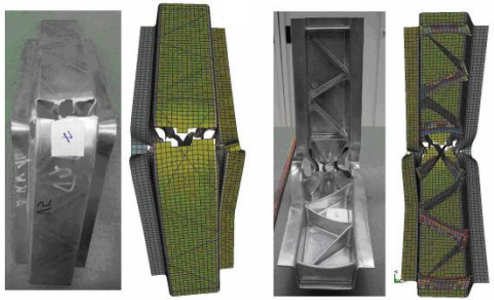


# LS-DYNA:
# Recent developments in GISSMO

Tobias Erhart, DYNAmore

April 2020

# Overview

- Update about new developments over the last 2-3 years
  - Clear arrangement of input: new keywords
  - Extended availability: beams, quadratic elements, …
  - New options for damage (GISSMO)
  - Further enhancements
  - Most features now available in release R11.0 or R11.1

# 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 **R11.0**
  - New options will be added exclusively to the new keywords
  - Of course, old inputs still work

***MAT_ADD_DAMAGE_GISSMO** *{OPTION}*

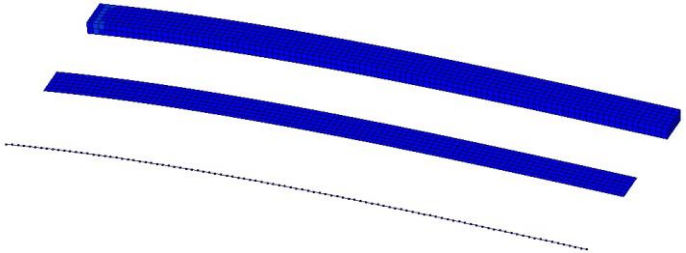
| Card 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | MID | | DTYP | REFSZ | NUMFIP | | | |
| Card 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Variable | LCSDG | ECRIT | DMGEXP | DCRIT | FADEXP | LCREGD | | |
| Card 3 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Variable | LCSRS | 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):

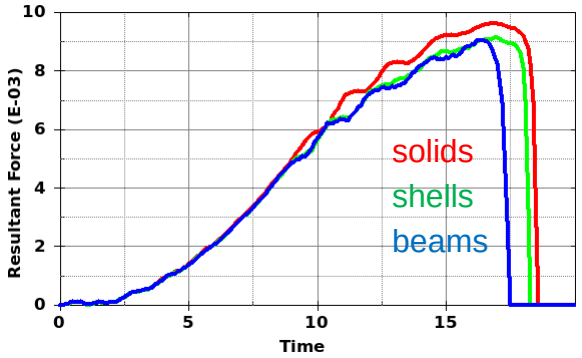
$$\eta = \frac{-p}{\sigma_{vm}} = \frac{\sigma_{xx}/3}{\sqrt{\sigma_{xx}^2 + 3\left(\sigma_{yz}^2 + \sigma_{zx}^2\right)}}$$

