On the prediction of material failure in LS-DYNA: A comparison between GISSMO and DIEM

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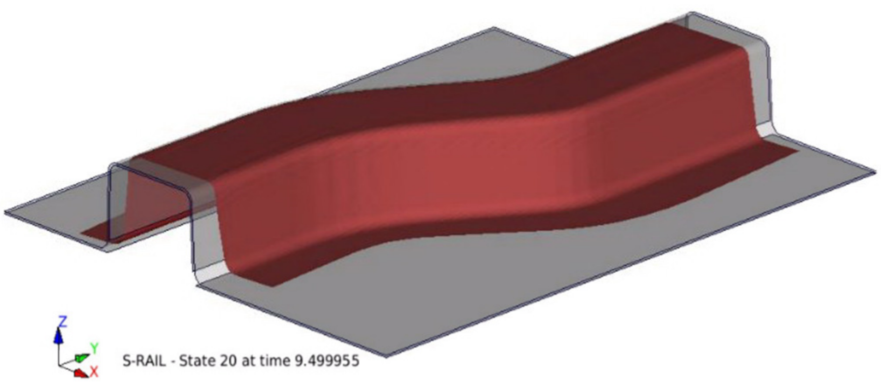
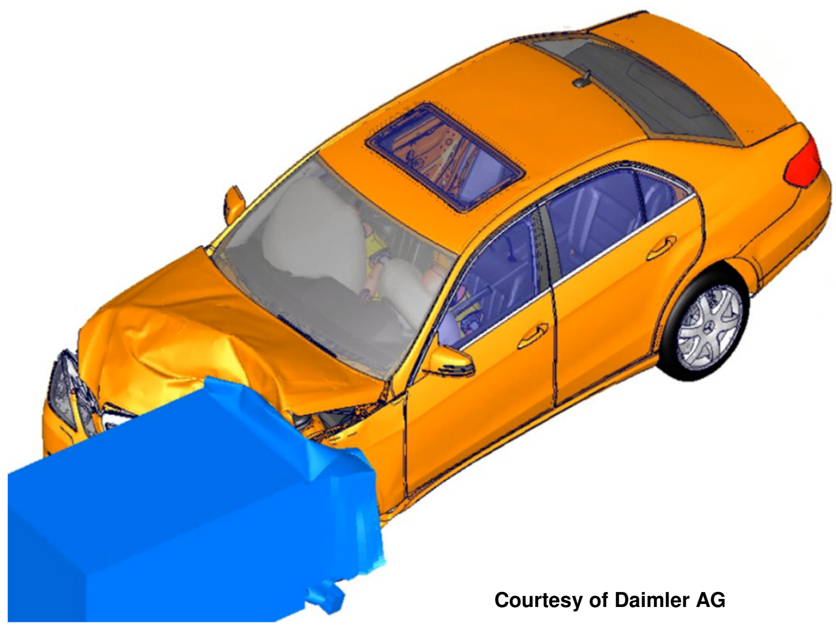
Motivation

Damage and failure play an important role in simulations

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





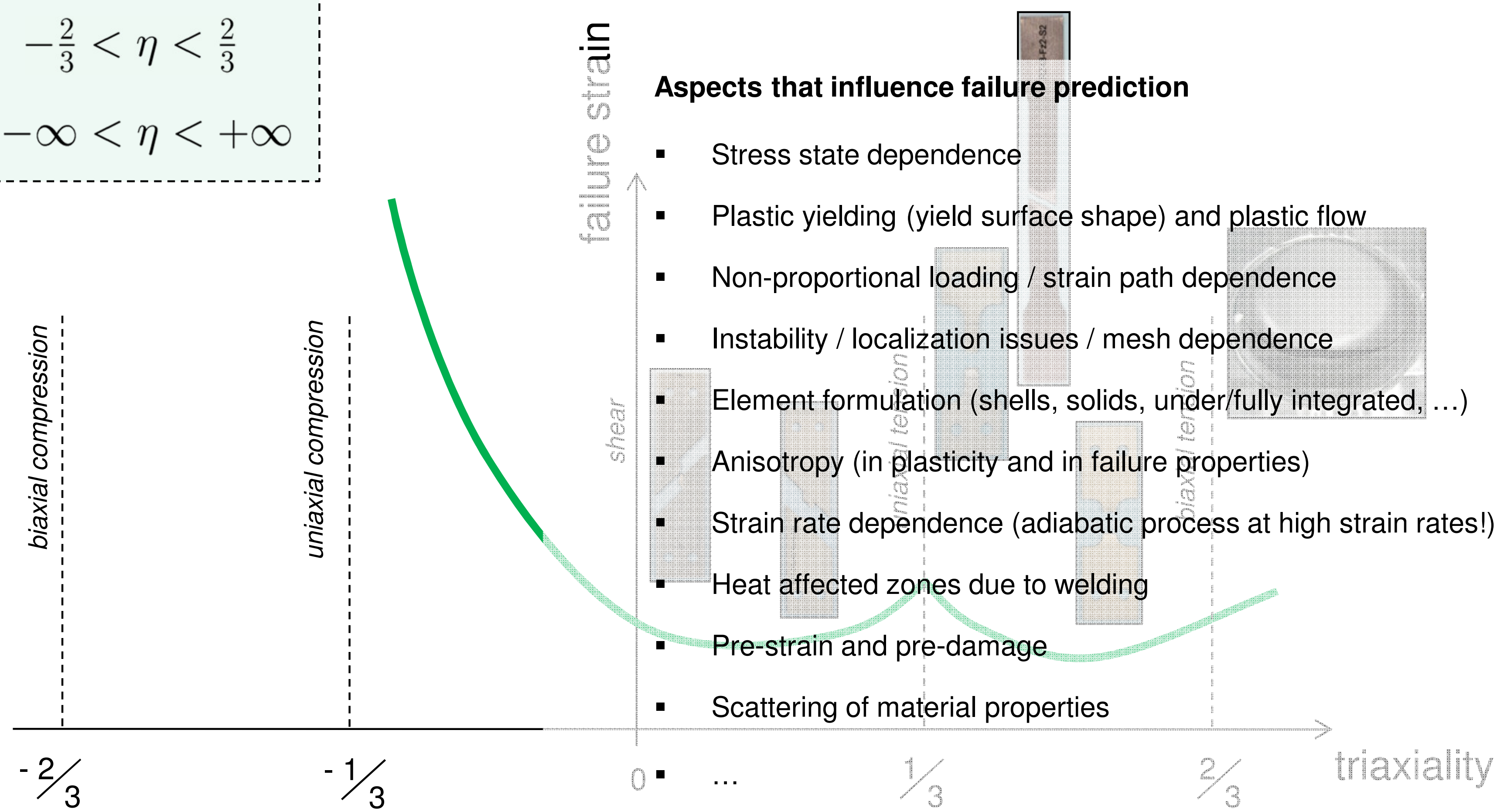
Courtesy of Daimler AG

Stress state dependence

Material failure strongly depends on the stress state

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

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



Aspects that influence failure prediction

- Stress state dependence
- Plastic yielding (yield surface shape) and plastic flow
- Non-proportional loading / strain path dependence
- Instability / localization issues / mesh dependence
- Element formulation (shells, solids, under/fully integrated, …)
- Anisotropy (in plasticity and in failure properties)
- Strain rate dependence (adiabatic process at high strain rates!)
- Heat affected zones due to welding
- Pre-strain and pre-damage
- Scattering of material properties
- …

Suitable specimens are needed for the accurate calibration of material failure

Prediction of failure

Current possibilities in LS-DYNA

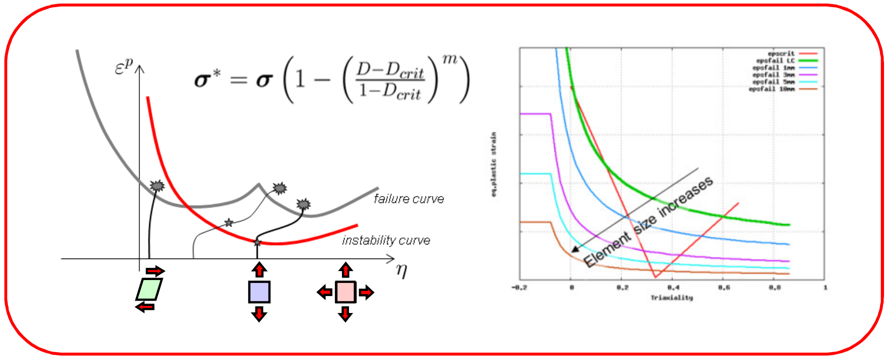
Several damage and failure models are currently available in LS-DYNA:

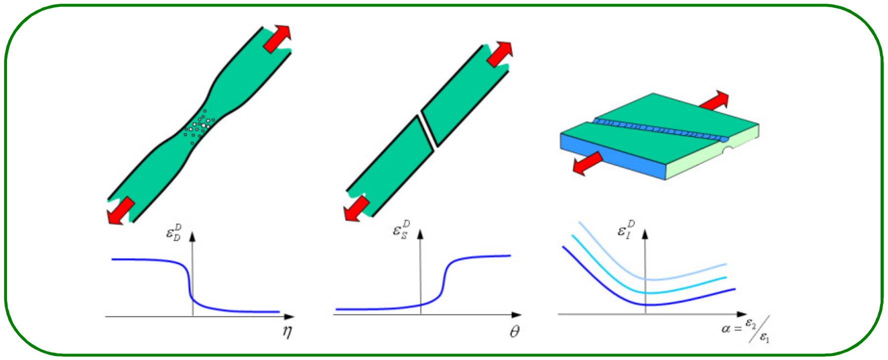
*MAT_15
*MAT_24
*MAT_123
*MAT_37_NLP_FAILURE
*MAT_39
*MAT_89
*MAT_104
*MAT_105
*MAT_120
*MAT_120_JC
*MAT_120_RCDC
*MAT_153
*MAT_187
*MAT_190
…
…
*MAT_USER_DEFINED_MATERIAL_MODEL

