eGISSMO example - Orthotropic damage

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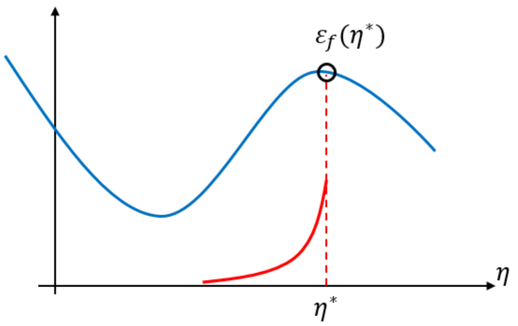
Introduction

- Short GISSMO review
- eGISSMO introduction
- Examples:
  - Going from GISSMO to eGISSMO (isotropic damage)
  - Going from 2 GISSMO card to one eGISSMO (orthotropic damage)

GISSMO review

- Input
  - Instability curve (when stress is coupled)
  - Failure strain as a function of triaxiality (and Lode parameter)
- Damage and instability evolution



$$\Delta F = \frac{n}{\varepsilon_i(\eta^*)} F^{\left(1-\frac{1}{n}\right)} \Delta\varepsilon^p_{eff}$$

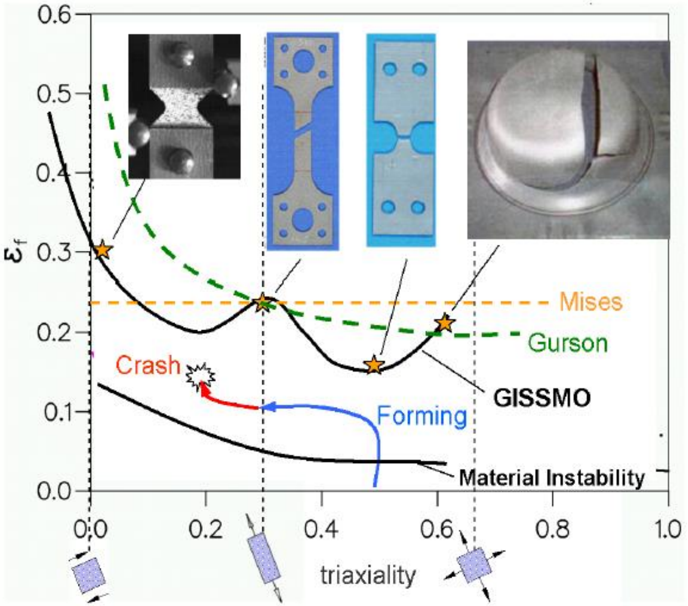
$$\Delta D = \frac{n}{\varepsilon_f(\eta^*)} D^{\left(1-\frac{1}{n}\right)} \Delta\varepsilon^p_{eff}$$

- Stress coupling

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

- Damage tensor

$$(1-D_1)\begin{bmatrix}1 & 0 & 0 & 0 & 0 & 0\\ 0 & 1 & 0 & 0 & 0 & 0\\ 0 & 0 & 1 & 0 & 0 & 0\\ 0 & 0 & 0 & 1 & 0 & 0\\ 0 & 0 & 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 0 & 0 & 1\end{bmatrix}$$



eGISSMO explained

- Up to 3 different GISSMO models combined
- Each damage variable can be driven by plastic strain (equivalent or components), material history variable or user defined function (*DEFINE_FUNCTION)
- The damage driving strain components can be defined in the element, material och principal coordinate systems
- User input Damage tensor

eGISSMO step by step (*MAT_ADD_GENERALIZED_DAMAGE)

Card 1	1	2	3	4	5	6	7	8
Variable	MID	IDAM	DTYP	REFSZ	NUMFIP		PDDT	NHIS
Type	I	I	I	F	F		I	I
Default	none	0	0	0.0	1.0		0	1

From MAT_ADD_EROSION

- MID: Material id for which this generalized damage definition applies
- IDAM: damage model flag (0: no damage, 1: GISSMO type)
- DTYP: damage behaviour flag (0: no-coupling, 1: coupling and failure)
- REFSZ: Reference element size
- NUMFIP: number of failed integration points for element deletion

- PDDT: Using pre-defined damage tensors. Considerable speed up.
- NHIS: Number of damage driving history variables (current maximum: NHIS=3)

eGISSMO step by step (*MAT_ADD_GENERALIZED_DAMAGE)

- Using predefined damage tensors for speed up
- Damage tensor coefficient cards are left blank
- PDDT=1 : Isotropic damage tensor
- PDDT=2 : 2-parameter isotropic deviatoric/volumetric split
- PDDT=3 : Lemaitre-based anisotropic damage tensor (*MAT_104)
- PDDT=4 : Anisotropic damage tensor with damage influence only in XX,YY and XY directions

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

For shells:

$$(1-D_1)\begin{bmatrix}1&0&0&0&0&0\\0&1&0&0&0&0\\0&0&1&0&0&0\\0&0&0&1&0&0\\0&0&0&0&1&0\\0&0&0&0&0&1\end{bmatrix}$$

1

$$\begin{bmatrix}1-\frac{2}{3}D_1-\frac{1}{3}D_2 & \frac{1}{3}D_1-\frac{1}{3}D_2 & 0 & 0 & 0 & 0\\ \frac{1}{3}D_1-\frac{1}{3}D_2 & 1-\frac{2}{3}D_1-\frac{1}{3}D_2 & 0 & 0 & 0 & 0\\ 0 & 0 & 1 & 0 & 0 & 0\\ 0 & 0 & 0 & 1-D_1 & 0 & 0\\ 0 & 0 & 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 0 & 0 & 1\end{bmatrix}$$

2

$$\begin{bmatrix}1-D_1 & 0 & 0 & 0 & 0 & 0\\ 0 & 1-D_2 & 0 & 0 & 0 & 0\\ 0 & 0 & 1 & 0 & 0 & 0\\ 0 & 0 & 0 & 1-\frac{1}{2}(D_1+D_2) & 0 & 0\\ 0 & 0 & 0 & 0 & 1-\frac{1}{2}D_2 & 0\\ 0 & 0 & 0 & 0 & 0 & 1-\frac{1}{2}D_1\end{bmatrix}$$

3

$$\begin{bmatrix}1-D_1 & 0 & 0 & 0 & 0 & 0\\ 0 & 1-D_2 & 0 & 0 & 0 & 0\\ 0 & 0 & 1-D_3 & 0 & 0 & 0\\ 0 & 0 & 0 & 1 & 0 & 0\\ 0 & 0 & 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 0 & 0 & 1\end{bmatrix}$$