  - Could be interesting for sophisticated bolt modeling or similar applications



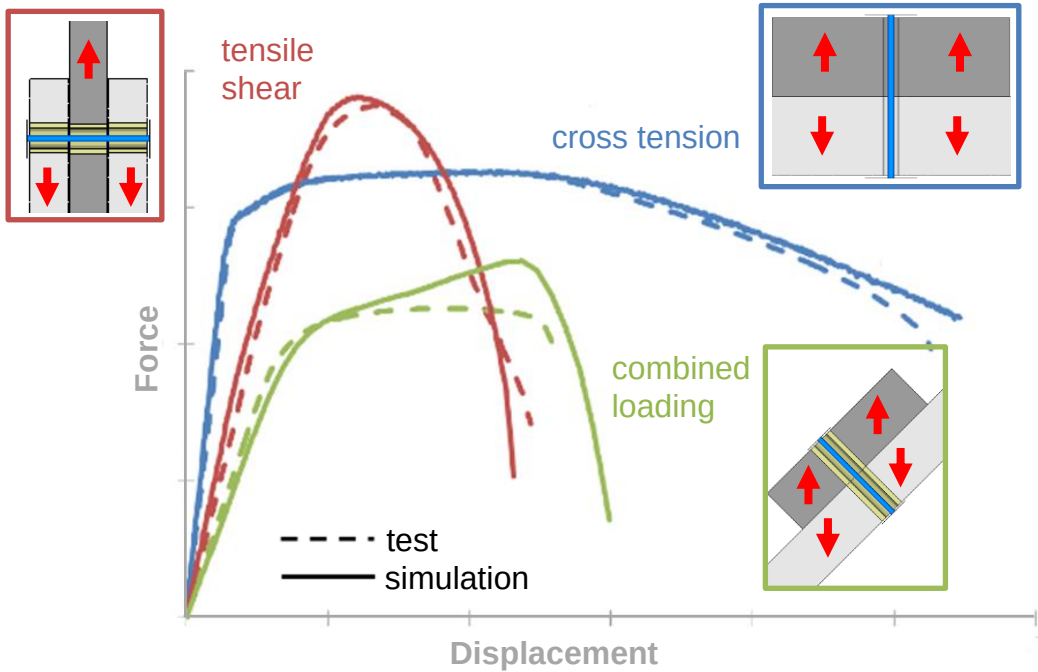
R9.3.1

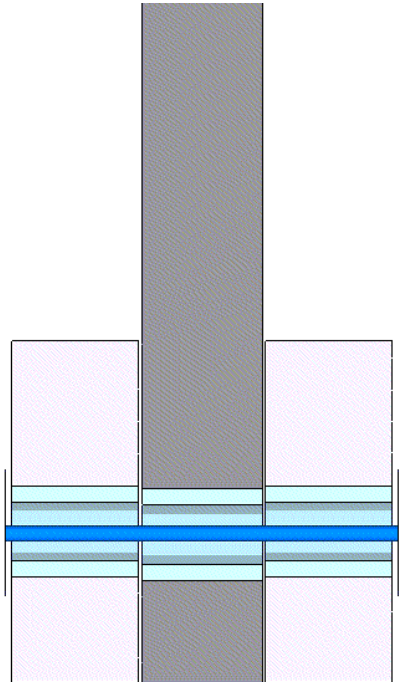
cantilever - tip displacement:
solid, shell, and beam elements