*MAT_ADD_EROSION:

IDAM>0 **GISSMO**

IDAM<0 **DIEM**



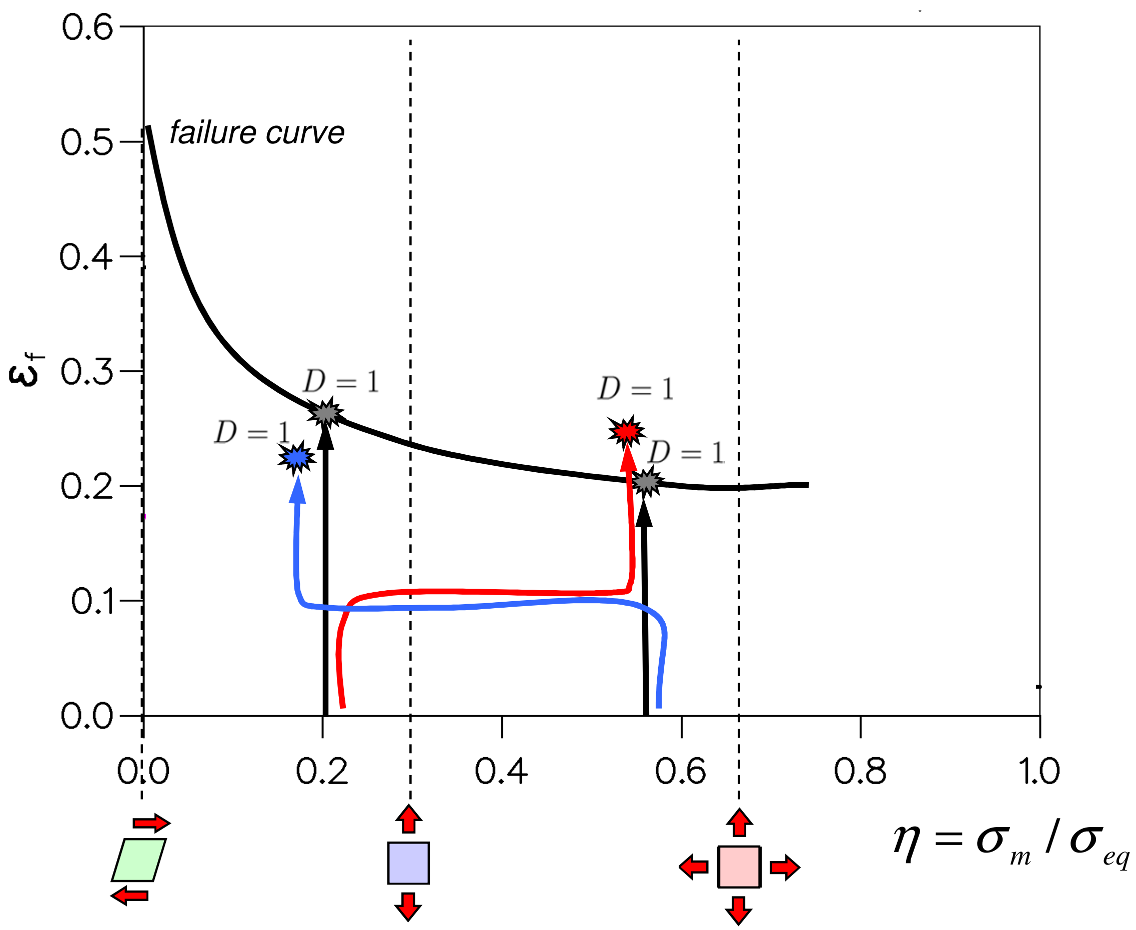


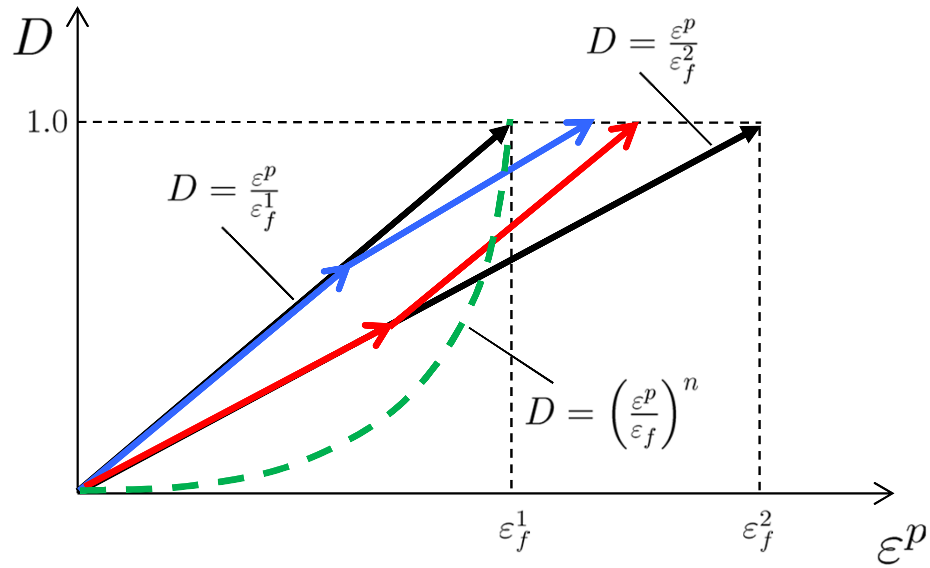
Description of GISSMO

(Generalized Incremental Stress State dependent MOdel)

Non-proportional loading

Accumulation of damage





$$D = \left(\frac{\varepsilon^p}{\varepsilon_f(\eta)}\right)^n$$

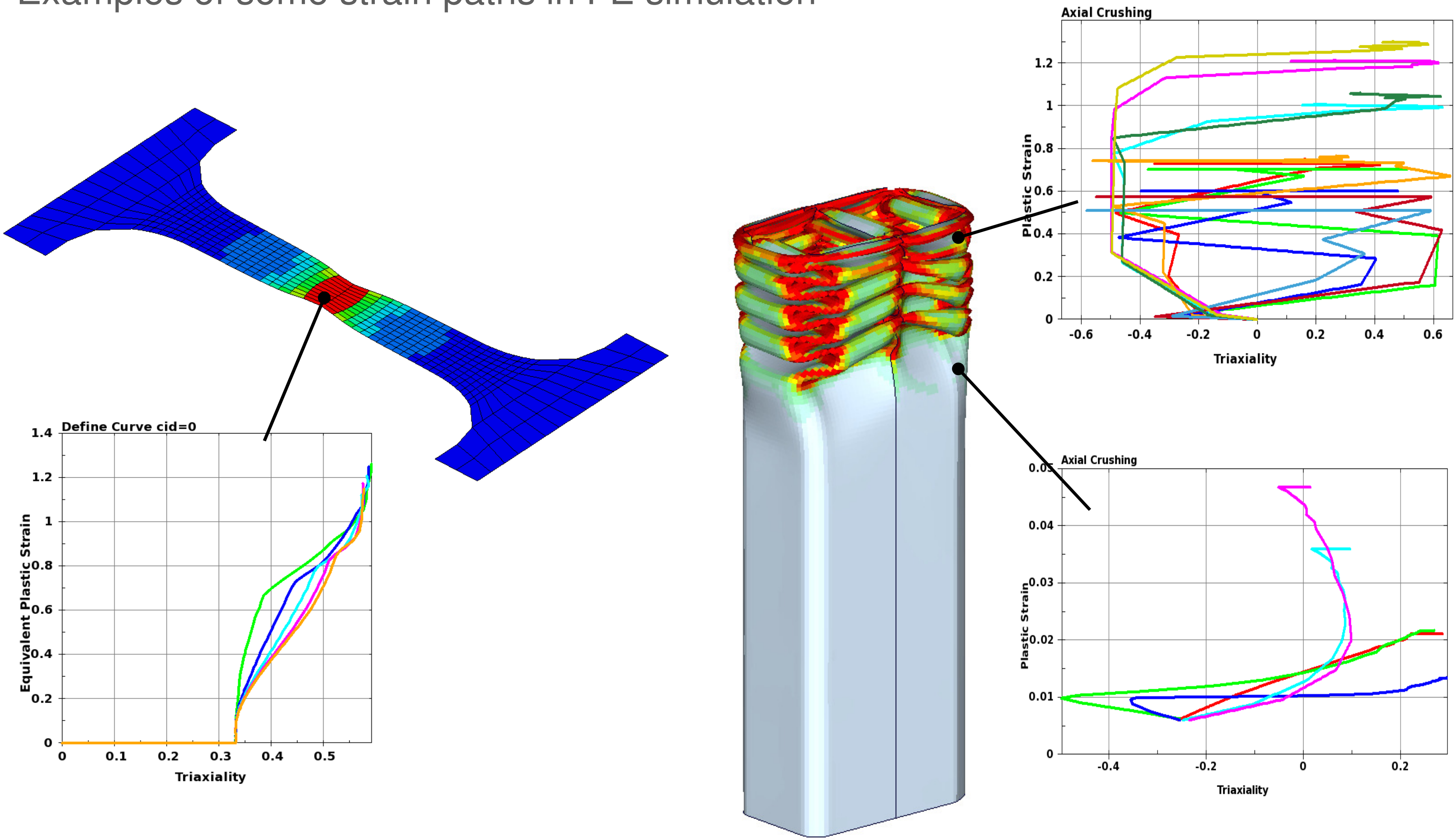
Differentiated under constant triaxiality

Damage is incrementally accumulated as a function of the plastic strain increment and of the failure curve. **Failure occurs when D = 1!**

$$\Delta D = \frac{n}{\varepsilon_f(\eta)} D^{\left(1-\frac{1}{n}\right)} \Delta \varepsilon_{eq}^p$$

