On Parameter Identification for the GISSMO Damage Model

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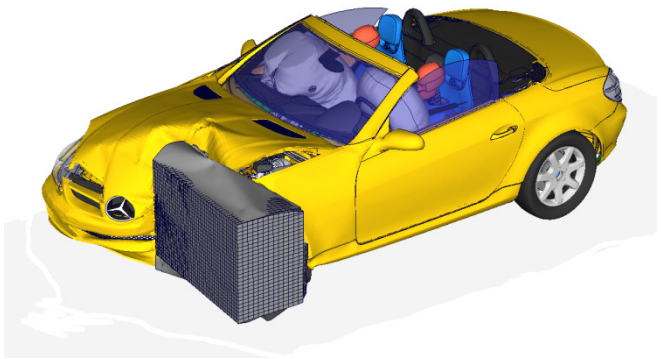
Goal

Identification of material parameters for metals, based on experimental data.

Representation of:

- Plasticity
- Damage
- Failure



Focus on the application in crash simulations (and metal forming)

Overview

- A generalized scalar damage model (GISSMO)
- Setup and analysis of material tests
- Calibration of a complete material card
  - Yield curve
  - Damage and failure
  - Regularization
- Example: Component tests
- Summary

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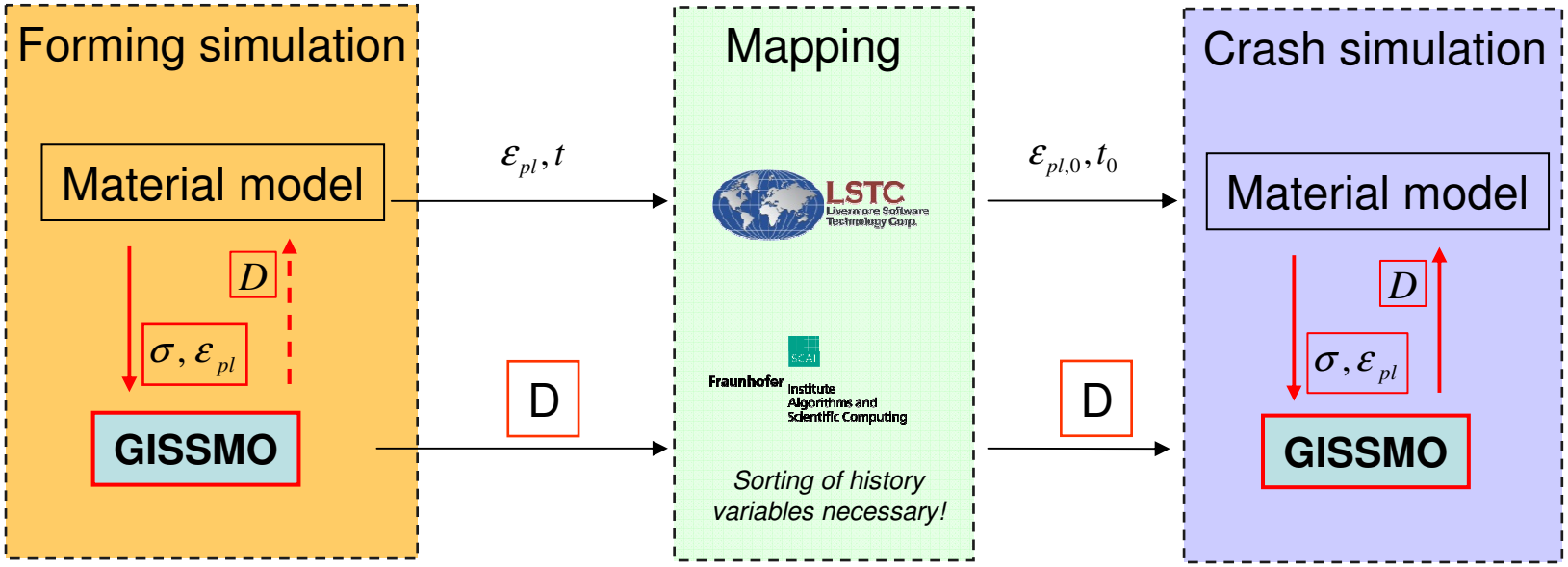
A generalized scalar damage model (GISSMO)

- **GISSMO** = **G**eneralized **I**ncremental **S**tress **S**tate dependent damage **MO**del
- Separate treatment of plasticity formulation and damage/failure prediction
- To be combined with arbitrary constitutive models, e.g. *MAT_024 (*von Mises*)
- Coupling of damage to stresses
- Failure strain in dependency of triaxiality

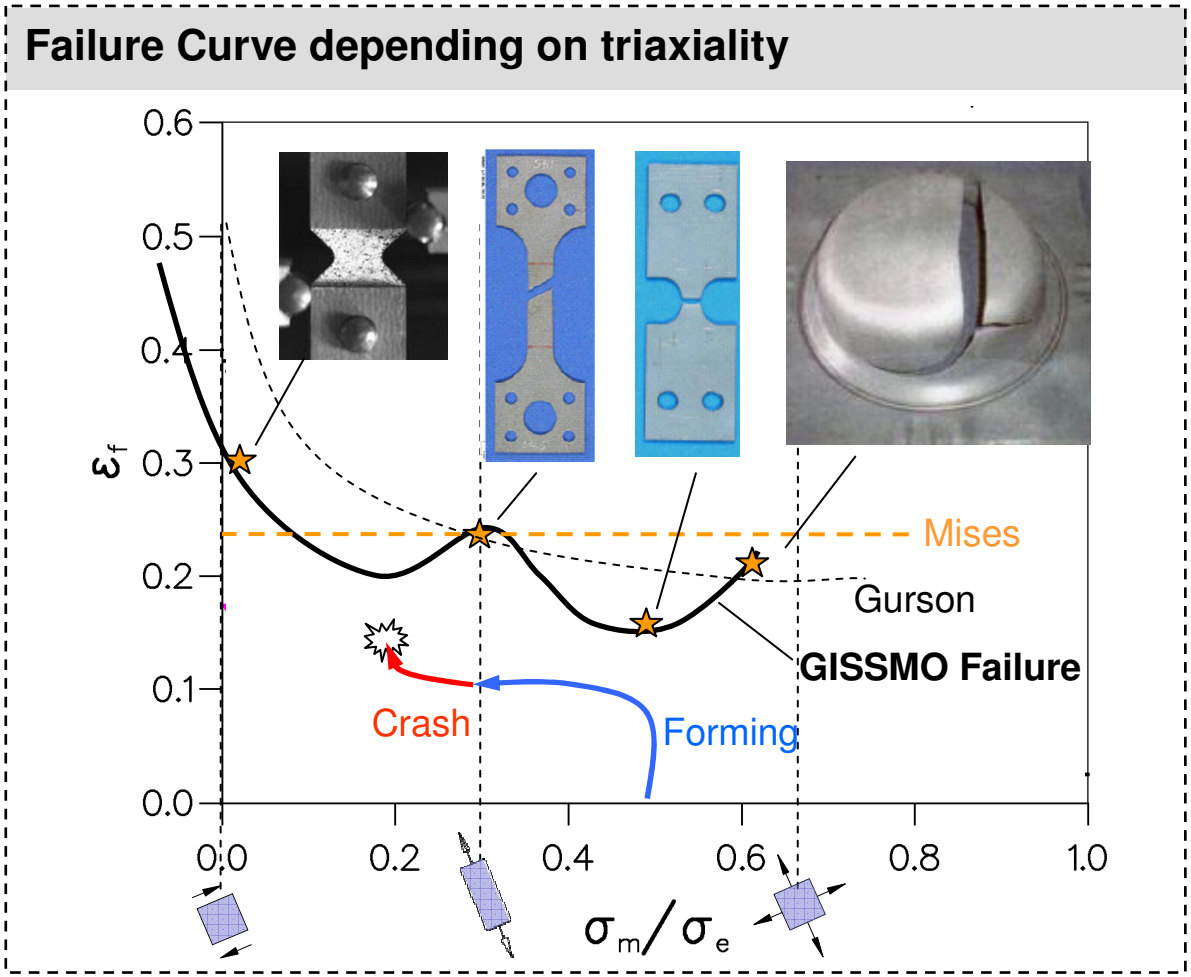
  triaxiality η: quotient of mean stress and *von Mises*-stress



