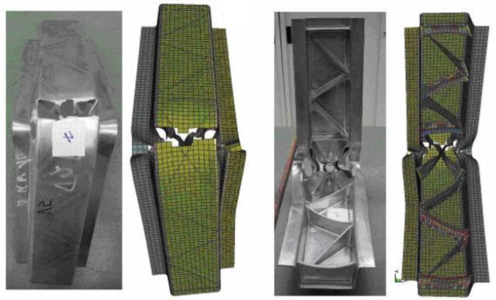
German LS-DYNA Forum 2018



News about the add-on failure and damage models in LS-DYNA

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Overview

- Add-on failure and damage models
  - `*MAT_ADD_EROSION`
  - `*MAT_ADD_GENERALIZED_DAMAGE` (eGISSMO)

- Update about new developments over last 1-2 years
  - Clear arrangement of input: new keywords
  - Extended availability: beams, quadratic elements, …
  - New failure criteria
  - New options for damage (GISSMO)
  - Further enhancements

Clear arrangement of input

- Separation into pure failure and damage models
  - `*MAT_ADD_EROSION`: only failure criteria remain
  - New keyword `*MAT_ADD_DAMAGE_GISSMO`
  - New keyword `*MAT_ADD_DAMAGE_DIEM`
- Available in R11
  - New options will be added exclusively to the new keywords
  - Of course, old inputs still work

***MAT_ADD_DAMAGE_GISSMO**_{OPTION}_

Card 1	1	2	3	4	5	6	7	8
Variable	MID		DTYP	REFSZ	NUMFIP			

Card 2	1	2	3	4	5	6	7	8
Variable	LCSDG	ECRIT	DMGEXP	DCRIT	FADEXP	LCREGD		

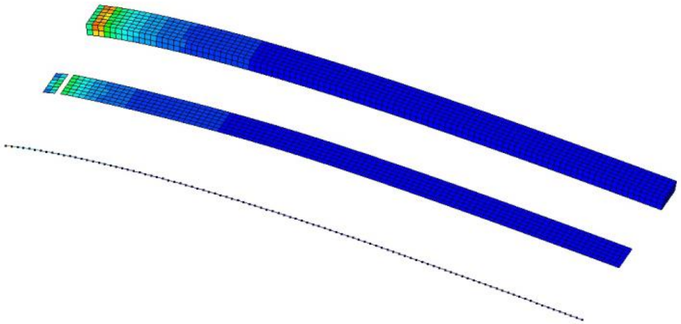
Card 3	1	2	3	4	5	6	7	8
Variable	LCSRS	SHRF	BIAXF	LCDLIM	MIDFAIL	HISVN		

Beam elements

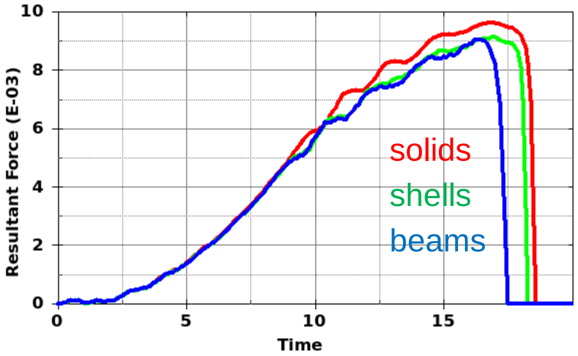
- Damage models DIEM and GISSMO
  - Now both support beam element type 1 (Hughes-Liu with cross section integration)
  - Triaxiality actually varies (non-zero transverse shear stresses):

$$\eta = \frac{-p}{\sigma_{vm}} = \frac{\sigma_{xx}/3}{\sqrt{\sigma_{xx}^2 + 3\left(\sigma_{yz}^2 + \sigma_{zx}^2\right)}}$$