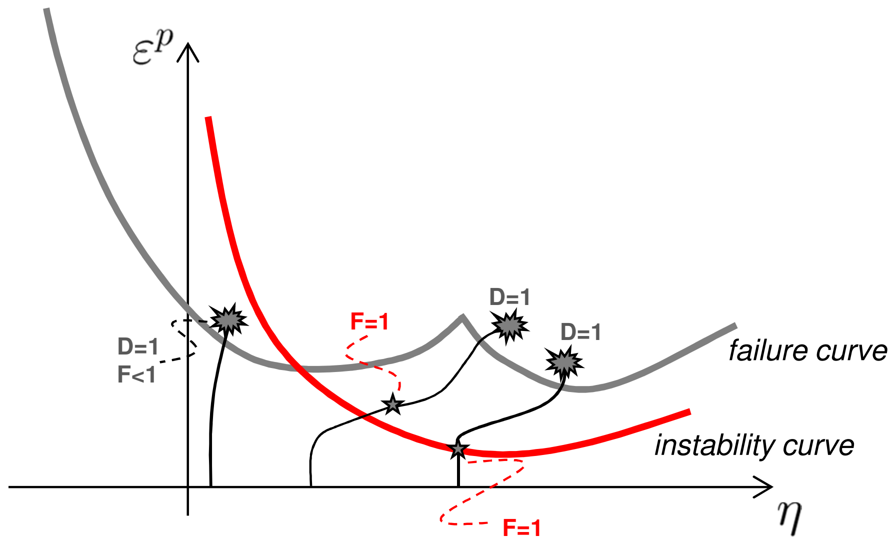
Non-proportional loading

Examples of some strain paths in FE simulation



Instability and Localization

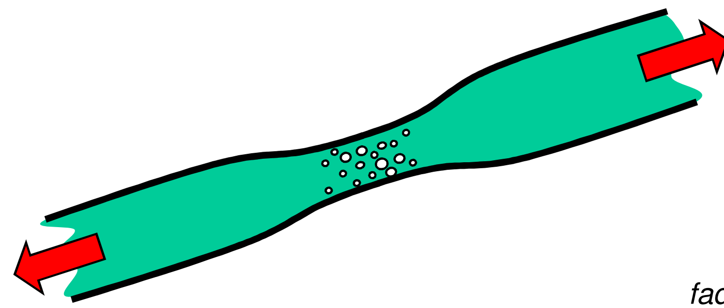
GISSMO – Coupling between stress and damage



$$\Delta F = \frac{n}{\varepsilon_{crit}(\eta)} F^{\left(1-\frac{1}{n}\right)} \Delta \varepsilon^p$$

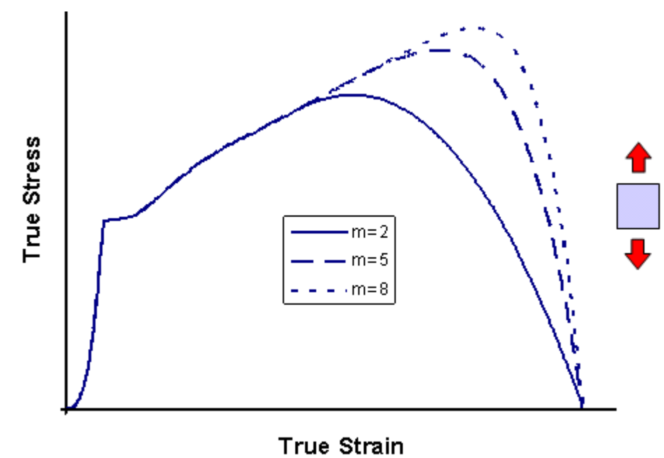
Similar to damage, an instability measure is incrementally accumulated as a function of the plastic strain increment and of the failure curve.
Coupling begins when F = 1!

DCRIT assumes the value of current damage when coupling begins.



fading exponent

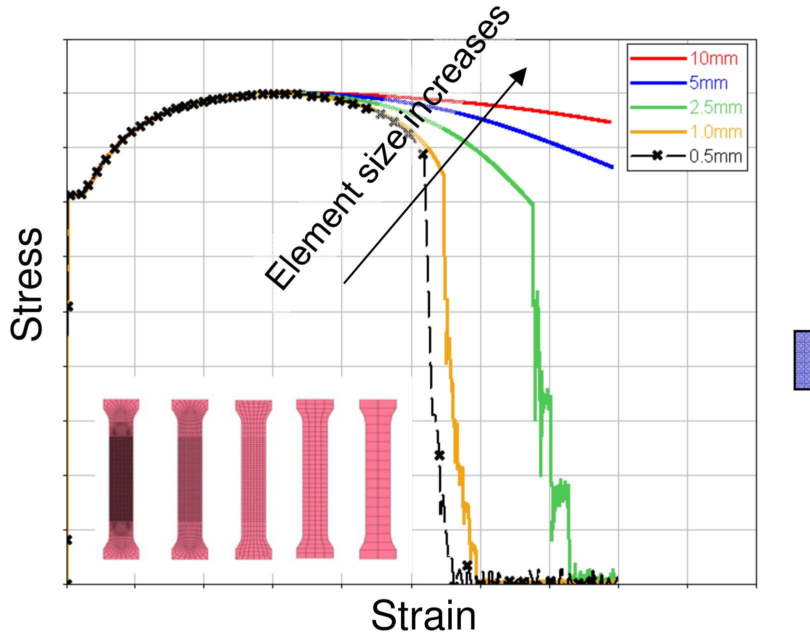
$$\boldsymbol{\sigma}^* = \boldsymbol{\sigma} \left(1 - \left(\frac{D-D_{crit}}{1-D_{crit}}\right)^m\right)$$



Mesh dependence

Regularization in GISSMO

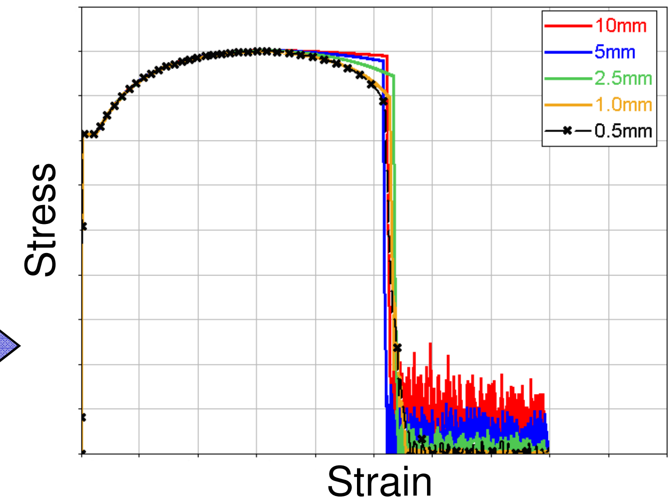
Mesh size dependence

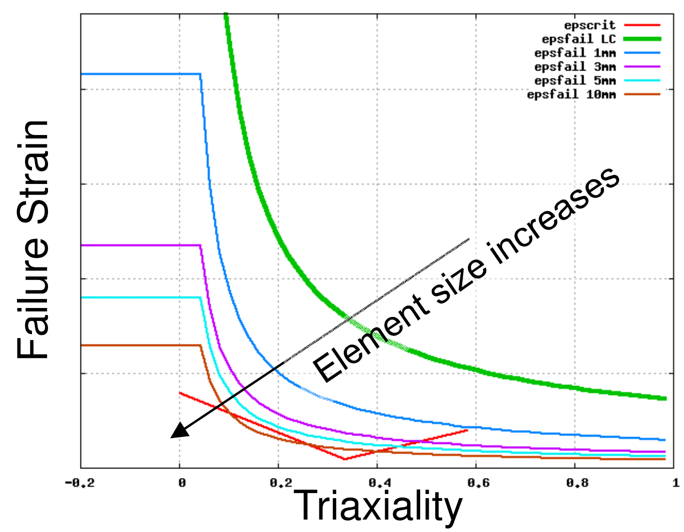


- Inherent mesh-size dependence of results in the post-critical region

- Simulation (and calibration) of tensile test specimen with different mesh sizes

Simple regularization





Description of DIEM

(Damage Initiation and Evolution Model)