Neukamm, Feucht & Haufe [2008-2011]

A generalized scalar damage model (GISSMO)

- Damage evolution and failure

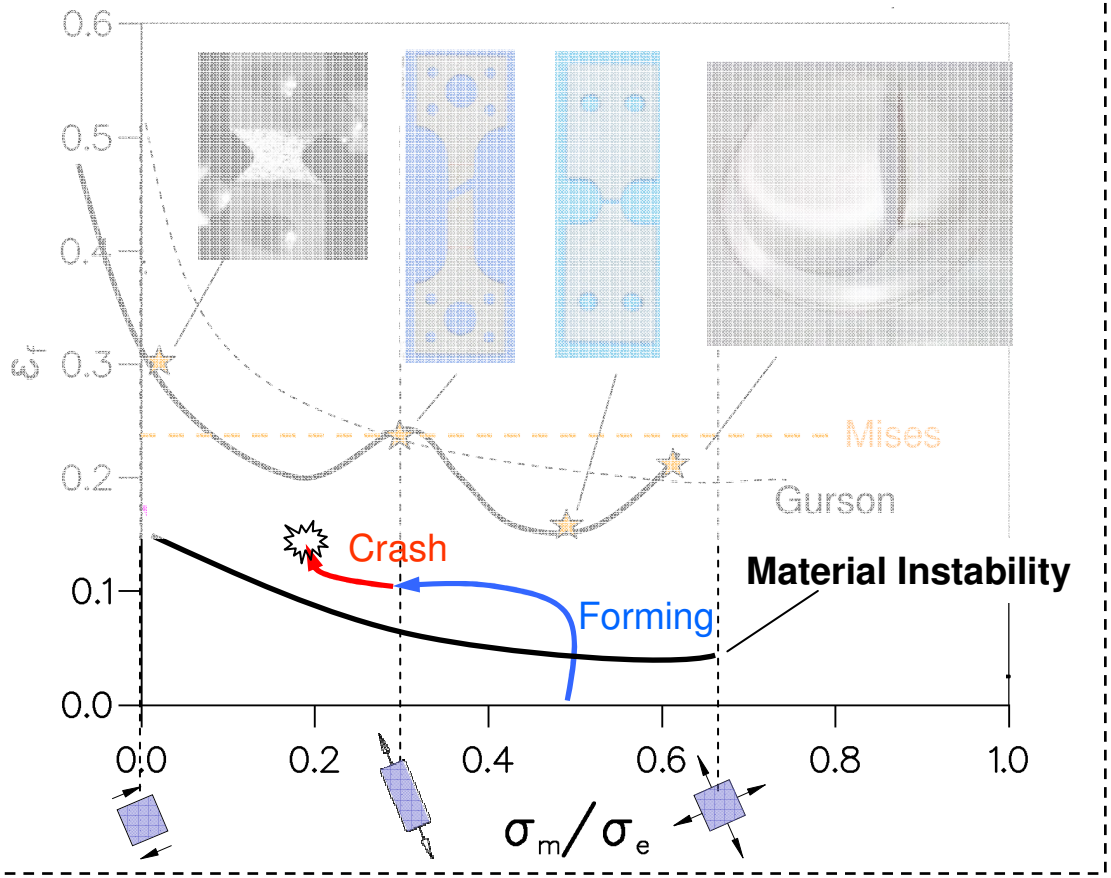


Neukamm, Feucht & Haufe [2008-2011]

A generalized scalar damage model (GISSMO)

- Instability: begin of mesh-size dependency

Material Instability depending on triaxiality



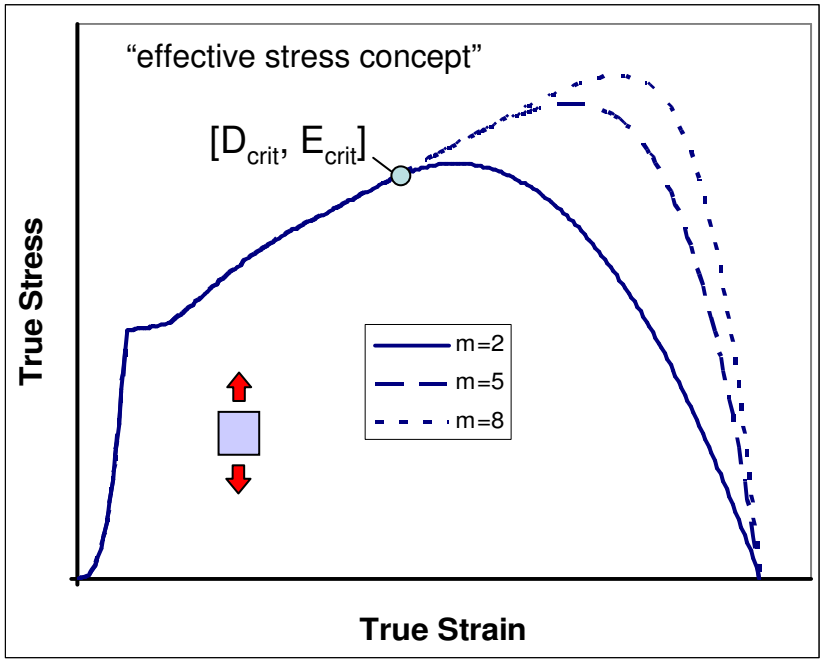
Neukamm, Feucht & Haufe [2008-2011]

A generalized scalar damage model (GISSMO)

- Coupling of damage to stresses and post-critical behavior

DCRIT, FADEXP: Post-critical behavior

$$\sigma^* = \sigma \left(1 - \left(\frac{D - D_{CRIT}}{1 - D_{CRIT}} \right)^{FADEXP} \right)$$



Neukamm, Feucht & Haufe [2008-2011]

