# Challenges in Crash and answers with Simcenter Radioss

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# Simcenter Radioss


## Democratizing Explicit Dynamics

Crash & Safety Dynamic Analysis Software

Industry-proven explicit solver for highly nonlinear simulation scenarios: crash & safety, high velocity dynamic events, ballistics & blast, drop & impact, material performance, fluid structure interaction

Automotive | Heavy equipment | Aerospace & defense | Marine | Energy | Electronics Electrical | Healthcare & goods

Best in quality, repeatability, and scalability

Quick learning curve, supporting multiple input & output standards and flexible workflows

Open platform for collaboration & innovation with fast-growing worldwide community: OpenRadioss




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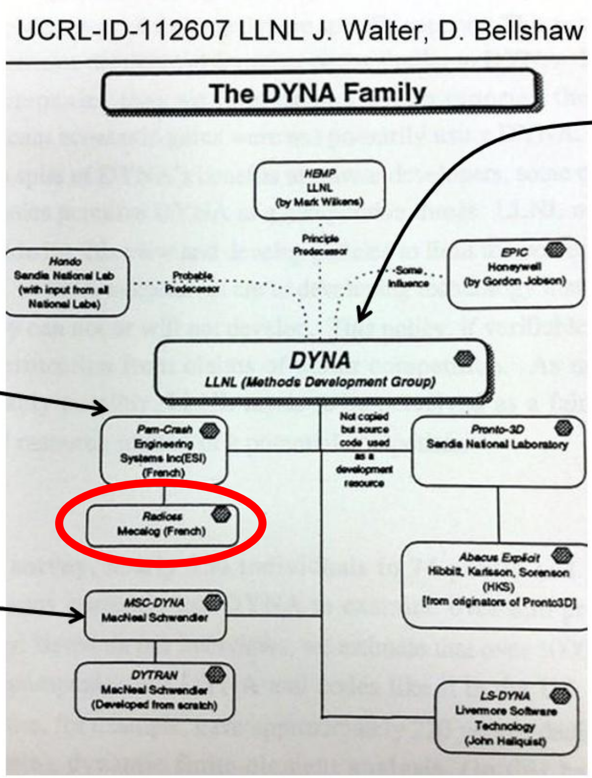
# Little bit of History

**PDB**

## Explicit FE codes were available in the mid '70s ( DYNA3D : 1976)



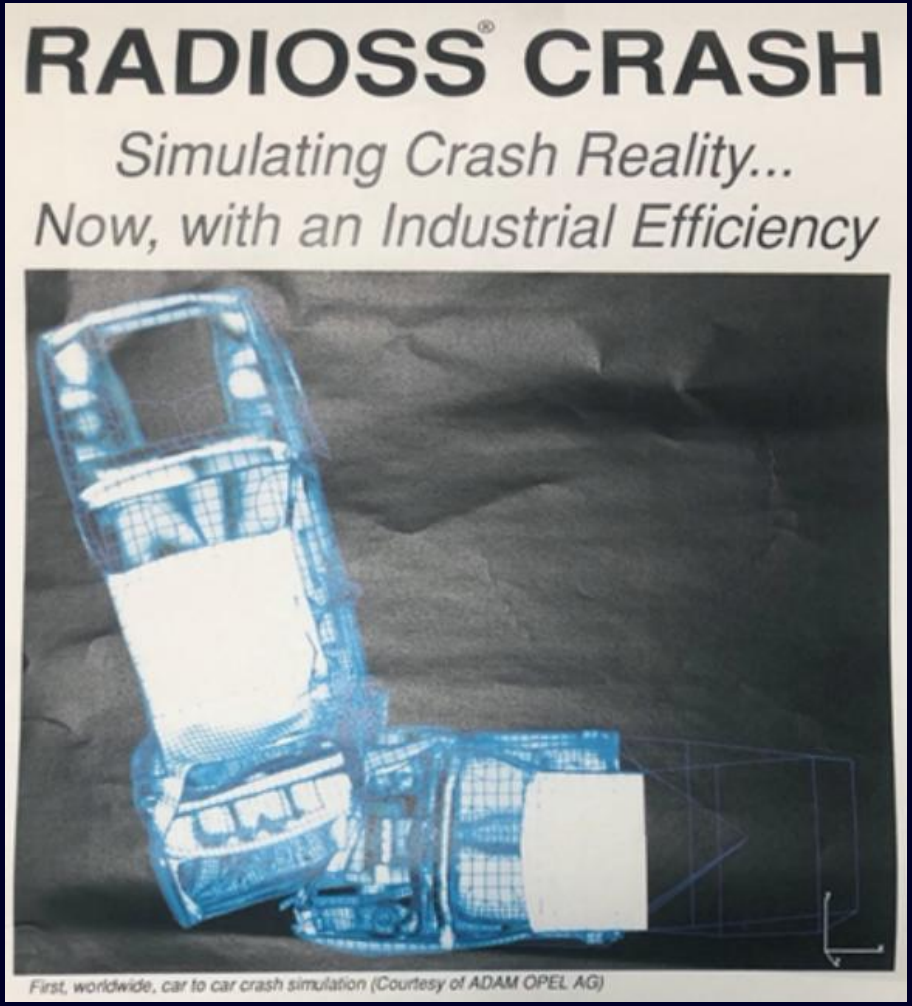

W.F. Noh
CEL
First coupled EL code
LLL, 1964

WHAMS
Northwestern/Argonne
Chicago IL

SAND86-0594
SNL, march 1987
Albuquerque NM.
L. Taylor & D. Flanagan

PISCES
Pisces International
San Leandro CA
explicit FVM CFD
H. Hancock

Source: **Paul Du Bois**: Presentation at the OpenRadioss Users meeting 2023 in Aachen (Germany)




Radioss advertisement: First car to car crash, performed in 1991

# Motivation

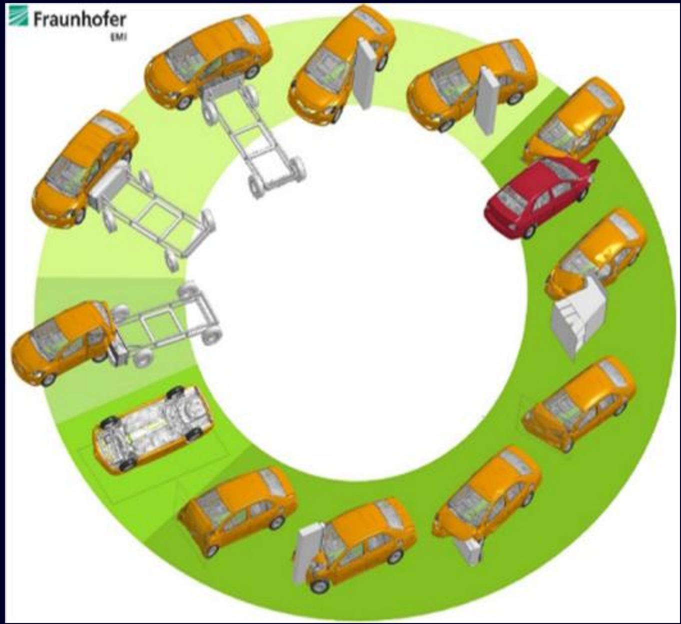
- Automotive industry is still driving the development of crash solvers, but other industries are catching up.

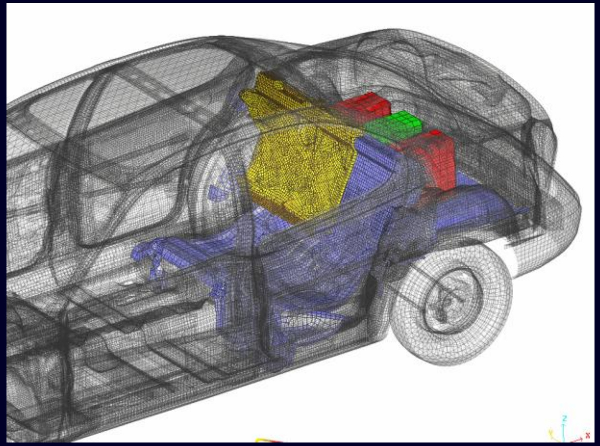
Simcenter Radioss has a large library of material models and failure criteria. Anyway, there is still a big demand on advanced material and fracture models to increase the quality of results.

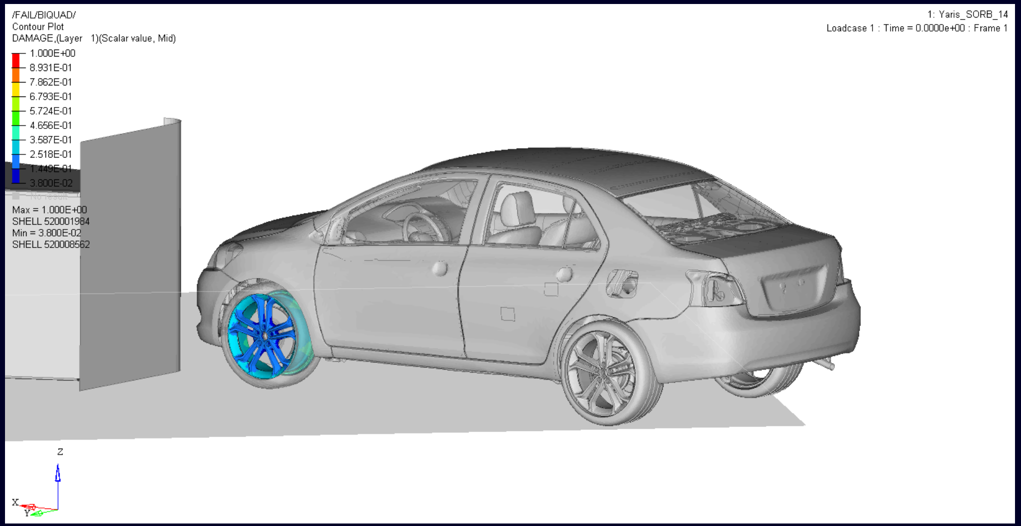
We are participating and investing in research projects to continually improving the crash solver.

**The final goal is:**

**<u>Reducing development time !!!</u>**





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# Challenge: Modeling materials – Elasto-Plastic materials

| Type | Description | Model | Law (MID) |
|---|---|---|---|
| Isotropic Elasticity | ~~Linear elastic model~~ Don't use it !!! | ~~Hook~~ | ~~(1)~~ |
| | Hyper elastic | Ogden-Mooney-Rivlin | (42) |
| Composite and Orthotropic materials | Linear elastic for orthotropic shells | Fabric | (19) |
| | Nonlinear pseudo-plastic orthotropic solids without strain rate effect | Honeycomb | (28) |
| | Nonlinear pseudo-plastic orthotropic solids with strain rate effect | Crushable foam | (50) |
| | Elastic-plastic orthotropic shells | Hill | (32) |
| | | Hill (tabulated) | (43) |

## Steps to create an Elasto-plastic material

a) **From real tests (best choice)**

b) Generic data input for a numerical/analytical model (in case of no test available): e.g. Johnson-Cook

The stress vs. plastic strain law is as follows:

$$\boxed{\sigma_{tr} = a + b\,(\varepsilon_{pl})^n}$$

a, the yield stress is read on the curve (and converted to true stress).

