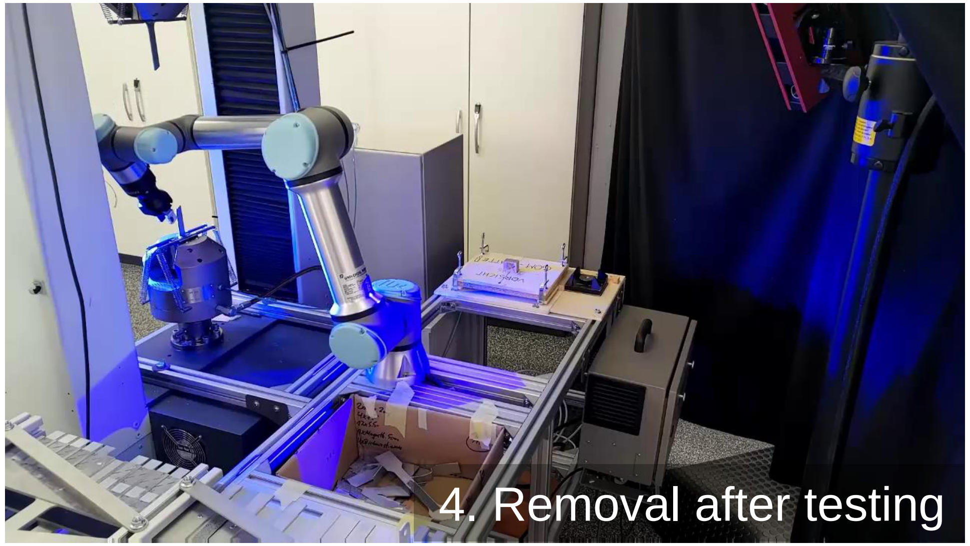








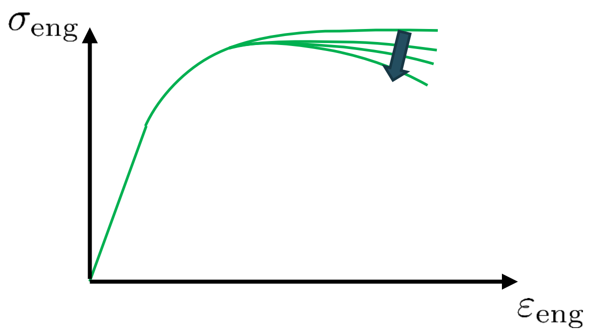
GISSMO

Why it's a good idea to use it

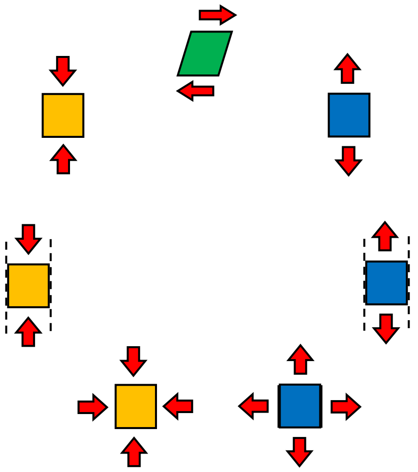
GISSMO – the motivation

Why GISSMO is needed

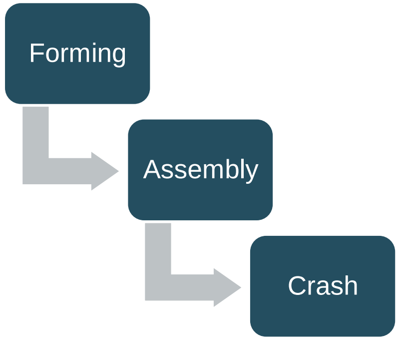
- FAIL already exists in *MAT_024 (and many others)
  - ➢ Simple element deletion based on critical equivalent plastic strain
- But, what about…



Damage evolution



Stress states

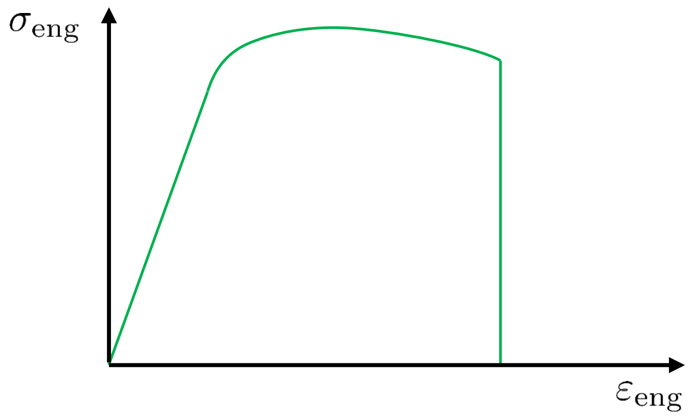


Process simulation

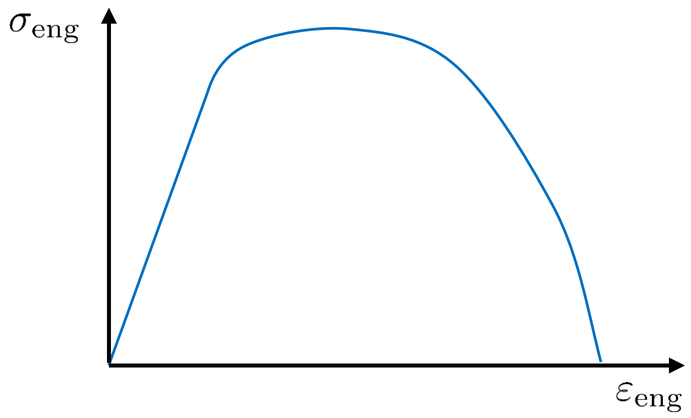
GISSMO – failure vs. damage

A definition

- **Failure:** Failing of the physical structure of a material
  - Sudden failure of the material without prior influence on the strength
  - Failure occurs when a certain criterion is met
  - Usually simpler than damage models



- **Damage:** Reduction of the physical strength of a material
  - Typically, incremental evolution of some damage parameter
  - Strength/stress can be decreased depending on the damage parameter
  - Usually more complex than failure models



Note: GISSMO can be damage and failure model simultaneously

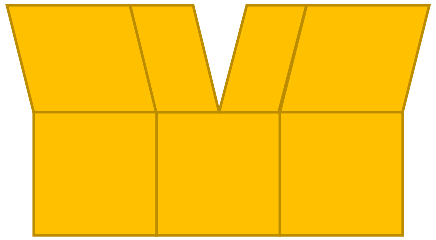
GISSMO – failure vs. damage

How to handle failure in FEM

- Approaches:
  - XFEM (enriched FEM to reproduce discontinuities like fractures)

Pro
- Mass is conserved
- Crack width independend of element size

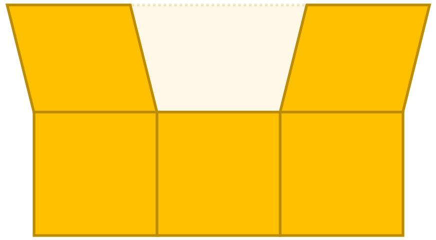
Contra
- Tricky to implement
- Expensive in calculation



  - Element deletion

Pro
- Easier to implement
- Fast

Contra
- Leads to loss of mass and empty areas inside of a part
- Strong influence of element sizes



Note: Deleting failed elements is state of the art in many simulation applications

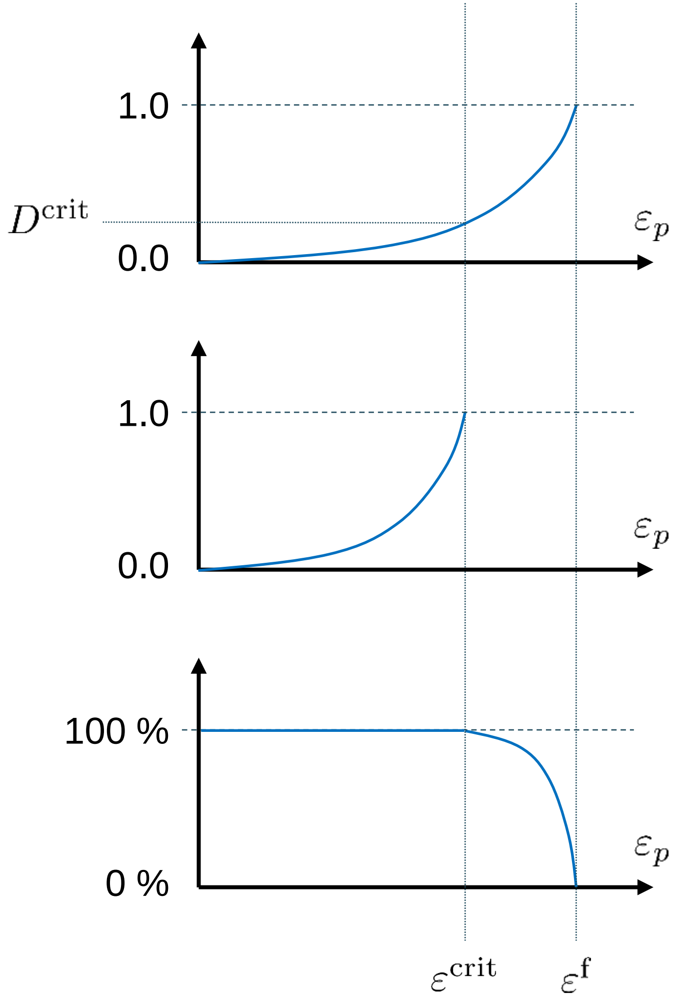
GISSMO – failure vs. damage

How damage is handled in GISSMO

Damage parameter D:

Coupling parameter F:

Stress coupling (reduction):



- GISSMO input:

DMGEXP: defines shape of D and F

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

$$\Delta F = \frac{\text{DMGEXP}}{\varepsilon_{p,loc}} F^{\left(1-\frac{1}{\text{DMGEXP}}\right)} \Delta\varepsilon_p$$

FADEXP: defines shape of coupling

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

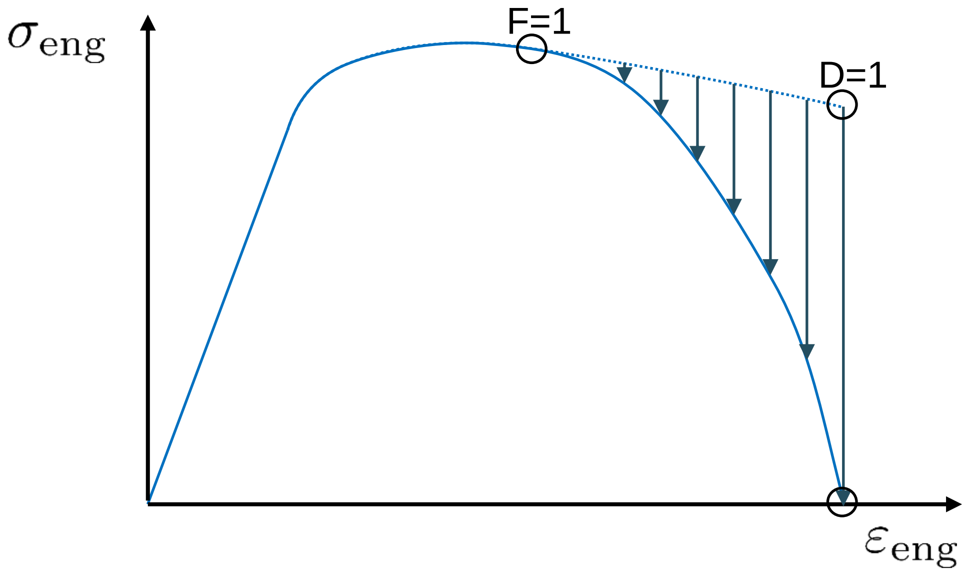
DCRIT or **ECRIT:** define onset of coupling

GISSMO – failure vs. damage

How damage is handled in GISSMO

- The coupling parameter F is accumulated until it reaches 1 at the onset of stress coupling
- The stress is continuously reduced and becomes 0 when the failure parameter D reaches the value 1

Stress-strain curve of a tensile test



Note: Your simulations might become more stable if elements are no longer deleted all of a sudden

GISSMO – failure vs. damage

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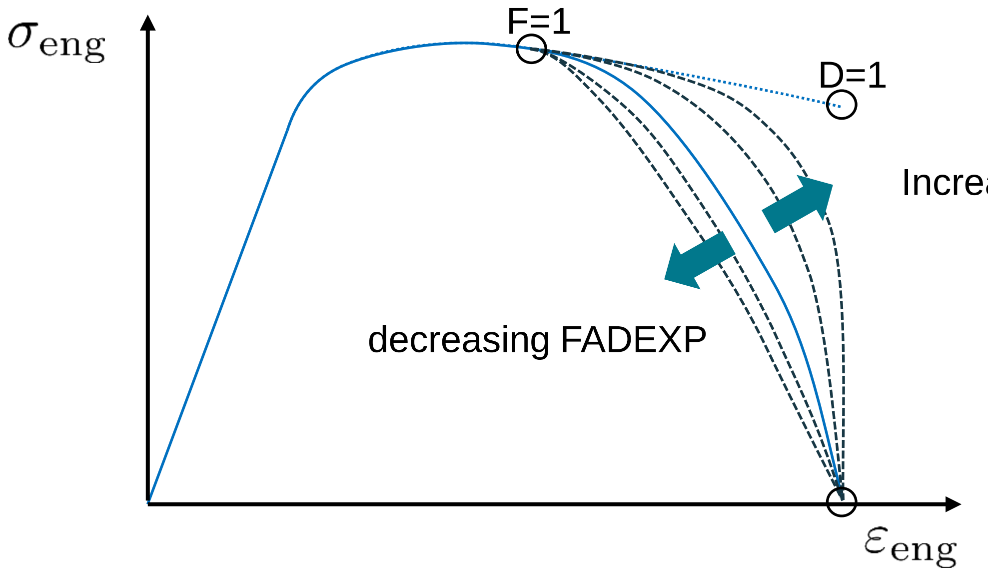


Note: Your simulations might become more stable if elements are no longer deleted all of a sudden

GISSMO – stress-state dependency

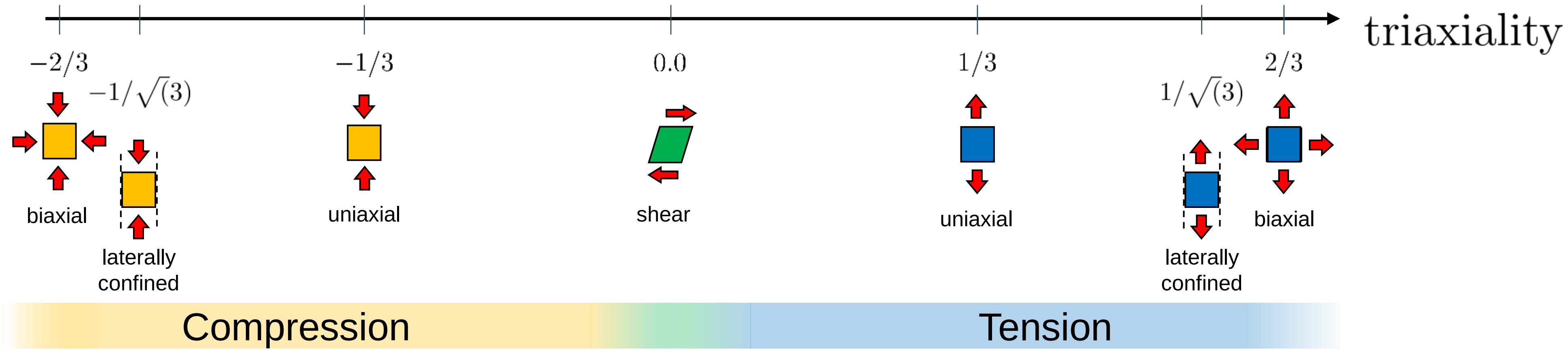
What a “stress state” is

- In-plane stress state (for shells)

$$\text{triaxiality } \eta = -\frac{\text{pressure}}{\text{equiv. stress}}$$

Shells: $-\frac{2}{3} < \eta < \frac{2}{3}$

Solids: $-\infty < \eta < +\infty$



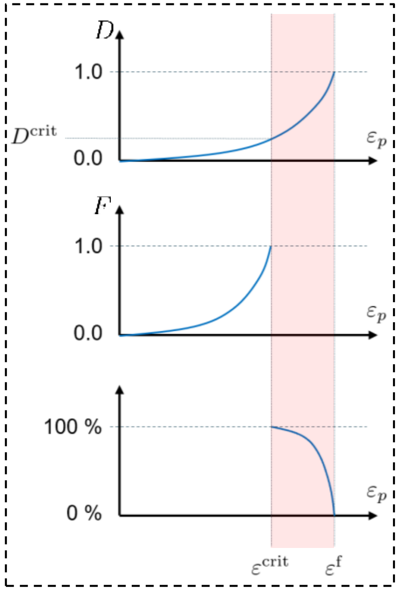
Note: For solid elements there is an additional dimension (lode parameter) to describe the stress state