4

eGISSMO step by step (*MAT_ADD_GENERALIZED_DAMAGE)

Card 2	1	2	3	4	5	6	7	8
Variable	HIS1	HIS2	HIS3	IFLG1	IFLG2	IFLG3		
Type	I	I	I	I	I	I		
Default	0	none	none	0	0	0		

$$\Delta F = \frac{n}{\varepsilon_i(\eta^*)} F^{\left(1-\frac{1}{n}\right)} \Delta HISn$$

$$\Delta D = \frac{n}{\varepsilon_f(\eta^*)} D^{\left(1-\frac{1}{n}\right)} \Delta HISn$$

- HISn: Choice of variables as driving quantity for damage

	IFLG1=0 **Material histories**	**IFLG1=1** **Specific plastic strain tensor components**	**IFLG1=2** **Predefined functions of plastic strain tensor**
HISn=0	Plastic strain	Local/global, principal or material frame (IFLG2)	3 parameter orthotropic damage
HISn>0	History variable n	n.a.	n.a.
HISn<0	n.a.	***DEFINE_FUNCTION** User defined functions	n.a.

eGISSMO step by step (*MAT_ADD_GENERALIZED_DAMAGE)

Card 2	1	2	3	4	5	6	7	8
Variable	HIS1	HIS2	HIS3	IFLG1	IFLG2	IFLG3		
Type	I	I	I	I	I	I		
Default	0	none	none	0	0	0		

IFLG2	Damage strain coordinate system (IFLG1=1)
0	Local element (shells) or global (solids) coordinate system
1	Material system, only applicable for non-isotropic material models
2	Principal strain system (rotating)
3	Principal strain system (Fixed when instbility starts, see *MAT_104)

eGISSMO step by step (*MAT_ADD_GENERALIZED_DAMAGE)

- Plastic strain tensor components for different cases:
- Direct use (IFLG1=1 and HIS1=HIS2=HIS3=0)
  - HIS1 =$\dot{\varepsilon}^p_{xx}$, HIS2 =$\dot{\varepsilon}^p_{yy}$, HIS3 =$\dot{\varepsilon}^p_{zz}$ (IFLG2=0: local/global system)
  - HIS1 =$\dot{\varepsilon}^p_{aa}$, HIS2 =$\dot{\varepsilon}^p_{bb}$, HIS3 =$\dot{\varepsilon}^p_{cc}$ (IFLG2=1: material system)
  - HIS1 =$\dot{\varepsilon}^p_{1}$, HIS2 =$\dot{\varepsilon}^p_{2}$, HIS3 =$\dot{\varepsilon}^p_{3}$ (IFLG2=2/3: principal system)

Example: IFLG1=1, IFLG2=1

$$\Delta F_1 = \frac{n_1}{\varepsilon_{i,aa}(\eta^*)} F_1^{\left(1-\frac{1}{n_1}\right)} \Delta\varepsilon^p_{aa}$$

....

Example: IFLG1=1, IFLG2=1

$$\Delta D_1 = \frac{n_1}{\varepsilon_{f,aa}(\eta^*)} D_1^{\left(1-\frac{1}{n_1}\right)} \Delta\varepsilon^p_{aa}$$

....

- Free functions (IFLG1=1 and HISNn<0):
  - HISn= $f_n(\dot{\varepsilon}^p_{xx}, \dot{\varepsilon}^p_{yy}, \dot{\varepsilon}^p_{zz}, \dot{\varepsilon}^p_{xy}, \dot{\varepsilon}^p_{yz}, \dot{\varepsilon}^p_{xz})$ (IFLG2=0: local/global system)
  - HISn= $f_n(\dot{\varepsilon}^p_{aa}, \dot{\varepsilon}^p_{bb}, \dot{\varepsilon}^p_{cc}, \dot{\varepsilon}^p_{ab}, \dot{\varepsilon}^p_{bc}, \dot{\varepsilon}^p_{ab})$ (IFLG2=1: material system)
  - HISn= $f_n(\dot{\varepsilon}^p_{1}, \dot{\varepsilon}^p_{2}, \dot{\varepsilon}^p_{3})$ (IFLG2=2/3: principal system)

```
*DEFINE_FUNCTION
      1234
fhis1(eaa,ebb,ezz,eab,ebz,eza)=sqrt(ebz**2+eza**2)
```

example defines a history variable (HIS1 = -1234)
as function of the transverse shear strains
in material coordinate system a-b-z for shells

eGISSMO step by step (*MAT_ADD_GENERALIZED_DAMAGE)

- IFGL1=2
  - 00,45 and 90 degree damage driving variables are predefined functions of the major principal strain, material angle and principal strain ratio.
  - Tailored for orthotropic damage, e.g. aluminium extrusions

$$\Delta\varepsilon_{00}^{p} = 2\left|\Delta\varepsilon_{1}^{p}\right|\langle cos^{2}\theta - |cos\theta sin\theta|\rangle\sqrt{\frac{1}{2}(1+\beta+\beta^{2})}$$

$$\Delta\varepsilon_{90}^{p} = 2\left|\Delta\varepsilon_{1}^{p}\right|\langle sin^{2}\theta - |cos\theta sin\theta|\rangle\sqrt{\frac{1}{2}(1+\beta+\beta^{2})}$$

$$\Delta\varepsilon_{45}^{p} = 4\left|\Delta\varepsilon_{1}^{p}\right||cos\theta sin\theta|\sqrt{\frac{1}{2}(1+\beta+\beta^{2})}$$

$$\theta = angle\ between\ principal\ and\ material\ direction$$

$$\beta = \frac{\dot{\varepsilon}_{2}^{p}}{\dot{\varepsilon}_{1}^{p}}$$

Example: IFLG1=2, IFLG2=1

$$\Delta F_{1} = \frac{n_{1}}{\varepsilon_{i,aa}(\eta^{*})} F_{1}^{(1-\frac{1}{n_{1}})} \Delta\varepsilon_{00}^{p}$$

....