# Beam elements

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

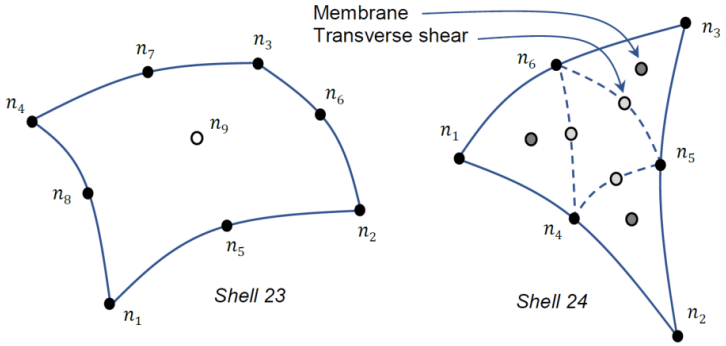


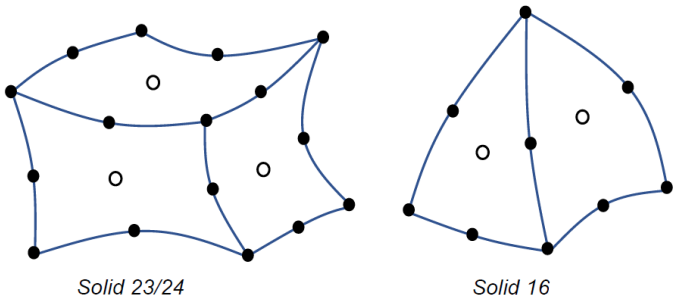



Courtesy of Daimler AG

# Higher-order elements

R11.0



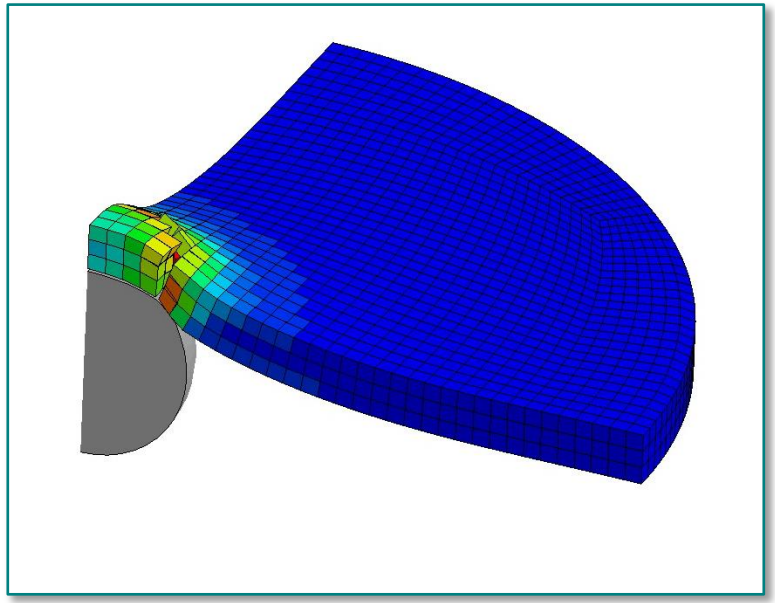



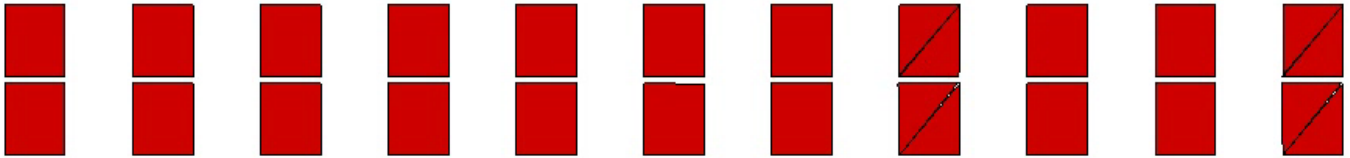

- Quadratic shells type 23 and 24
  - Mainly intended for implicit analysis
  - But also available in explicit
  - Now fully support the add-on failure and damage models
- Quadratic solids type 16, 23, and 24
  - Also available for explicit and implicit
  - Also fully support the add-on failure and damage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