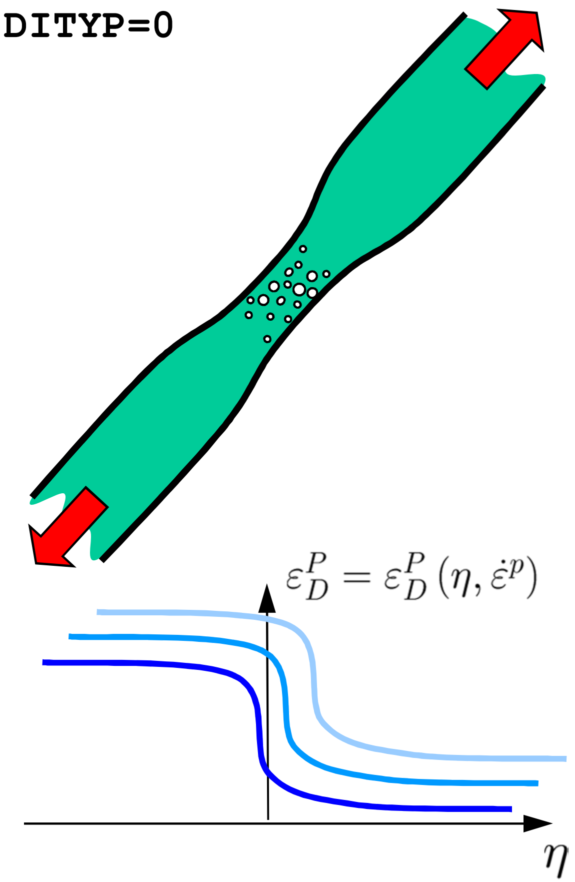
Stress state dependence

Multiple criteria may be defined in DIEM

Damage Initiation variable $\longrightarrow \omega_D$

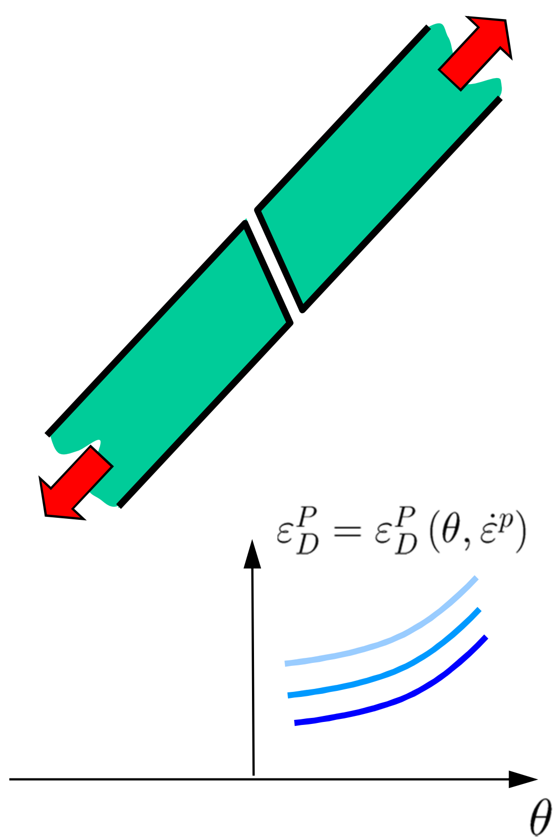
Ductile initiation criterion

DITYP=0



Shear initiation criterion

DITYP=1



Accumulation of the damage initiation variable:

$$\omega_D^i = \int_0^{\varepsilon^p} \frac{\mathrm{d}\varepsilon^p}{\varepsilon_D^p}$$

(Non-proportional loading is taken into account)

Definition of the shear stress function:

$$\theta = \frac{2(\sigma_{eq} + k_s p)}{\sigma_{major} - \sigma_{minor}}$$

pressure influence parameter

Instability and localization

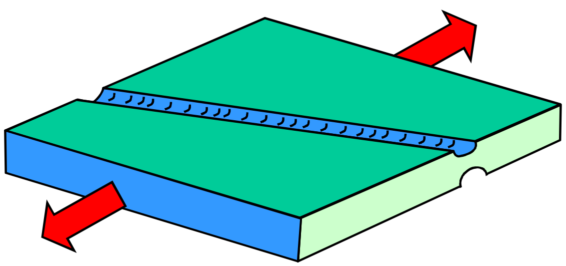
Two different criteria in DIEM (shells only)

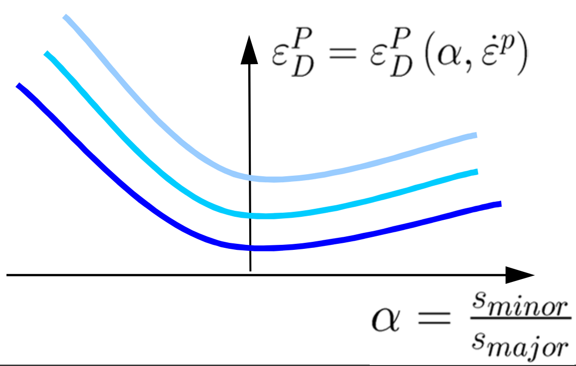
Damage Initiation variable $\longrightarrow$ ω_D

Instability initiation criterion

`DITYP=2` $\longrightarrow$ MSFLD

`DITYP=3` $\longrightarrow$ FLD





The MSFLD damage initiation criterion (DITYP=2) only considers the evolution of plastic strain if the pressure is negative (i.e., compressive stress states have no effect). The damage initiation variable is defined as

$$\omega_D^i = \max_{t \leq T} \frac{\varepsilon^p}{\varepsilon_D^p}$$

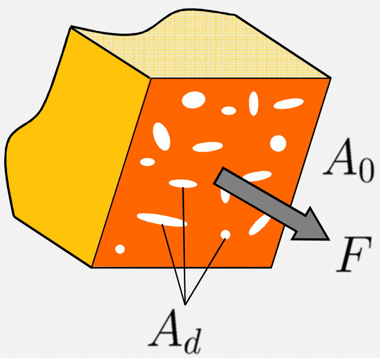
If DITYP=3, the FLD damage initiation criterion is activated and ω_D accumulates according to

$$\omega_D^i = \int_0^{\varepsilon^p} \frac{d\varepsilon^p}{\varepsilon_D^p}$$

Dissipation of energy upon fracture

Damage Evolution type (DETYP)

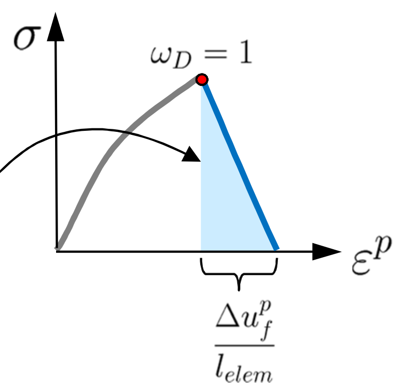
Idea of scalar damage



$$D = \frac{A_d}{A_0}$$

with $0.0 \leq D \leq 1.0$

$$\sigma = (1 - D)\tilde{\sigma}$$



Damage evolution is given by

$$\dot{D} = \frac{\dot{u}^p}{\frac{\partial u_f^p}{\partial D}}$$

where the plastic displacement at failure reads

$$u_f^p = u_f^p(\eta, D)$$

Definition of the plastic displacement:

$$\dot{u}^p = \begin{cases} 0 & \text{if } \omega_D < 1 \\ l_{elem}\dot{\varepsilon}^p & \text{if } \omega_D > 1 \end{cases}$$

intrinsic regularization!

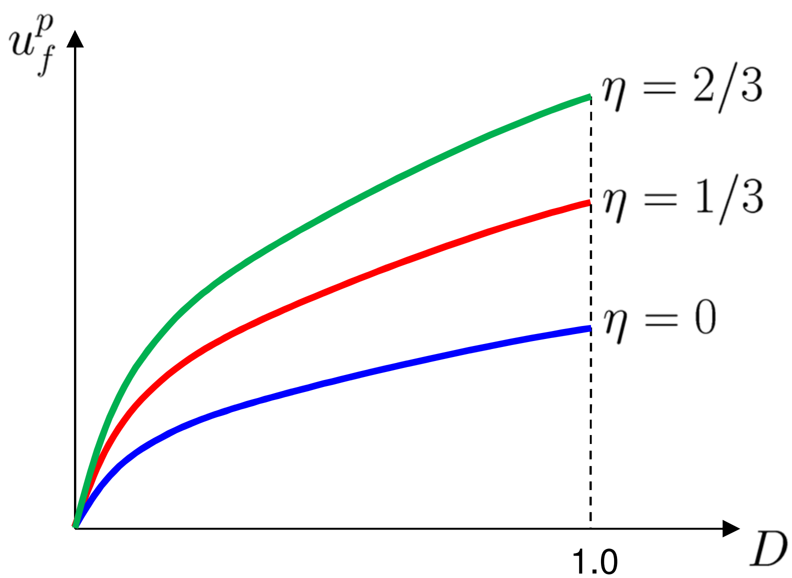
Damage Evolution

Example of input in LS-DYNA

current plastic displacement

$$\Delta D = \frac{\ell_{t+1} \Delta \varepsilon^p}{\left.\frac{\partial u_f^p}{\partial D}\right|_{\eta_{t+1}, D_{t+1}}}$$

$t+1 \longrightarrow$ *current time step*



LS-DYNA Input (example)

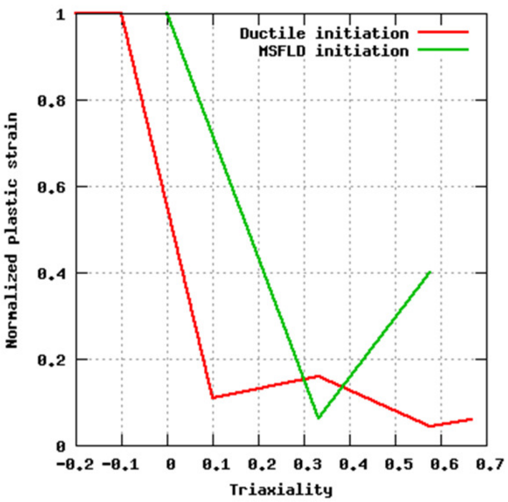
```
*DEFINE_TABLE
$      tbid
        700
$                damage
                    0.0
                    0.5
                    1.0
*DEFINE_CURVE
$      lcid      sidr      scla      sclo
        701         0       1.0       1.0
$         triaxiality                u_f^p
               0.0000                0.000
               0.3333                0.000
               0.6666                0.000
*DEFINE_CURVE
$      lcid      sidr      scla      sclo
        702         0       1.0       1.0
$         triaxiality                u_f^p
               0.0000                0.098
               0.3333                0.140
               0.6666                0.176
*DEFINE_CURVE
$      lcid      sidr      scla      sclo
        703         0       1.0       1.0
$         triaxiality                u_f^p
               0.0000                1.400
               0.3333                2.000
               0.6666                2.500
```