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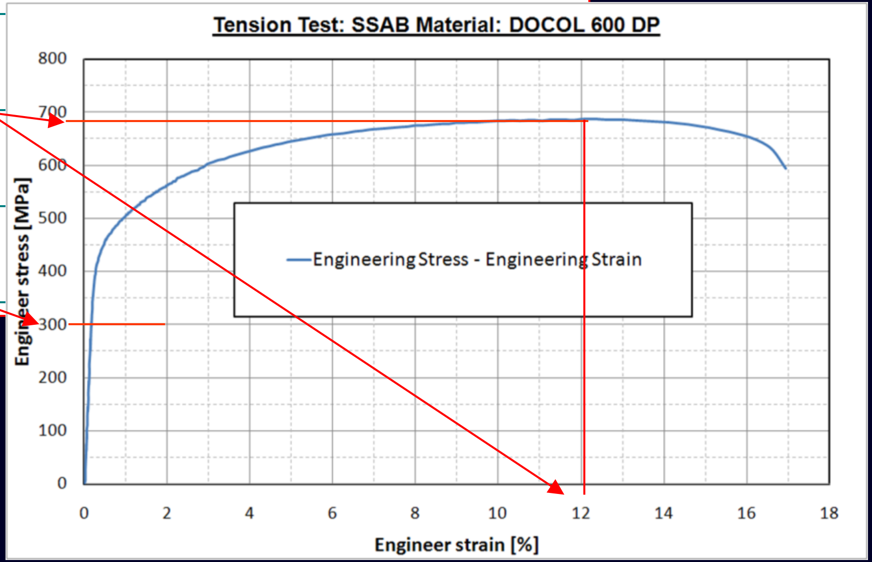
# Challenge: Modeling materials – Elasto-Plastic materials

```
##--------------------------------------------------------------------------------------------------
## Material Law No 2. JOHNSON-COOK / ZERILLI-ARMSTRONG ELASTOPLASTIC
##--------------------------------------------------------------------------------------------------
#---1----|----2----|----3----|----4----|----5----|----6----|----7----|----8----|----9----|---10----|
/MAT/PLAS_JOHNS/2
Steel_DP600
#---1----|----2----|----3----|----4----|----5----|----6----|----7----|----8----|----9----|---10----|
#        Init. dens.          Ref. dens.
            7.80E-06
#                  E                   Nu UTS_Input
               210.0                  0.3          1
#---1----|----2----|----3----|----4----|----5----|----6----|---
#              Yield                  UTS                   Ag
                 0.3                0.686                 0.12
#---1----|----2----|----3----|----4----|----5----|----6----|---
#                  c                 EPS0         Icc   Fsmooth

#---1----|----2----|----3----|----4----|----5----|----6----|---
#                  m               T_melt               rhoCp

#---1----|----2----|----3----|----4----|----5----|----6----|---
```




Still too complex ?



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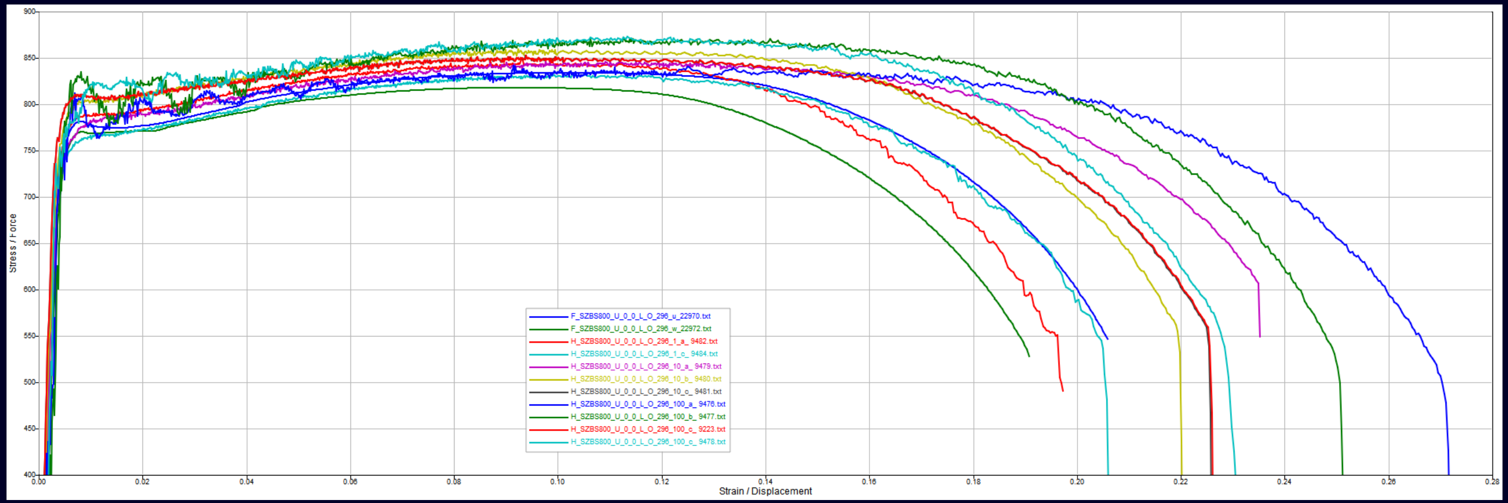
# Challenge: Modeling materials – Elasto-Plastic materials

- Create a new material law : **/MAT/PLAS_PREDEF/**
  - **STEEL** Mild steel
  - HSS High Strength Steel
  - UHSS Ultra HSS
  - AA5182 Aluminum AA5182
  - AA6082-T6 Aluminum AA6082-T6
  - PA6GF30 Plastic PA6GF30
  - PPT40 Plastic PP T40

```
#---1----|----2----|----3----|----4----|----…
/MAT/PLAS_PREDEF/4711
This is a Simple Mild Steel material
STEEL
#---1----|----2----|----3----|----4----|----…
```

- Advantage
  - Very user friendly
  - Unit conversion done automatically
- Usage
  - For fast material substitution

**Source: Salzgitter: SZBS800 3.6 Orientation 0 deg. Tensile Test Data div. Strain-rates**



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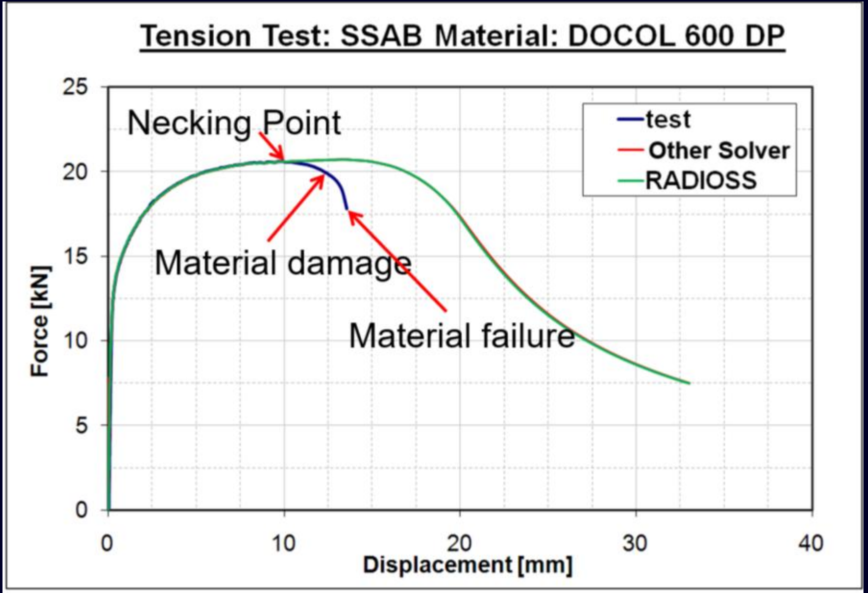
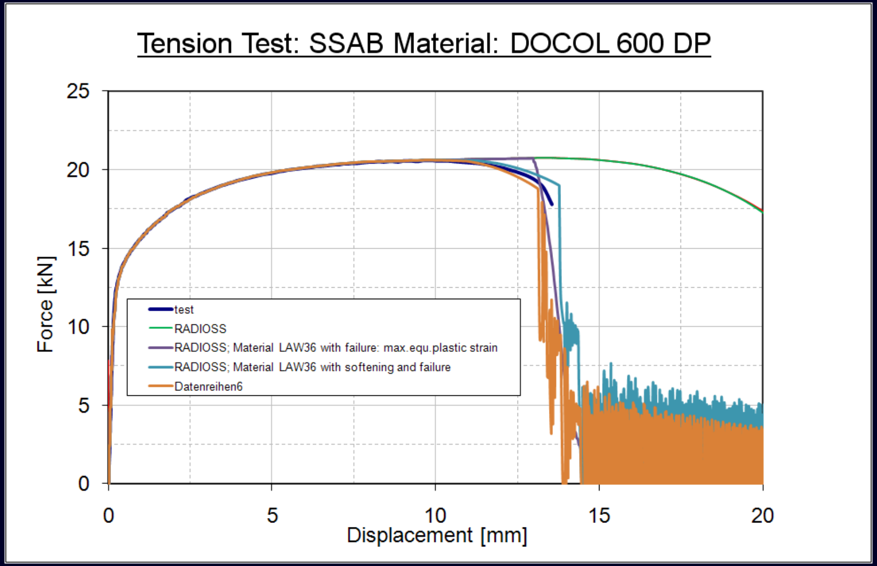
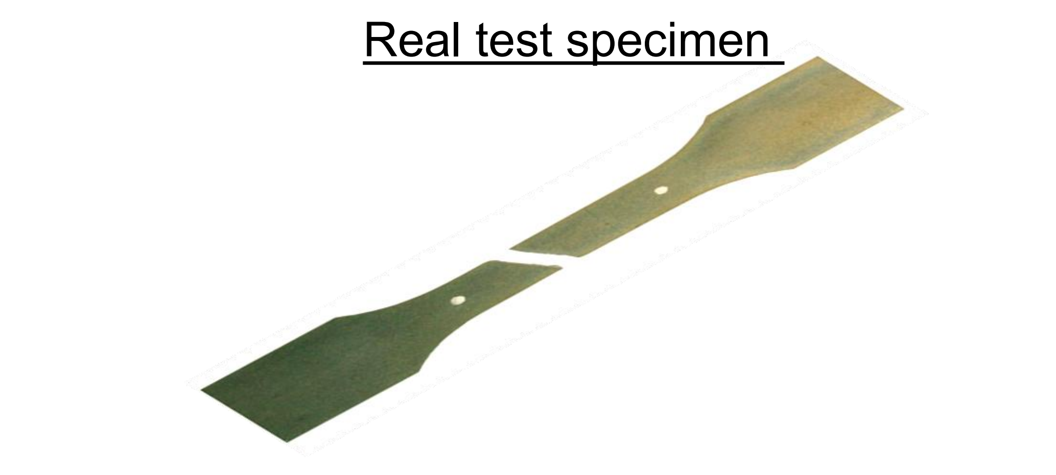
# Challenge: Modeling materials – Elasto-Plastic materials

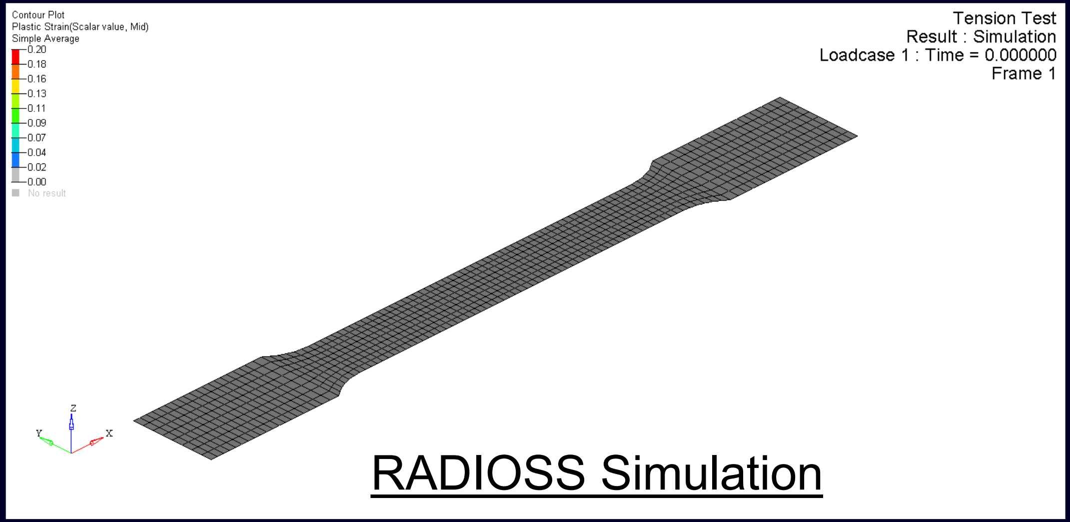
## Material Card Generation – Validation Simulation