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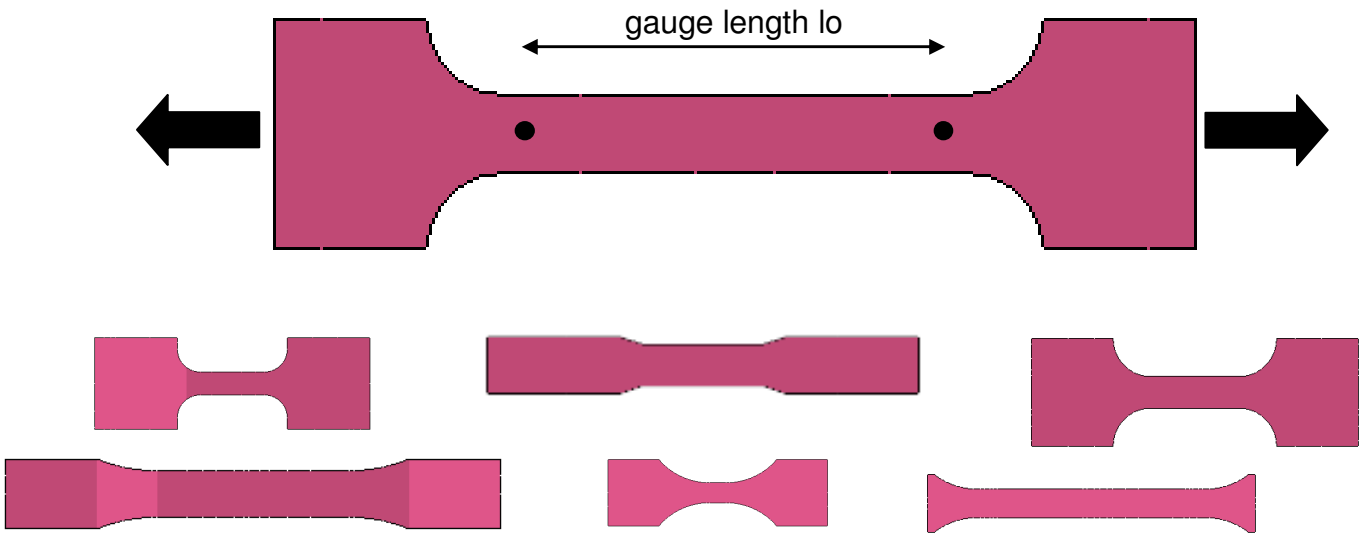
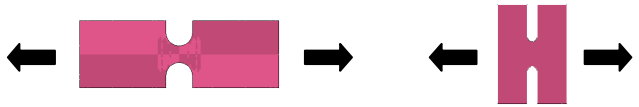
Setup and analysis of material tests

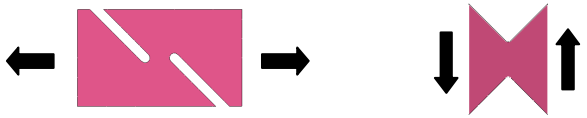
- (Quasi-static) uniaxial tensile tests



- Notched tensile tests



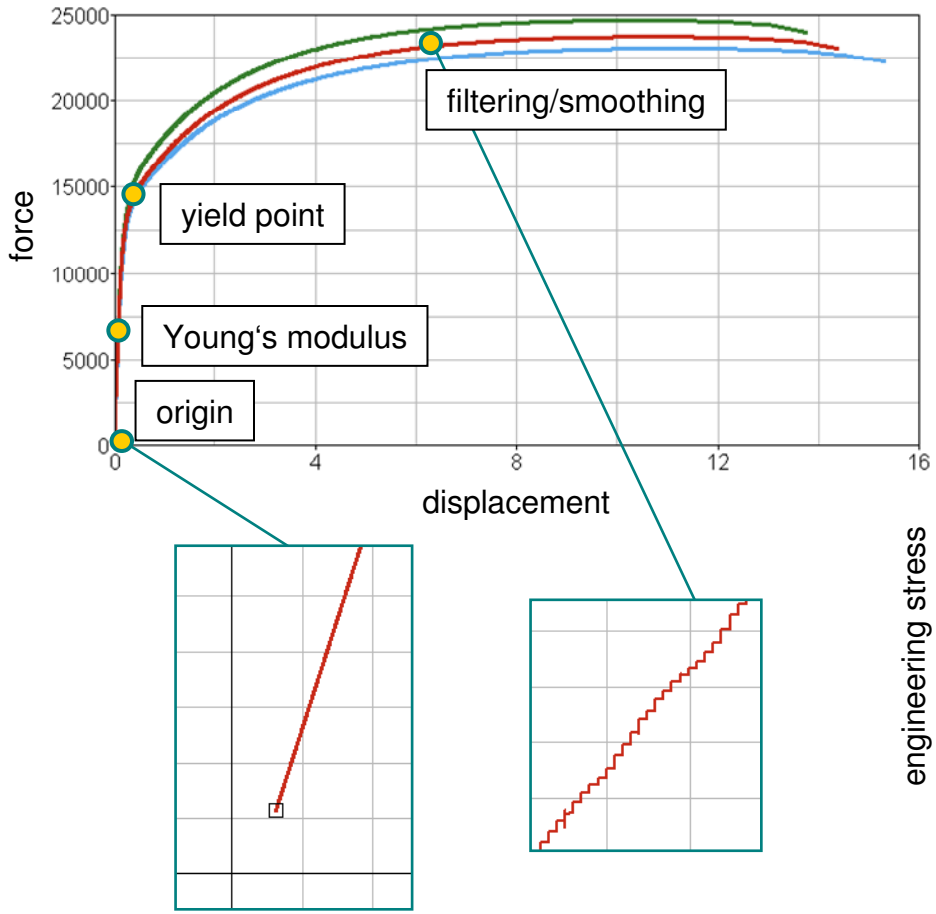
- Shear tests



Setup and analysis of material tests

- Preparation of test curves

  Global force vs. displacement curve



$$\sigma_{eng} = \frac{F}{A_0}$$

$$\varepsilon_{eng} = \frac{\Delta l}{l_0}$$

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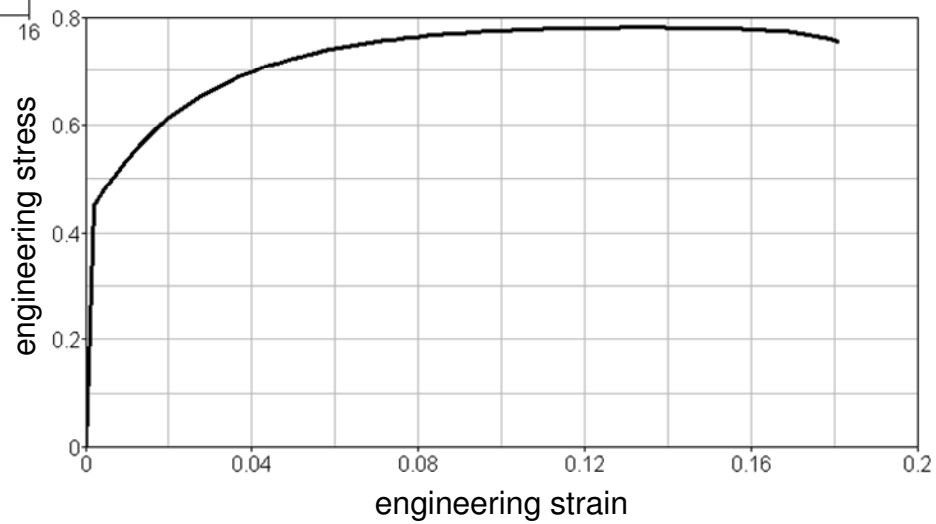
Engineering stress vs. strain curve