  - Could be interesting for sophisticated bolt modeling or similar applications

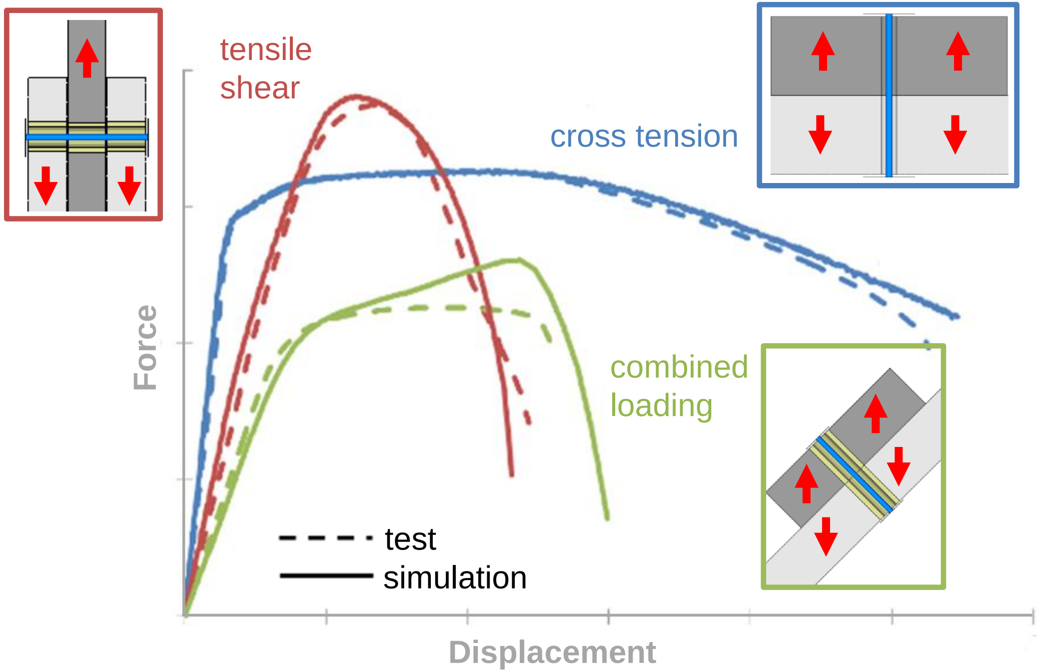


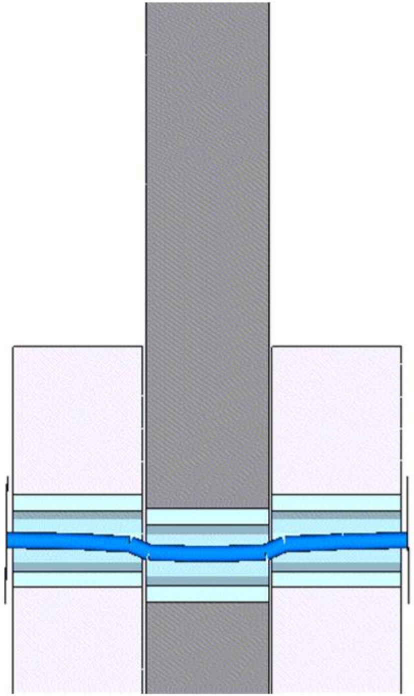
cantilever - tip displacement:
solid, shell, and beam elements



Beam elements

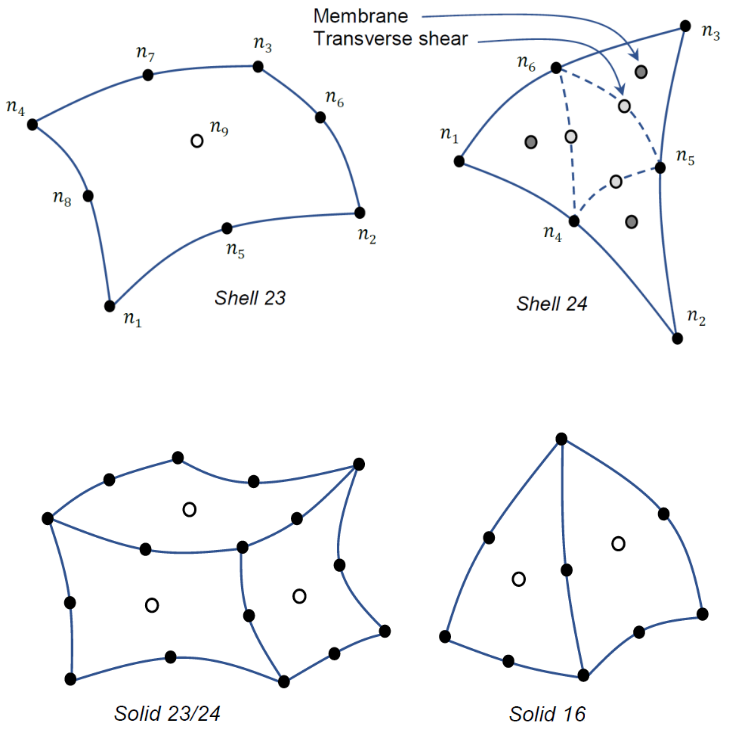
- Application: bolt modeling (H-L beams and GISSMO)