R11.0

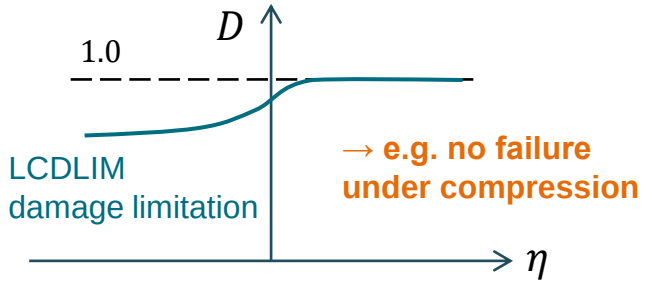


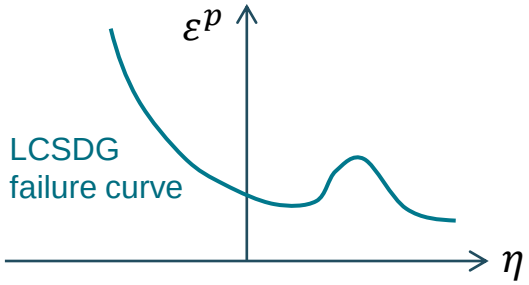


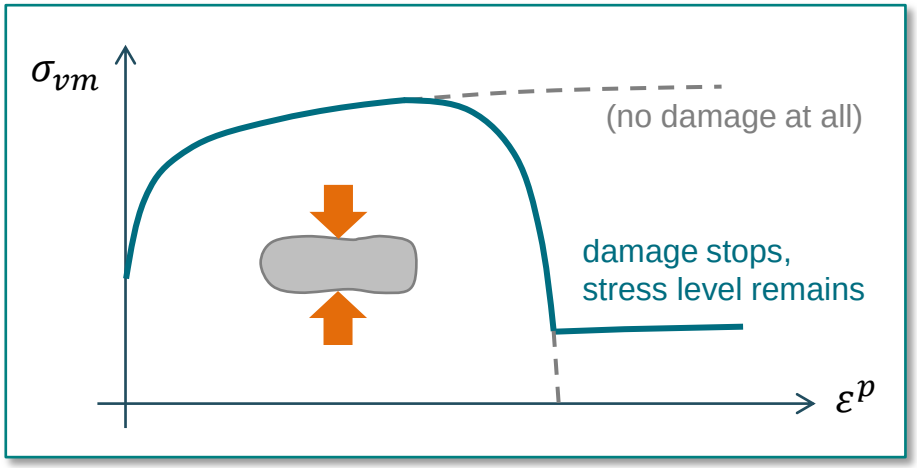
# Damage limitation

R11.0

- 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, …

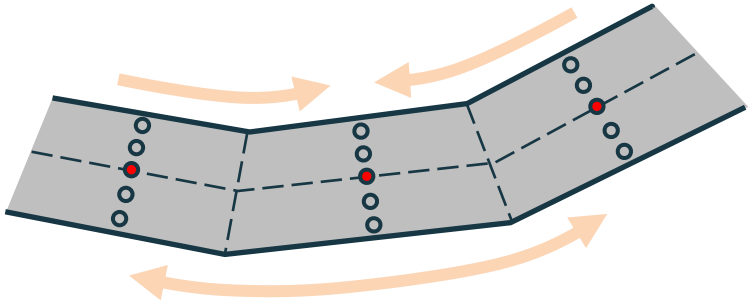


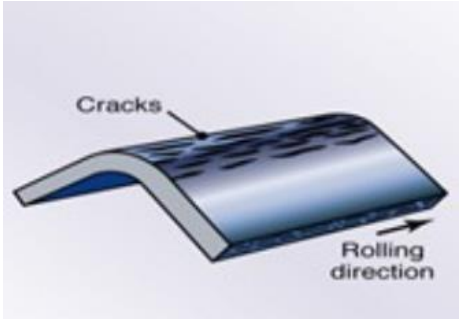



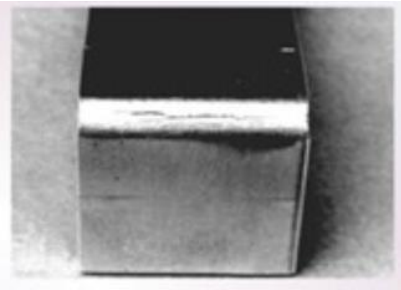
# Mid-plane failure

- 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



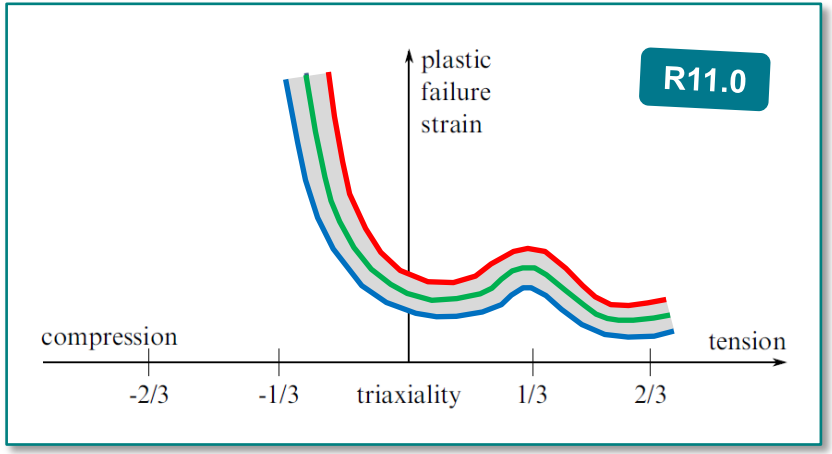
R11.0

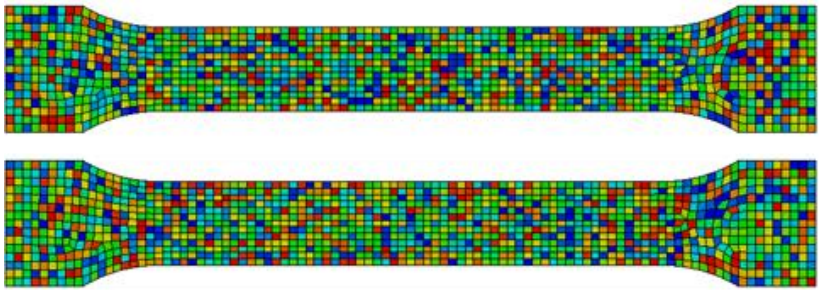


# Stochastic distribution

- 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

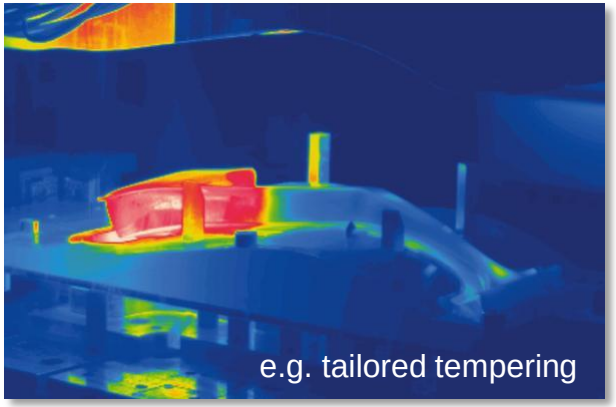
R11.0

- 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 (LCSDG) a 3-dimensional table