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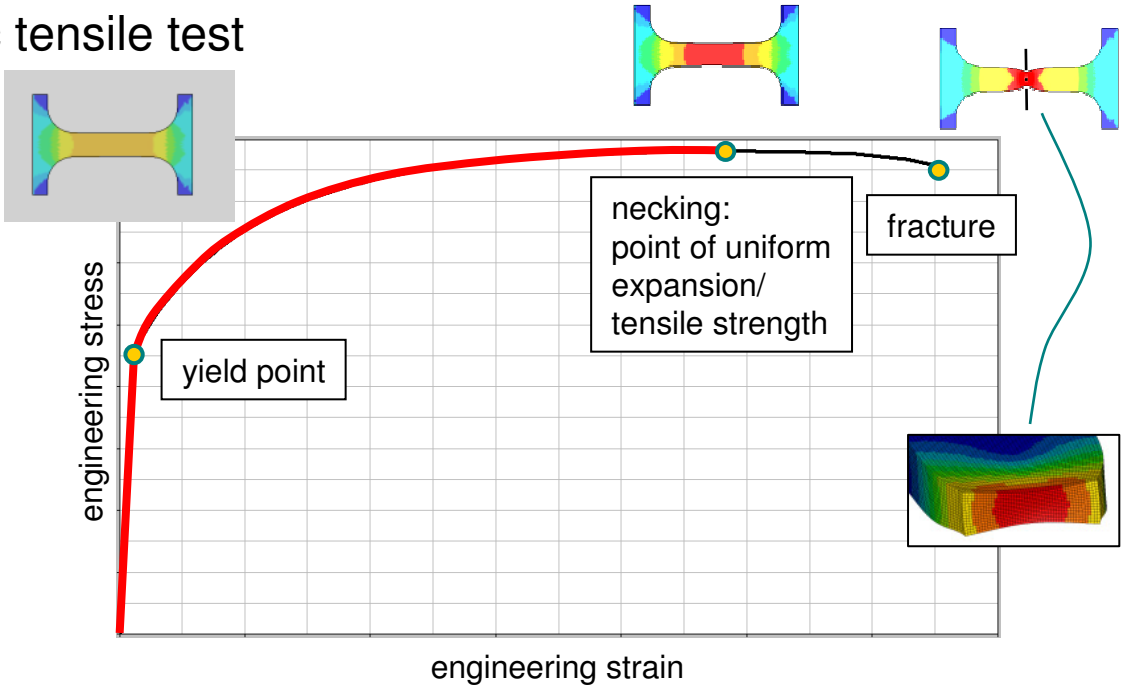
Calibration of a complete material card: Yield curve

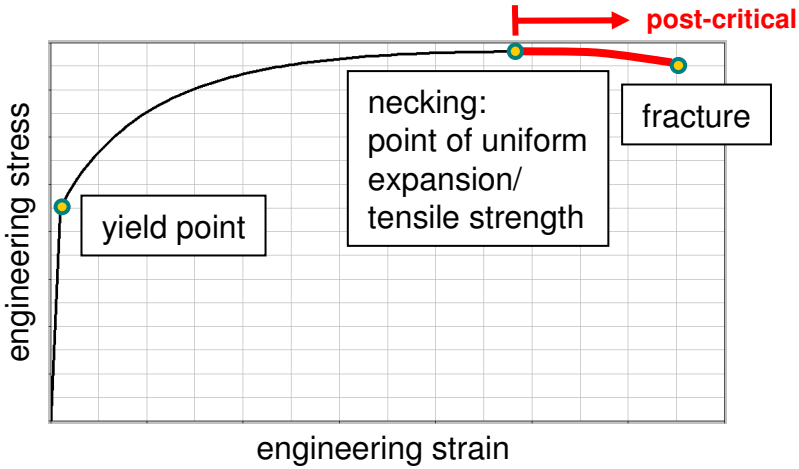
- Plasticity formulation / constitutive model: *von Mises* in *MAT_024
- Yield curve: isotropic hardening curve (eff. stress vs. eff. plastic strain)
- Quasistatic tensile test



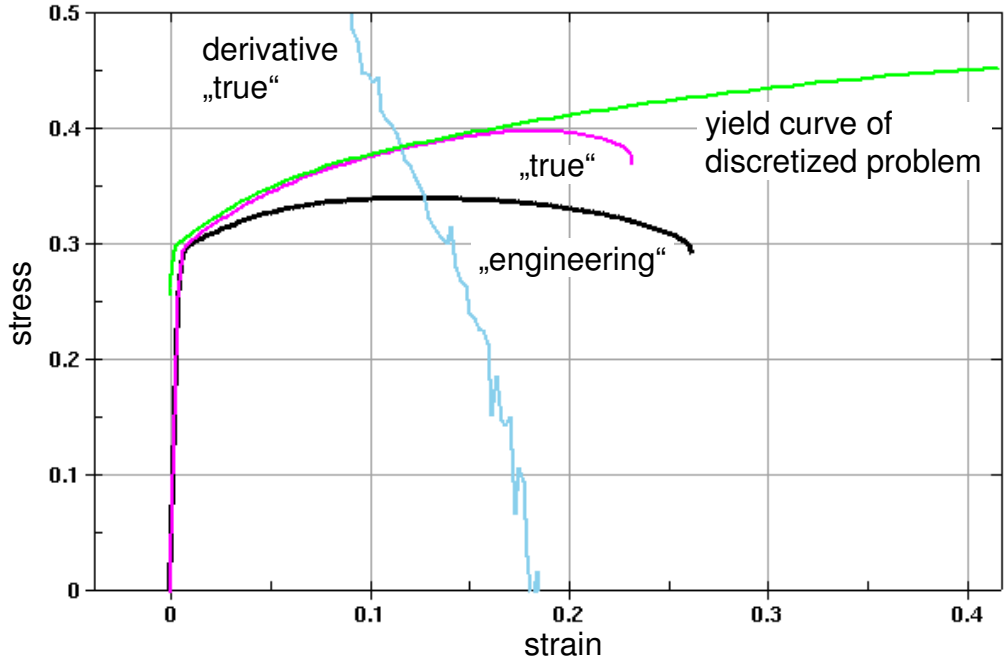
- Up to the point of uniform expansion: direct conversion of test curve
  - Engineering values → true (or logarithmic) values → compensation of elastic part
  - Stress: $\sigma_{true} = \sigma_{eng}(1+\varepsilon_{eng})$
  - Strain: $\varepsilon_{true} = \ln(1+\varepsilon_{eng}), \qquad \varepsilon_{true,plast} = \varepsilon_{true} - \frac{\sigma_{true}}{E}$

Calibration of a complete material card: Yield curve

- Beyond point of uniform expansion: iterative matching by reverse engineering
  - Individual or analytic approaches e. g. *Gosh*, *Hocket-Sherby*, *Swift*, *Voce*

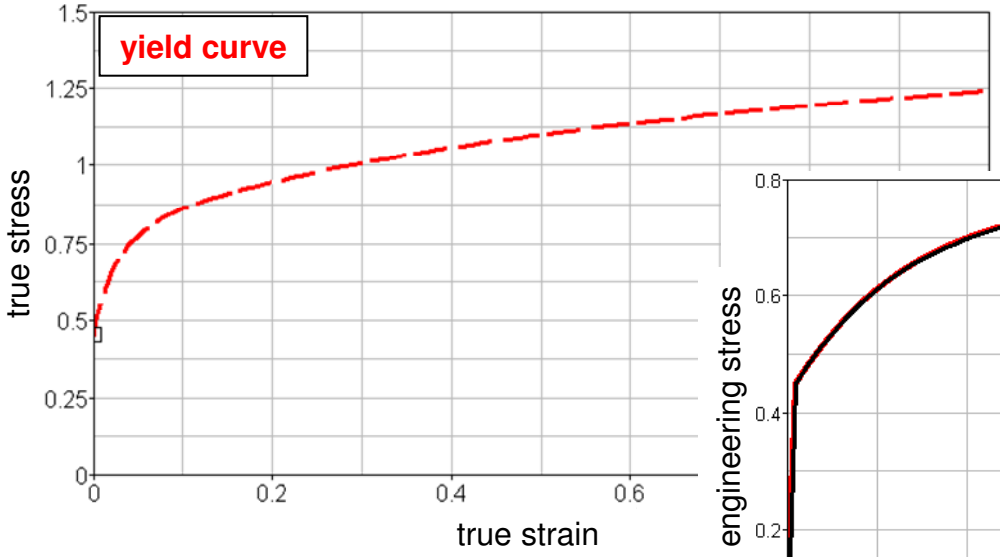


- Optimization using LS-OPT
  - Extrapolation *Hocket-Sherby* with two (out of four) free parameters
  - Variation of yield curve
  - Aim: optimize correlation between engineering stress-strain curves resulting from experiment and simulation