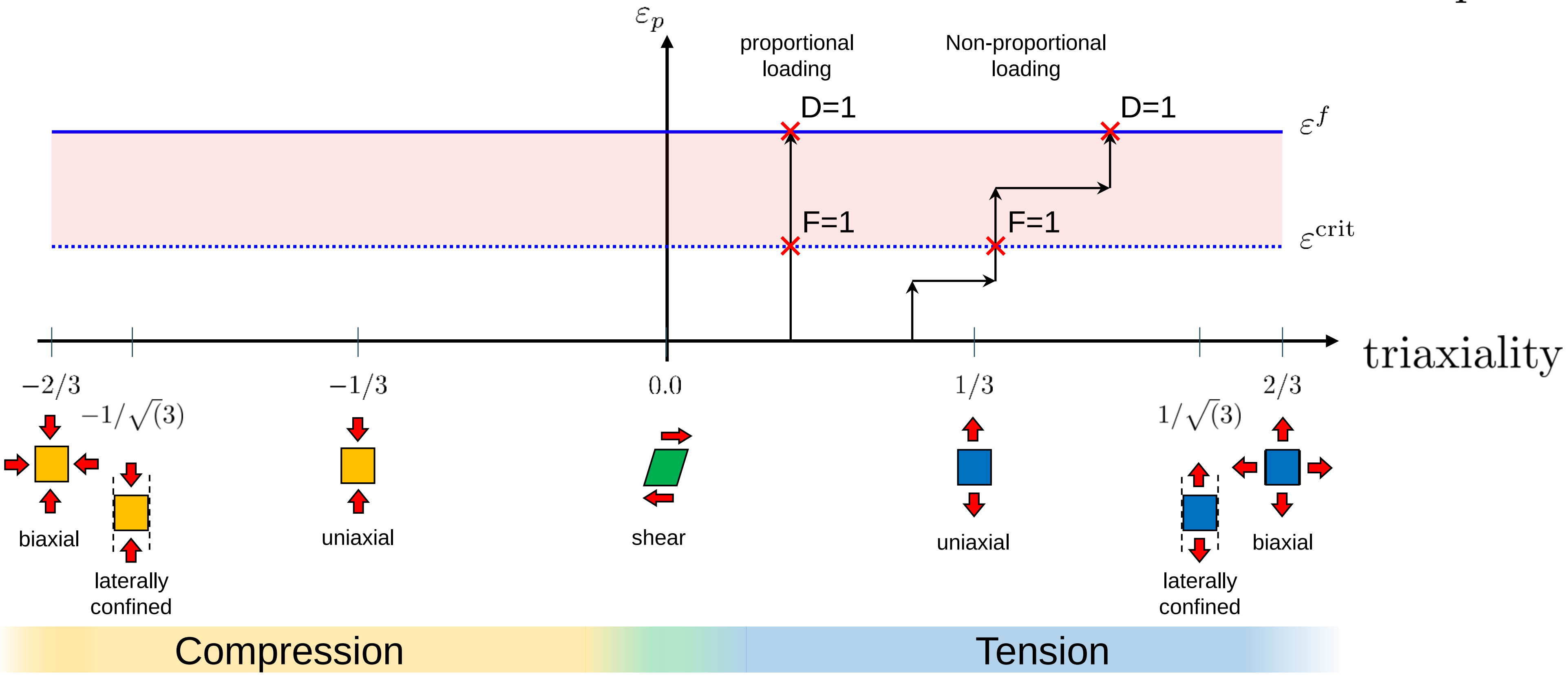
GISSMO – stress-state dependency

The road to failure

- Loading for constant $\varepsilon^{\text{crit}}$ and ε^{f}

$$\text{triaxiality } \eta = -\frac{\text{pressure}}{\text{equiv. stress}}$$





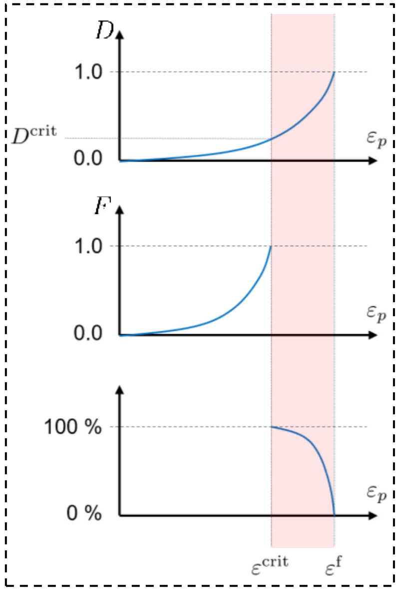
Note: For solid elements there is an additional dimension (lode parameter) to describe the stress state

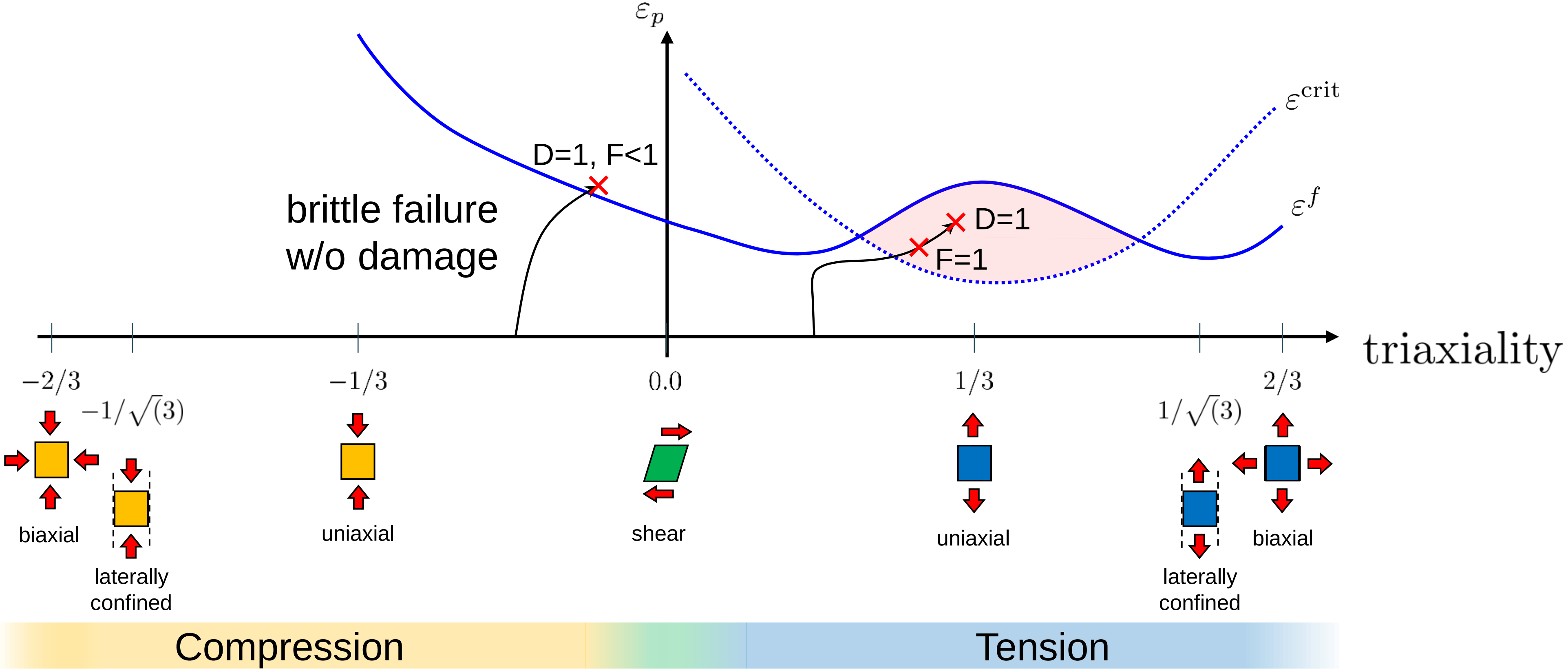
GISSMO – stress-state dependency

The road to failure

- Non-proportional loading for general damage and failure curves

$$\text{triaxiality } \eta = -\frac{\text{pressure}}{\text{equiv. stress}}$$



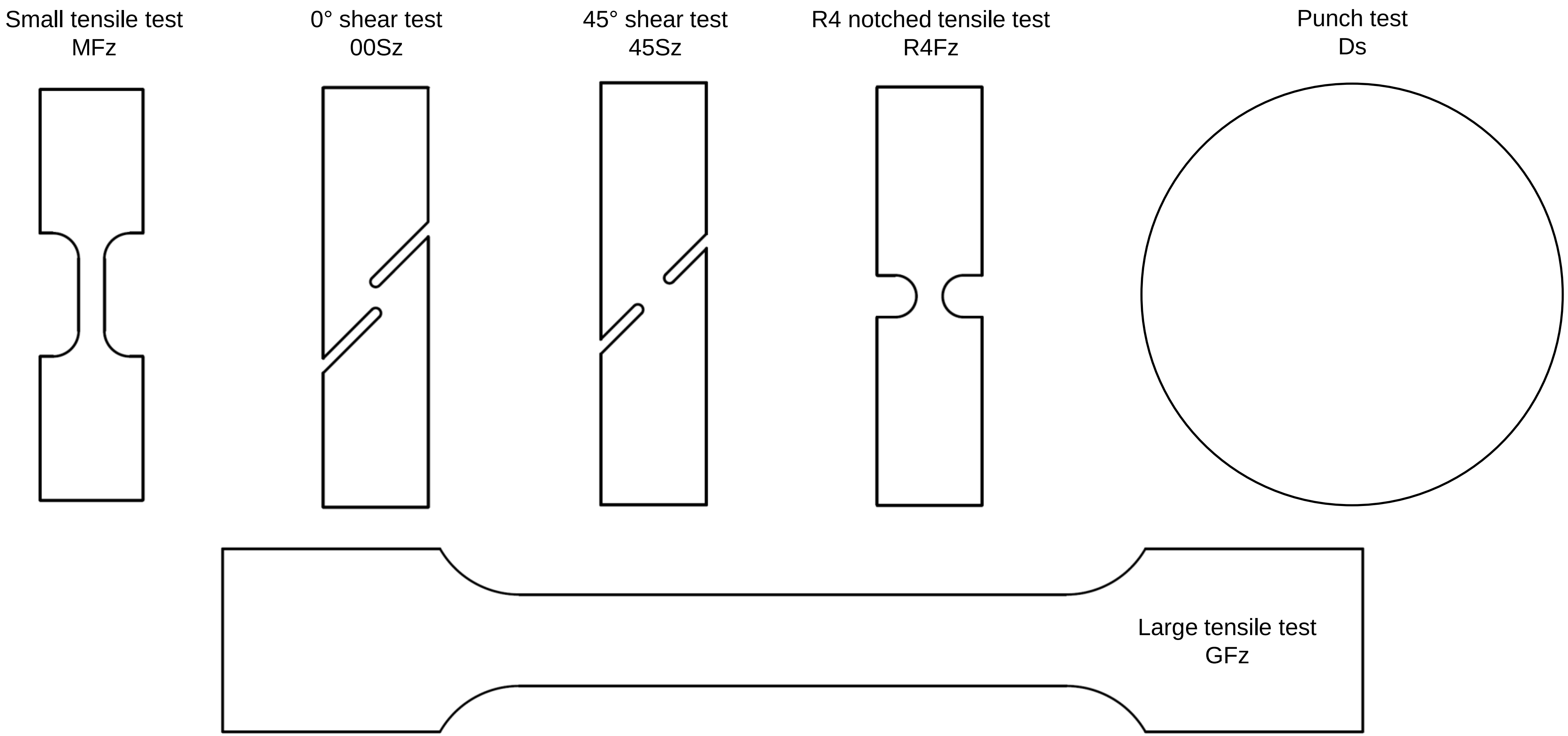


Note: for non-proportional loading, F=1 and D=1 are generally not directly on the curve