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

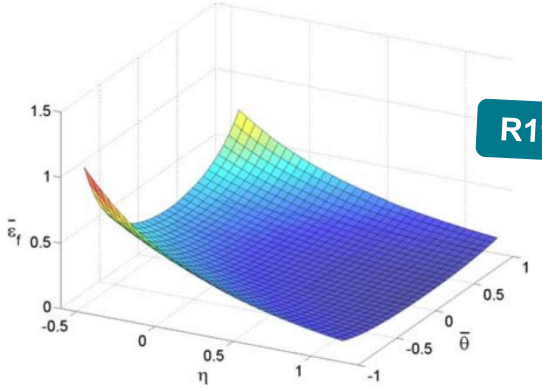
  - HISV could be hardness, porosity, pre-strain, …
  - Similar approach is used for history-dependent yield stress in `*MAT_TAILORED_PROPERTIES (*MAT_251)`

$$\sigma_y = \sigma_y(\varepsilon^p, \dot{\varepsilon}^p, \mathrm{HISV})$$



# 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




R11.0

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

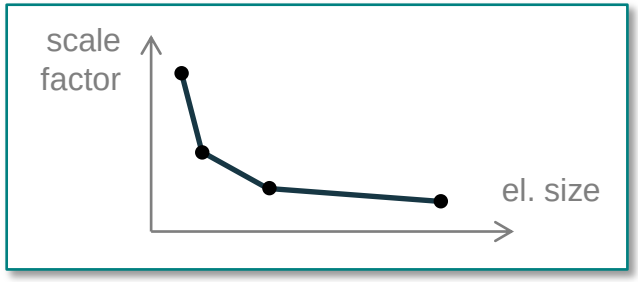
$$\bar{\varepsilon}_f = \left\{ \frac{A}{c_2} \left[ \sqrt{\frac{1+c_1^2}{3}} \cos\left(\frac{\bar{\theta}\pi}{6}\right) + c_1 \left( \eta + \frac{1}{3} \sin\left(\frac{\bar{\theta}\pi}{6}\right) \right) \right] \right\}^{-\frac{1}{n}}$$