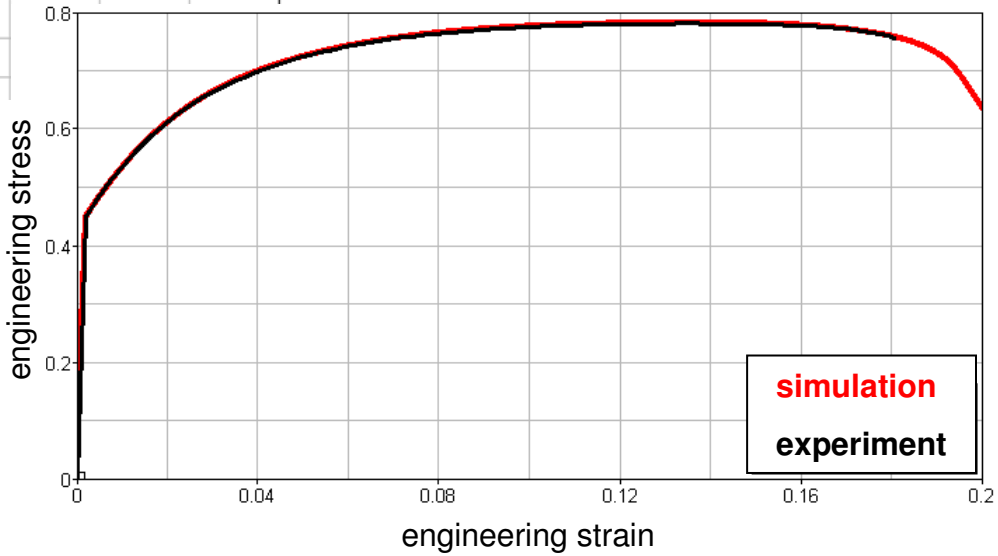


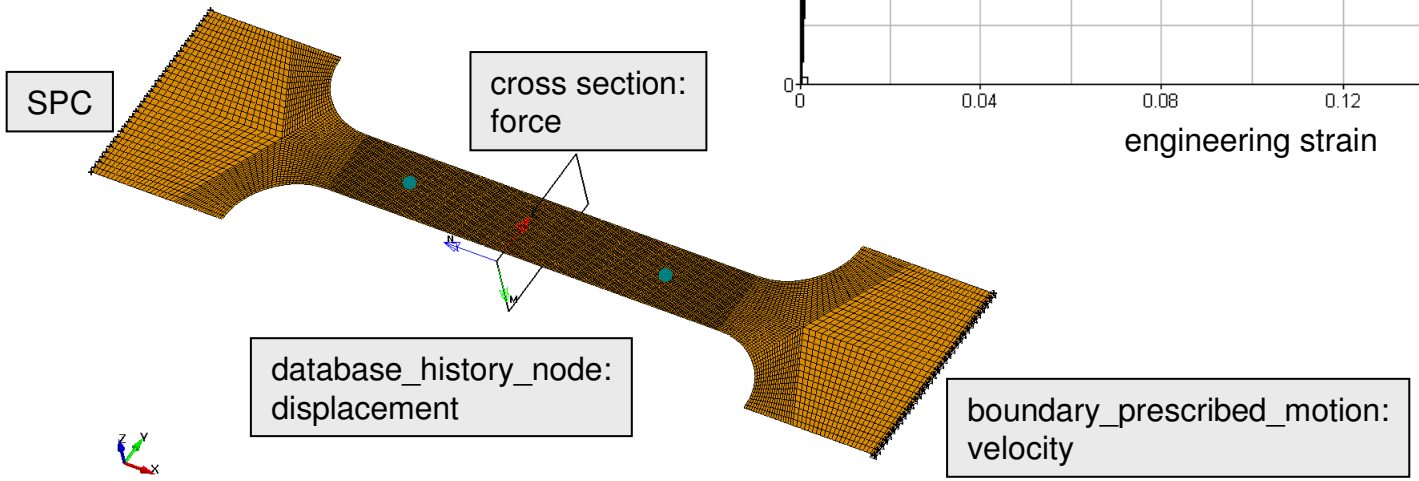
Calibration of a complete material card: Yield curve

- Comparison: experiment and simulation



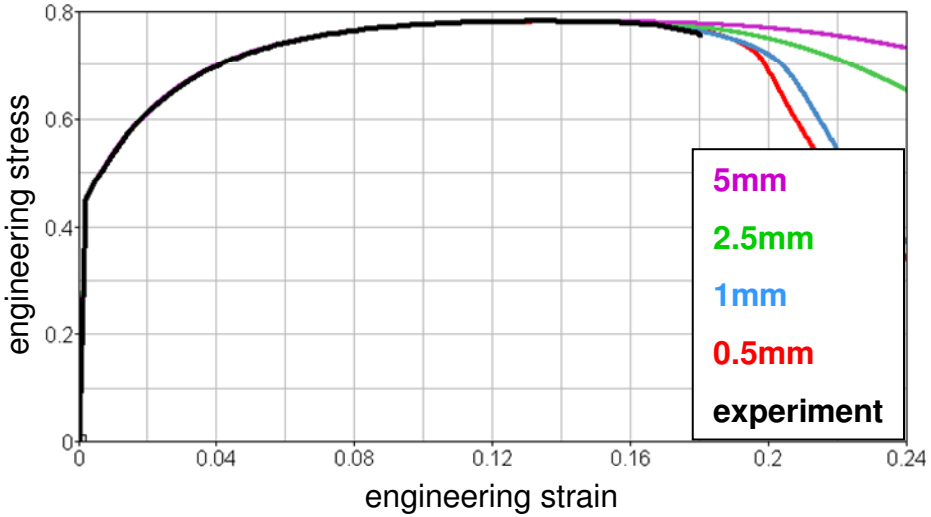
Shell
Element type 16
Element length ~0.5mm