## /MAT/LAW36 (Plas_Tab)

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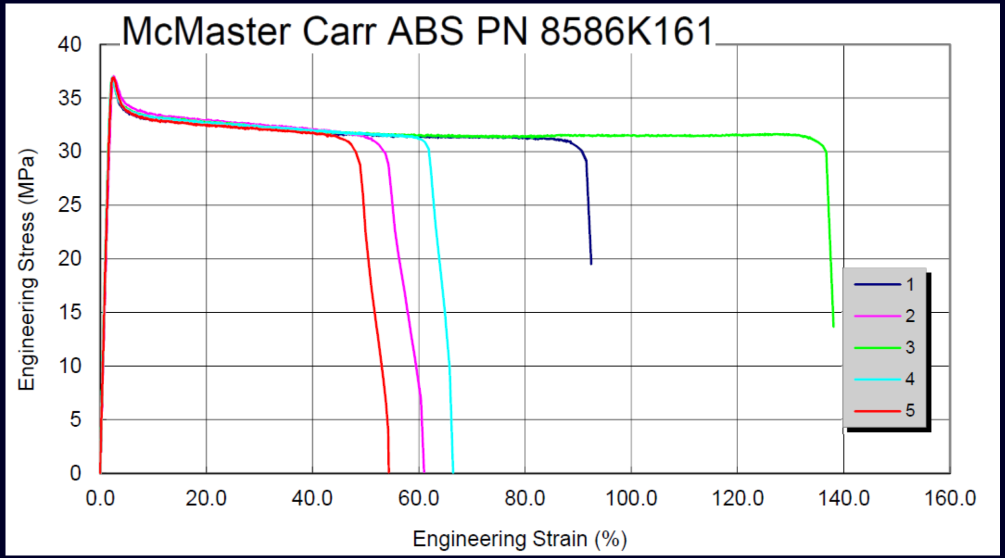
# Challenge: Modeling materials – Elasto-Plastic materials - Polymeres

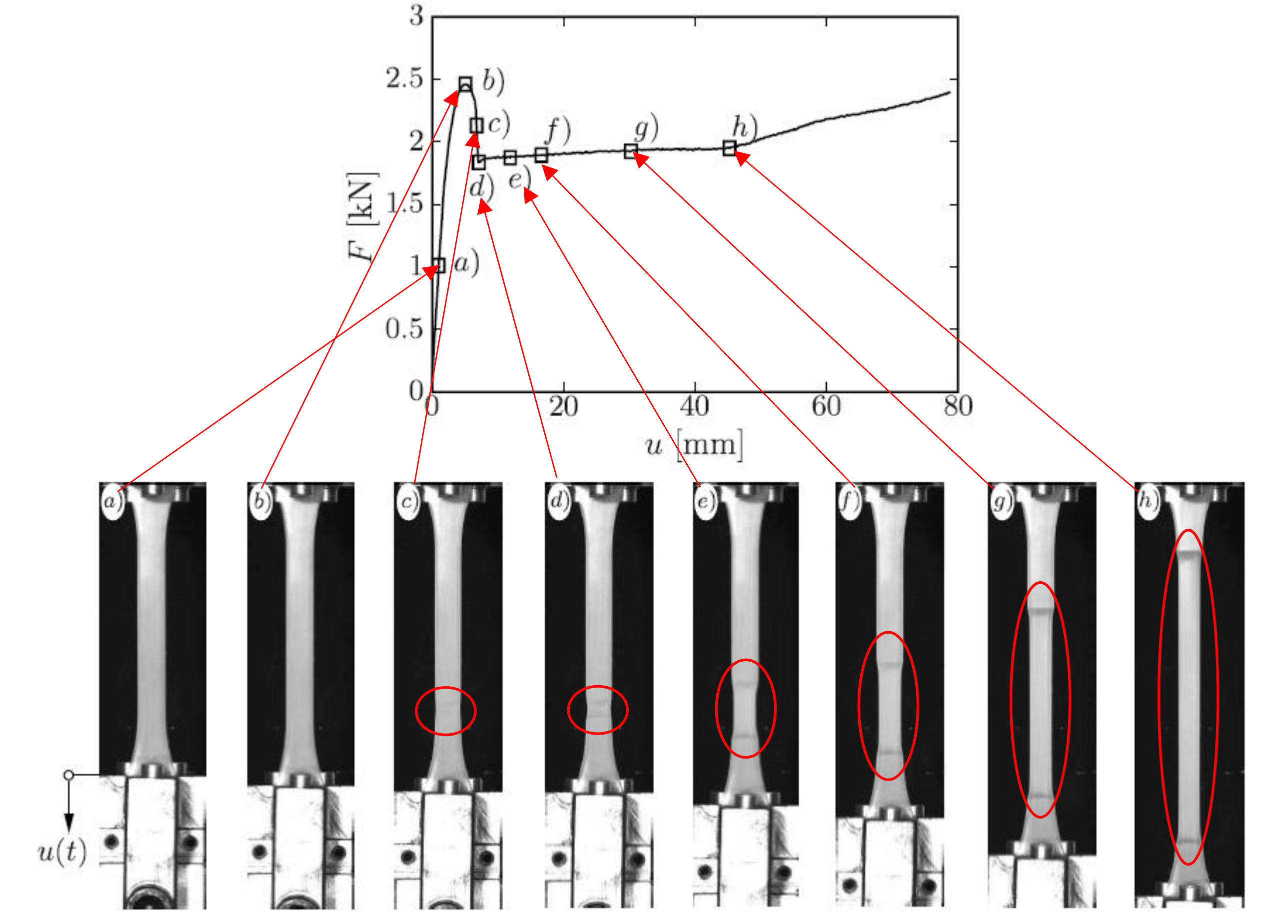
## Material Card Generation – Validation Simulation /MAT/LAW76 (Plas-Tab - SAMP)

Material Tests – What reality shows:




Applus DatapointLabs

Tensile test of a Polyamide (PA) material




Source: "Thermal effects in the material modelling of polyamide 6 during short-term dynamic loading processes"
Dipl.-Ing. Joachim Strauch
5. January 2019



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# Challenge: Modeling materials – Elasto-Plastic materials - Polymeres

## Material Card Generation – Validation Simulation /MAT/LAW76 (Plas-Tab - SAMP)

Real test specimen

### /MAT/LAW76 (SAMP)

**Block Format Keyword**

This law describes a semi-analytical elasto-plastic material using user-defined functions for the work-hardening portion for tension, compression and shear (stress as function of strain).

**Format**

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
|---|---|---|---|---|---|---|---|---|---|
| /MAT/LAW76/*mat_ID*/*unit_ID* or /MAT/SAMP/*mat_ID*/*unit_ID* | | | | | | | | | |
| *mat_title* | | | | | | | | | |
| $\rho_i$ | | | | | | | | | |
| $E$ | | $\nu$ | | | | | | | |
| $tab\_ID_t$ | $tab\_ID_c$ | $tab\_ID_s$ | | | | | | | |
| $Fscale_t$ | | $Fscale_c$ | | $Fscale_s$ | | | | $XFAC$ | |
| $\nu_p$ | | $fct\_ID_{pr}$ | $Fscale_{pr}$ | | $F_{smooth}$ | $F_{cut}$ | | | |
| $\varepsilon_p^f$ | | $\varepsilon_p'$ | | | | | | | |
| $fct\_ID_1$ | | | $Fscale_1$ | | | | | | |
| $I_{form}$ | $IQUAD$ | $ICONV$ | | | | | | | |

```
#---1----|----2----|----3----|----4----|----5----|
/TABLE/1/1000
curve_list TENSION strain rates
        2
    10010                              1.0e-4
    10020                                 1.0
#---1----|----2----|----3----|----4----|----5----|
#---1----|----2----|----3----|----4----|----5----|
/FUNCT/10010
eps_vs_sigma funct dt=1.0e-4
              0.0000              .100000
              1.0000              .200000
#---1----|----2----|----3----|----4----|----5----|
#---1----|----2----|----3----|----4----|----5----|
/FUNCT/10020
eps_vs_sigma funct dt=1.0
              0.0000             1.000000
              1.0000             2.000000
#---1----|----2----|----3----|----4----|----5----|
```

```
#---1----|----2----|----3----|----4----|----5----|
/TABLE/1/1001
curve_list COMPRESSION strain rates
        2
    10030                              1.0e-4
    10040                                 1.0
#---1----|----2----|----3----|----4----|----5----|
#---1----|----2----|----3----|----4----|----5----|
/FUNCT/10030
eps_vs_sigma funct dt=1.0e-4
              0.0000              .200000
              1.0000              .400000
#---1----|----2----|----3----|----4----|----5----|
#---1----|----2----|----3----|----4----|----5----|
/FUNCT/10040
eps_vs_sigma funct dt=1.0
              0.0000             2.000000
              1.0000             4.000000
#---1----|----2----|----3----|----4----|----5----|
```

```
#---1----|----2----|----3----|----4----|----5----|
/TABLE/1/1002
curve_list SHEAR strain rates
        2
    10050                              1.0e-4
    10060                                 1.0
#---1----|----2----|----3----|----4----|----5----|
#---1----|----2----|----3----|----4----|----5----|
/FUNCT/10050
eps_vs_sigma funct dt=1.0e-4
              0.0000              .050000
              0.5000              .060000
              1.0000              .065000
#---1----|----2----|----3----|----4----|----5----|
#---1----|----2----|----3----|----4----|----5----|
/FUNCT/10060
eps_vs_sigma funct dt=1.0
              0.0000              .500000
              0.5000              .600000
              1.0000              .650000
#---1----|----2----|----3----|----4----|----5----|
```



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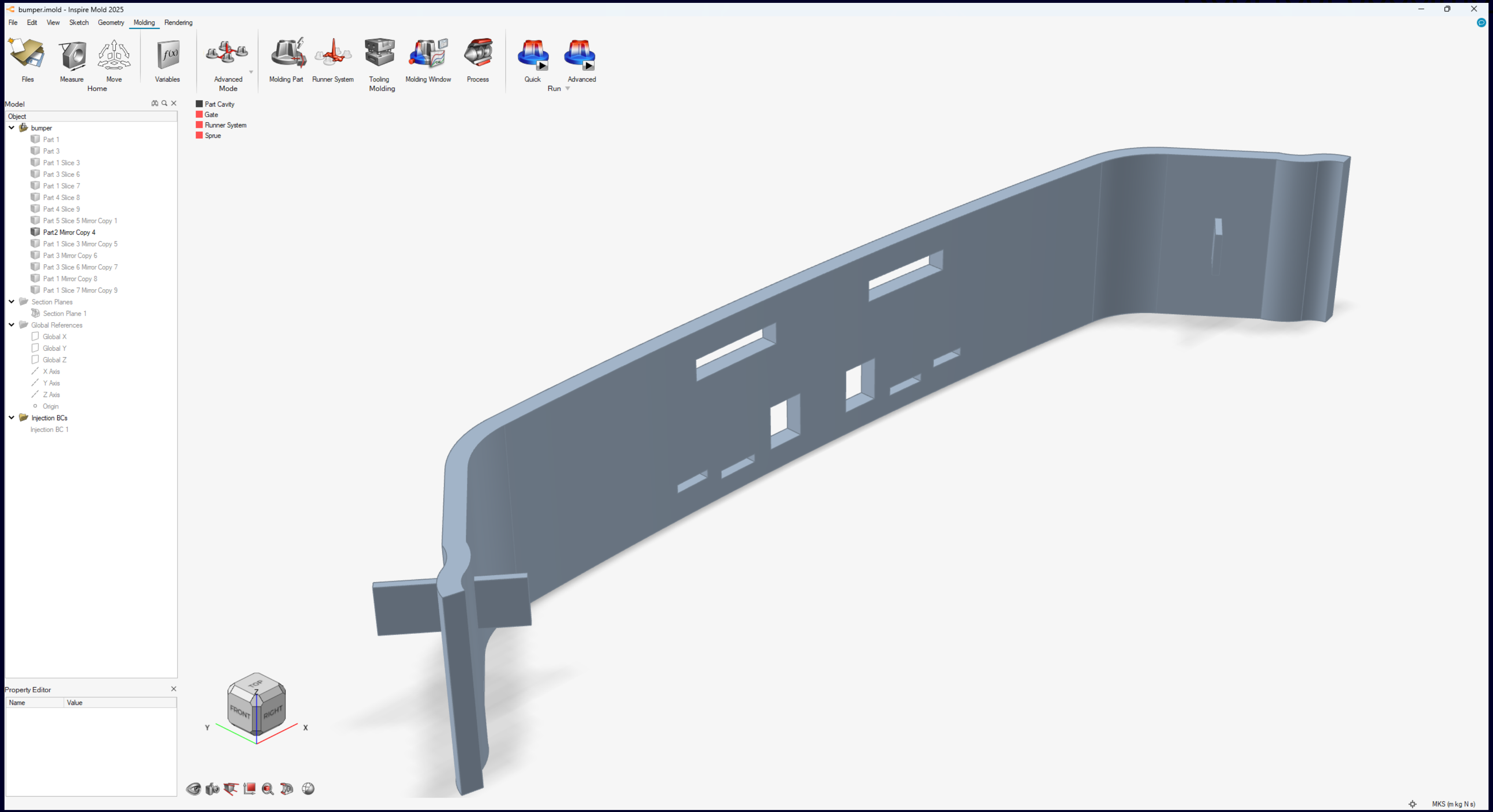
# Challenge: Modeling materials – Elasto-Plastic materials - Polymeres