Example: IFLG1=2, IFLG2=1

$$\Delta D_{1} = \frac{n_{1}}{\varepsilon_{f,aa}(\eta^{*})} D_{1}^{(1-\frac{1}{n_{1}})} \Delta\varepsilon_{00}^{p}$$

....

eGISSMO step by step (*MAT_ADD_GENERALIZED_DAMAGE)

Card 2	1	2	3	4	5	6	7	8
Variable	HIS1	HIS2	HIS3	IFLG1	IFLG2	IFLG3		
Type	I	I	I	I	I	I		
Default	0	none	none	0	0	0		

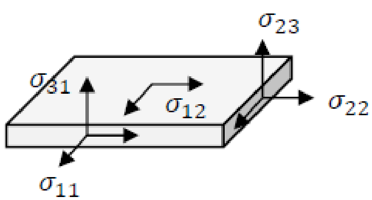
- IFLG3=0 : Erosion occurs when one of the damage parameters (D1,D2 or D3) reaches unity
- IFLG3=1 : Erosion occurs when a single damage parameter D reaches unity. The damage tensor components are based on this single damage parameter.
  - Used together with IFLG1=2

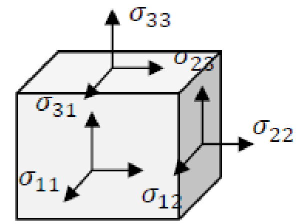
eGISSMO step by step (*MAT_ADD_GENERALIZED_DAMAGE)

- Damage tensor coefficients as functions of damage variables D1,D2 and D3

Card 3	1	2	3	4	5	6	7	8
Variable	D11	D22	D33	D44	D55	D66		

(plane stress)





(full 3-d)

Card 4 (shells)	1	2	3	4	5	6
Variable	D12	D21	D24	D42	D14	D41

Card 4 (solids)	1	2	3	4	5	6
Variable	D12	D21	D23	D32	D13	D31

$$\begin{bmatrix}\sigma_{11}\\ \sigma_{22}\\ 0\\ \sigma_{12}\\ \sigma_{23}\\ \sigma_{31}\end{bmatrix} = \begin{bmatrix} D_{11} & D_{12} & 0 & D_{14} & 0 & 0\\ D_{21} & D_{22} & 0 & D_{24} & 0 & 0\\ 0 & 0 & D_{33} & 0 & 0 & 0\\ D_{41} & D_{42} & 0 & D_{44} & 0 & 0\\ 0 & 0 & 0 & 0 & D_{55} & 0\\ 0 & 0 & 0 & 0 & 0 & D_{66}\end{bmatrix}\begin{bmatrix}\tilde{\sigma}_{11}\\ \tilde{\sigma}_{22}\\ 0\\ \tilde{\sigma}_{12}\\ \tilde{\sigma}_{23}\\ \tilde{\sigma}_{31}\end{bmatrix}$$

$$\begin{bmatrix}\sigma_{11}\\ \sigma_{22}\\ \sigma_{33}\\ \sigma_{12}\\ \sigma_{23}\\ \sigma_{31}\end{bmatrix} = \begin{bmatrix} D_{11} & D_{12} & D_{13} & 0 & 0 & 0\\ D_{21} & D_{22} & D_{23} & 0 & 0 & 0\\ D_{31} & D_{32} & D_{33} & 0 & 0 & 0\\ 0 & 0 & 0 & D_{44} & 0 & 0\\ 0 & 0 & 0 & 0 & D_{55} & 0\\ 0 & 0 & 0 & 0 & 0 & D_{66}\end{bmatrix}\begin{bmatrix}\tilde{\sigma}_{11}\\ \tilde{\sigma}_{22}\\ \tilde{\sigma}_{33}\\ \tilde{\sigma}_{12}\\ \tilde{\sigma}_{23}\\ \tilde{\sigma}_{31}\end{bmatrix}$$

eGISSMO step by step (*MAT_ADD_GENERALIZED_DAMAGE)

- Example: Anisotropic damage as in *MAT_104, plane stress

```
...
$      D11        D22        D33        D44        D55        D66
      1001       1002       1003       1004       1005       1006
...
*DEFINE_FUNCTION
1001
f11(d1,d2,d3)=1.-d1
*DEFINE_FUNCTION
1002
f22(d1,d2,d3)=1.-d2
*DEFINE_FUNCTION
1003
f33(d1,d2,d3)=1.
*DEFINE_FUNCTION
1004
f44(d1,d2,d3)=1.-(d1+d2)/2.
...
```

(Card 4 left empty)

$$\begin{bmatrix}\sigma_{11}\\ \sigma_{22}\\ 0\\ \sigma_{12}\\ \sigma_{23}\\ \sigma_{31}\end{bmatrix}=\begin{bmatrix}1-D_1 & 0 & 0 & 0 & 0 & 0\\ 0 & 1-D_2 & 0 & 0 & 0 & 0\\ 0 & 0 & 1 & 0 & 0 & 0\\ 0 & 0 & 0 & 1-\frac{1}{2}(D_1+D_2) & 0 & 0\\ 0 & 0 & 0 & 0 & 1-\frac{1}{2}D_2 & 0\\ 0 & 0 & 0 & 0 & 0 & 1-\frac{1}{2}D_1\end{bmatrix}\begin{bmatrix}\tilde{\sigma}_{11}\\ \tilde{\sigma}_{22}\\ 0\\ \tilde{\sigma}_{12}\\ \tilde{\sigma}_{23}\\ \tilde{\sigma}_{31}\end{bmatrix}$$

eGISSMO step by step (*MAT_ADD_GENERALIZED_DAMAGE)

- Card 5 and 6: GISSMO parameters
- 2 cards per history variable

Card 5...	1	2	3	4	5	6	7	8
Variable	LCSDG	ECRIT	DMGEXP	DCRIT	FADEXP	LCREG		
Type	I	F	F	F	F	I		
Default	0	0.0	1.0	0.0	1.0	0		

Card 6...	1	2	3	4	5	6	7	8
Variable	LCSRS	SHRF	BIAXF	LCDLIM	MIDFAIL	NFLOC		
Type	I	F	F	I	F	F		
Default	0	0.0	0.0	0	0.0	0.0		

eGISSMO step by step (*MAT_ADD_GENERALIZED_DAMAGE)

- eGISSMO output
- ND different depending on the material model. It is found in the d3hsp file.

```
GISSMO damage history listing

PID          1 : first damage history variable ND   =    6
```

ND	Triaxiality variable, σ_m/σ_{vm}
ND+1	Lode parameter
ND+2	Single damage parameter D (1.E-20 ≤ D ≤ 1), IFLG3=1
ND+3	Damage parameter D1
ND+4	Damage parameter D2
ND+5	Damage parameter D3
ND+6	Damage threshold DCRIT1
ND+7	Damage threshold DCRIT2
ND+8	Damage threshold DCRIT3
ND+12	History variable HIS1
ND+13	History variable HIS2
ND+14	History variable HIS3
ND+15	Angle between principal and material axes (in radians)
ND+21	Characteristic element size (used in LCREG)