Calibration of a dual-phase steel

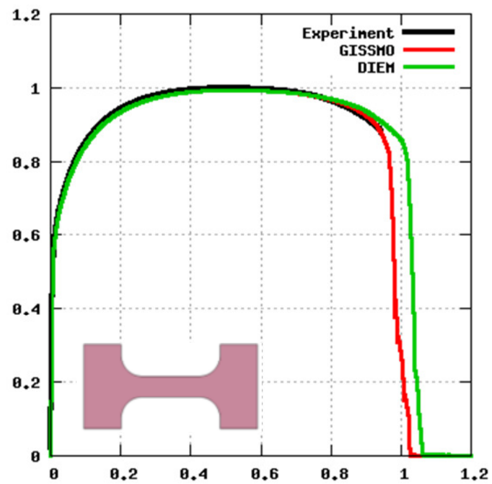
Calibration of a dual-phase steel

Calibration of GISSMO and DIEM through reverse engineering

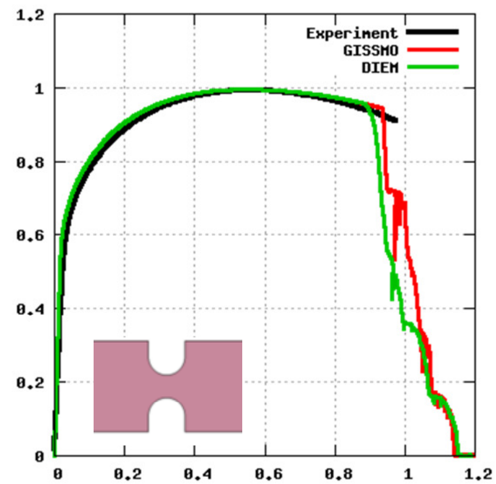
DIEM definitions



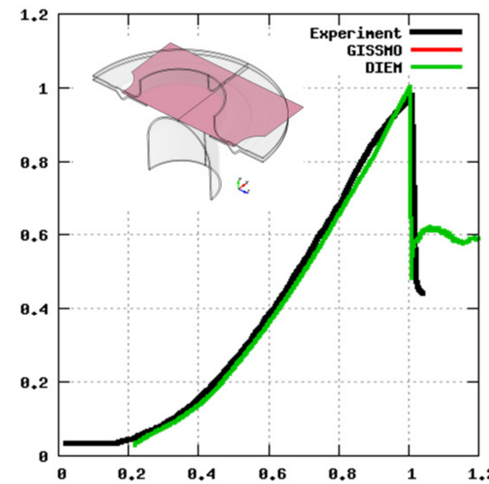
Small tensile



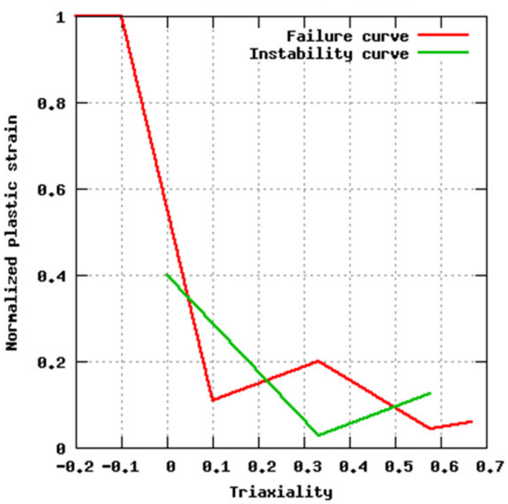
Notched specimen



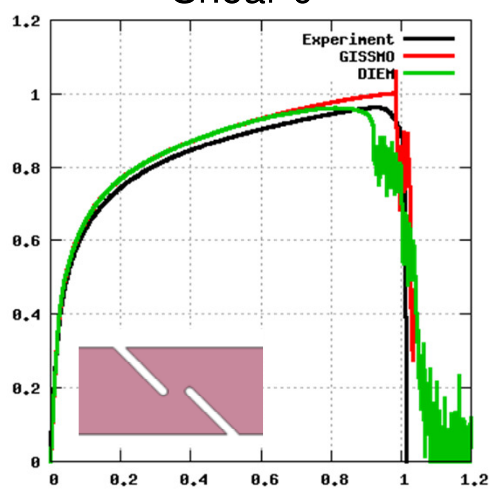
Biaxial tension



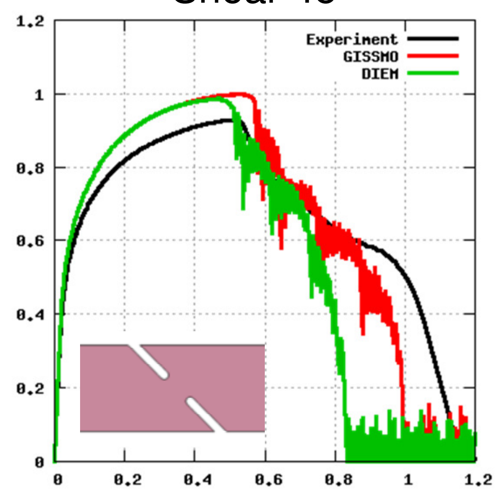
GISSMO definitions



Shear 0°



Shear 45°

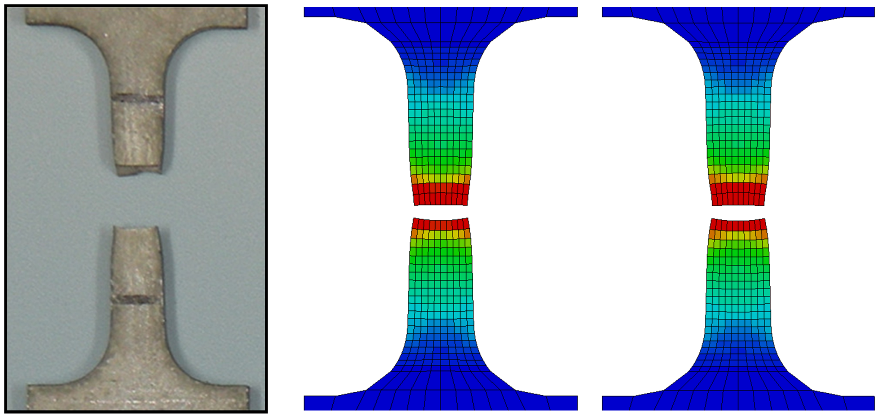


*MAT_024
Shells ETYP=16
Element size ~0.5mm

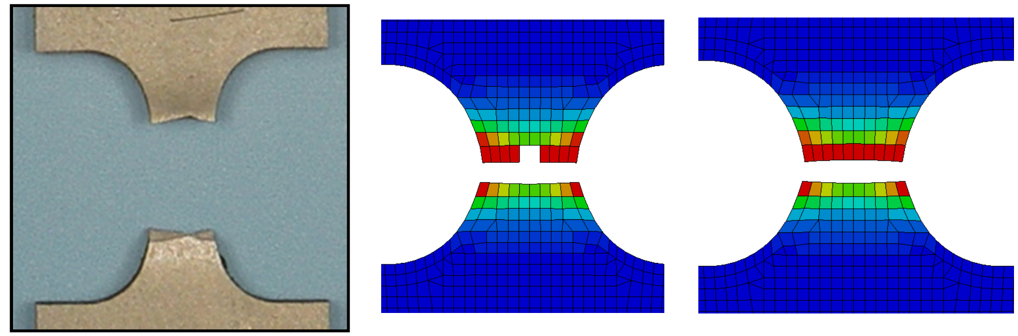
Calibration of a dual-phase steel

Comparison between experiment and simulation result

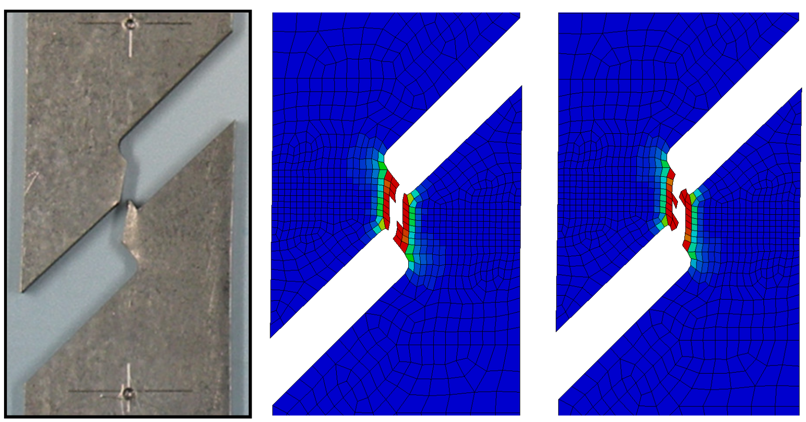
Small tensile *GISSMO* *DIEM*



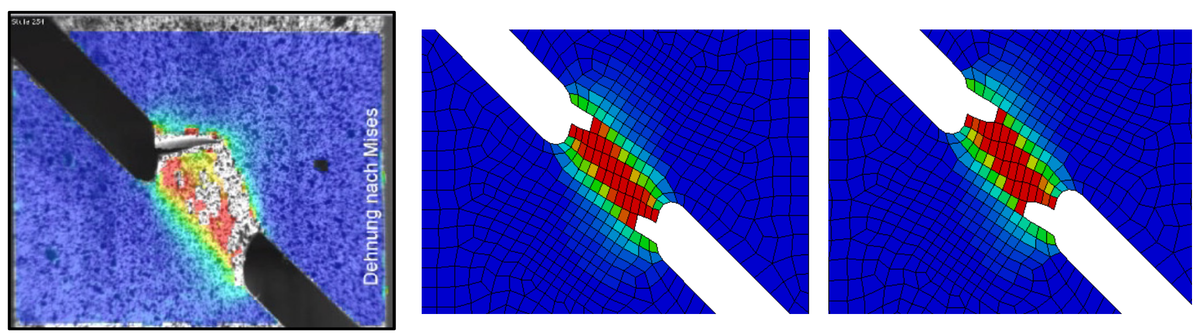
Notched specimen *GISSMO* *DIEM*



Shear 0° *GISSMO* *DIEM*

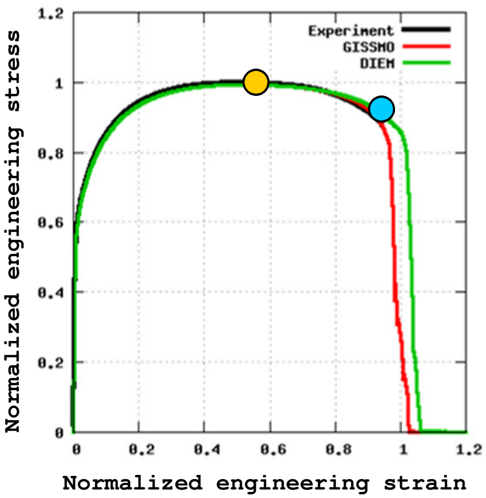


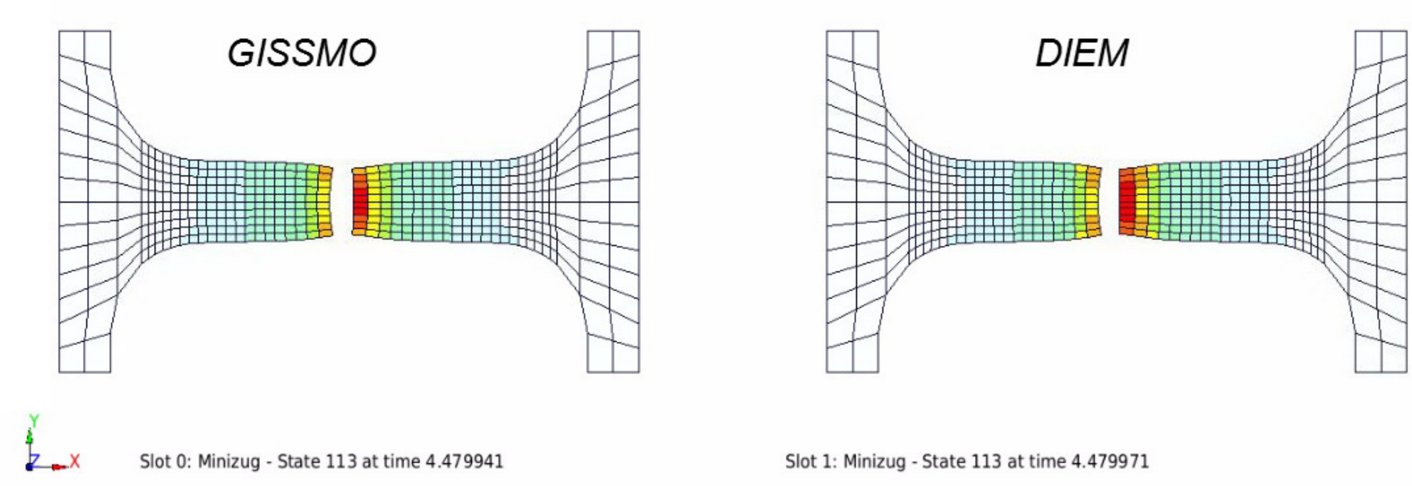
Shear 45° *GISSMO* *DIEM*