## Material Card Generation – Validation Simulation /MAT/LAW93 (Converse)

For short fibers, the manufacturing simulation is mandatory ! ➔ Inspire Mold



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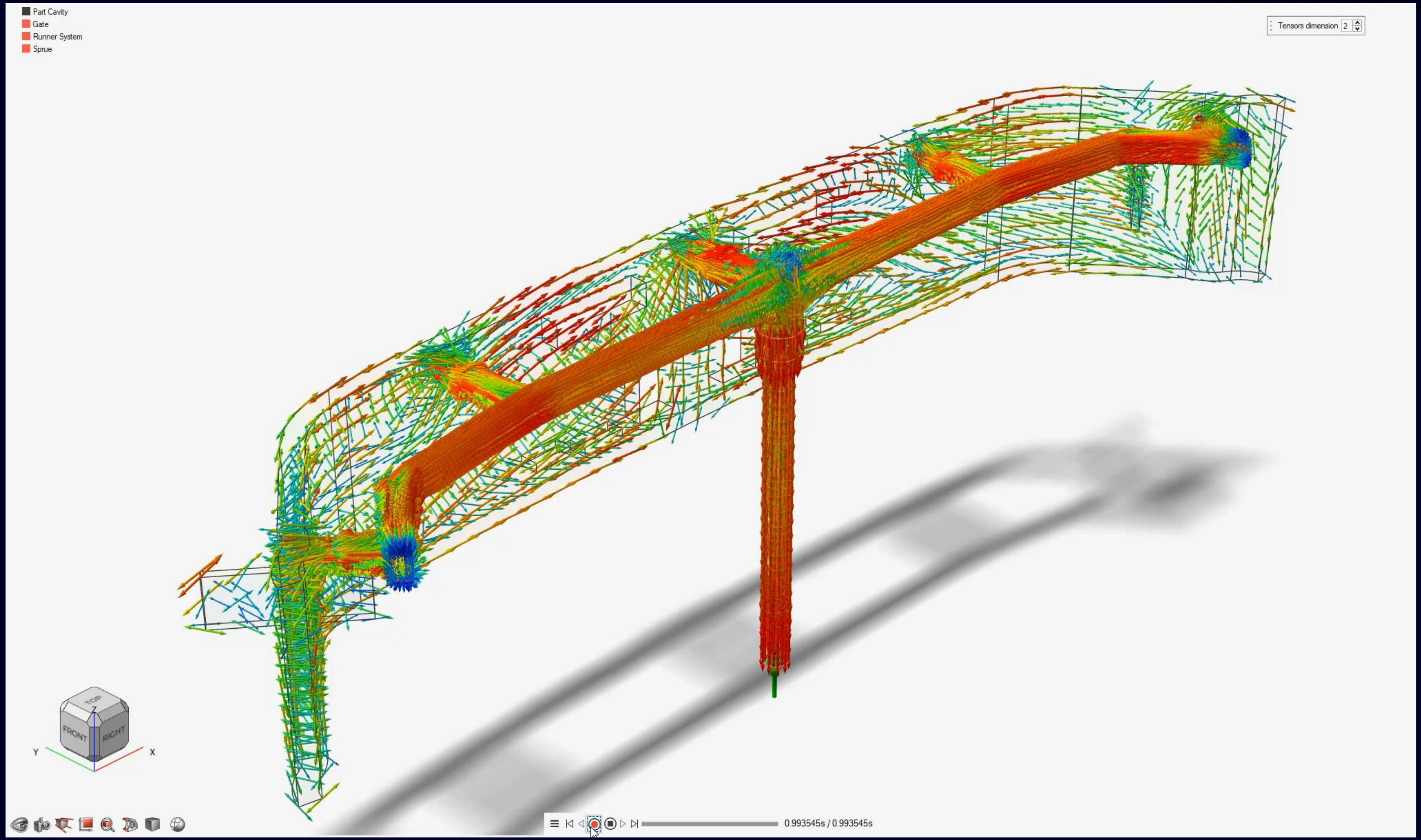
# Challenge: Modeling materials – Elasto-Plastic materials - Polymeres

## Material Card Generation – Validation Simulation /MAT/LAW93 (Converse)

For short fibers, the manufacturing simulation is mandatory ! ➔ Inspire Mold

Real test specimen



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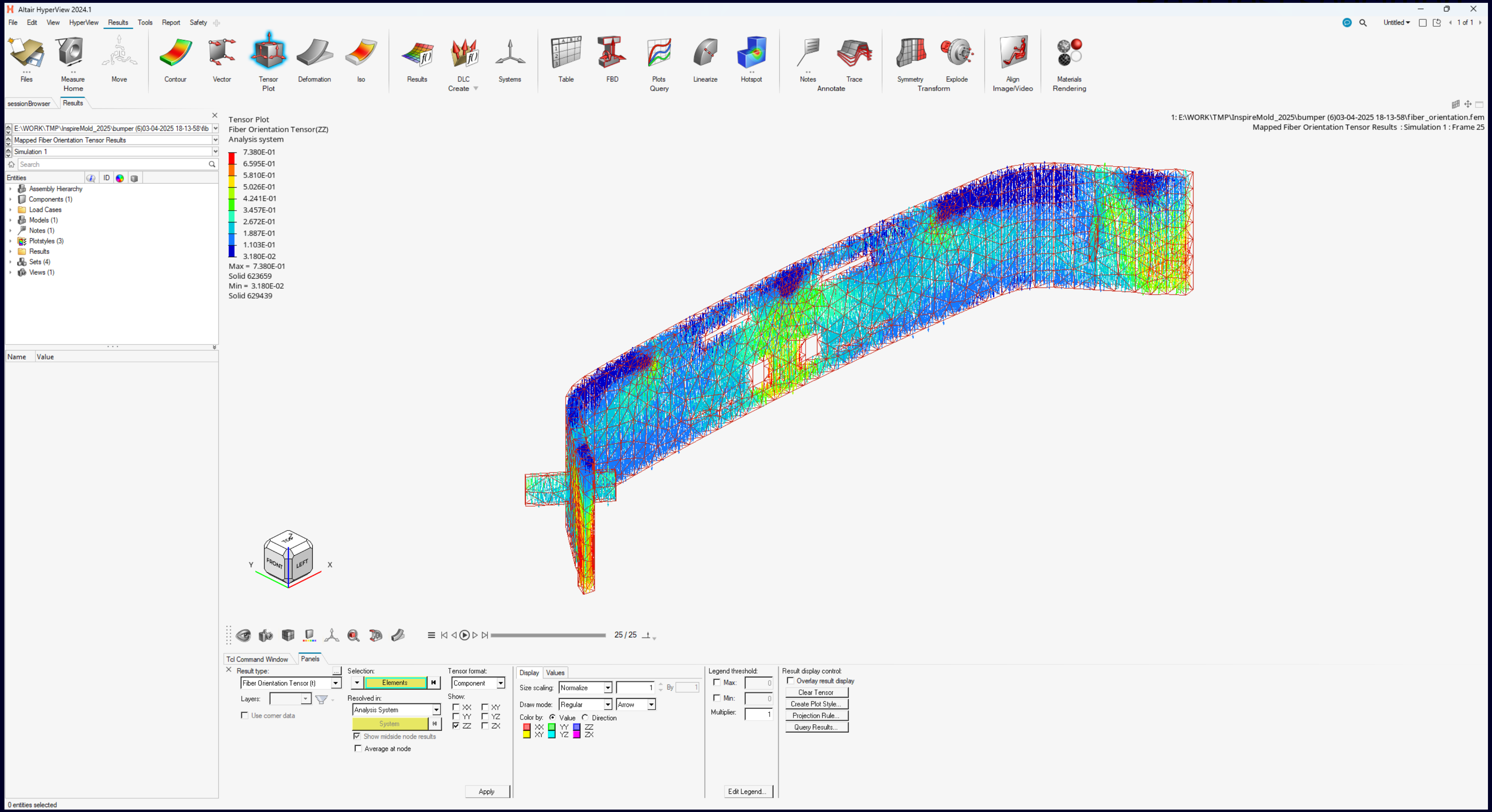
# Challenge: Modeling materials – Elasto-Plastic materials - Polymeres

## Material Card Generation – Validation Simulation /MAT/LAW93 (Converse)

### Front bumper --- Checking the Fiber orientation tensor - in HyperView



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# Challenge: Modeling materials – Elasto-Plastic materials