GISSMO – calibration

That test are needed to for the calibration

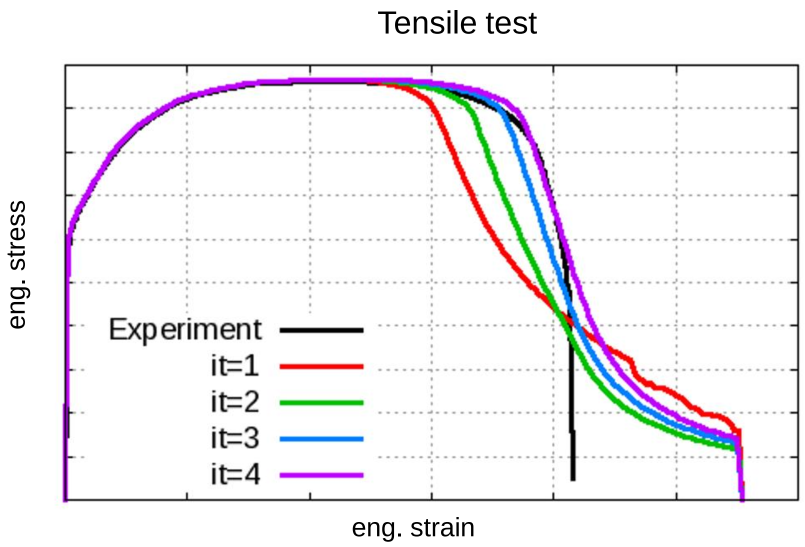
- Standard set for GISSMO calibration for shell elements

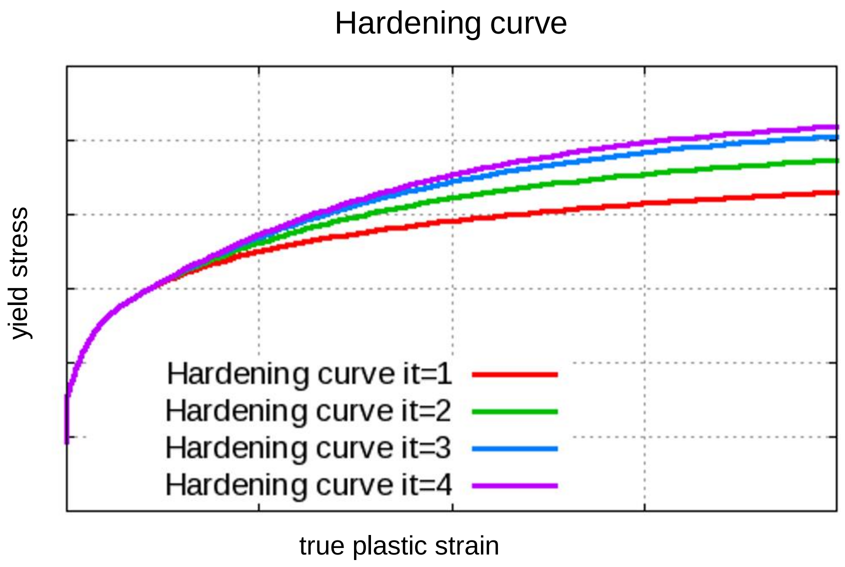


GISSMO – calibration – plastic behavior

Inverse identification through simulation of experiments

- Identification of hardening curve is iteratively performed by simulating the tensile tests
- Up to the necking point the identification is straightforward (conversion from engineering to true stress strain curve, removal of elastic strains)
- From the necking point on an extrapolation is necessary
- Each iteration verifies if the current extrapolation can reproduce the experiment

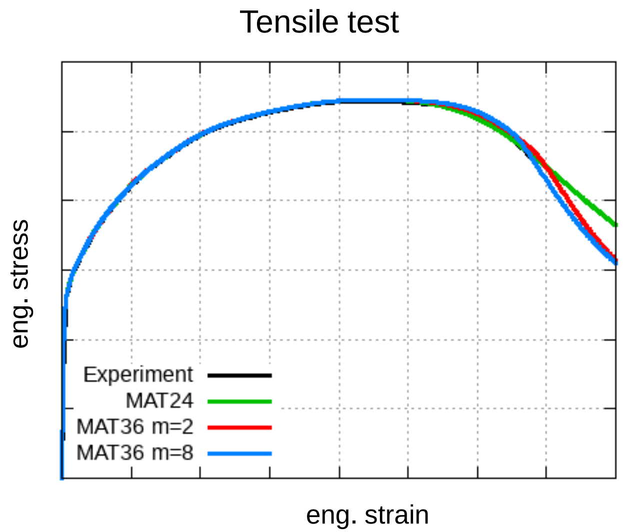


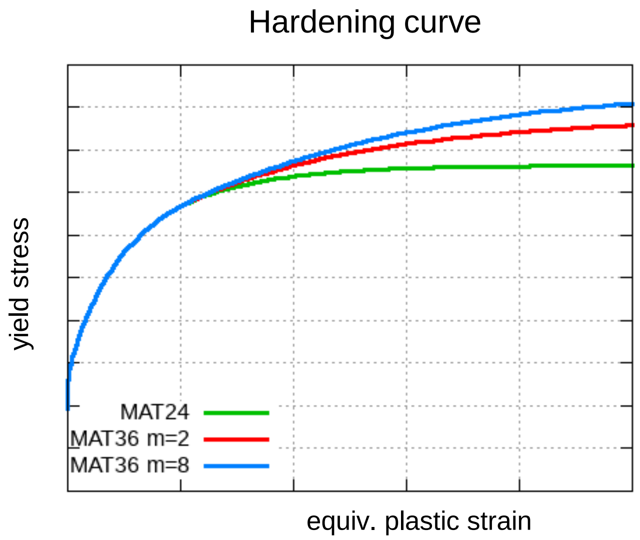


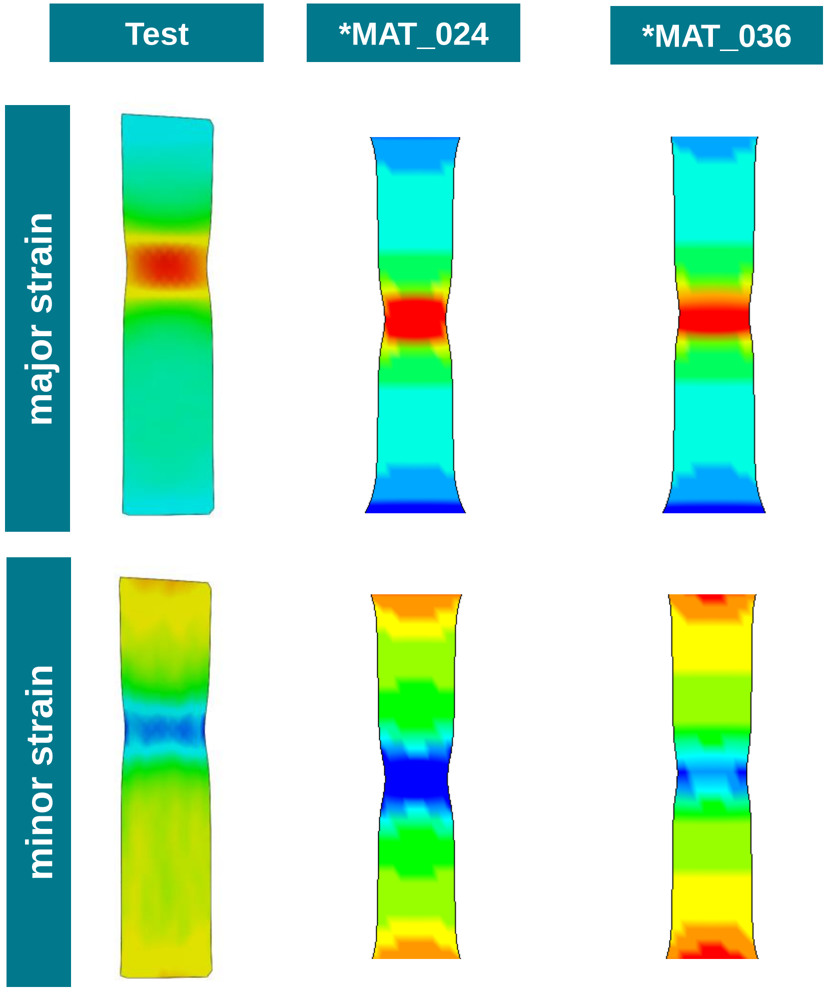
GISSMO – calibration – plastic behavior

Inverse identification through simulation of experiments

- More accurate plasticity descriptions can be achieved by using more sophisticated models (e.g., Barlat-based plasticity model)
- In this example, an R-value of 0.6 was measured → $\varepsilon_2^p = 0.6\varepsilon_3^p$
- *MAT_024 (R=1) is in this case more limited than *MAT_036