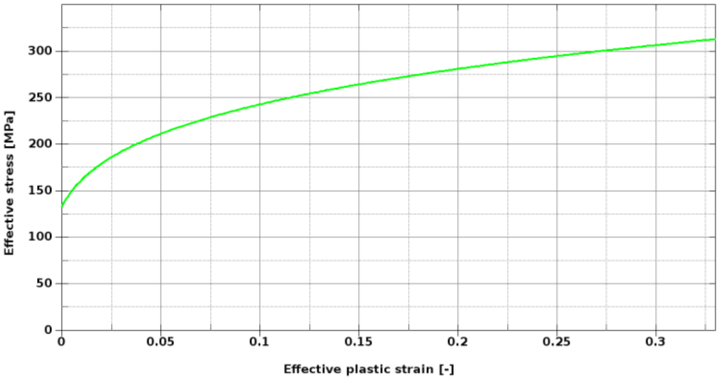
eGISSMO example

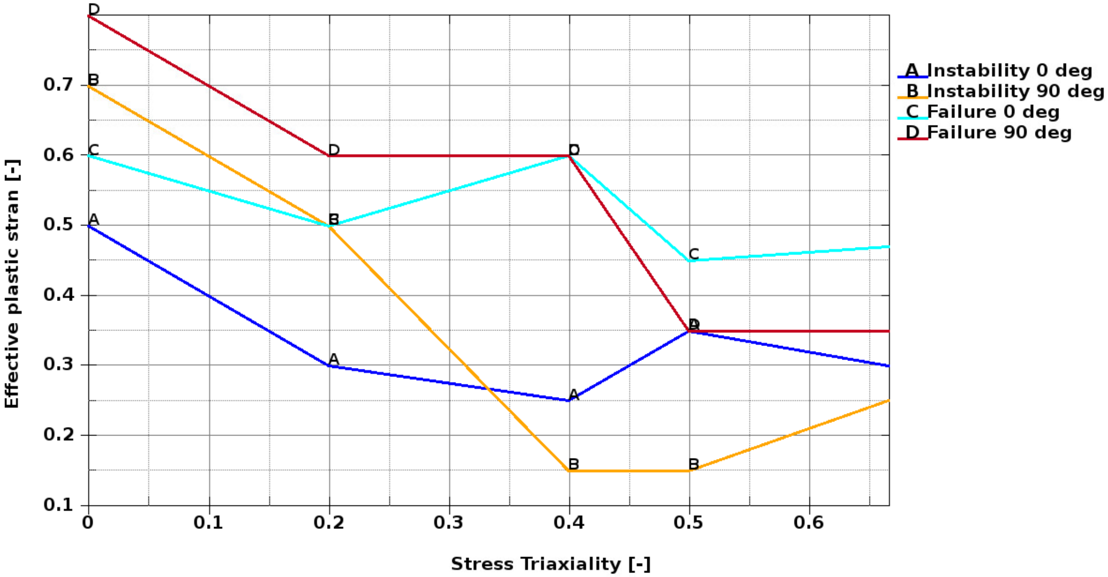
- Two separate GISSMO cards are developed for extrusion and transverse directions respectively for an aluminium extrusion.
- Firstly, create the corresponding eGISSMO cards in each direction (isotropic) damage.
- Secondly, combine the two GISSMO isotropic damage functions into one eGISSMO card.
- *MAT_BARLAT_YLD2000 with anisotropy is used for the plasticity

Material

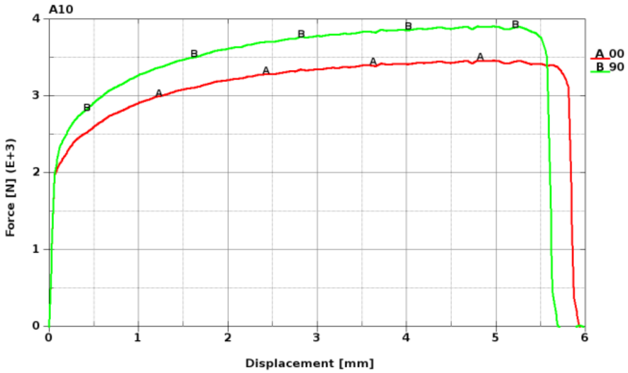
- Ficticious Aluminium extrusion
- Plasticity is modeled with Barlat YLD 2000 criteria (*MAT_133)

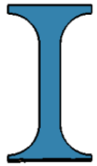
σ_{00}	σ_{45}	σ_{90}	R_{00}	R_{45}	R_{90}	R_B	σ_B
133.	120.	147.	0.6	1.6	1.05	1.	140.