## /MAT/ELASTO_PLASTIC: Generic Modular Model for plasticity in Simcenter Radioss

### *Elasticity*

**ELAS_ISOTROPIC**
- *Isotropic elasticity*

**ELAS_ORTHOTROPIC**
- *Orthotropic elasticity*

**ELAS_ANISOTROPIC**
- *Anisotropic elasticity*

**ELAS_VISC_ISOTROPIC**
- *Viscous and isotropic elasticity*

**ELAS_TEMP_ISOTROPIC**
- *Temperature and isotropic elasticity*

### *Yield criteria*

**CRIT_VONMISES**
- *Quadratic isotropic*

**CRIT_HERSHEY**
- *Non-quadratic isotropic*

**CRIT_HILL**
- *Quadratic orthotropic*

**CRIT_BARLAT1989**
- *Non-quadratic orthotropic*

**CRIT_BARLAT2000**
- *Non-quadratic orthotropic*

### *Work hardening laws*

**HARD_POWERLAW**
- *Johnson-Cook power law*

**HARD_VOCE**
- *Voce exponential law*

**HARD_LINVOCE**
- *Linear + 1Voce term exponential law*

**HARD_*TAB***
- *Tabulated isotropic hardening*

### *Strain-rate dependencies*

**SRATE_JOHNSONCOOK**
- *Johnson-Cook strain rate dependency*

**SRATE_COWPER**
- *Cowper-Symonds strain rate dep.*

**SRATE NLINE**
- *Non-linear strain rate dependency*

**SRATE_TAB**
- *Tabulated strain rate dependency*

***Option: Scaled stress + FCUT or Viscoplastic model***

### *Thermal softenings*

**THERM_JOHNSONCOOK**
- *Johnson-Cook thermal softening*

**THERM_ZHAO**
- *Zhao thermal softening*

**THERM_TAB**
- *Tabulated thermal softening*

### *Self-heating*

**HEAT_TAYLOR**
- *Extended Taylor Quinney self heating*

**HEAT_TAB**
- *Tabulated self heating*

### *Kinematic hardening*

**KINE_PRAGER**
- *Linear kinematic hardening*

**KINE_CHABOCHE**
- *Non-linear kinematic hardening*

# Challenge: Modeling materials – Elasto-Plastic materials - Isotropic

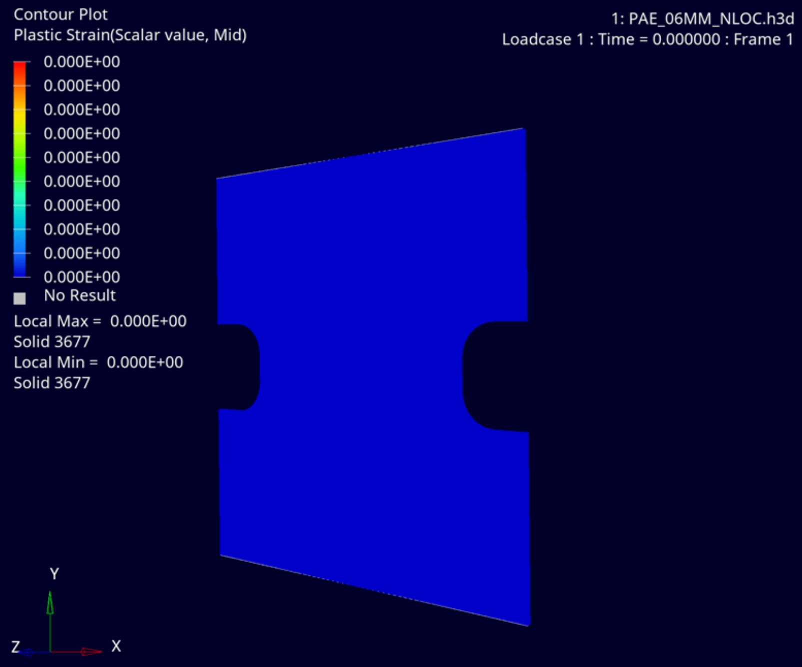
*/MAT/LAW2 (JOHNSON_COOK)*

```
/MAT/PLAS_JOHNS/1
Steel
#              RHO_I
               7.8E-9
#                  E                  Nu      Iflag     flagVP                Pmin
              210000                  .3          0          0                   0
#                  a                   b                     n             EPS_max             SIG_max0
                 270               450.0                   0.6                   0                    0
#                  c           EPS_DOT_0        ICC    Fsmooth               F_cut                Chard
              0.0236               0.003          0          1              10000.                    0
#                  m              T_melt                 rhoC_p                 T_r                 Tmax
                   0                   0                      0                   0                    0
```

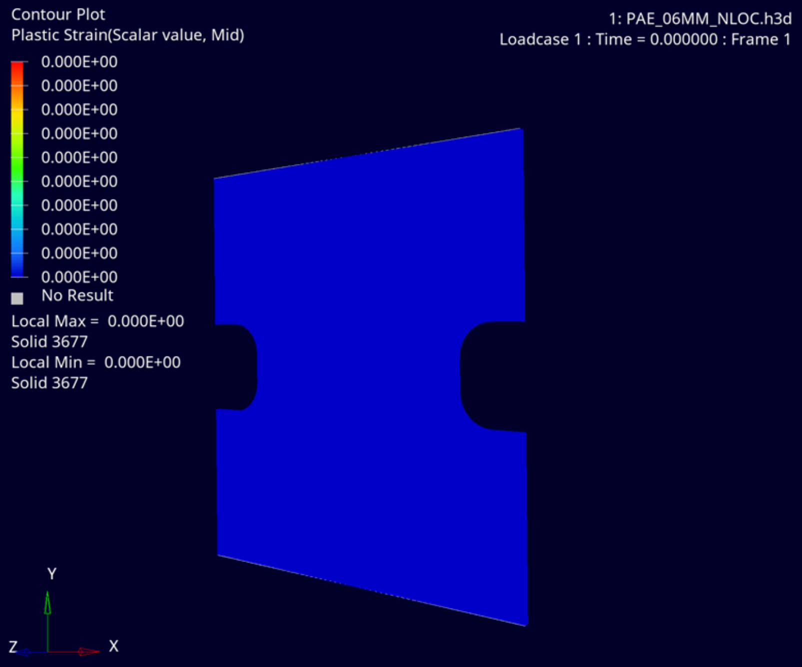
*/MAT/ELASTO_PLASTIC*

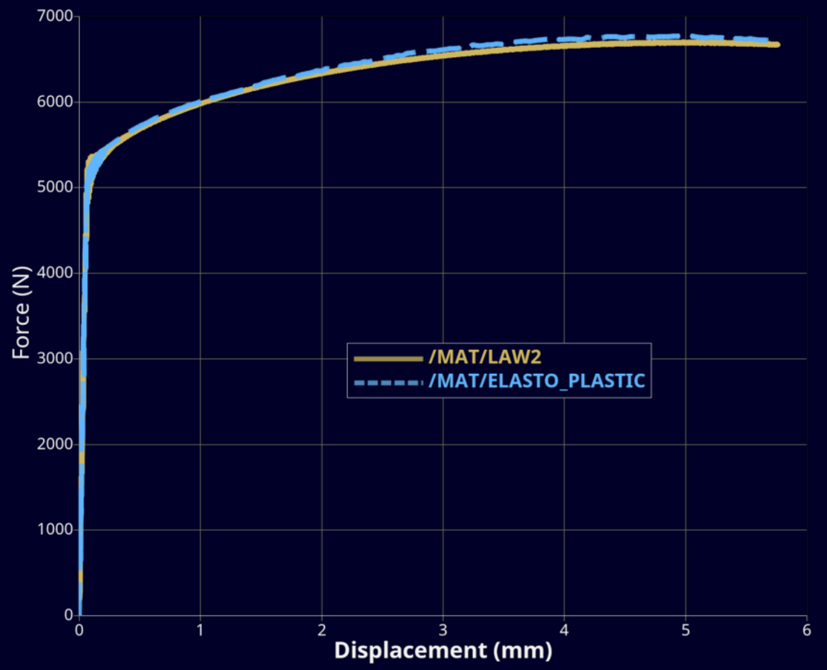
```
/MAT/ELASTO_PLASTIC/1
elasto_plastic_modular_material
#              RHO_I
               7.8E-9
#           KEY_TYPE
      ELAS_ISOTROPIC              210000                  .3
        CRIT_VONMISES
        HARD_POWERLAW                 270               450.0                 0.6
     SRATE_JOHNSONCOOK             0.0236               0.003                   2             10000.0
```

*/MAT/LAW2*




*/MAT/ELASTO_PLASTIC*



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# Challenge: Modeling materials – Elasto-Plastic materials - Orthotropic

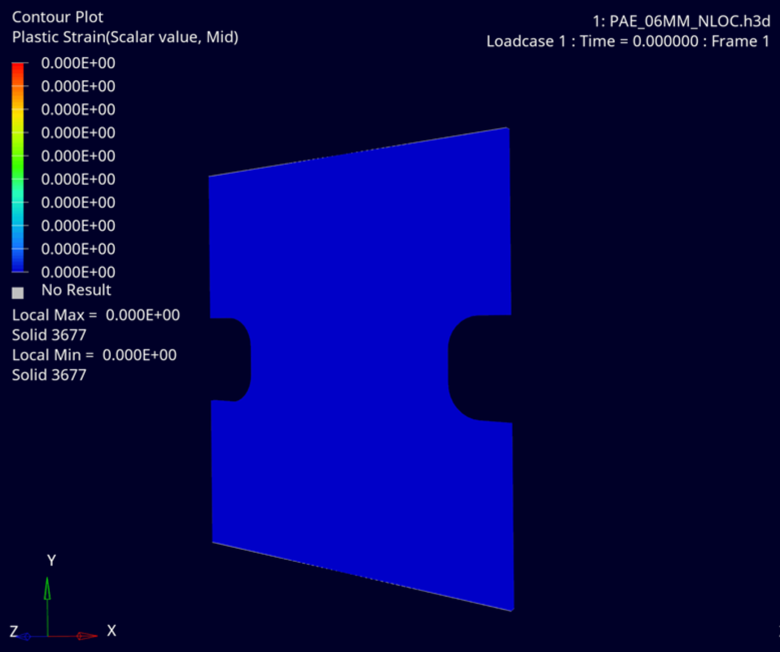
*/MAT/LAW93  (CONVERSE)*

```
/MAT/LAW93/1
plastic
#              RHO_I
          2.730E-09
#                E11                 E22                 E33                 G12                Nu12
              225654              195400               90000            75187.97                0.30
#                G13                 G23                Nu13                Nu23
            75187.97            75187.97                0.28                0.32
#     Nrate       VP                Fcut
          0        1                 0.0
#               SigY                 QR1                 CR1                 QR2                 CR2
             282.972             208.273              23.869                 0.0                 0.0
#                R11                 R22                 R12
                 2.0                 1.5                0.93
#                R33                 R13                 R23
                0.85                 1.0                 1.0
```

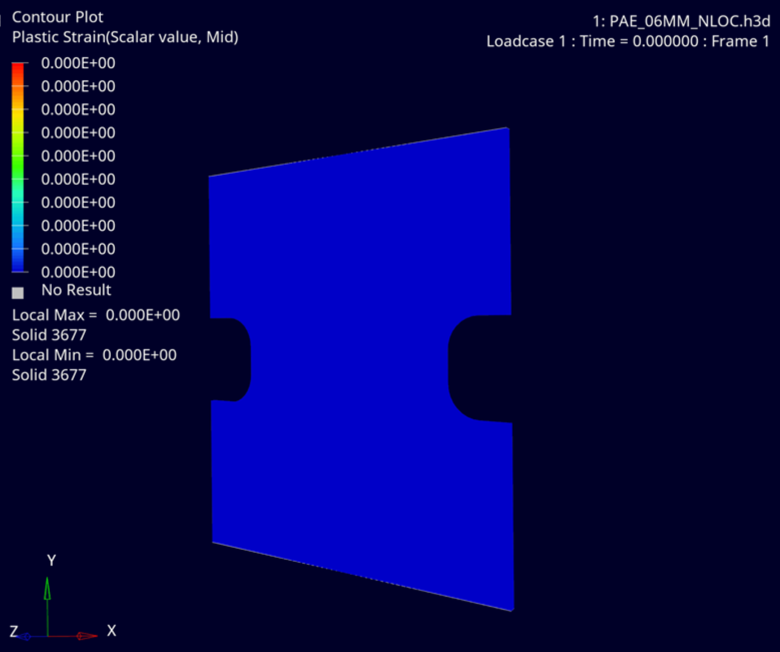
*/MAT/ELASTO_PLASTIC*

```
/MAT/ELASTO_PLASTIC/1
elasto_plastic_modular_material
#              RHO_I
          2.730E-09
#           KEY_TYPE
    ELAS_ORTHOTROPIC              225654              195400               90000                 0.3
                0.32                0.28            75187.97            75187.97            75187.97
           CRIT_HILL
                 2.0                 1.5                0.85                0.93                 1.0
                 1.0
           HARD_VOCE             282.972             208.273              23.869
```