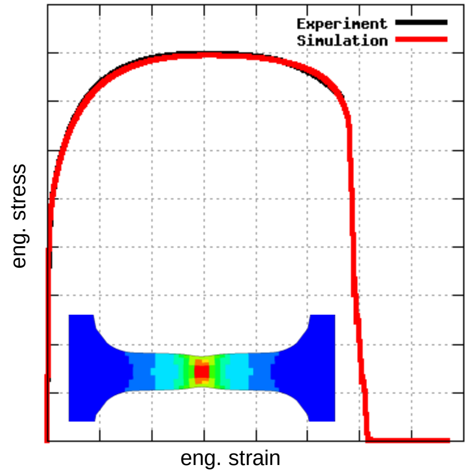




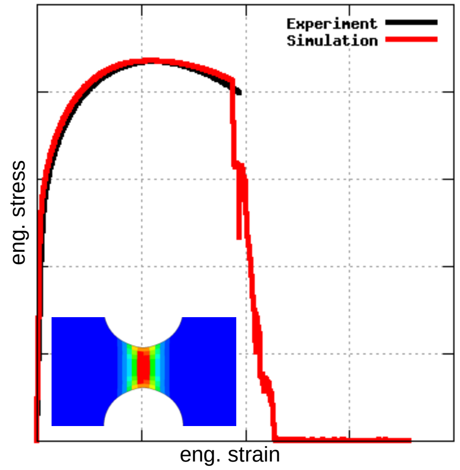
GISSMO – calibration

Exemplary material calibration – Overview

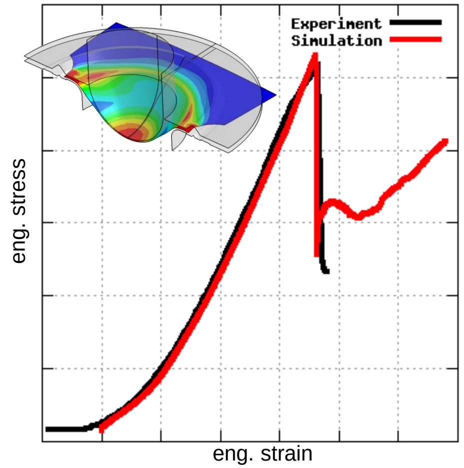
Small tensile test



Notched specimen

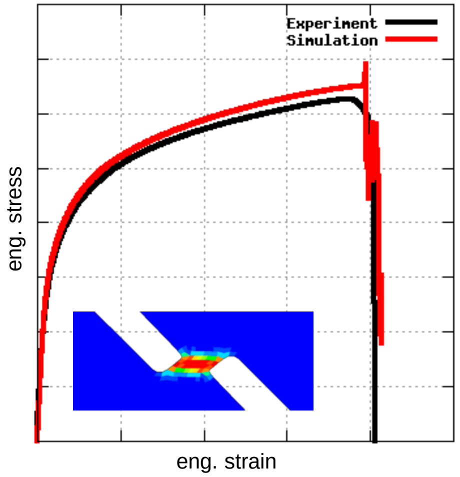


Biaxial test

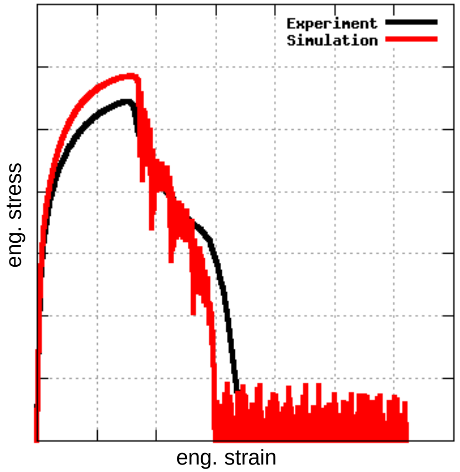


Element size 0.5 mm
Shell elements – ELFORM = 16
Damage exponent 2.0
Fading exponent 2.0