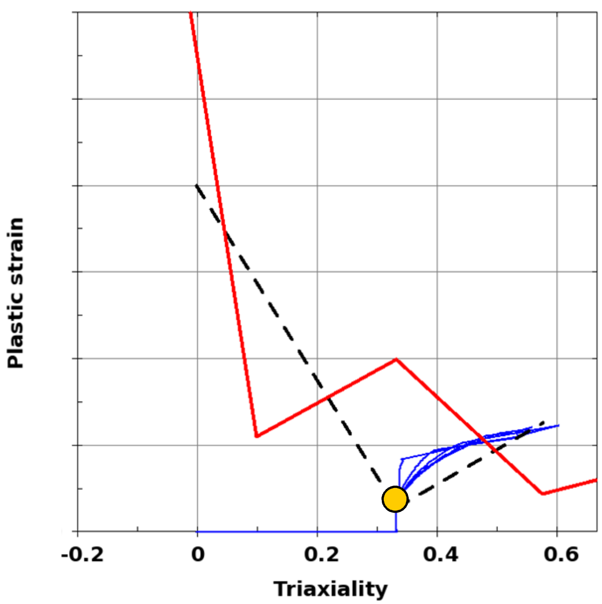


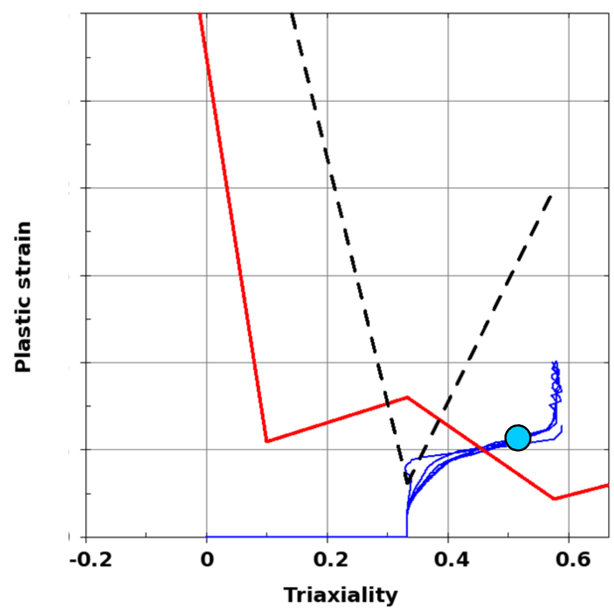
GISSMO x DIEM

Results of the tensile test



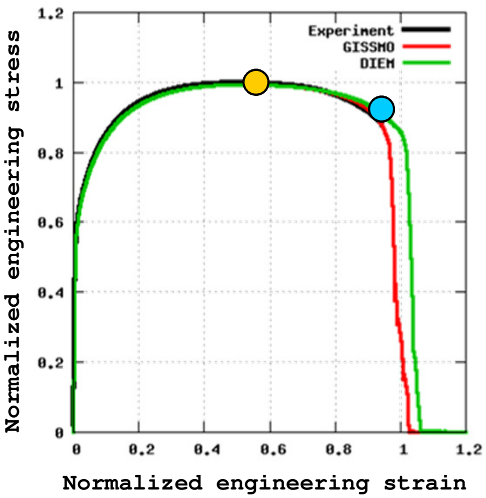


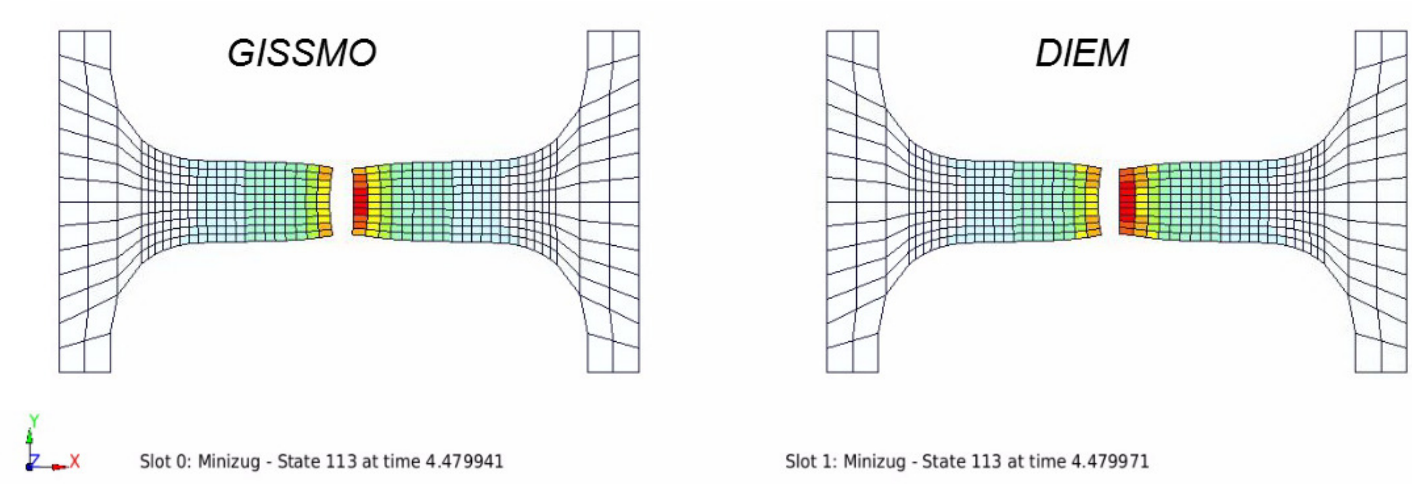


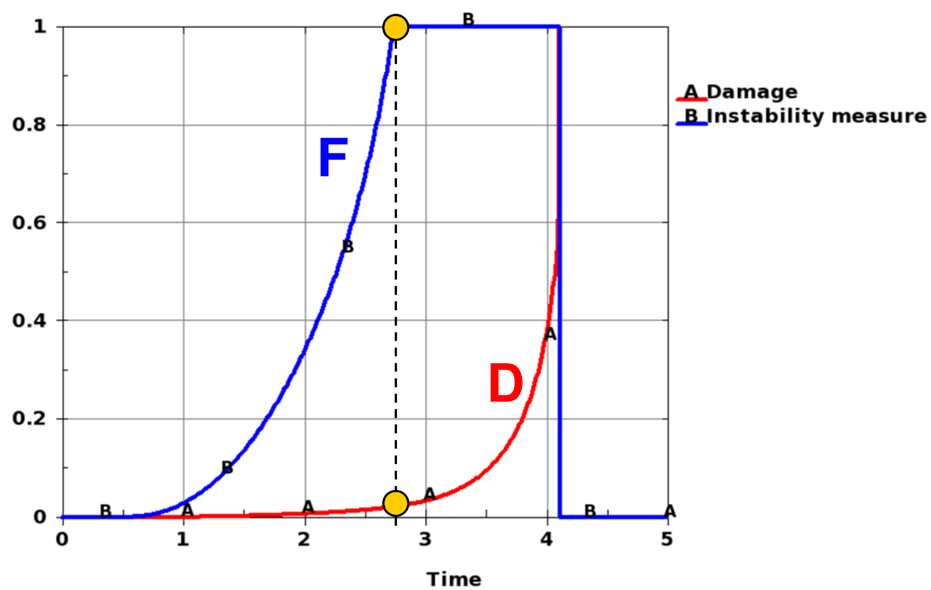


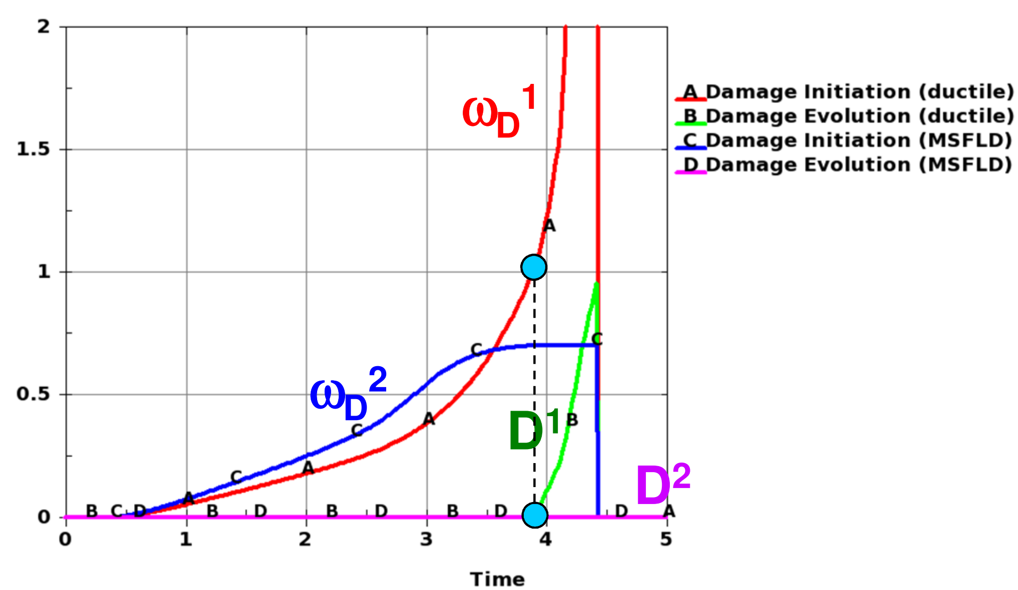
GISSMO x DIEM

Results of the tensile test





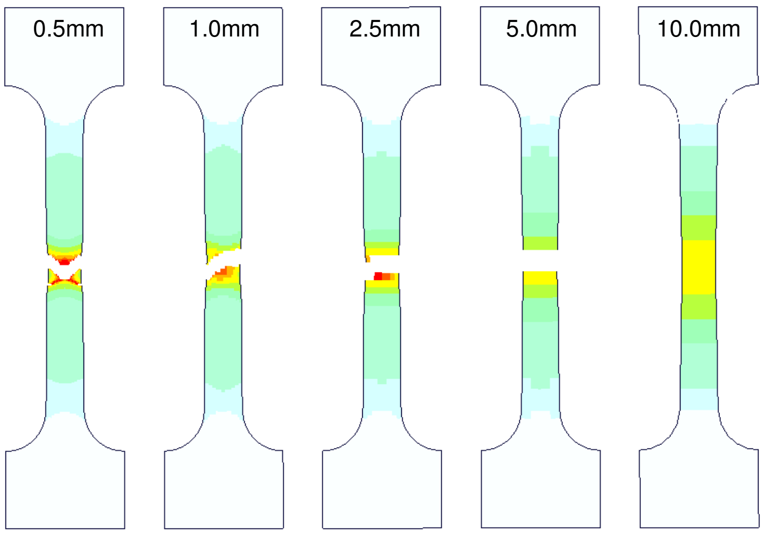




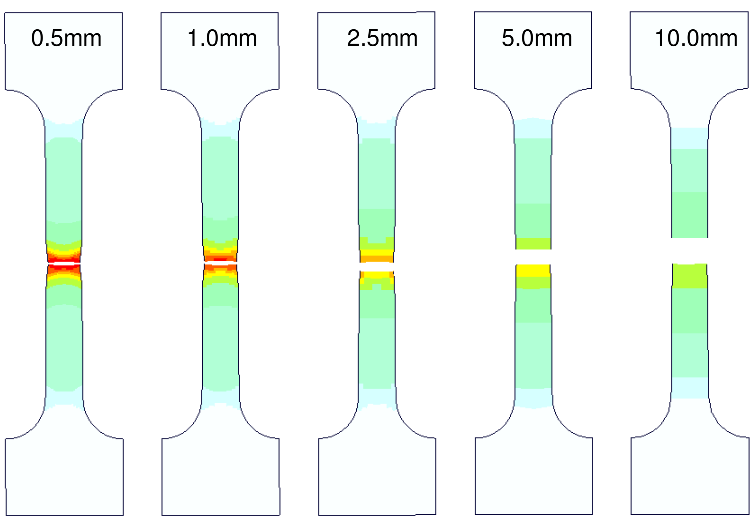
Calibration of a dual-phase steel

Effects of mesh dependence – GISSMO and DIEM

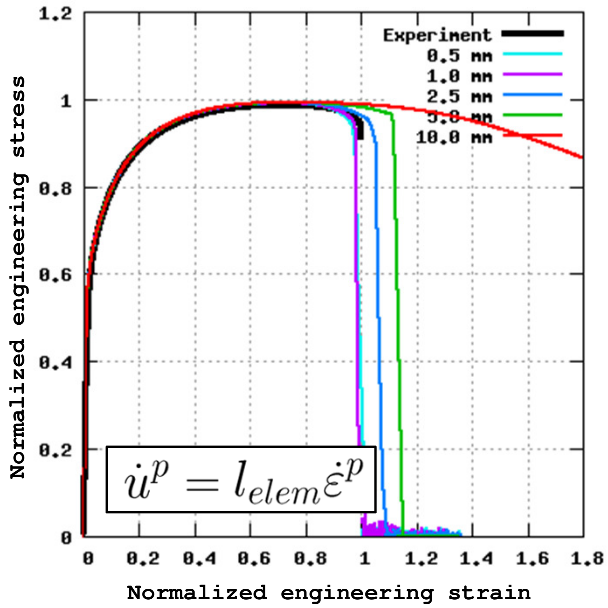
DIEM



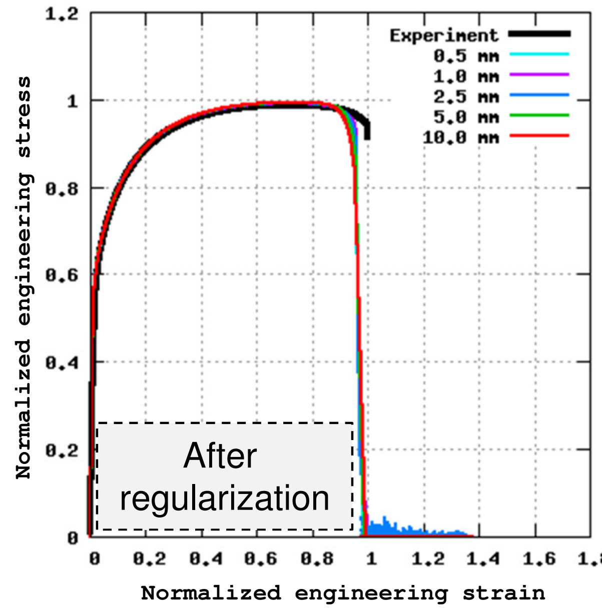
GISSMO

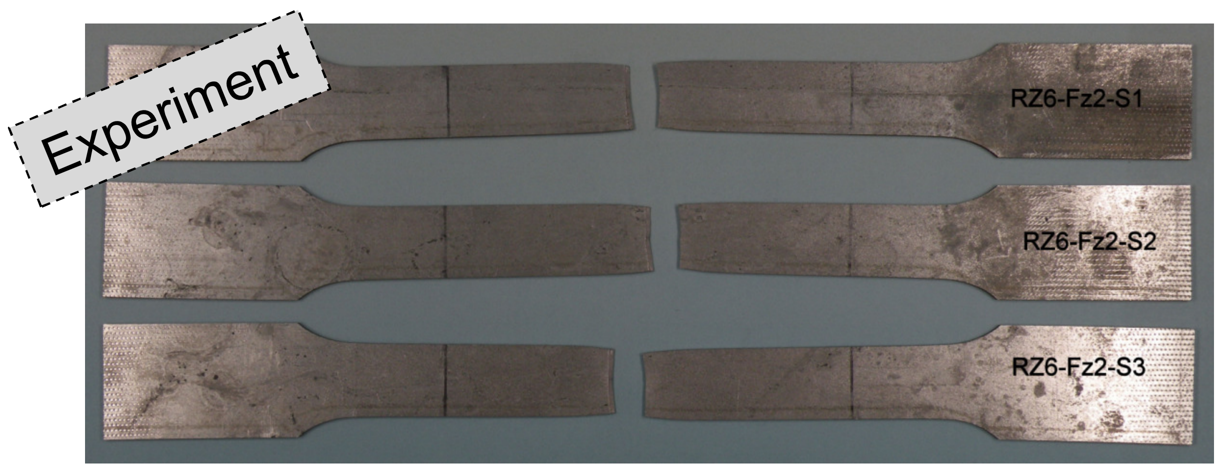


Large tensile – DIEM



Large tensile – GISSMO





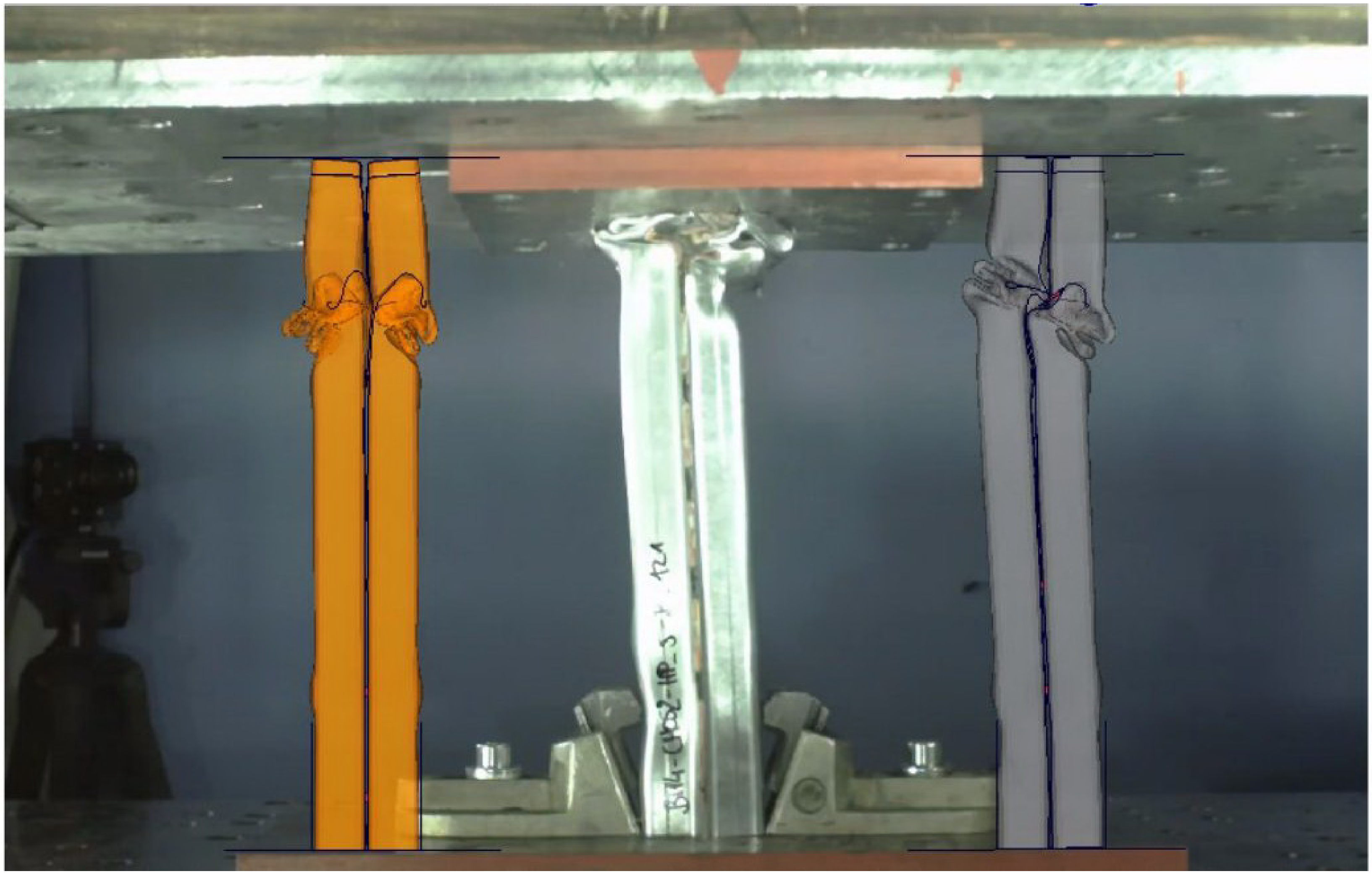
Validation – Dual-phase steel

Side rail under axial crushing, first results

*MAT_024
Shells ETYP=16
Element size ~3.0mm

DIEM

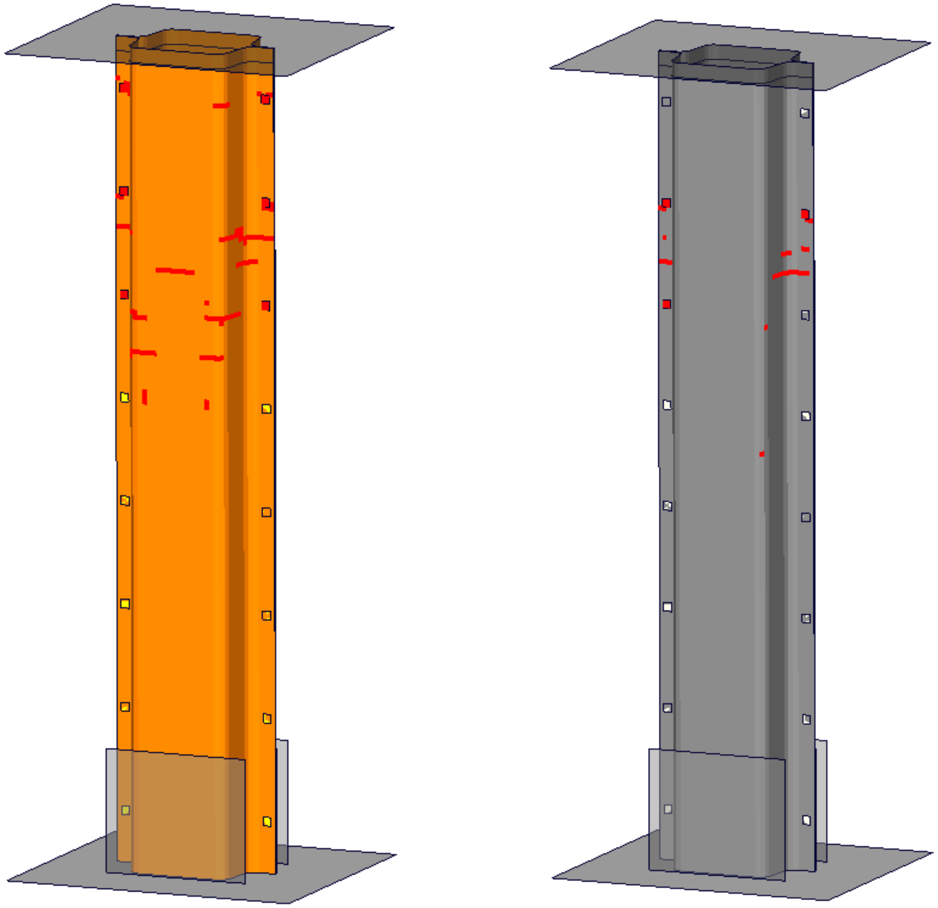
GISSMO



Validation – Dual-phase steel

Side rail under axial crushing, first results

failed elements