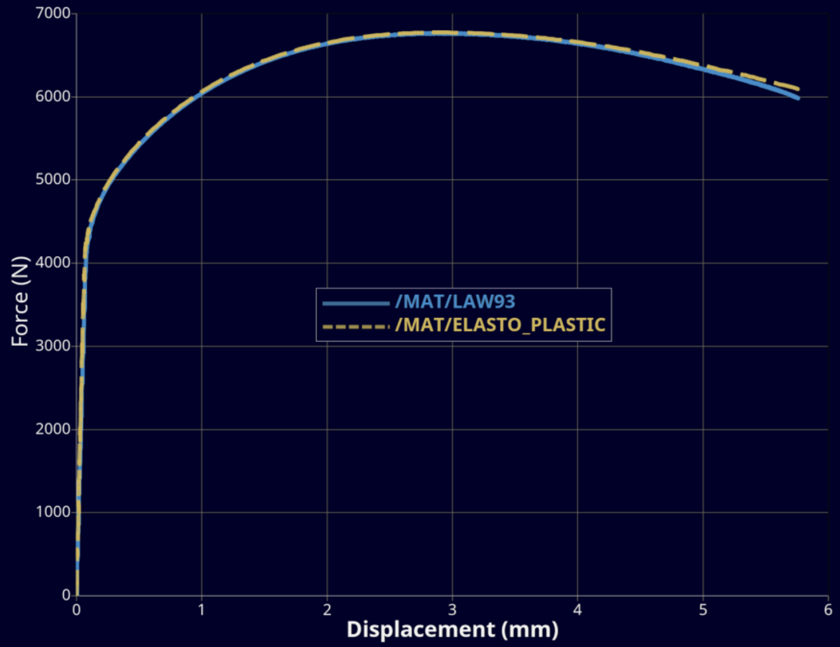
*/MAT/LAW93 – Cutting Plane*



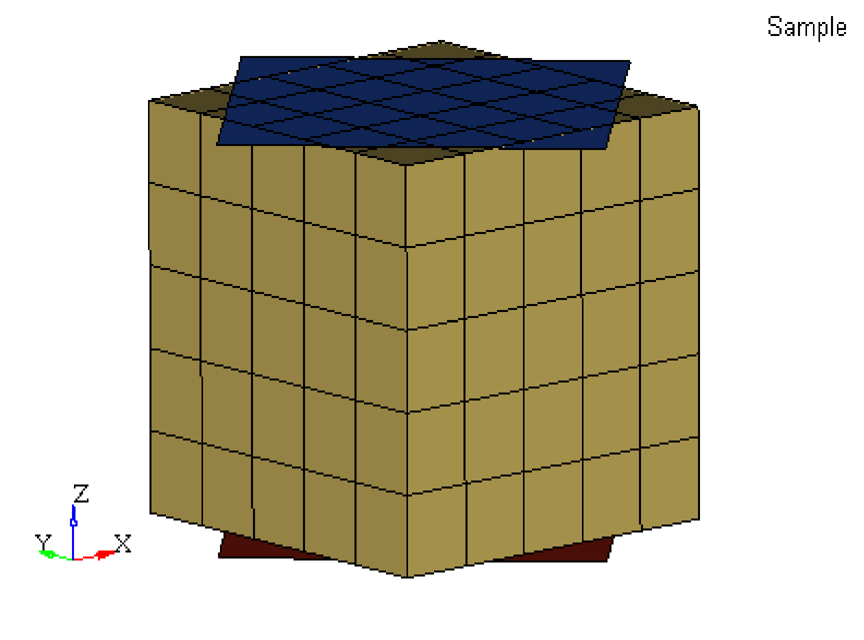

*/MAT/ELASTO_PLASTIC*

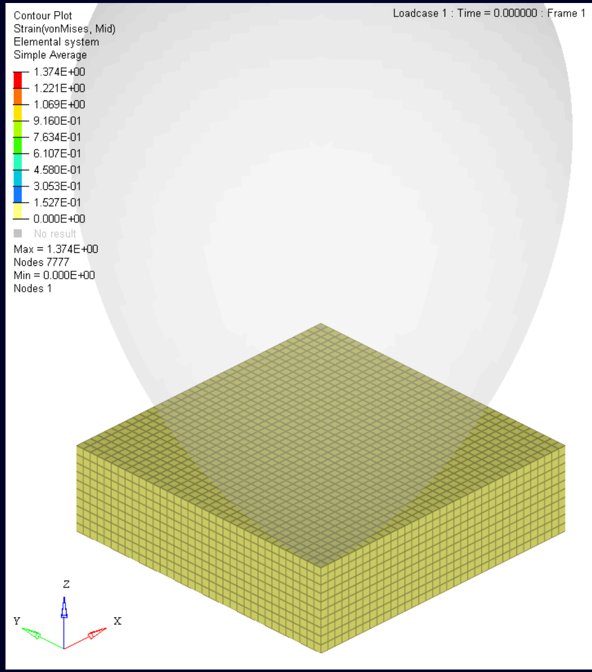


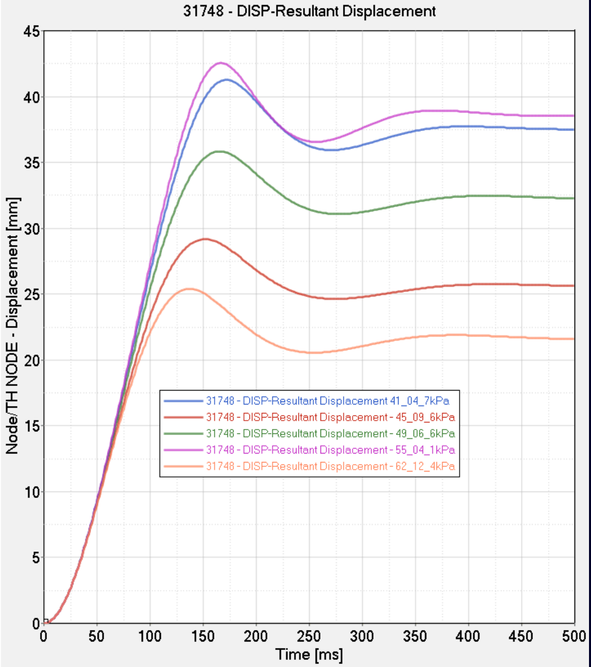

*Force - displacement curves.*



# Challenge 1: Modeling materials – Foam (elastic)



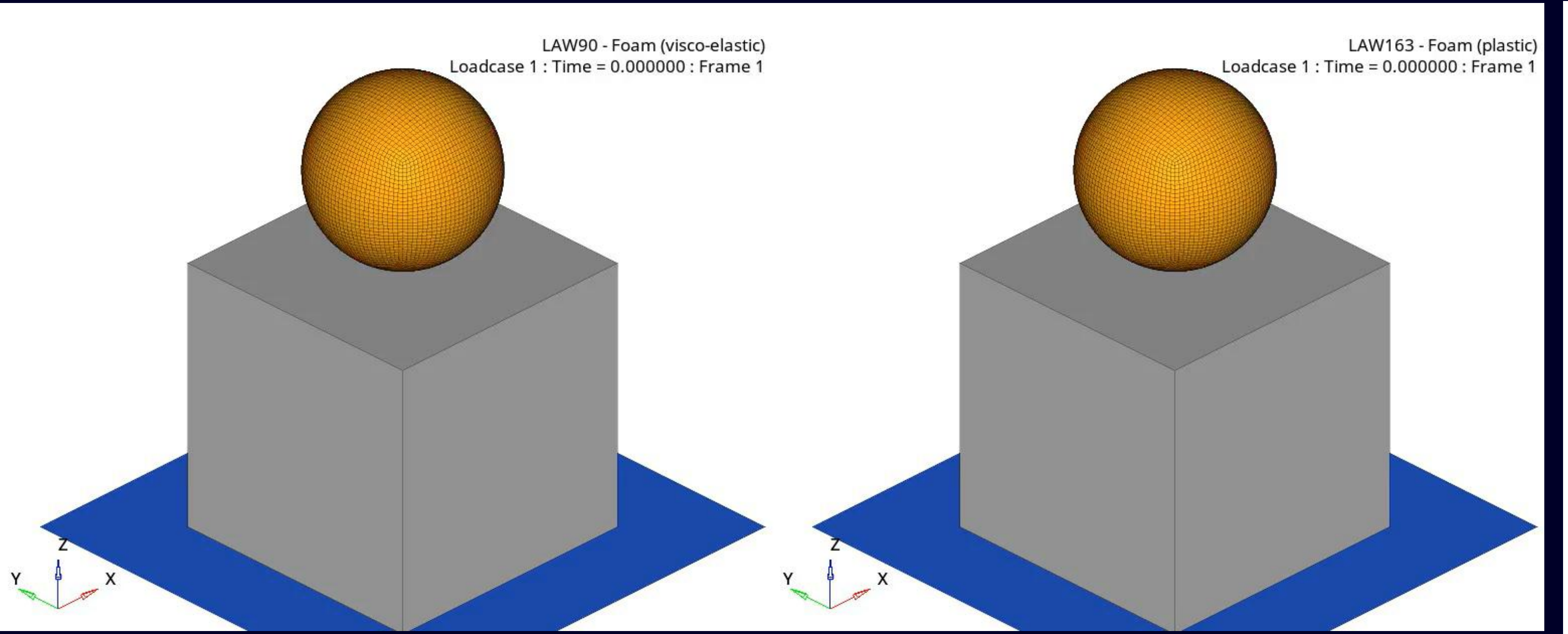



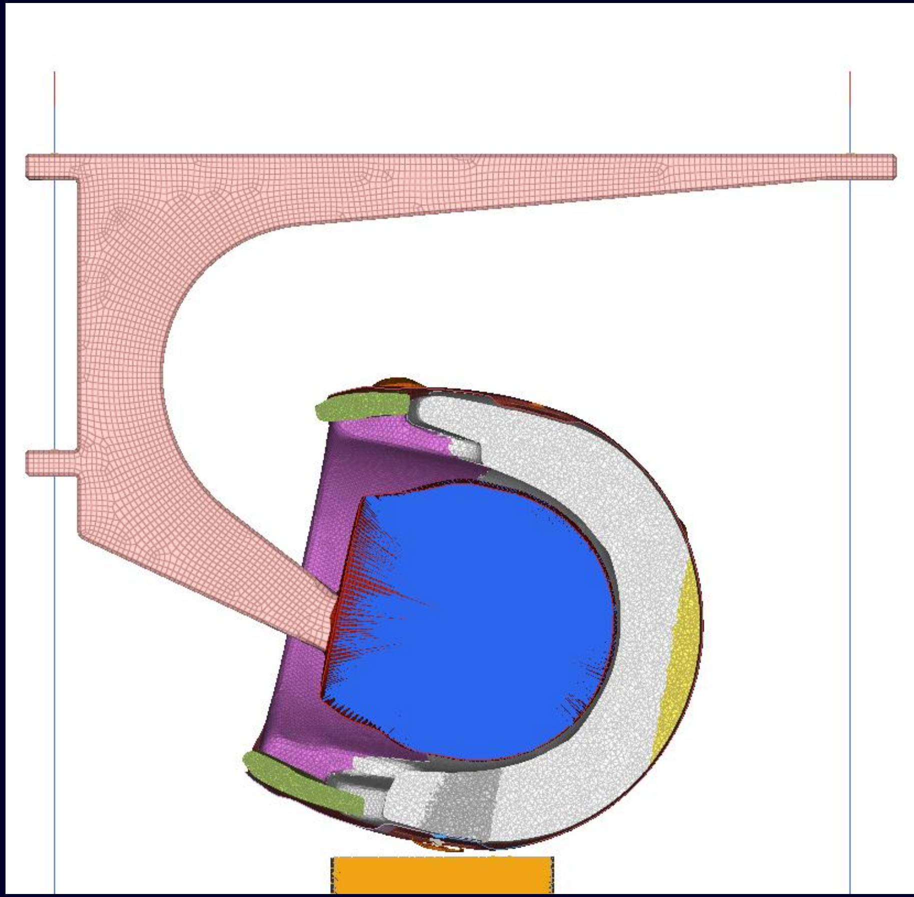



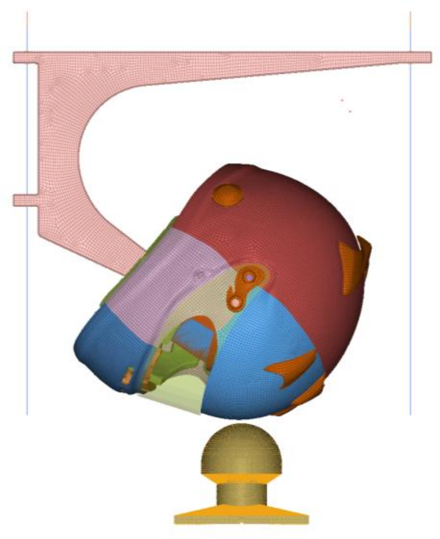

| Density | Test | Simulation - RADIOSS |
|---|---|---|
| 40 | 36 mm | 37 mm |
| 45 | 24 mm | 24 mm |
| 50 | 31 mm | 32 mm |
| 55 | 38 mm | 38 mm |
| 65 | 30 mm | 30 mm |
| 65 | 20 mm | 21 mm |
| 73 | 21 mm | 21 mm |
| 75 | 29 mm | 29 mm |