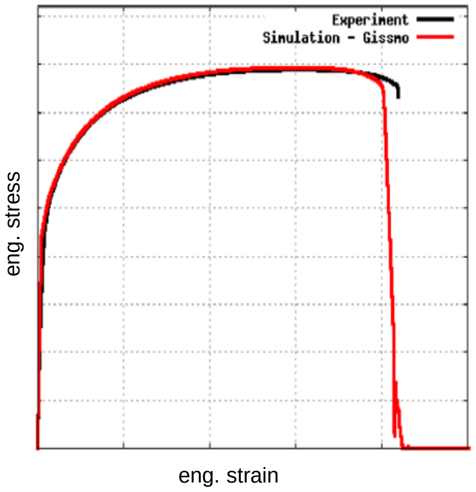
Shear test 0°



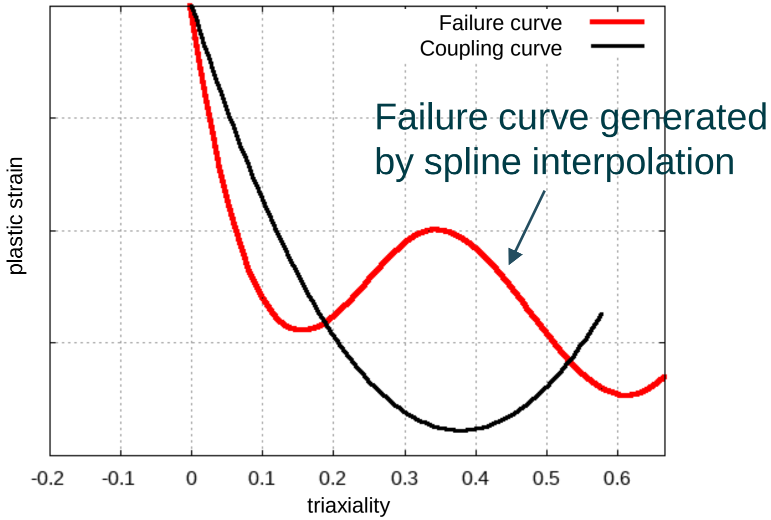
Shear test 45°



Large tensile test

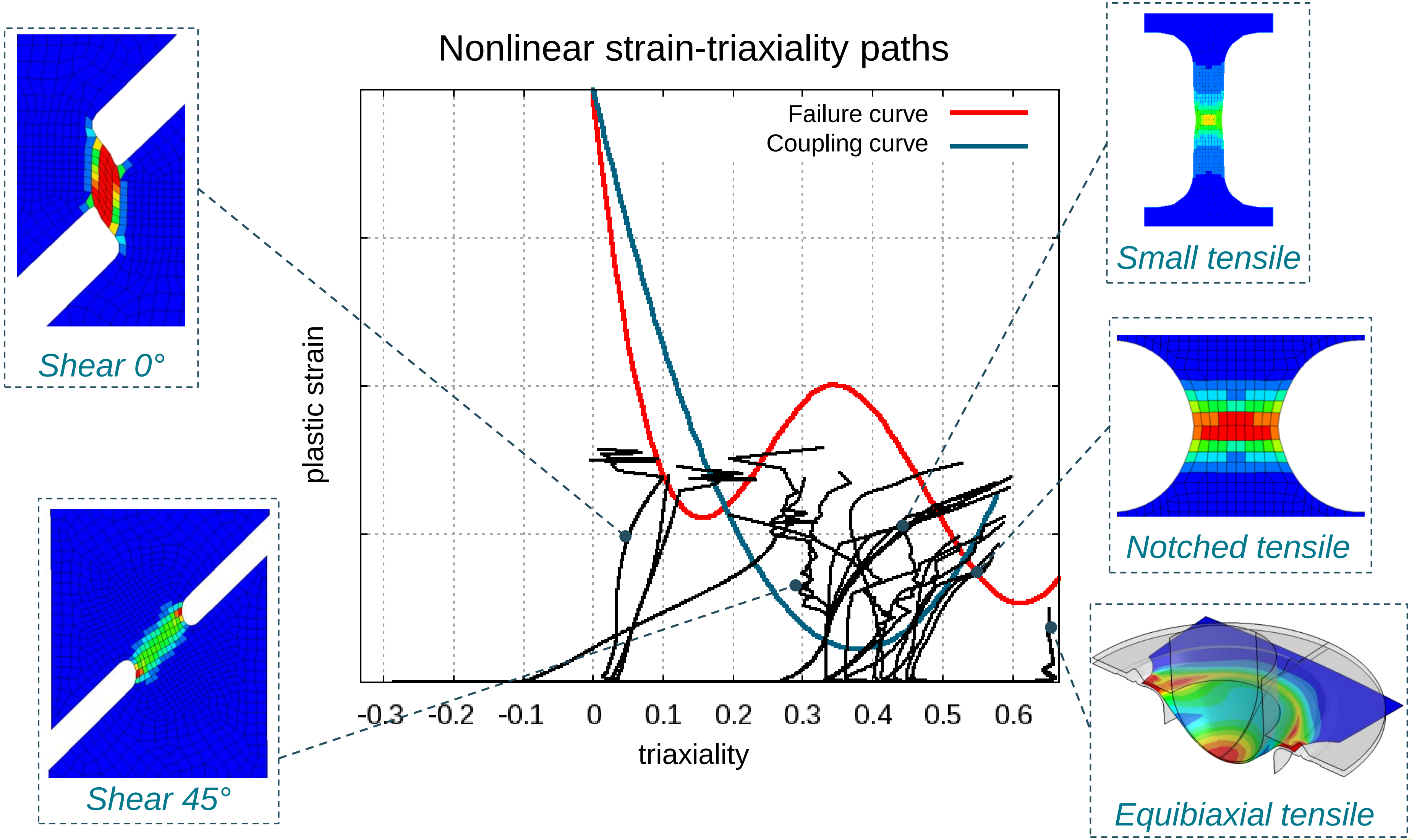


GISSMO curves



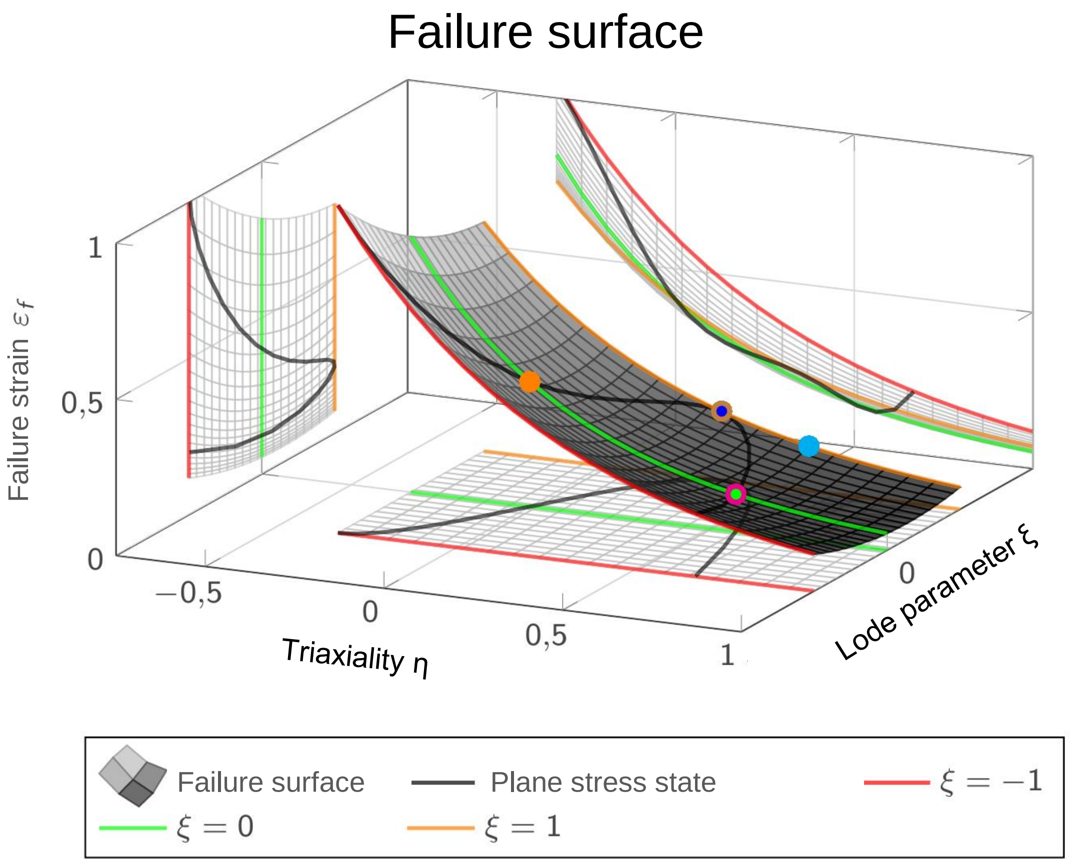
GISSMO – calibration

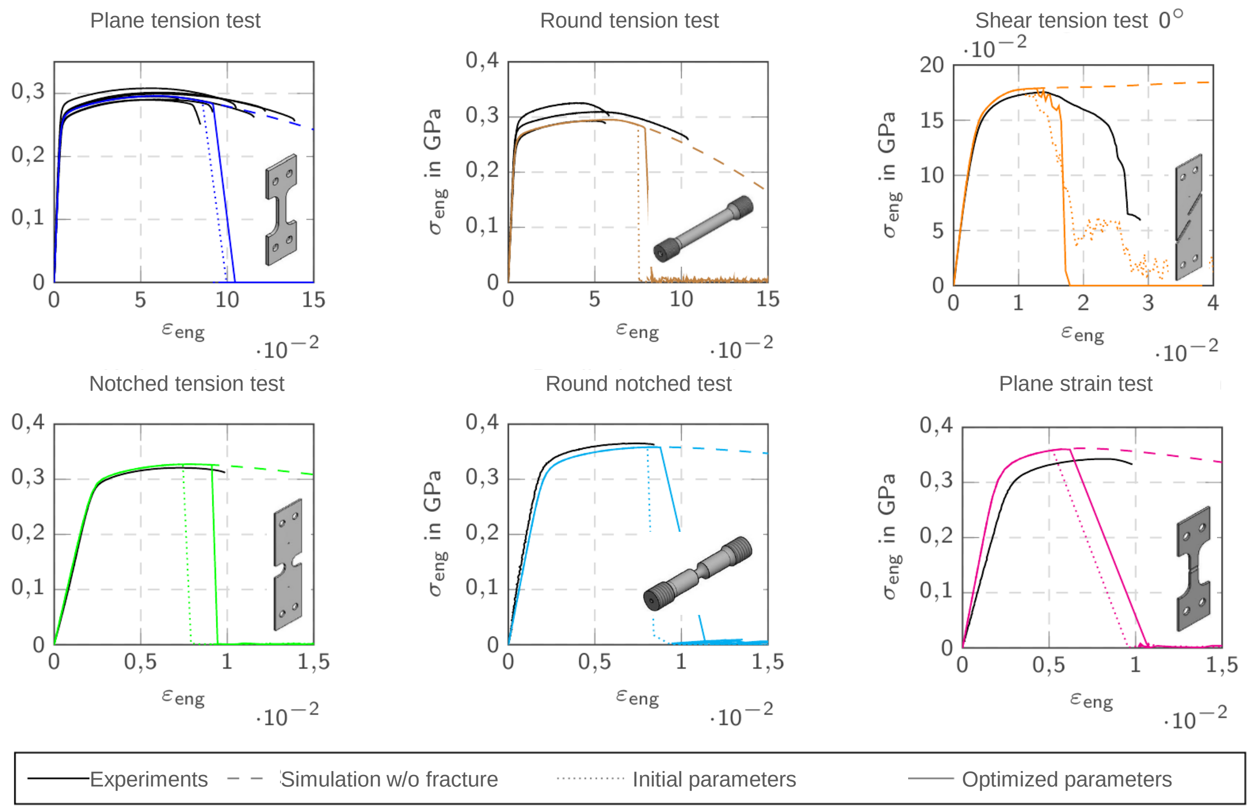
Exemplary material calibration



GISSMO – calibration of solid elements

Experimental data and GISSMO material parameter identification for cast aluminium





[M. Blind: Materialmodellierung von in der Crashsimulation Vorderachsbauteilen. Bachelor thesis, 2018]

GISSMO – mesh dependence

Different Types

- The expression “mesh dependence” is somewhat vague and can as such have different interpretations. Therefore, it is important to highlight the main differences between the typical interpretations of this term.

- Geometrical mesh dependence
  - A consequence of discretization using finite elements
  - May affect solution under any loading (purely elastic, plastic, etc.)
  - Generally converging when mesh is fine enough
  - Shells and solids affected in a similar way

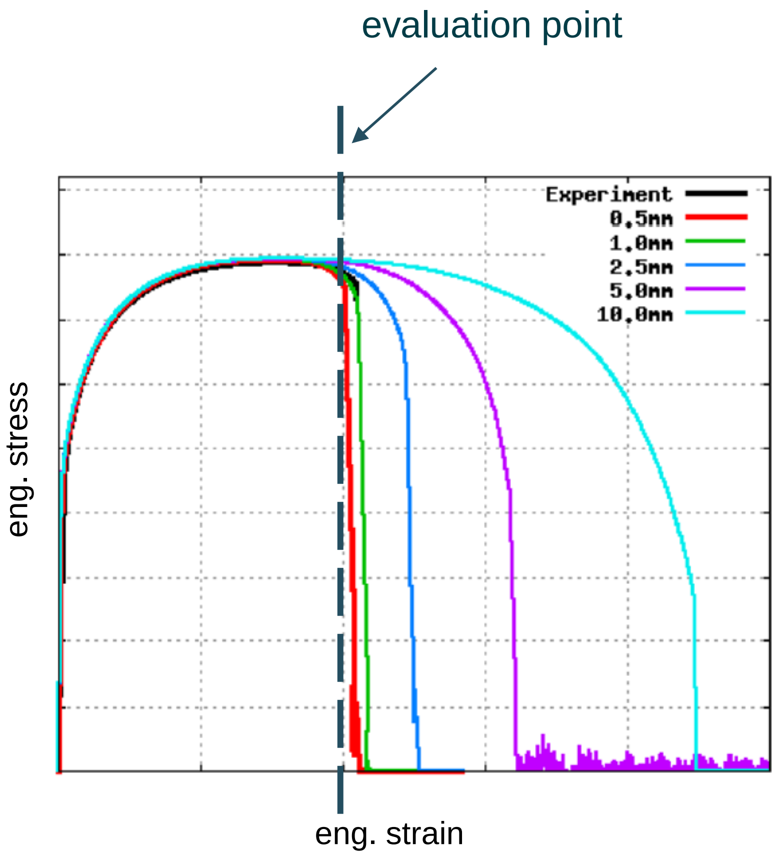
- Spurious mesh dependence
  - A consequence of local continuum mechanics
  - Only affects solution under certain conditions (e.g., after the necking point under a uniaxial stress state)
  - Generally non-converging regardless how fine the mesh is
  - Shells generally exhibit more spurious mesh dependence than solids