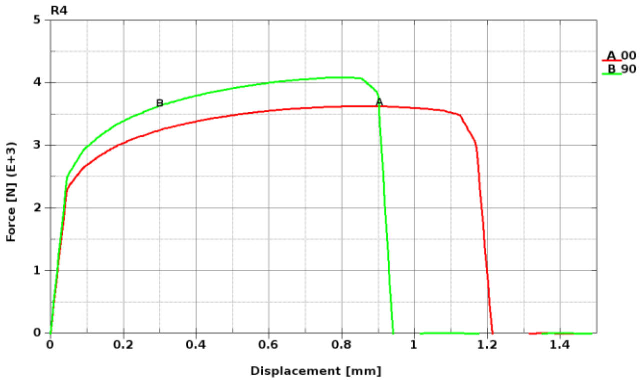


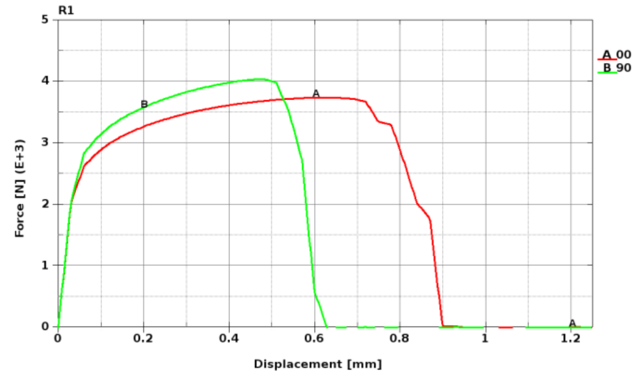


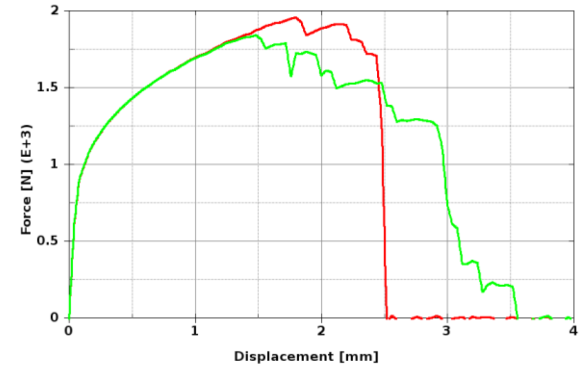
Tensile test results

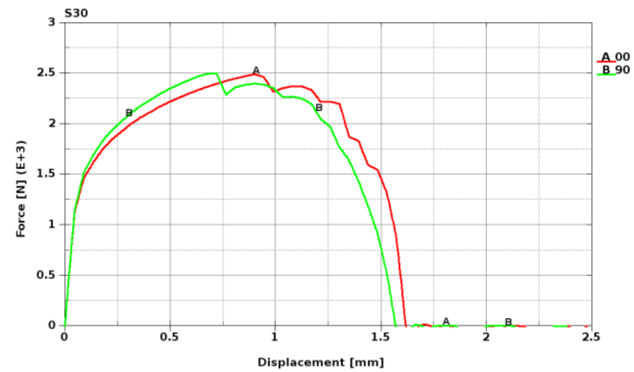












Extrusion direction

Transverse direction

From GISSMO to eGISSMO – Isotropic Damage

- One damage variable
- Damage tensor

$$\begin{bmatrix} \sigma_{11} \\ \sigma_{22} \\ \sigma_{33} \\ \sigma_{12} \\ \sigma_{23} \\ \sigma_{31} \end{bmatrix} = (1 - D_1) \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \tilde{\sigma}_{11} \\ \tilde{\sigma}_{22} \\ \tilde{\sigma}_{33} \\ \tilde{\sigma}_{12} \\ \tilde{\sigma}_{23} \\ \tilde{\sigma}_{31} \end{bmatrix}$$

- Damage driving quantity: Effective plastic strain

- Damage and Instability evolution

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

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

Extrusion direction eGISSMO cards – Isotropic damage

Damage is coupled

Damage model activated

Number of failed IP's before deletion

Number of damage history variables

```
*MAT_ADD_GENERALIZED_DAMAGE
$#     mid      idam      dtyp     refsz    numfip    unused      pddt      nhis
         1         1         1       0.0     -80.                    0         1
$#    his1      his2      his3     iflg1     iflg2     iflg3
         0         0         0         0         0         0
$#     d11       d22       d33       d44       d55       d66
         1         1         1         1         1         1
$#     d12       d21       d24       d42       d14       d41
         0         0         0         0         0         0
$#   lcsdg     ecrit    dmgexp     dcrit    fadexp     lcreg
       102    -101.0       2.0       0.0       3.5       103
         0       0.0       0.0         0
```

Extrusion direction eGISSMO cards – Isotropic damage

Effective plastic strain drives the damage

Not active for IFLG1=0

```
*MAT_ADD_GENERALIZED_DAMAGE
$#     mid      idam      dtyp     refsz    numfip    unused      pddt      nhis
         1         1         1       0.0       -80                   0         1
$#    his1      his2      his3     iflg1     iflg2     iflg3
         0         0         0         0         0         0
$#     d11       d22       d33       d44       d55       d66
         1         1         1         1         1         1
$#     d12       d21       d24       d42       d14       d41
         0         0         0         0         0         0
$#   lcsdg     ecrit    dmgexp     dcrit    fadexp     lcreg
       102    -101.0       2.0       0.0       3.5       103
         0       0.0       0.0         0
```

	IFLG1=0 Material histories	IFLG1=1 Specific plastic strain tensor components	IFLG1=2 Predefined functions of plastic strain tensor
HISn=0	Plastic strain	Local/global, principal or material frame (IFLG2)	3 parameter orthotropic damage
HISn>0	History varible n	n.a.	n.a.
HISn<0	n.a.	*DEFINE_FUNCTION User defined functions	n.a.

Extrusion direction eGISSMO cards – Isotropic damage

$$\begin{bmatrix}\sigma_{11}\\ \sigma_{22}\\ \sigma_{33}\\ \sigma_{12}\\ \sigma_{23}\\ \sigma_{31}\end{bmatrix} = (1-D_1)\begin{bmatrix}1&0&0&0&0&0\\0&1&0&0&0&0\\0&0&1&0&0&0\\0&0&0&1&0&0\\0&0&0&0&1&0\\0&0&0&0&0&1\end{bmatrix}\begin{bmatrix}\tilde{\sigma}_{11}\\ \tilde{\sigma}_{22}\\ \tilde{\sigma}_{33}\\ \tilde{\sigma}_{12}\\ \tilde{\sigma}_{23}\\ \tilde{\sigma}_{31}\end{bmatrix}$$

Alternatively:
Use pddt=1 for predefined isotropic damage tensor

```
*MAT_ADD_GENERALIZED_DAMAGE
$#     mid      idam      dtyp     refsz    numfip    unused      pddt      nhis
         1         1         1       0.0      -80.                   0         1
$#    his1      his2      his3     iflg1     iflg2     iflg3
         0         0         0         0         0         0
$#     d11       d22       d33       d44       d55       d66
         1         1         1         1         1         1
$#     d12       d21       d24       d42       d14       d41
         0         0         0         0         0         0
$#   lcsdg     ecrit    dmgexp     dcrit    fadexp     lcreg
       102    -101.0       2.0       0.0       3.5       103
         0       0.0       0.0         0
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*DEFINE_FUNCTION
$#     fid                                                               heading
         1
$#
funcd(d1)=1.-d1
```