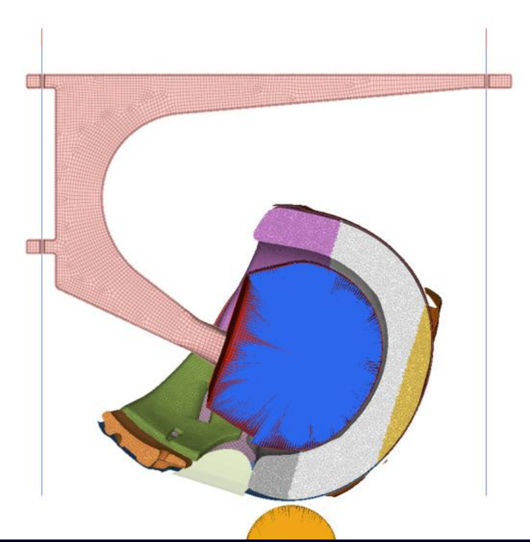
FAT AK-27 FOAM – Project results (Paul Du Bois)

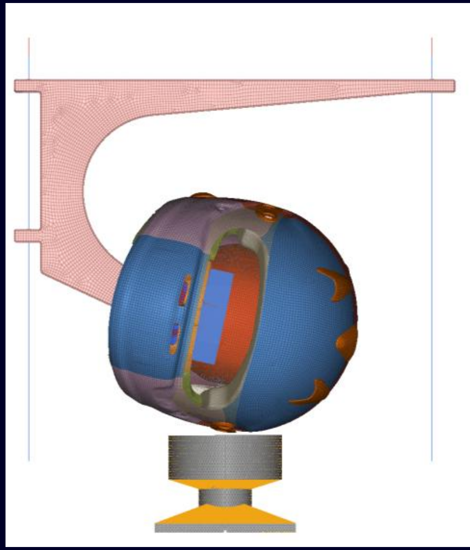
# Challenge: Modeling materials – Foam (plastic/crushable)











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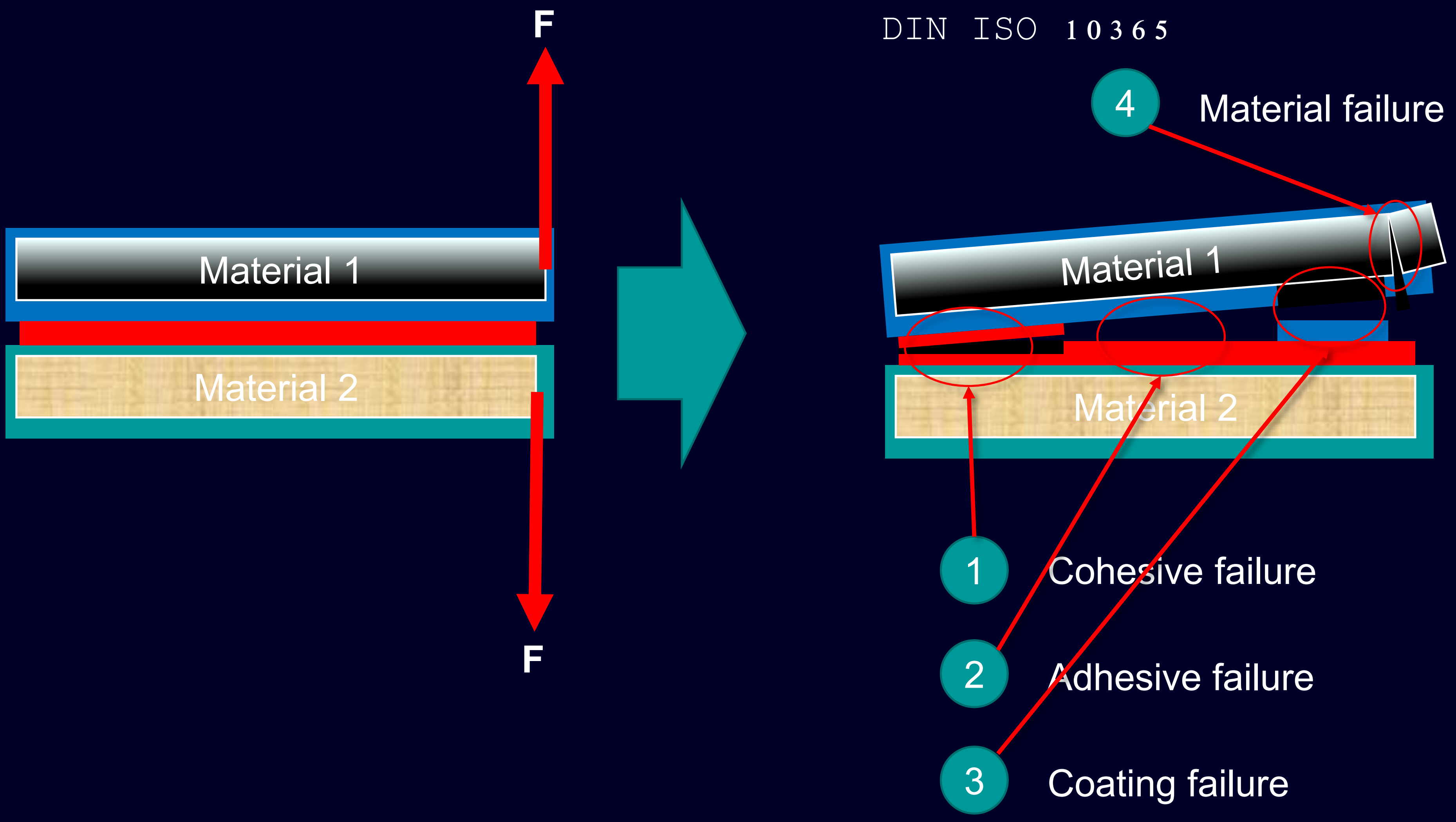
# Challenge: Modeling materials – Adhesives



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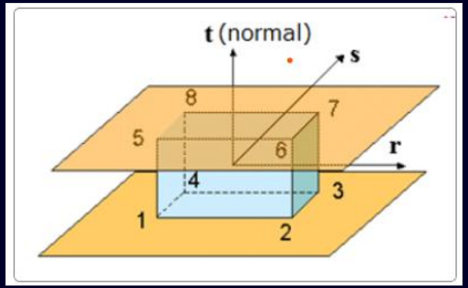
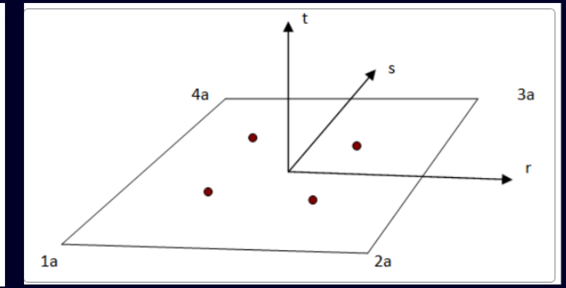
# Challenge: Modeling materials – Adhesives



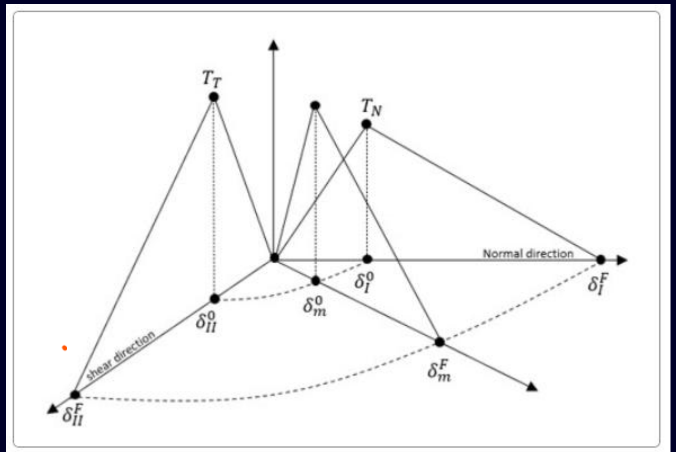




*Figure 1. Representative scheme of the mixed mode model*

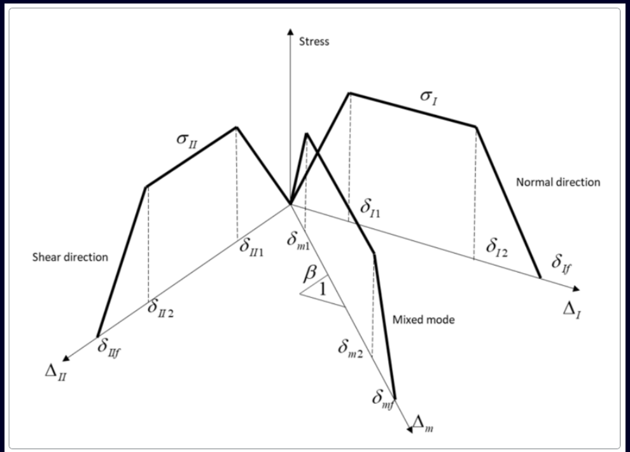
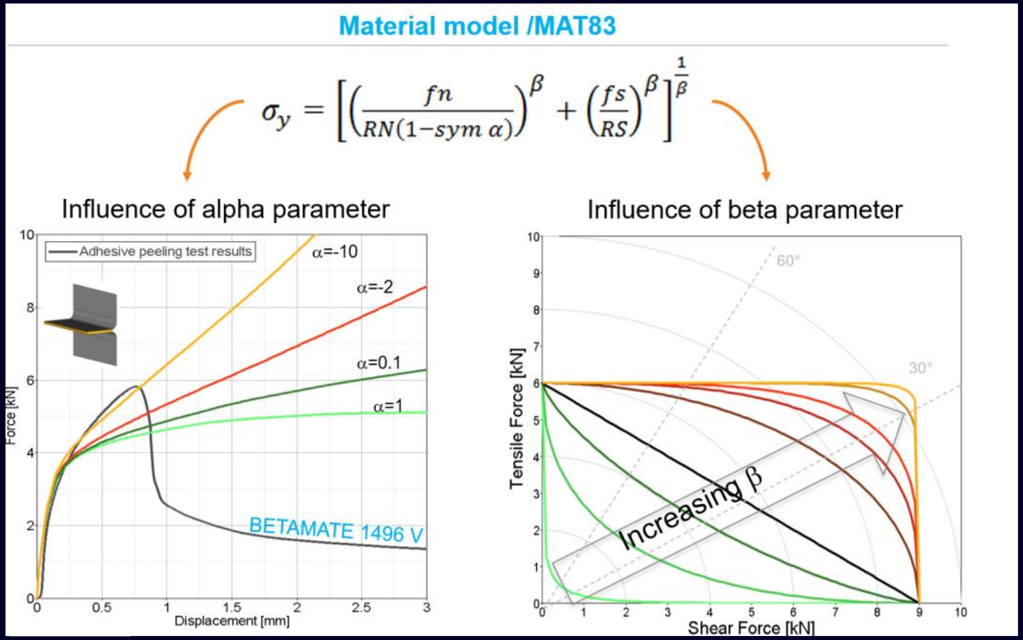
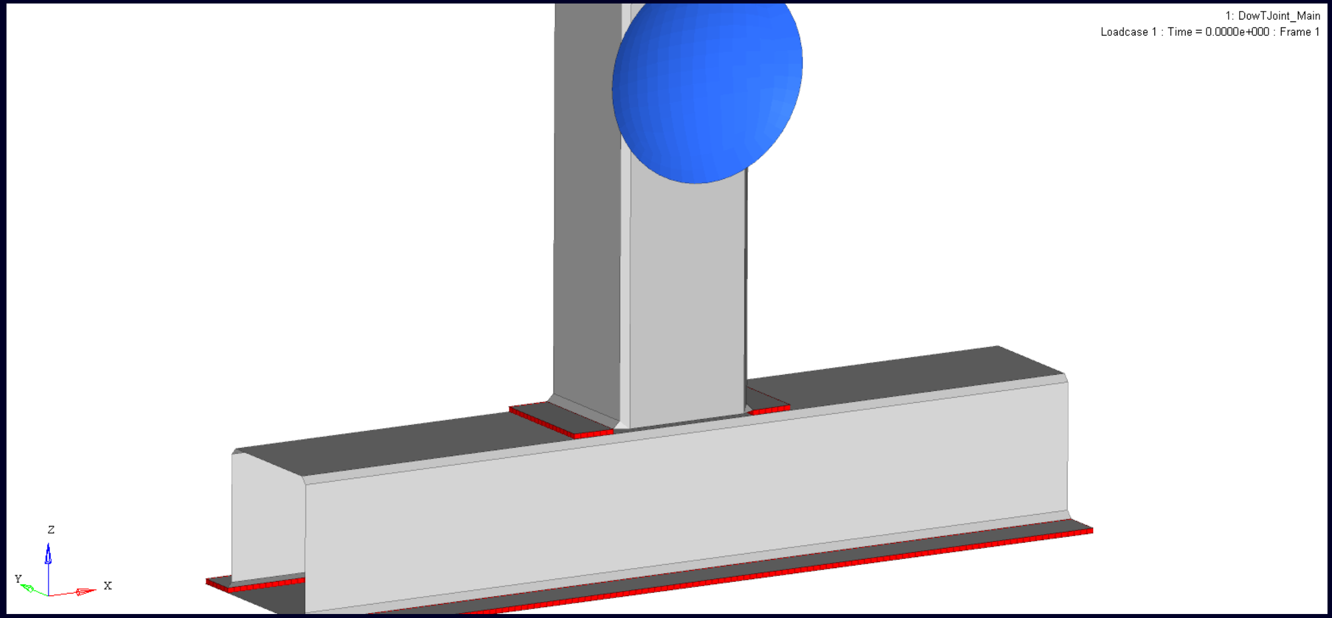