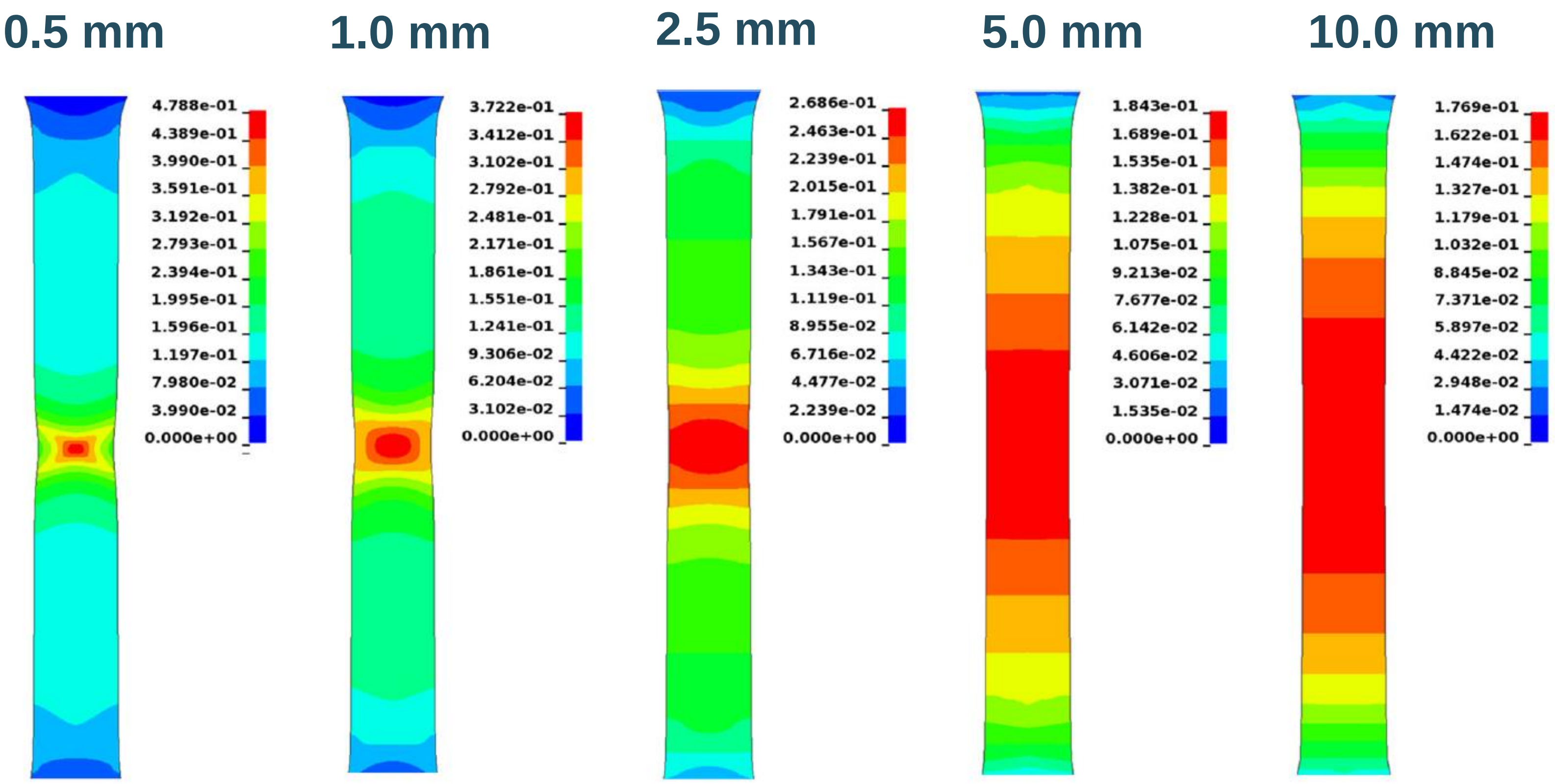
Regularization strategies are intended to tackle the spurious mesh dependence

GISSMO – spurious mesh dependence

Simulation of the large tensile test, evaluation at the same deformation point

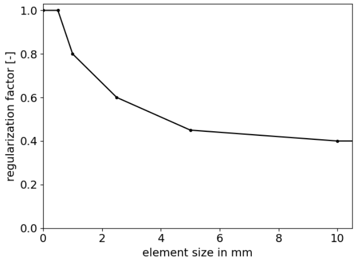
Different plastic strain distribution for each mesh size, failure takes place at different deformation points.



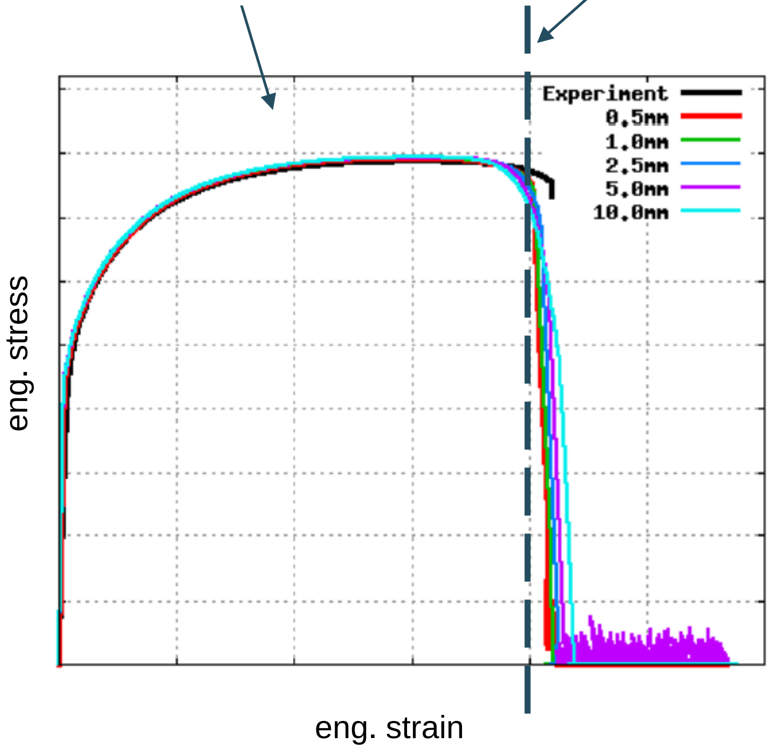


GISSMO – spurious mesh dependence

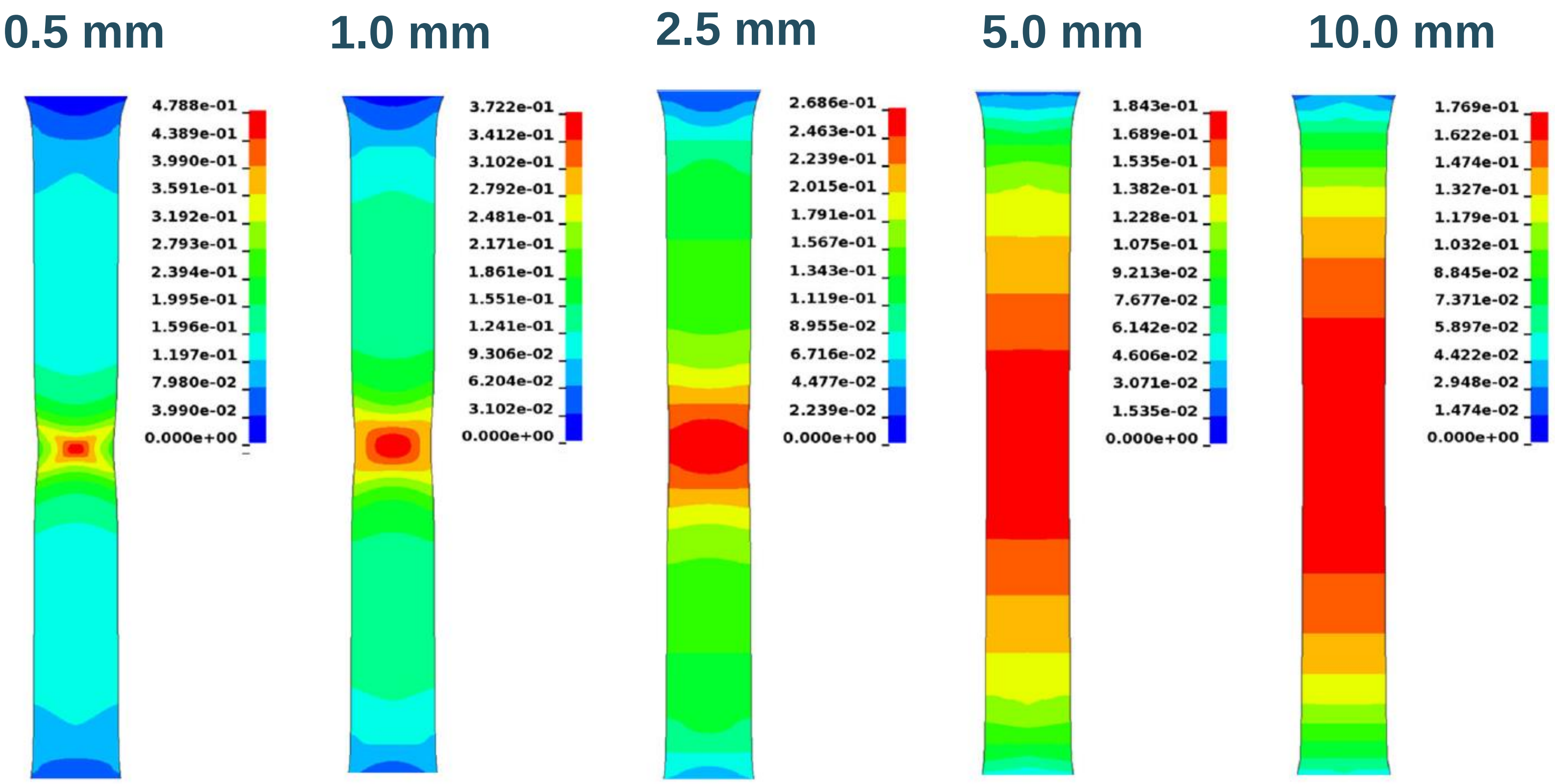
Simulation of the large tensile test, evaluation at the same deformation point