Same damage coupling for all stress components

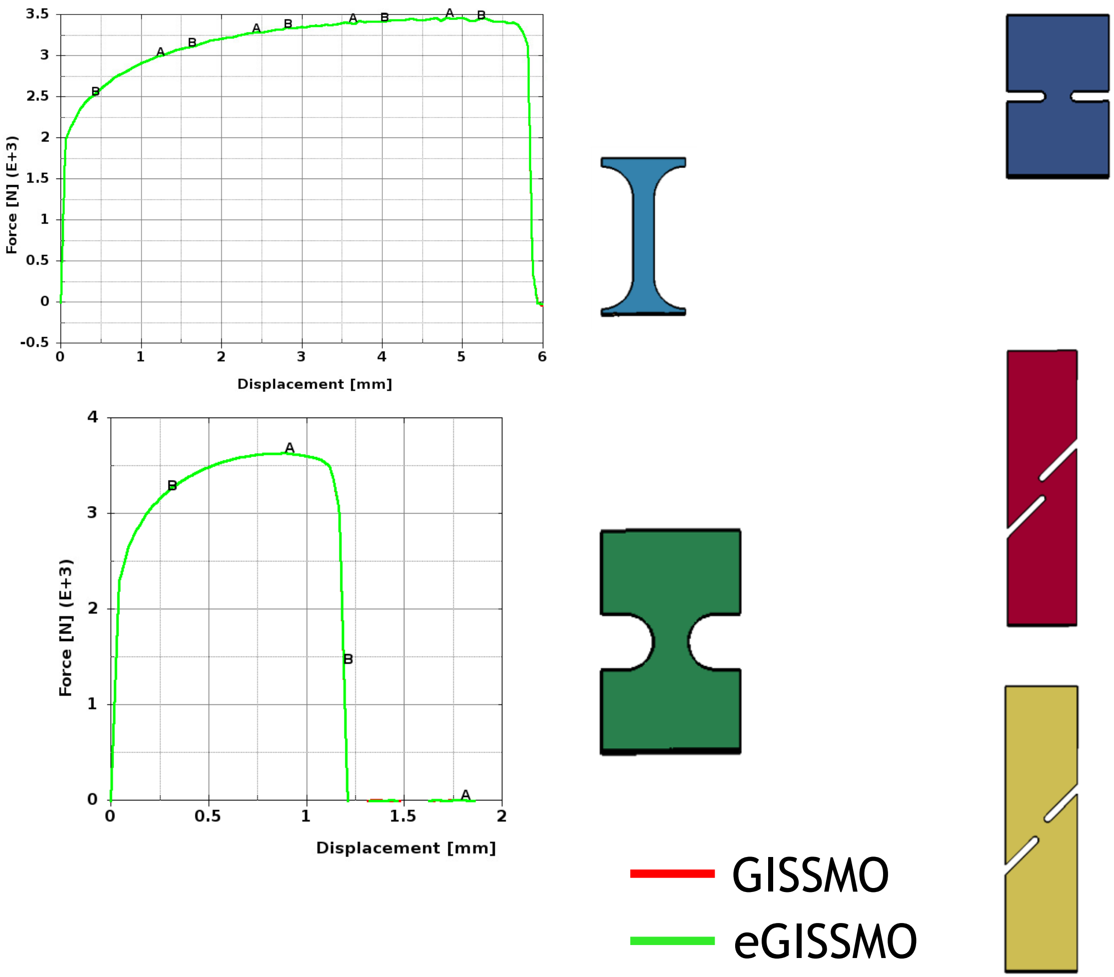
Extrusion direction eGISSMO cards – Isotropic damage

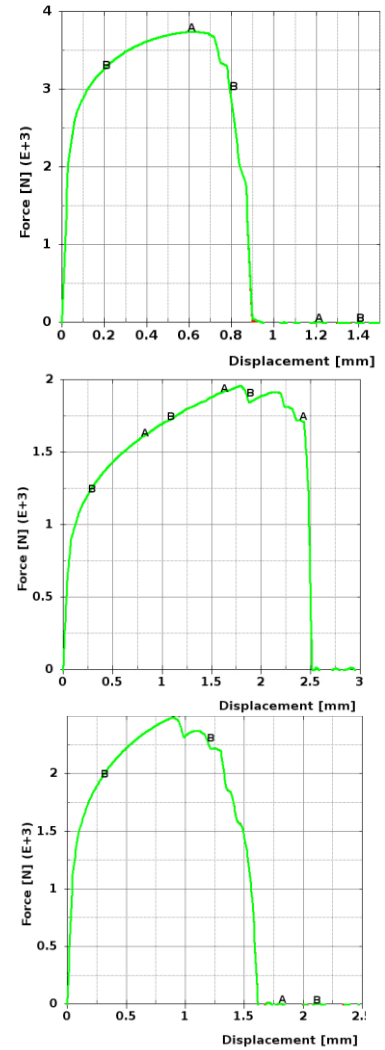
- One GISSMO card necessary

```
*MAT_ADD_GENERALIZED_DAMAGE
$#      mid      idam      dtyp     refsz    numfip    unused      pddt      nhis
          1         1         1       0.0      -80.                   0         1
$#     his1      his2      his3     iflg1     iflg2     iflg3
          0         0         0         0         0         0
$#      d11       d22       d33       d44       d55       d66
          1         1         1         1         1         1
$#      d12       d21       d24       d42       d14       d41
          0         0         0         0         0         0
$#    lcsdg     ecrit    dmgexp     dcrit    fadexp     lcreg
        102    -101.0       2.0       0.0       3.5       103
          0       0.0       0.0         0
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*DEFINE_FUNCTION
$#      fid                                                               heading
          1
$#                                                                       function
funcd(d1)=1.-d1
```

Extrusion direction eGISSMO cards – Isotropic damage

- Identical results for all test specimen when the corresponding GISSMO curves are used without modification





Moving to orthotropic damage

- The two GISSMO cards (extrusion and transversal) are combined into one eGISSMO card.
- Thus, the failure model now has two history variables (D1 and D2).
- Both damage history variables are driven by the effective plastic strain.
  - If the material is deformed in <u>extrusion</u> direction, then <u>D1</u> is increasing
  - If the material is deformed in <u>transverse</u> direction, then <u>D2</u> is increasing

$$\Delta F_1 = \frac{n_1}{\varepsilon_{i,aa}(\eta^*)} F_1^{\left(1-\frac{1}{n_1}\right)} \Delta\varepsilon^p \quad \varepsilon_{aa}^p > 0$$

....

$$\Delta D_1 = \frac{n_1}{\varepsilon_{f,aa}(\eta^*)} D_1^{\left(1-\frac{1}{n_1}\right)} \Delta\varepsilon^p \quad \varepsilon_{aa}^p > 0$$

....

- Using the damage tensor from *MAT_104

$$\begin{bmatrix} \sigma_{11} \\ \sigma_{22} \\ 0 \\ \sigma_{12} \\ \sigma_{23} \\ \sigma_{31} \end{bmatrix} = \begin{bmatrix} 1-D_1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1-D_2 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1-\frac{1}{2}(D_1+D_2) & 0 & 0 \\ 0 & 0 & 0 & 0 & 1-\frac{1}{2}D_2 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1-\frac{1}{2}D_1 \end{bmatrix} \begin{bmatrix} \tilde{\sigma}_{11} \\ \tilde{\sigma}_{22} \\ 0 \\ \tilde{\sigma}_{12} \\ \tilde{\sigma}_{23} \\ \tilde{\sigma}_{31} \end{bmatrix}$$