Courtesy of Daimler AG

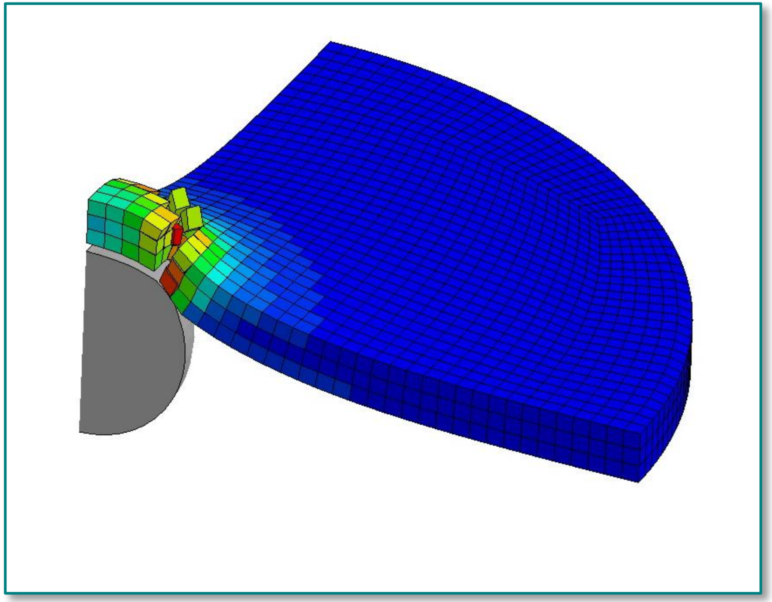
Higher-order elements

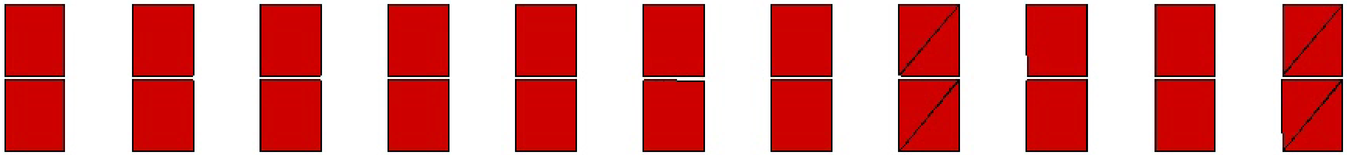


- Quadratic shells type 23 and 24
  - Mainly intended for implicit analysis
  - But also available in explicit
  - Now fully support the add-on failure and damage models
- Quadratic solids type 16, 23, and 24
  - Also available for explicit and implicit
  - Also fully support the add-on failure and damage models

Simple node splitting method

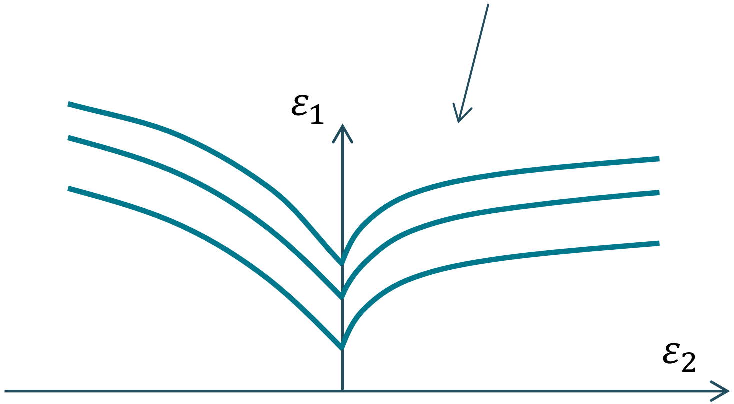
- Initially tied nodes open up after failure
  - Related keyword:
    *CONSTRAINED_TIED_NODES_FAILURE
  - Duplicate/coincident shell or solid nodes not merged but tied in the beginning
  - A failure variable is responsible for opening up the connection
  - Now supports GISSMO damage