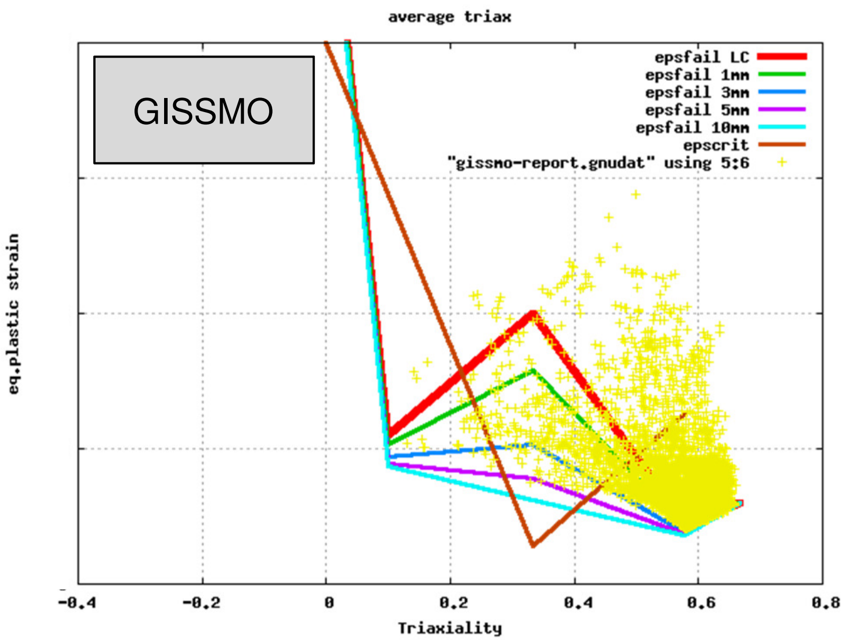


DIEM

GISSMO

DIEM

to be done…



GISSMO

Summary

Summary

Final comments and conclusions

LS-DYNA currently provides state-of-the-art failure and damage models for the prediction of material ductile fracture. GISSMO and DIEM belong to the most advanced of these models and are generally recommended for metal failure prediction in LS-DYNA.

General features of GISSMO and DIEM:

- Modular structure
- Dependence of stress state
- Non-proportional loading is taken into account
- Numerical tools for treatment of mesh dependence
- Possibility of mapping damage from a previous simulation
- Strain rate dependence may be considered

Conclusions regarding the comparison between GISSMO and DIEM:

- Underlying formulation is different but objectives are similar
- Both models seem to deliver results of comparable quality
- Current regularization method of GISSMO is more general than DIEM’s
- Further investigation is still needed to better grasp the differences between the two models

Summary
Further reading

- F. Neukamm, M. Feucht, A. Haufe, K. Roll. 2008. *On Closing the Constitutive Gap Between Forming and Crash Simulation*. (http://www.dynalook.com/international-conf-2008/MetalForming3-3.pdf)

- J. Effelsberg, A. Haufe, M. Feucht, F. Neukamm, P. DuBois. 2012. *On parameter identification for the GISSMO damage model*. (http://www.dynalook.com/international-conf-2012/metalforming25-a.pdf)

- T. Borrvall, T. Johansson, M. Schill, J. Jergéus, K. Mattiasson, P. DuBois. 2013. *A General Damage Initiation and Evolution Model (DIEM) in LS-DYNA*. (http://www.dynalook.com/9th-european-ls-dyna-conference/a-general-damage-initiation-and-evolution-model-diem-in-ls-dyna)

- F. Andrade, M. Feucht, A. Haufe. 2014. *On the Prediction of Material Failure in LS-DYNA: A Comparison Between GISSMO and DIEM*. (http://www.dynalook.com/13th-international-ls-dyna-conference/constitutive-modeling/on-the-prediction-of-material-failure-in-ls-dyna-r-a-comparison-between-gissmo-and-diem)

Thank you!