Extrusion direction eGISSMO cards – Isotropic damage

Plastic strain components drives the damage

Material coordinate system

```
*MAT_ADD_GE
$#     mid      idam      dtyp     refsz    numfip    unused      pddt      nhis
         1         1         1       0.0      -80.                   3         2
$#    his1      his2      his3     iflg1     iflg2     iflg3
      -301      -302         0         1         1         0
$#     d11       d22       d33       d44       d55       d66
         0         0         0         0         0         0
$#     d12       d21       d24       d42       d14       d41
         0         0         0         0         0         0
$EXTRUSION DIRECTION GISSMO CARDS
$#   lcsdg     ecrit    dmgexp     dcrit    fadexp     lcreg
       102    -101.0       2.0       0.0       3.5       103
         0       0.0       0.0         0
$TRANSVERSE DIRECTION GISSMO CARDS
$#   lcsdg                                               reg
       202                                               103
         0
```

	IFLG1=0 Material histories	IFLG1=1 Specific plastic strain tensor components	IFLG1=2 Predefined functions of plastic strain tensor
HISn=0	Plastic strain	Local/global, principal or material frame (IFLG2)	3 parameter orthotropic damage
HISn>0	History varible n	n.a.	n.a.
HISn<0	n.a.	*DEFINE_FUNCTION User defined functions	n.a.

eGISSMO Card

Functions 301 and 302 drives the damage

Pre-determined damage tensor

```
*MAT_ADD_GENERALIZED_DAMAGE
$#     mid      idam      dtyp     refsz    numfip    unused      pddt      nhis
         1         1         1       0.0      -80.                   3         2
$#    his1      his2      his3     iflg1     iflg2     iflg3
      -301      -302         0         1         1         0
$#     d11       d22       d33       d44       d55       d66
         0         0         0         0         0         0
$#     d12       d21       d24       d42       d14       d41
         0         0         0         0         0         0
$EXTRUSION DIRECTION GISSMO CARDS
$#   lcsdg     ecrit    dmgexp     dcrit    fadexp     lcreg
       102    -101.0       2.0       0.0       3.5       103
         0       0.0       0.0         0
$TRANSVERSE DIRECTION GISSMO CARDS
$#   lcsdg     ecrit    dmgexp     dcrit    fadexp     lcreg
       202    -201.0       2.0       0.0       2.2       103
         0       0.0       0.0         0
```

Two history variables

Extrusion

Transverse

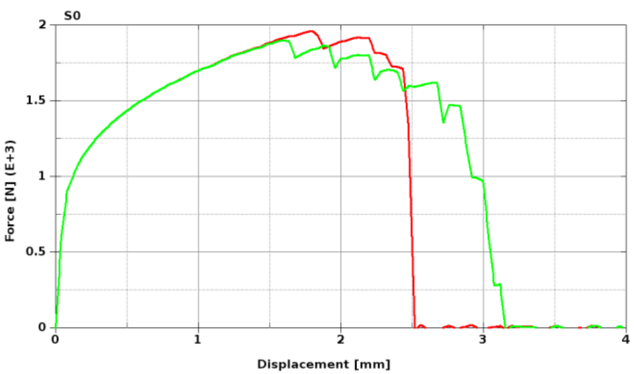
Damage driving variable function

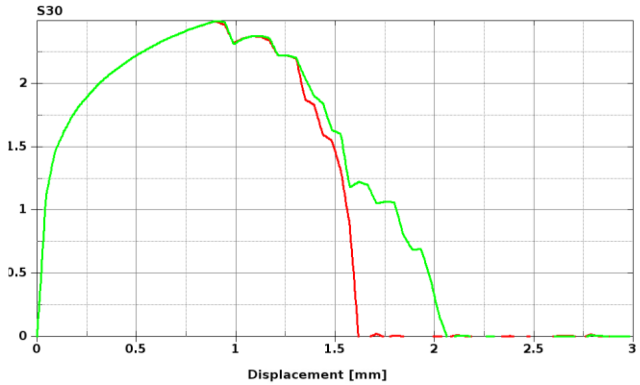
- Only generate damage when the corresponding plastic strain component is positive.
- This is done by generating different functions for the two history variables

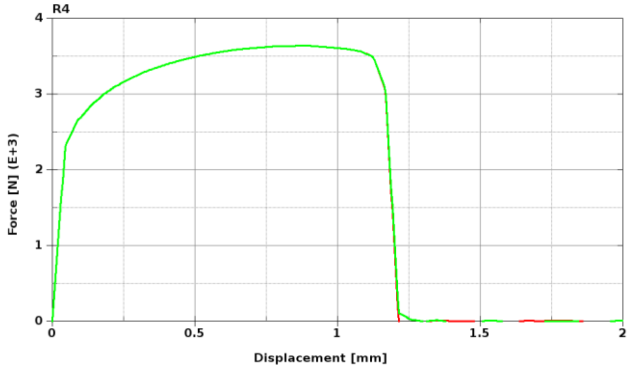
- HISn<0: *DEFINE_FUNCTIONS Ids defining the damage driving functions

```
*DEFINE_FUNCTION
$#      fid                                                              heading
        301
$#                                                                      function
fhis(eaa,ebb,ecc,eab,ebc,eca)=max(0,eaa)*sqrt(2./3.*(eaa**2+ebb**2+
2*eab**2+ecc**2+2*ebc**2+2*eca**2))/(1.e-8+eaa)
*DEFINE_FUNCTION
$#      fid                                                              heading
        302
$#                                                                      function
fhis2(eaa,ebb,ecc,eab,ebc,eca)=max(0,ebb)*sqrt(2./3.*(eaa**2+ebb**2+
2*eab**2+ecc**2+2*ebc**2+2*eca**2))/(1.e-8+ebb)
```