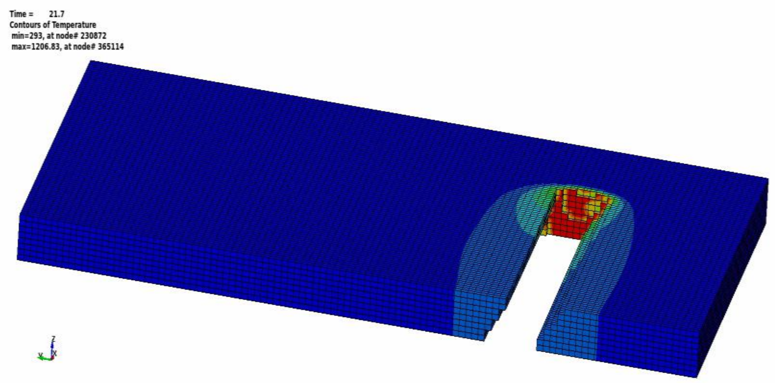




New failure criteria

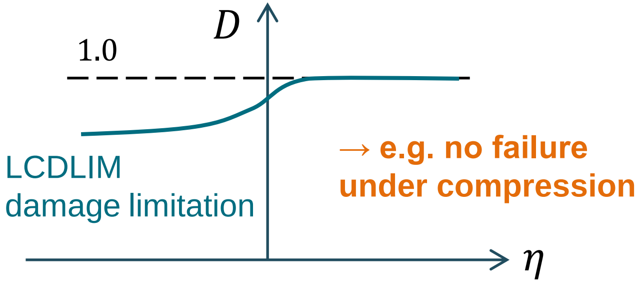
- New options in `*MAT_ADD_EROSION`
  - Maximum temperature: MXTMP → e.g. laser cutting
  - Minimum timestep: DTMIN
  - Strain rate dependent FLD: Table LCFLD>0
  - Thickness dependent FLD: Table LCFLD<0

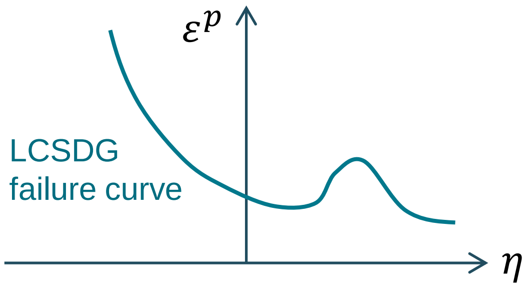


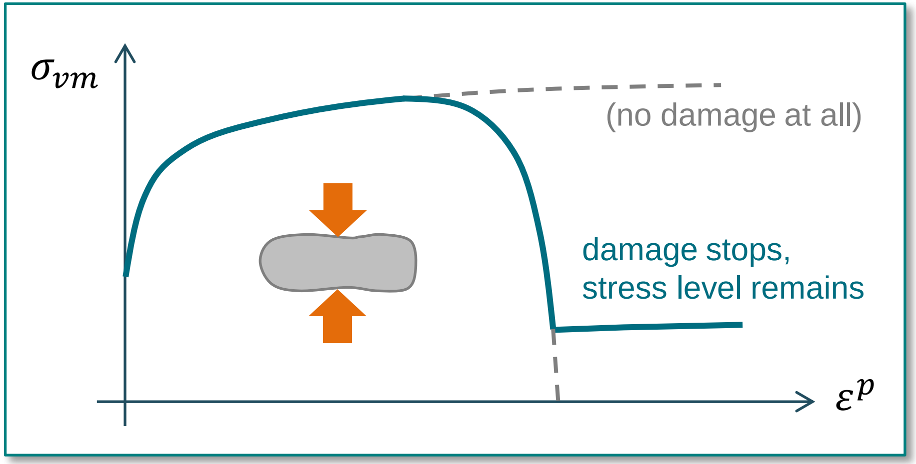


Damage limitation

- New option LCDLIM for GISSMO
  - Define limit for damage value (< 1.0)
  - Curve input: function of triaxiality
  - No damage accumulation afterwards
  - Similar approach as ”SLIM”
    in composite materials 54, 58, …