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;
}
```

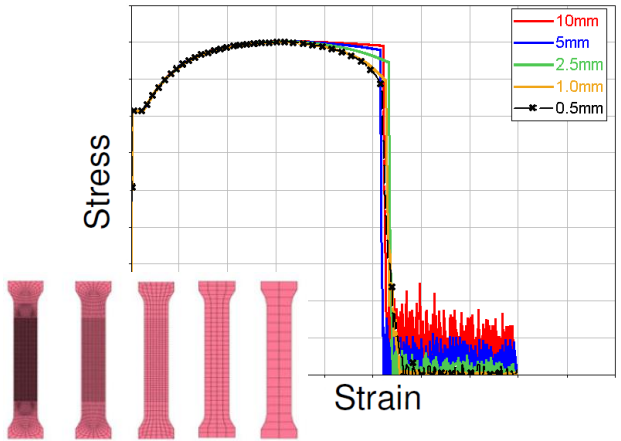
# Mesh dependence: Regularization in GISSMO

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




R11.0

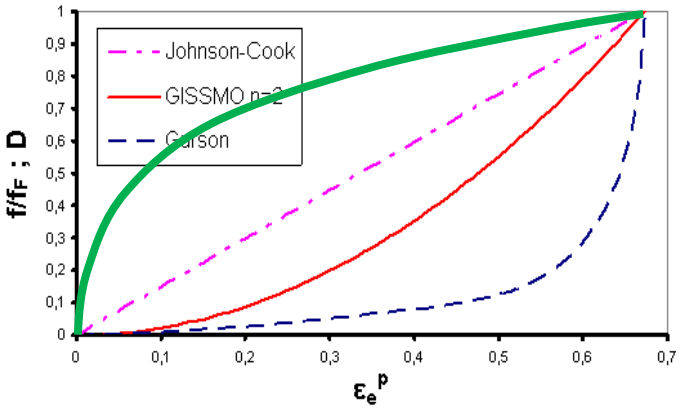
- Now: 2 new table options
  - Table LCREGD>0: failure strain is function of **rate** and element size
  - Table LCREGD<0: failure strain is function of **triaxiality** and element size (more general approach than using reduction factors SHRF and BIAXF)



# Nonlinear damage accumulation

R11.0

- Improvements for unusual damage evolution
  - In most cases, DMGEXP is 1.0 or greater in this equation: $\Delta D = \frac{\mathrm{DMGEXP} \times D^{\left(1-\frac{1}{\mathrm{DMGEXP}}\right)}}{\varepsilon_f} \Delta\varepsilon_p$
  - 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

R11.0

  - Reference size related plastic strain is computed first (hisvar ND+17):

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

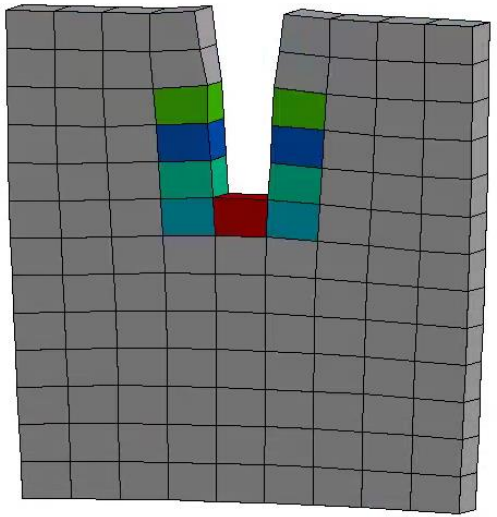
  - Reference size related damage computed from that (hisvar ND+9):

$$\Delta D_{ref} = \frac{\mathrm{DMGEXP}}{\varepsilon^p_f(|\mathrm{REFSZ}|)} D_{ref}^{\,1-1/\mathrm{DMGEXP}}\,\Delta\varepsilon^p_{ref}$$

# “Crashfront“ method

R11.1

- Pre-damage for neighbors of failed elements
  - Adopted from composite materials, e.g. `*MAT_054` or `*MAT_058`
  - Parameter **SOFT** is softening reduction factor for failure/critical strain in crashfront elements
    - SOFT=0: inactive