Tensile test results – eGISSMO vs GISSMO extrusion

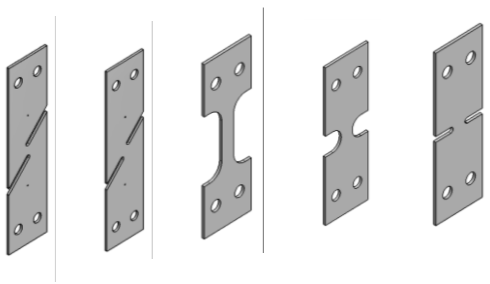


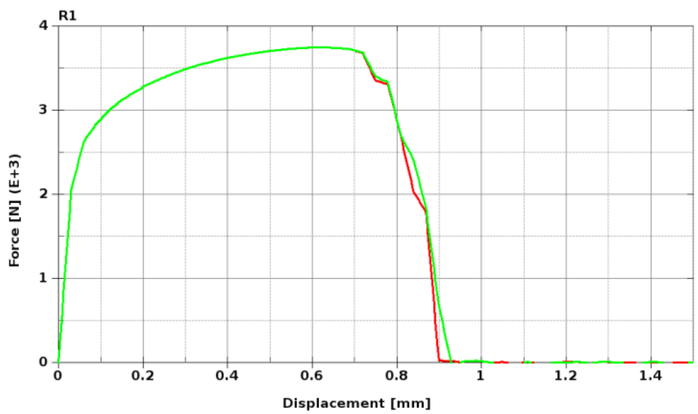


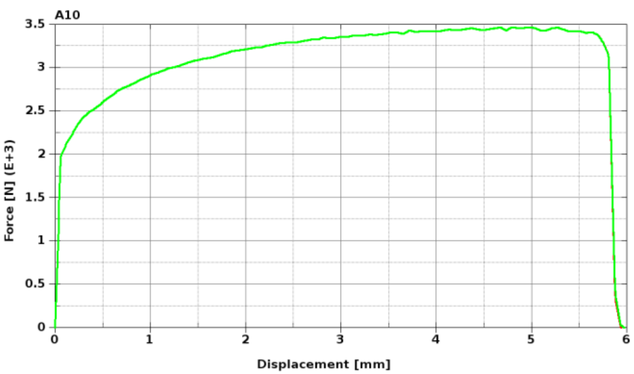


eGISSMO ortho

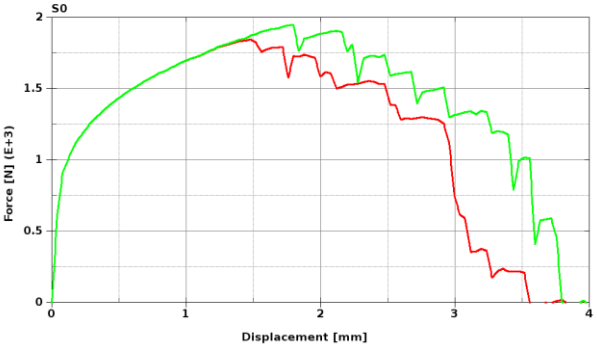
GISSMO iso

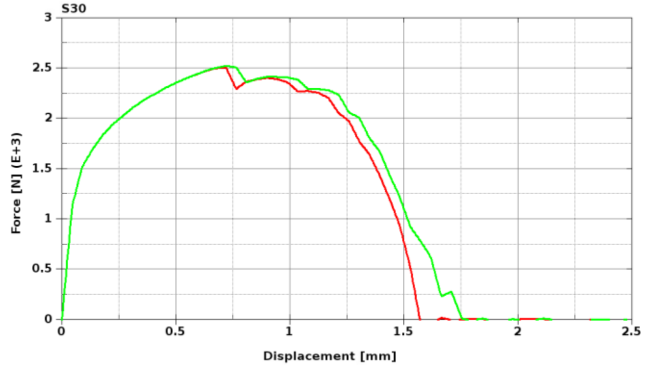


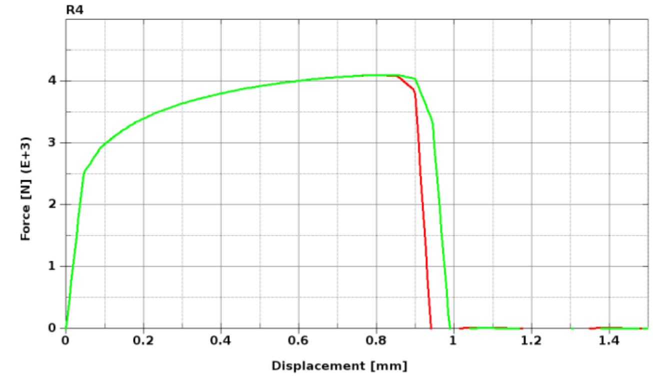




Tensile test results – eGISSMO vs GISSMO transverse

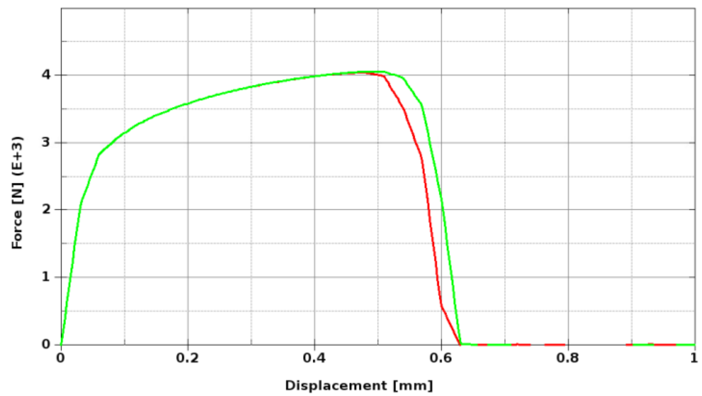


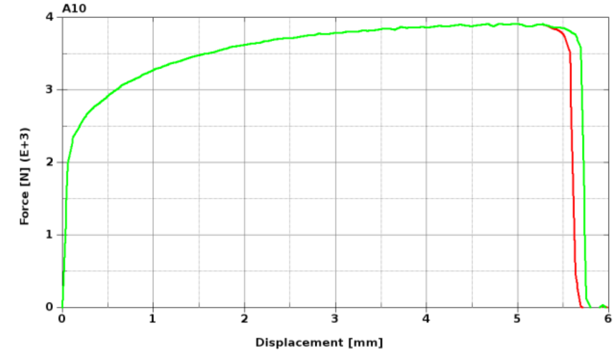


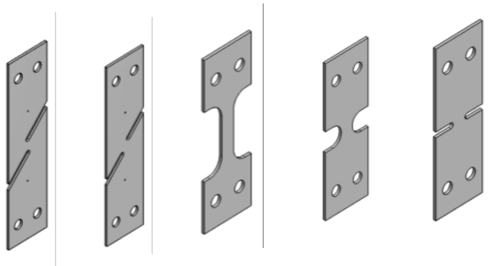


eGISSMO ortho

GISSMO iso







Conclusion

- GISSMO is an add-on damage model:
  - Generally driven by effective plastic strain
  - Isotropic
- eGISSMO allows the user to combine up to 3 GISSMO cards:
  - Driven by effective plastic strain, history variables or strain components
  - User defined history variables by function
  - Can be used to for damage that is orthotropic, volumetric deviatoric split, etc.
  - User defined damage tensor for damage-stress coupling
  - Usage of pre-defined damage tensors for increased speed
- eGISSMO is a highly flexible damage/failure model and its similarity to GISSMO makes it easy for users with GISSMO experience to advance to eGISSMO.
- www.dynalook.com

11th European LS-DYNA Conference 2017, Salzburg, Austria

Short Introduction of a New Generalized Damage Model

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Thank you!

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