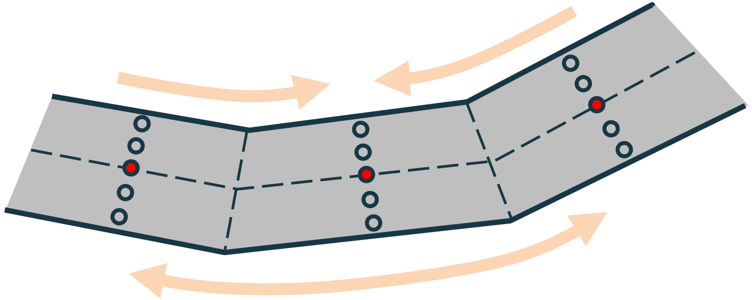


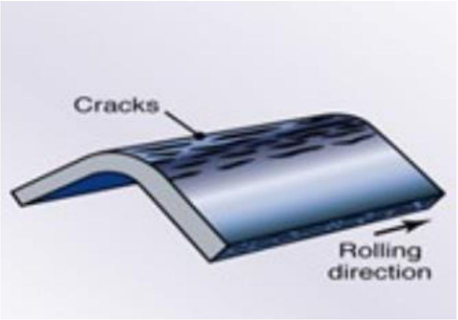


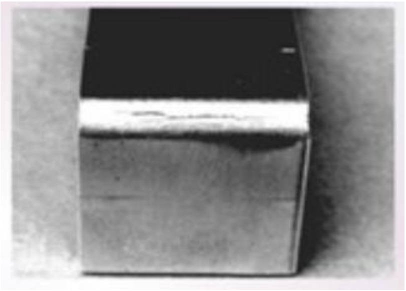


Mid-plane failure

- Potential improvement for shell elements under bending
  - Default: evaluation of instability at each integration point through thickness
  - Failure often too early in bending dominated problems
  - New MIDFAIL flag to locate critical strain evaluation at the mid-plane integration point
  - Several options (MIDFAIL = 1, 2, 3) to govern final failure and the behavior of the remaining IP’s

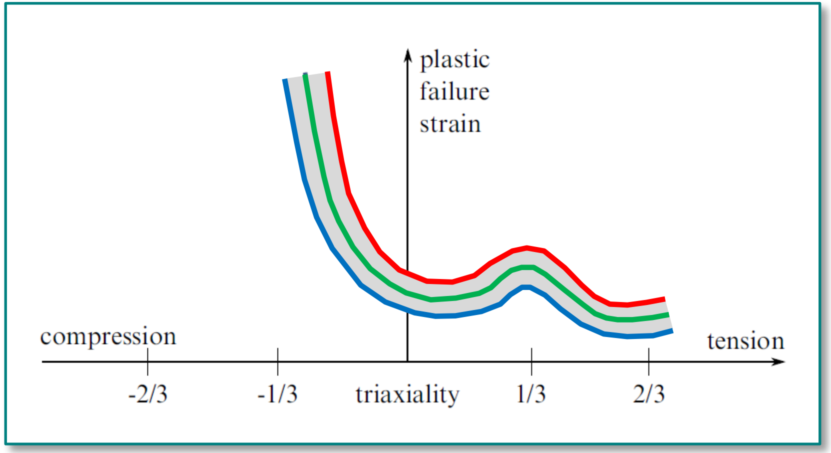


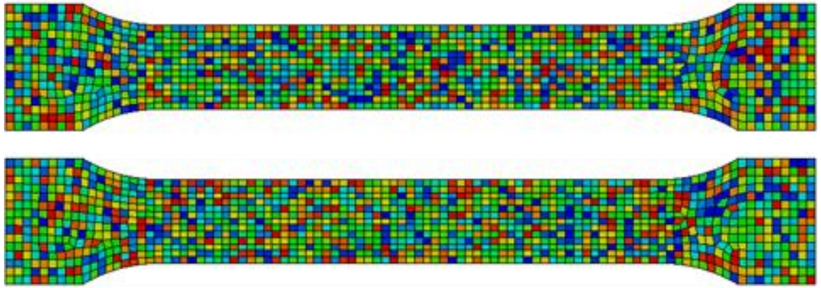




Stochastic distribution

- Spatially varying failure behavior
  - New option _STOCHASTIC for *MAT_ADD_DAMAGE_GISSMO
  - Failure strain can be varied through definitions in *DEFINE_STOCHASTIC_VARIATION
    - different distribution types (uniform, Gaussian, …)
  - e.g. in case of scattering of material properties in manufacturing