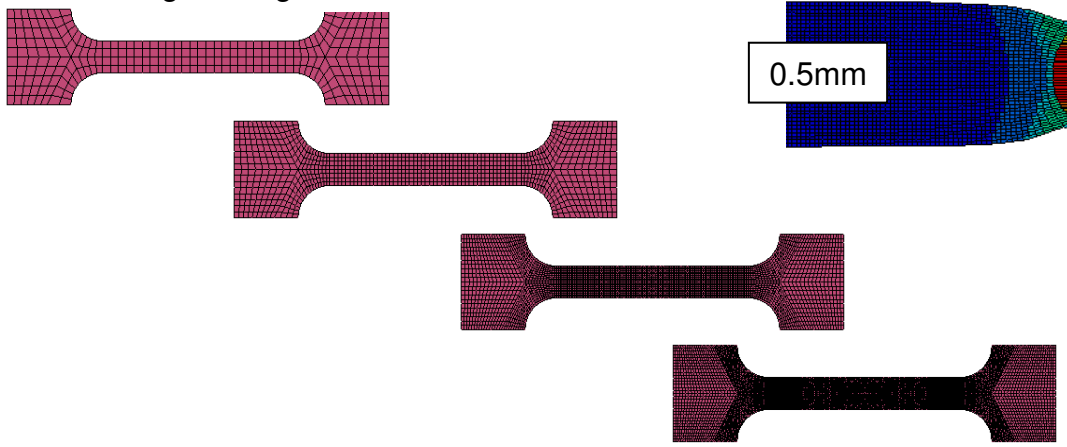


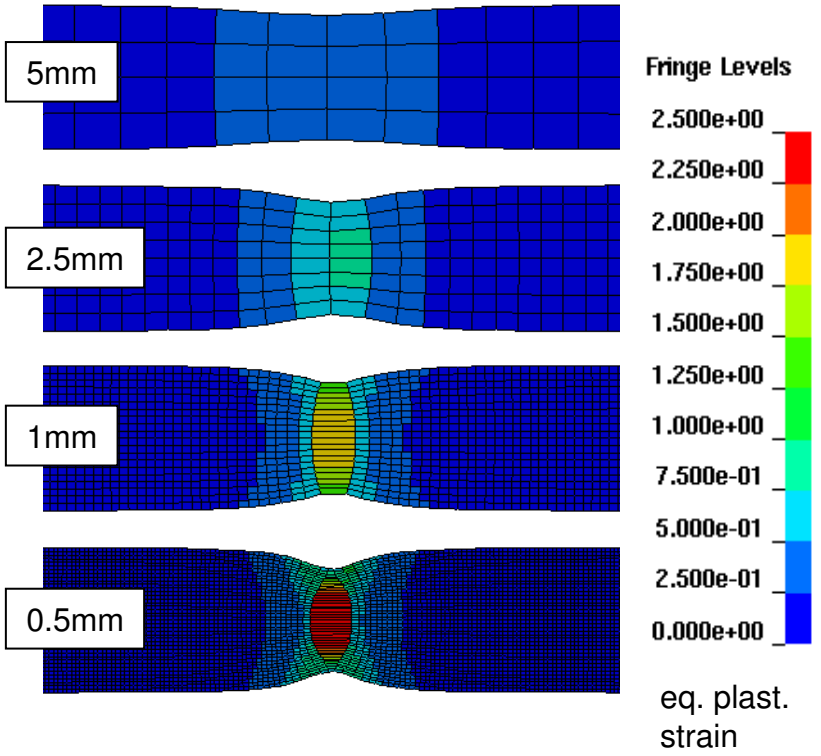


Calibration of a complete material card: Yield curve

- Element-size dependent behavior in the post-critical range of deformation
  → need for regularization







Calibration of a complete material card: Damage/failure

- Example of a LS-DYNA input for GISSMO

```
*MAT_PIECEWISE_LINEAR_PLASTICITY
$      MID        RO         E        PR      SIGY      ETAN      FAIL      TDEL
        10
$        C         P      LCSS      LCSR        VP
...
*MAT_ADD_EROSION
$      MID      EXCL    MXPRES     MNEPS    EFFEPS    VOLEPS    NUMFIP       NCS
        10
$   MNPRES     SIGP1     SIGVM     MXEPS     EPSSH     SIGTH   IMPULSE    FAILTM
$     IDAM    DMGTYP     LCSDG     ECRIT     DMGEXP    DCRIT     FADEXP    LCREGD
        1         1       100      -200          2              -300       400
$   SIZFLG    REFSZ     NAHSV     LCSRS      SHRF      BIAXF
                            14
```

Standard material input (i.e. *MAT_024)

Standard failure parameters (optional)

GISSMO failure parameters

Coupling

Damage exponent

Regularization of failure curve

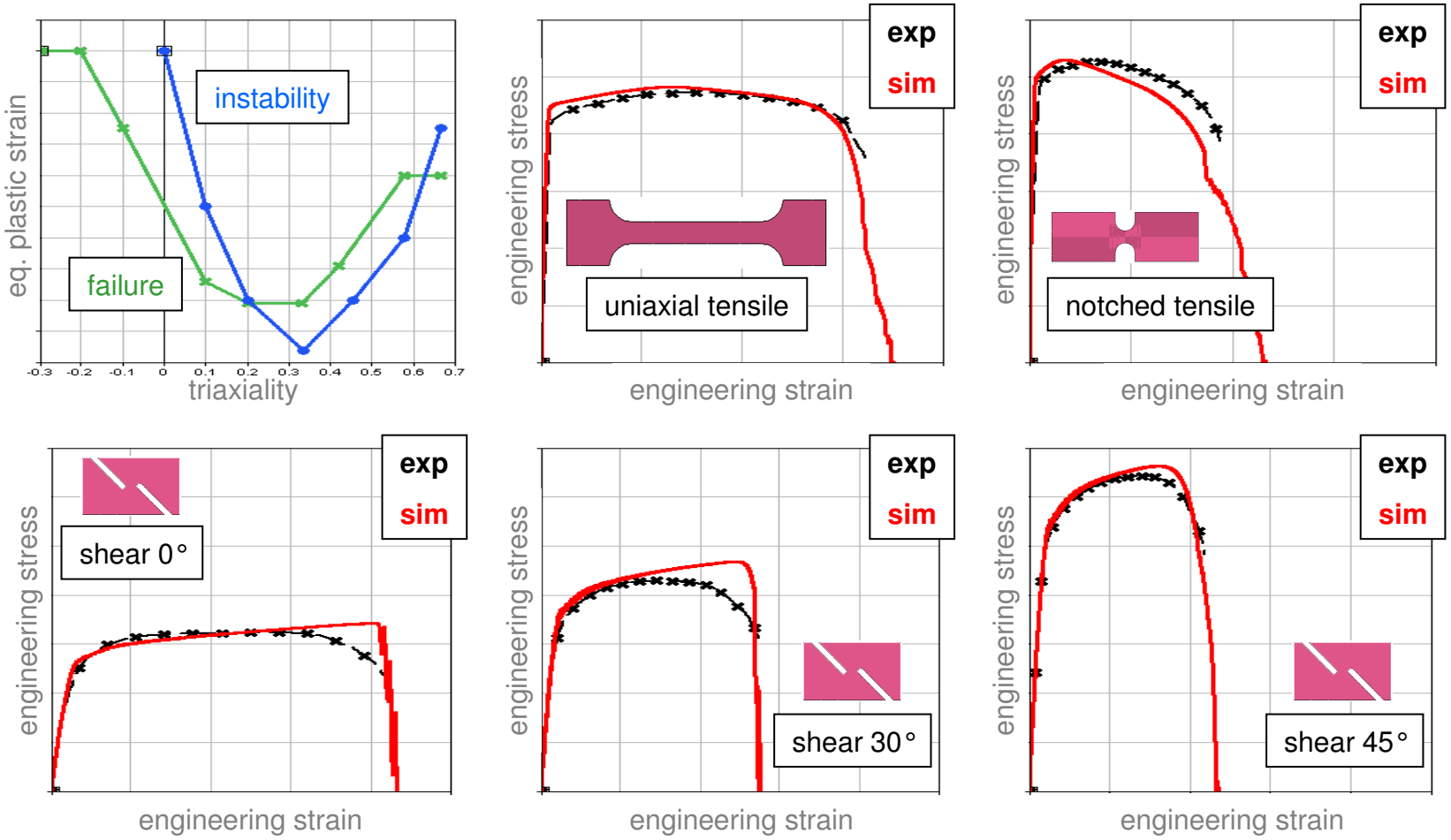
Failure curve

Critical damage

Critical plastic strain (curve definition)

Fadeout exponent (curve definition)