    - SOFT>0: plastic failure strain, $\varepsilon_f$ (LCSDG), and critical plastic strain, $\varepsilon_{\mathrm{p,loc}}$ (ECRIT), will be scaled
    - SOFT<0: only plastic failure strain, $\varepsilon_f$ (LCSDG), will be scaled by |SOFT|
  - Faster crack growth?!



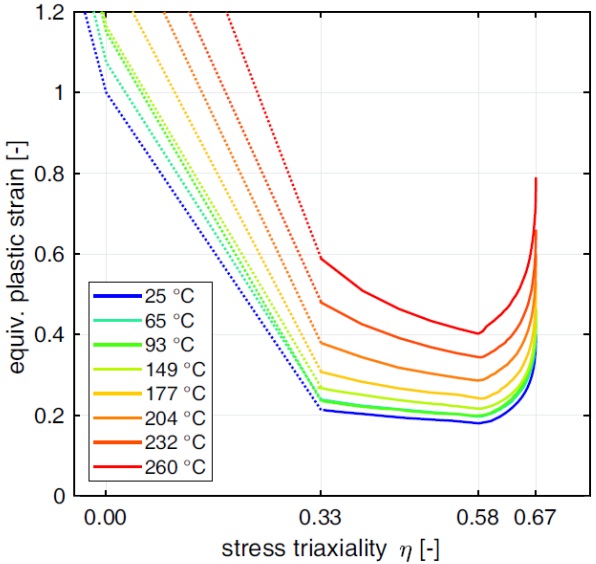
# Temperature dependence

R11.1

- If LCSDG and/or ECRIT<0 refer to a *DEFINE_TABLE_3D
  - Failure/critical strain becomes a function of
    - temperature (TABLE_3D),
    - Lode parameter (TABLE),
    - and triaxiality (CURVE)

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

  - Requirement: HISVN=0
  - Fully coupled thermo-mechanical simulations (e.g. hot forming)
  - Paper by Camberg et al. (Numisheet 2020) →



# Bending indicator

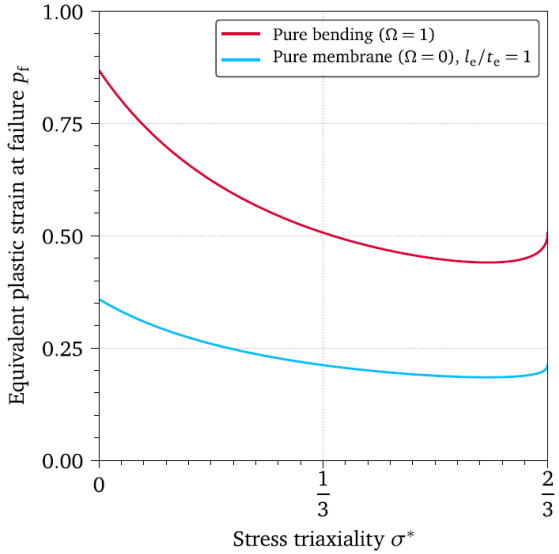
R12.0

- New option **LP2BI** for `*MAT_ADD_DAMAGE_GISSMO`
  - For shell elements (with NUMFIP=1)
  - Lode parameter is replaced by bending indicator:

$$\Omega = \frac{1}{2}\frac{\left|\varepsilon_{p,33}^{T} - \varepsilon_{p,33}^{B}\right|}{\max\left\{\left|\varepsilon_{p,33}^{T}\right|, \left|\varepsilon_{p,33}^{B}\right|\right\}}$$

$\Omega = 0$: pure membrane
$\Omega = 1$: pure bending

  - Adopted from `*MAT_258` (Costas et al. 2018)




  - Paper at 16th International LS-DYNA Conference by Thornton Tomasetti, Novelis, and DYNAmore

# Summary and outlook

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

- More improvements to come
  - Dependance on more and more variables
  - User interface for damage models
  - …

# Thank you