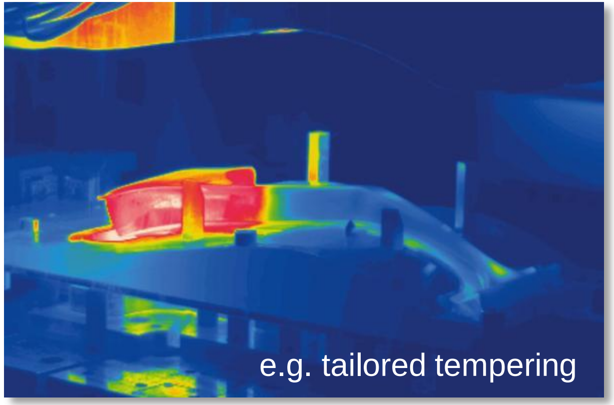
Tailored failure

- Additional history variable governs failure strain
  - New option HISVN allows input of constant value (>0) or location (<0) in `*INITIAL_STRESS_SHELL/SOLID`
  - Makes failure strain a 3-dimensional table

$$\varepsilon_f^p = \varepsilon_f^p(\eta, \bar{\theta}, \mathrm{HISV})$$

  - HISV could be hardness, porosity, pre-strain, …
  - Similar approach is used for history-dependent yield stress in `*MAT_TAILORED_PROPERTIES (*MAT_251)`

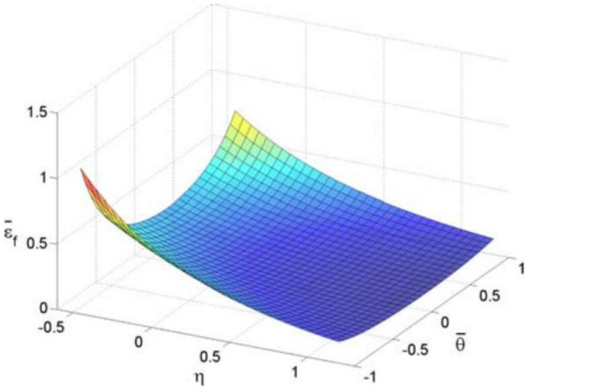
$$\sigma_y = \sigma_y(\eta, \bar{\theta}, \mathrm{HISV})$$



e.g. tailored tempering

Analytical failure function

- Alternative input for failure strain curve/surface
  - Instead of curve or table input (LCSDG>0), an analytical function can be defined (LCSDG<0) using `*DEFINE_FUNCTION` with arguments triaxiality and Lode parameter



  - Direct implementation of equations from relevant literature, e.g., Johnson-Cook, Wierzbicki, Mohr, e.g.,

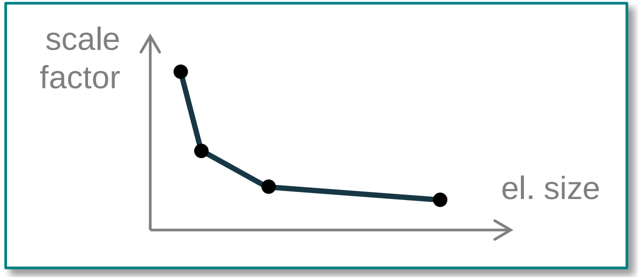
$$\bar{\varepsilon}_f = \left\{ \frac{A}{c_2} \left[\sqrt{\frac{1+c_1^2}{3}} \cos\left(\frac{\bar{\theta}\pi}{6}\right) + c_1 \left(\eta + \frac{1}{3} \sin\left(\frac{\bar{\theta}\pi}{6}\right)\right)\right]\right\}^{-\frac{1}{n}}$$

Mohr-Coulomb criterion in Bai and Wierzbicki (2001)