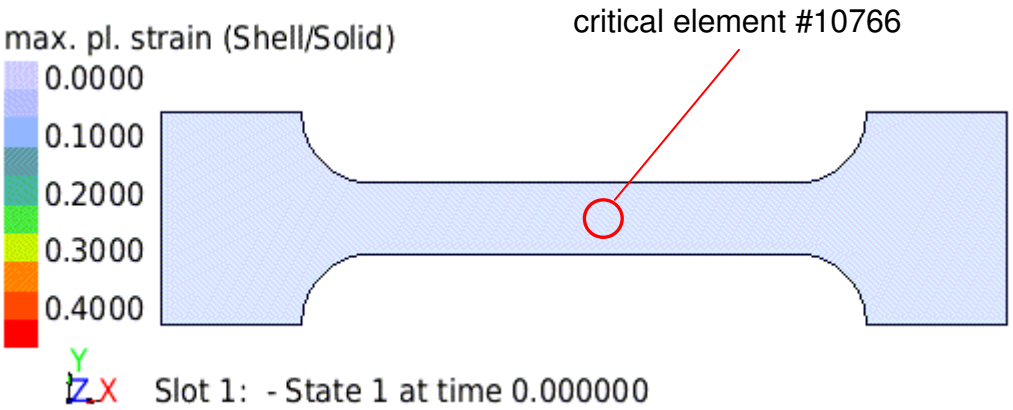
Calibration of a complete material card: Damage/failure

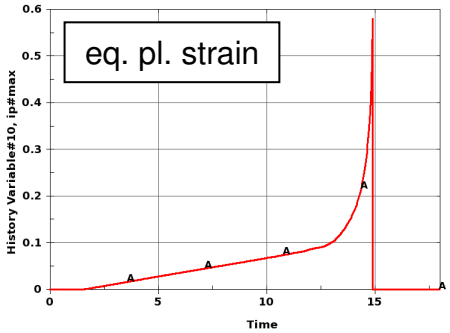


LS-OPT: Identification of fading exponent FADEXP and the two load curves for LCSDG (failure) and ECRIT (instability); mesh size Le~0.5mm

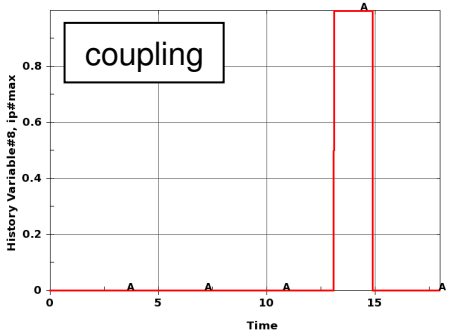
Calibration of a complete material card: Damage/failure

- Some history variables from the simulation of a uniaxial tensile test





Element #10766



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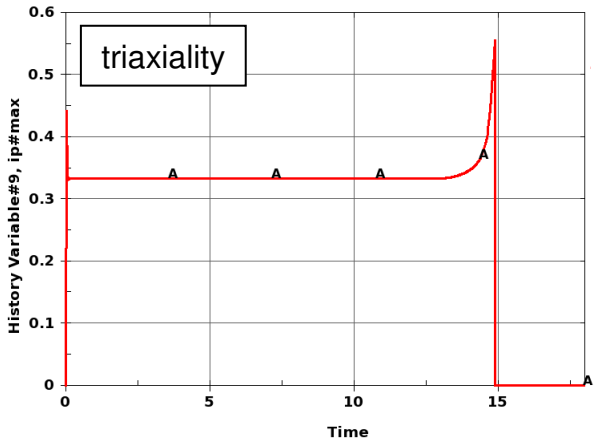

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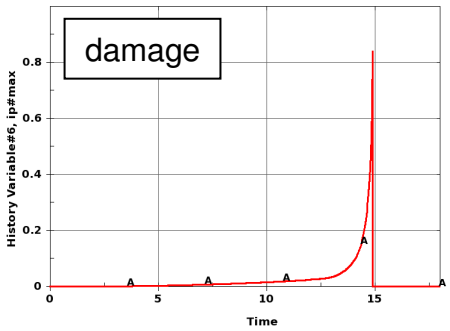
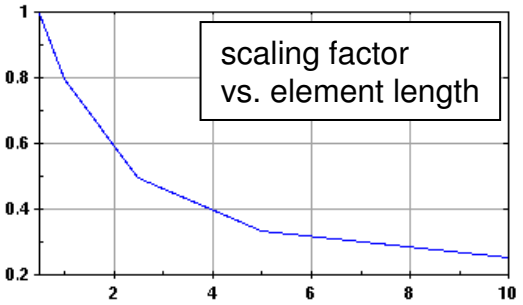
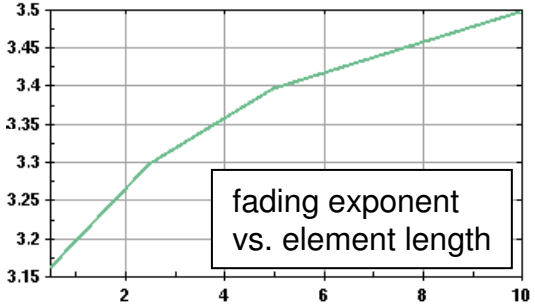