evaluation point

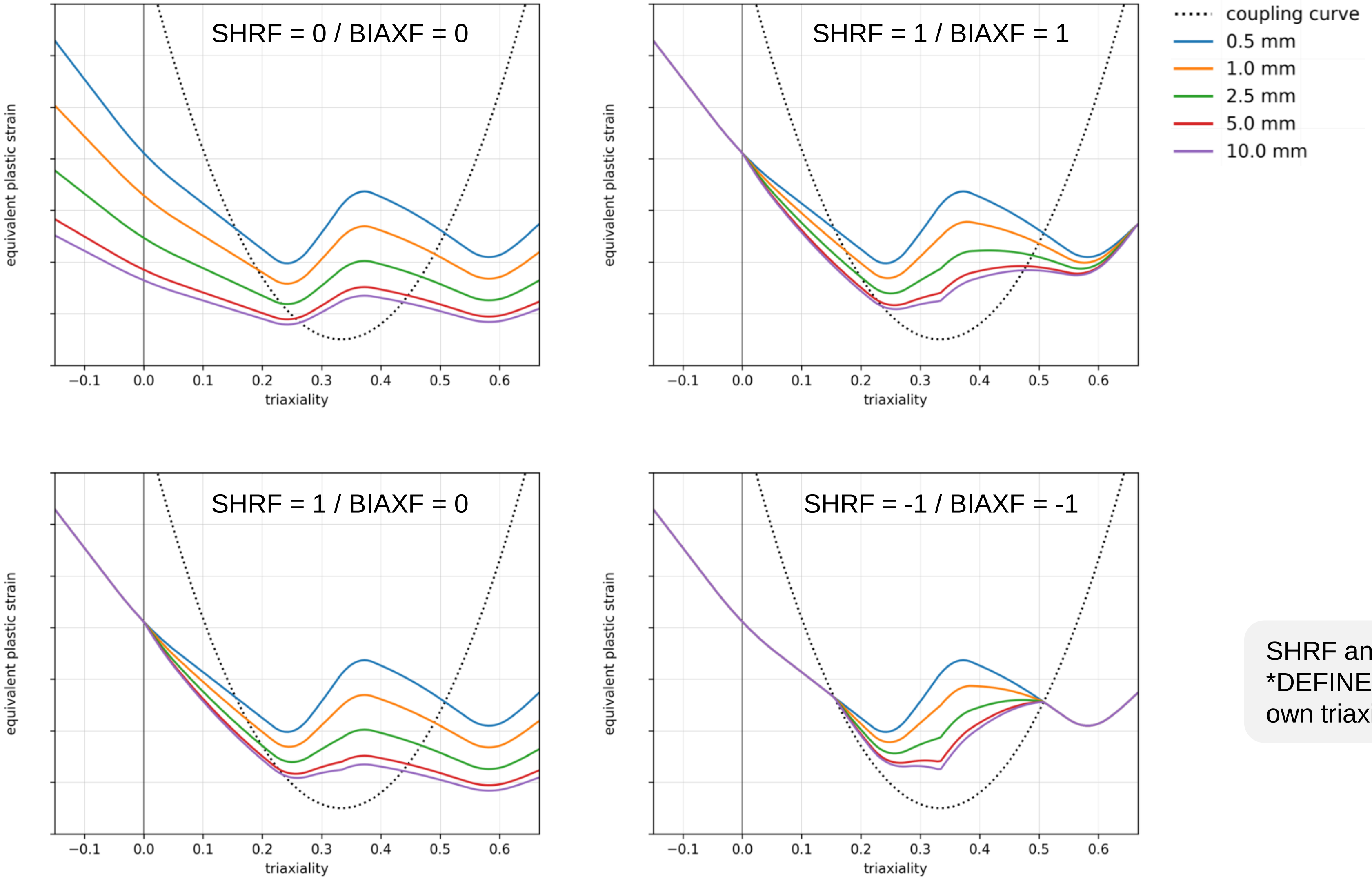


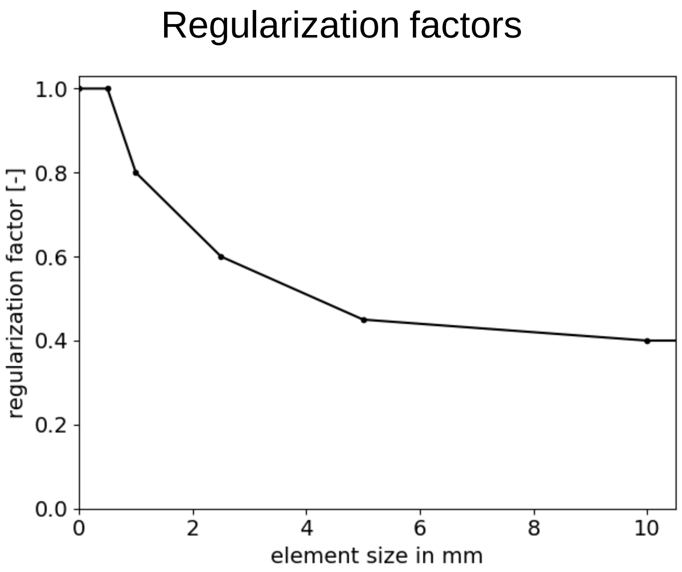
No change of plastic strain distribution, however, the deformation point at which failure occurs is now identical



GISSMO – spurious mesh dependence

Regularization beyond the uniaxial stress state





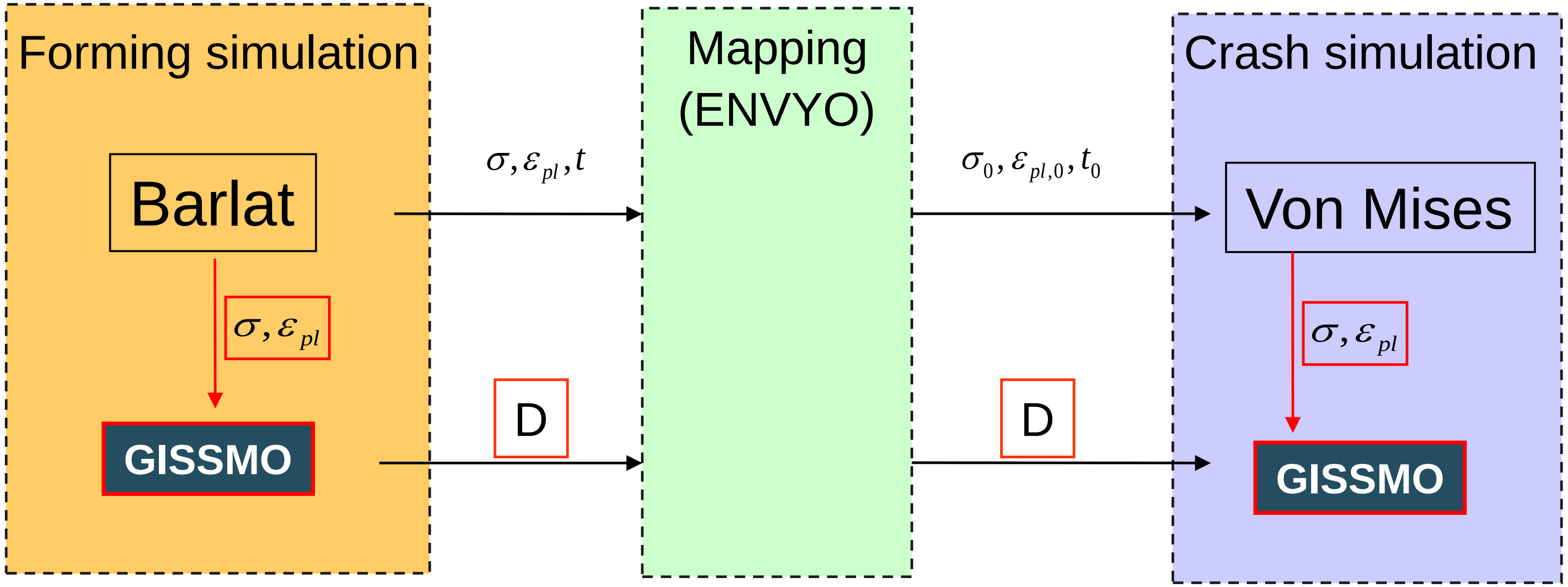
New

SHRF and BIAXF can be reproduced with *DEFINE_TABLE or the user can define his/her own triaxiality-dependent regularization

GISSMO – process simulation

How can GISSMO be helpful in process simulation

- Schematic representation of the process simulation



Note: damage can also already be calculated for the element size of the following simulation

GISSMO – keyword

What the actual input looks like

- *MAT_ADD_DAMAGE_GISSMO (up to R10: *MAT_ADD_EROSION)

```
*MAT_ADD_DAMAGE_GISSMO
$#     MID                   DTYP     REFSZ    NUMFIP
         1                      1       3.0       -80
$#   LCSDG     ECRIT    DMGEXP     DCRIT    FADEXP    LCREGD
         2        -3       2.0                 4.0         4
$#   LCSRS      SHRF     BIAXF    LCDLIM   MIDFAIL     HISVN      SOFT     LP2BI
                   1
*DEFINE_CURVE
$#    LCID      SIDR       SFA       SFO      OFFA      OFFO    DATTYP     LCINT
         2
$#                A1                  O1
… failure curve
*DEFINE_CURVE
$#    LCID      SIDR       SFA       SFO      OFFA      OFFO    DATTYP     LCINT
         3
$#                A1                  O1
… instability curve (coupling onset)
*DEFINE_CURVE
$#    LCID      SIDR       SFA       SFO      OFFA      OFFO    DATTYP     LCINT
         4
$#                A1                  O1
… regularization factors
```

Thank You

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