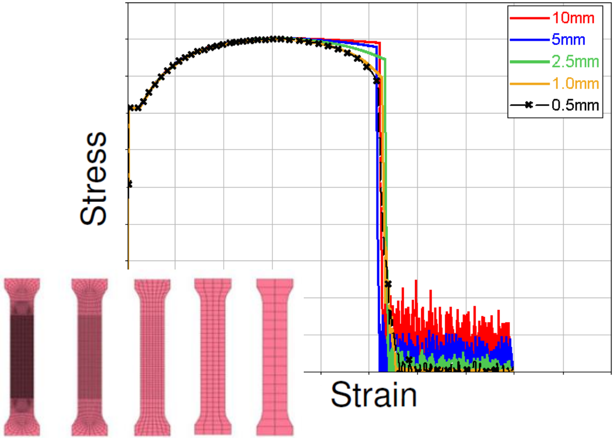
```
*DEFINE_FUNCTION
       100
double eps_f(double triax, double lodeb)
{
   double pi = 3.14159;
   double c1 = 0.1;
   …
   term2 = triax+sin(lodeb*pi/6.)/3.;
   …
   eps = ... +c1*term2 ...;
   return eps;
}
```

Mesh dependence: Regularization in GISSMO

- So far: Failure strain is function of element size
  - Curve LCREGD
- Allows calibration of (uniaxial) test data with different mesh sizes

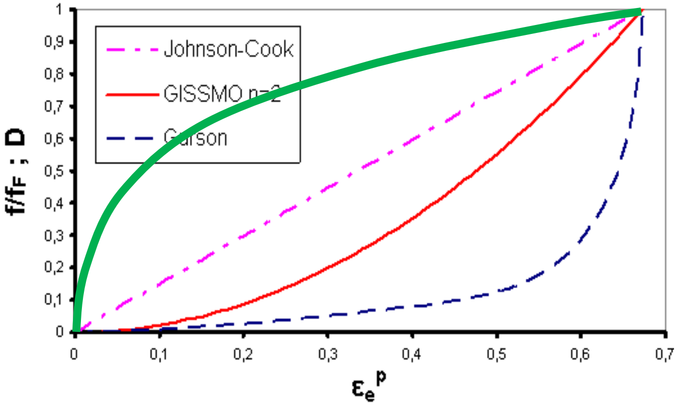


- Now: 2 new table options
  - Table LCREGD>0: failure strain is function of **rate** and element size
  - Table LCREGD<0: failure strain is function of **triaxiality** and element size (more general approach than using reduction factors SHRF and BIAXF)



Nonlinear damage accumulation

- Improvements for unusual damage evolution
  - In most cases, DMGEXP is 1.0 or greater in this equation: $\Delta D = \frac{\text{DMGEXP} \times D^{\left(1-\frac{1}{\text{DMGEXP}}\right)}}{\varepsilon_f} \Delta \varepsilon_p$
  - which means that damage increases slowly in the beginning and faster in the end
  - But non-metallic materials might show a contrary behavior, requiring **DMGEXP<1**
  - Already worked before to some extent, but now really made robust even for very small values



Mapping in process simulation

- Transfer of result quantities between process operations
  - e.g., from forming to crash: different discretization levels (element sizes)
  - GISSMO offers option REFSZ>0 from the beginning
    - reference size related damage output on history variable ND+9
  - New option REFSZ<0 works a little differently
    - Reference size related plastic strain is computed first (hisvar ND+15):

$$\Delta\varepsilon_{ref}^{p} = \frac{\varepsilon_f^p(|\mathrm{REFSZ}|) - \varepsilon_{crit}^p}{\varepsilon_f^p(l_e) - \varepsilon_{crit}^p}\Delta\varepsilon^p \qquad (\text{if } F \geq 1)$$

    - Reference size related damage computed from that (hisvar ND+9):

$$\Delta D_{ref} = \frac{\mathrm{DMGEXP}}{\varepsilon_f^p(|\mathrm{REFSZ}|)} D_{ref}{}^{1-1/\mathrm{DMGEXP}}\,\Delta\varepsilon_{ref}^{p}$$

Summary and outlook

- Add-on failure and damage models under constant development
  - Requests from customers
  - Efficiency
  - Generalizations

- More improvements to come
  - Non-local options (reduce strength in neighbors to failed elements)
  - Dependance on more and more variables (e.g. temperature)
  - User interface for damage models
  - …

Your questions, please