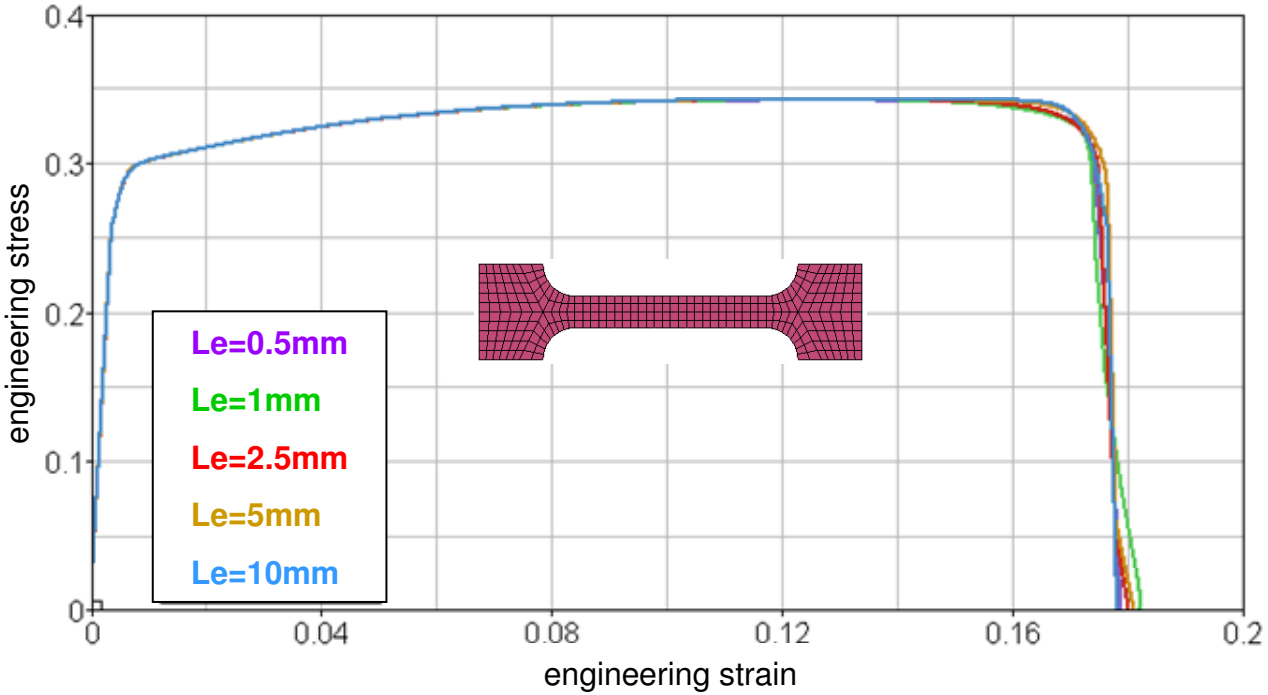
Element #10766

Calibration of a complete material card: Regularization

- Regularization of equivalent plastic strain to failure and fading exponent

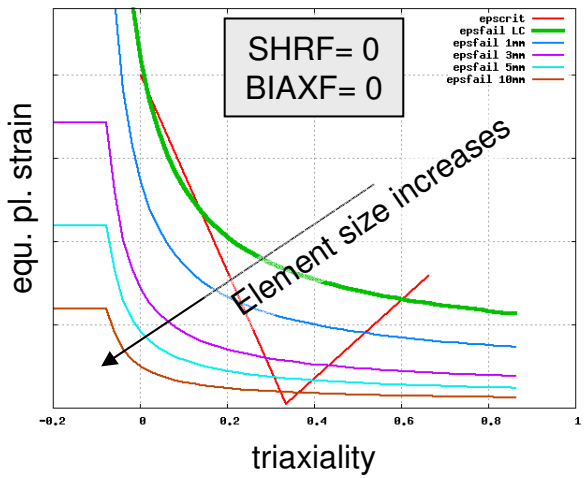


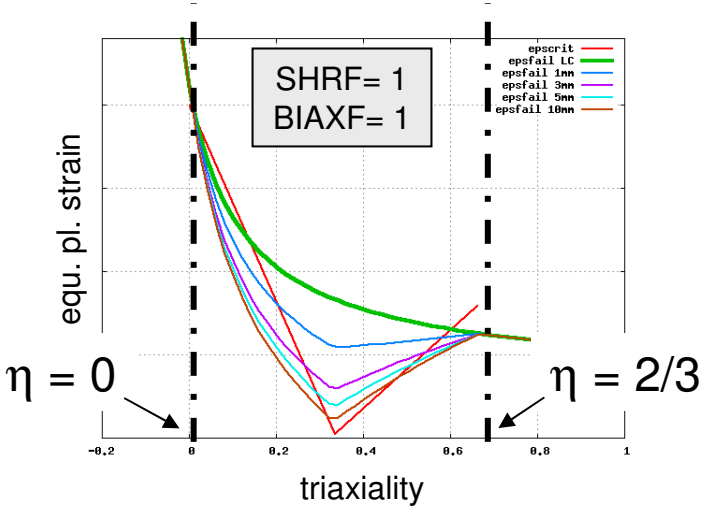


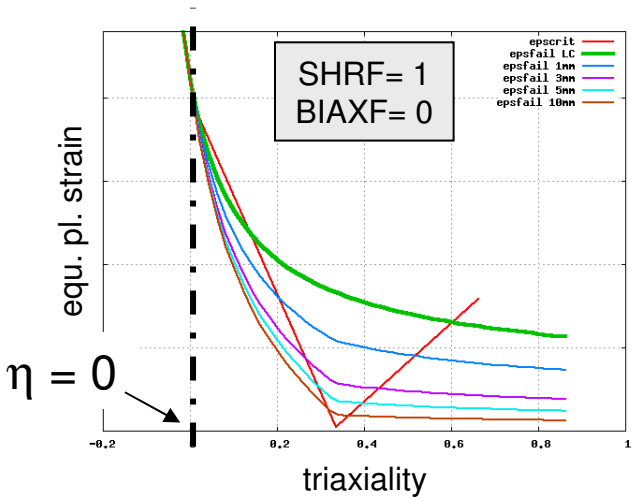


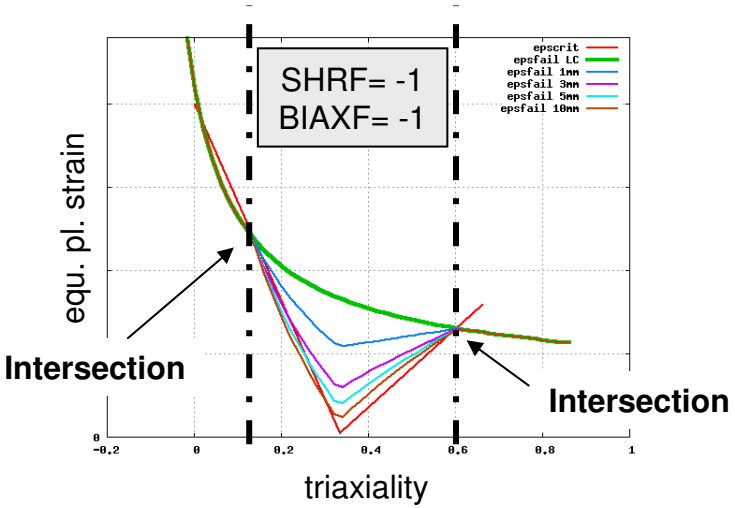
Calibration of a complete material card: Regularization

- Regularization under shear and biaxial stress states (LS-DYNA > 971 R5)









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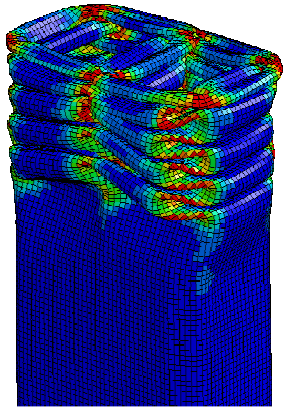
Example: Component tests

- shell elements (ETYP=16)
- SHRF=1 and BIAXF=0

- Drop test / axial crushing of an extruded aluminum profile

  → No regularization under shear-dominated stress states

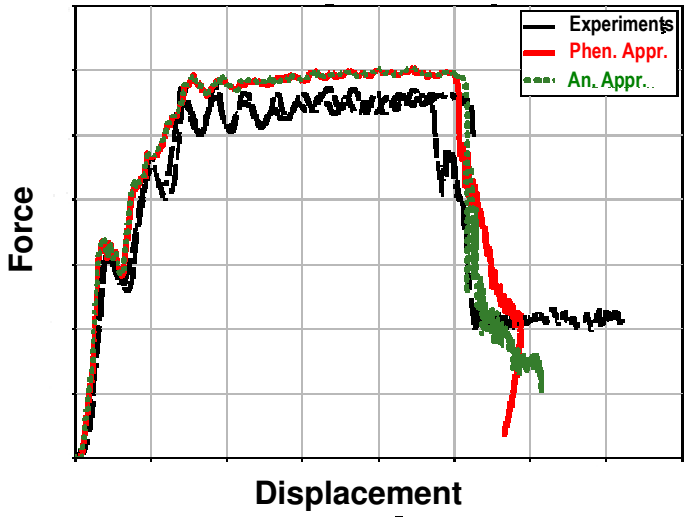
  → Limited failure on the edges

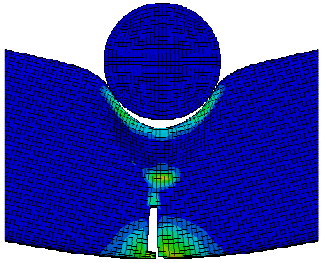


- Three-point bending test

  → Regularization under biaxial stress states

  → Failure occurs





Summary

- GISSMO damage model suitable to capture the physics of damage and failure in a variety of stress states
- User-friendly identification of material parameters using numerical optimization
- Accuracy of failure description depends on the range of stress states covered by specimen tests

New features in GISSMO starting from Release 5:

- Further improvement of the instability treatment
- Enhanced description of failure for solid elements (Lode angle)
- Extended capabilities for stress-state dependent regularization (SHRF&BIAXF)

Thank you!