Figure 2.

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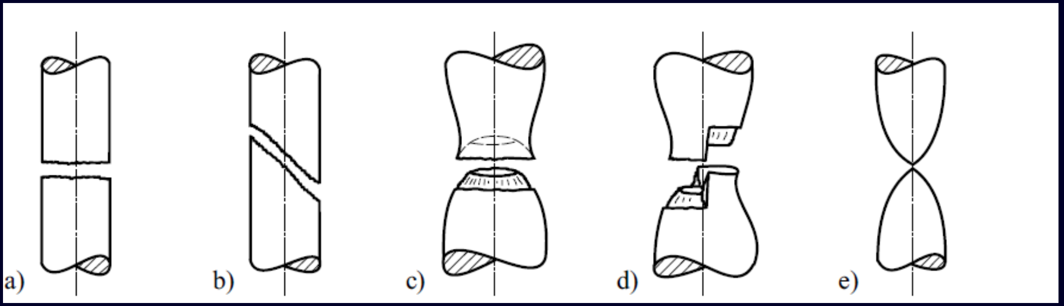
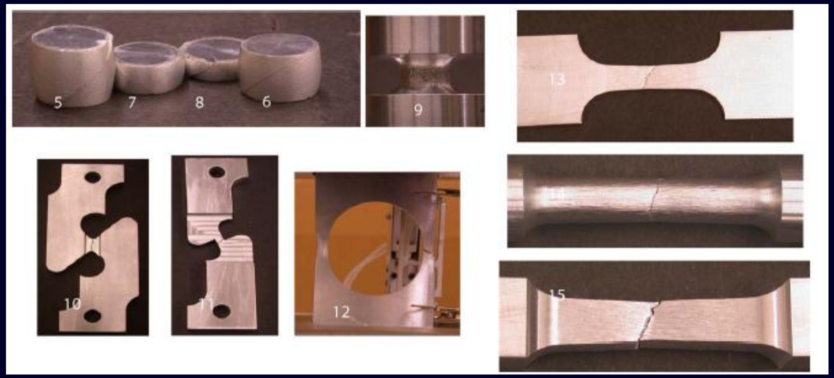
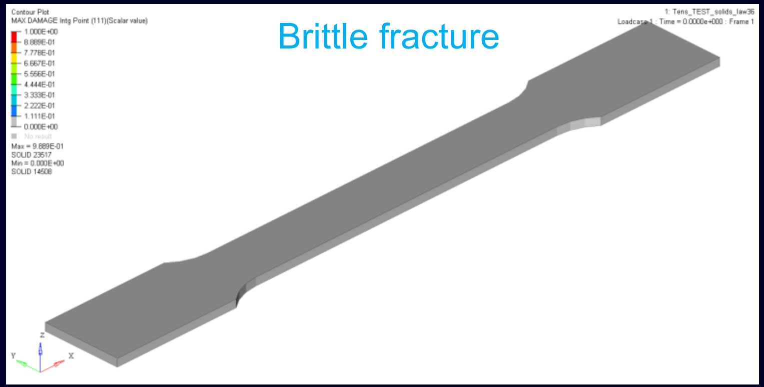
# Challenge: Modeling Failure criteria

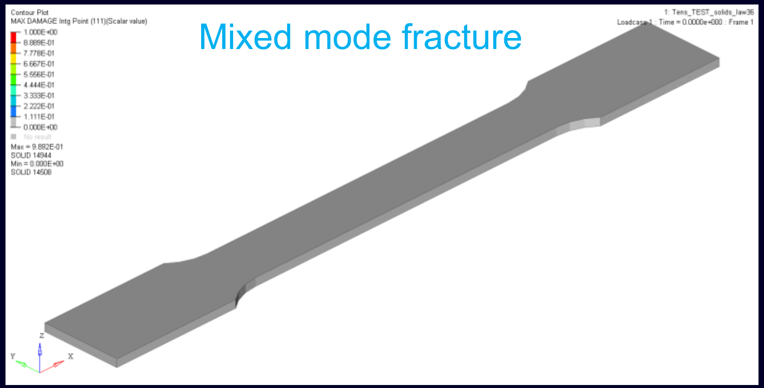
## Multiphysics … Nonlinear … up to Crash

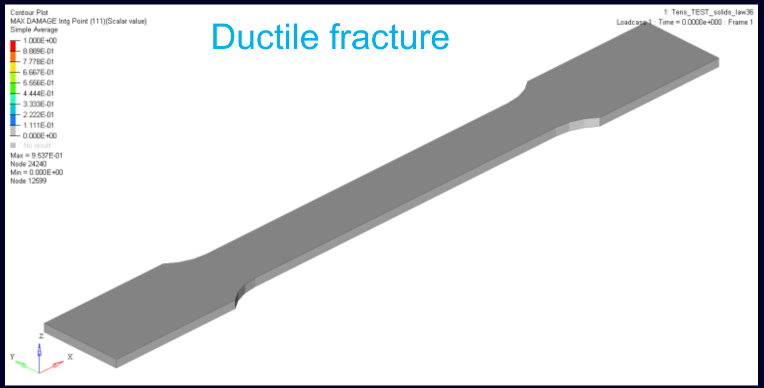



Different fracture modes:
a) Normal fracture b) shear fracture c+d) mixed mode fracture e) ductile fracture



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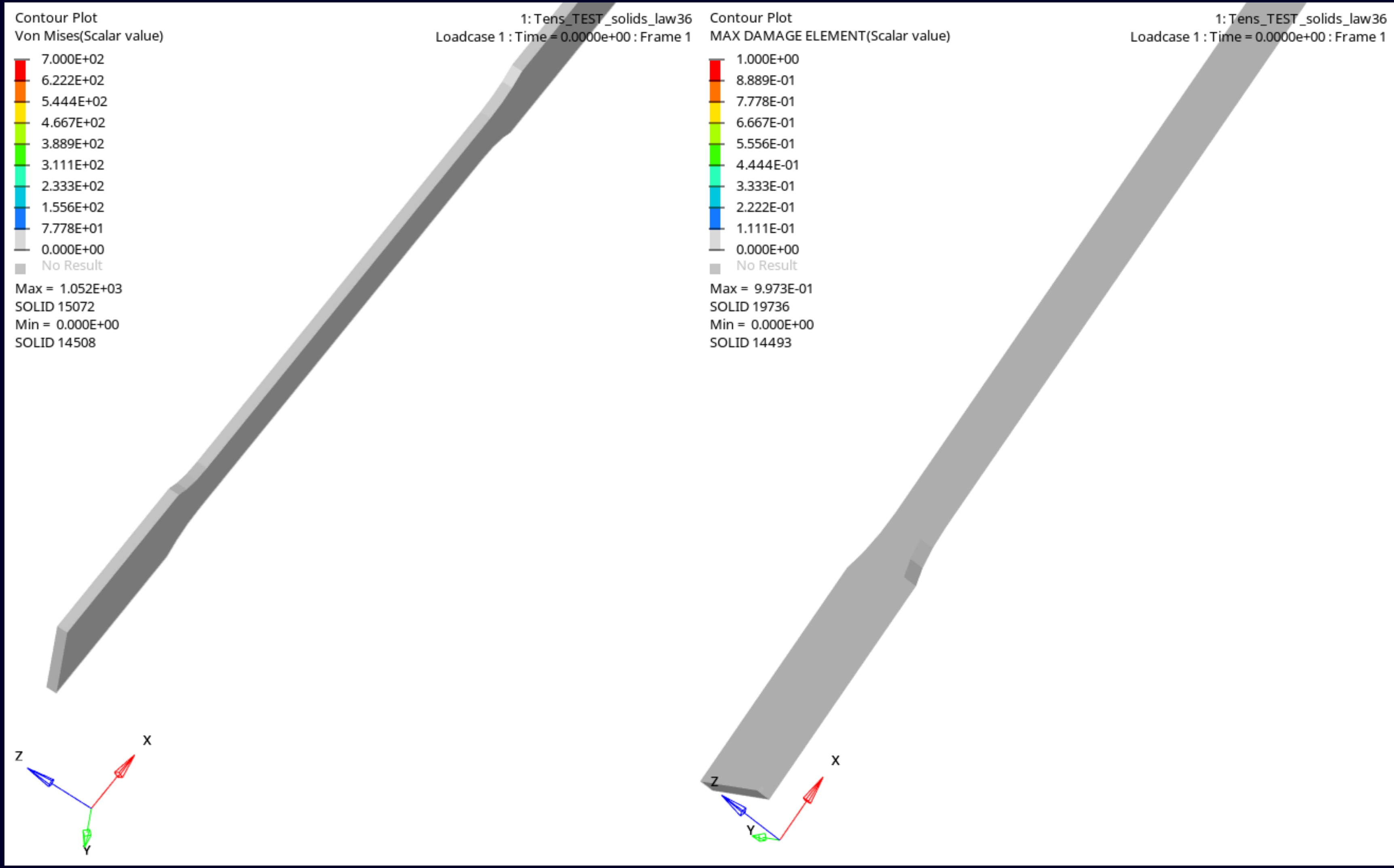
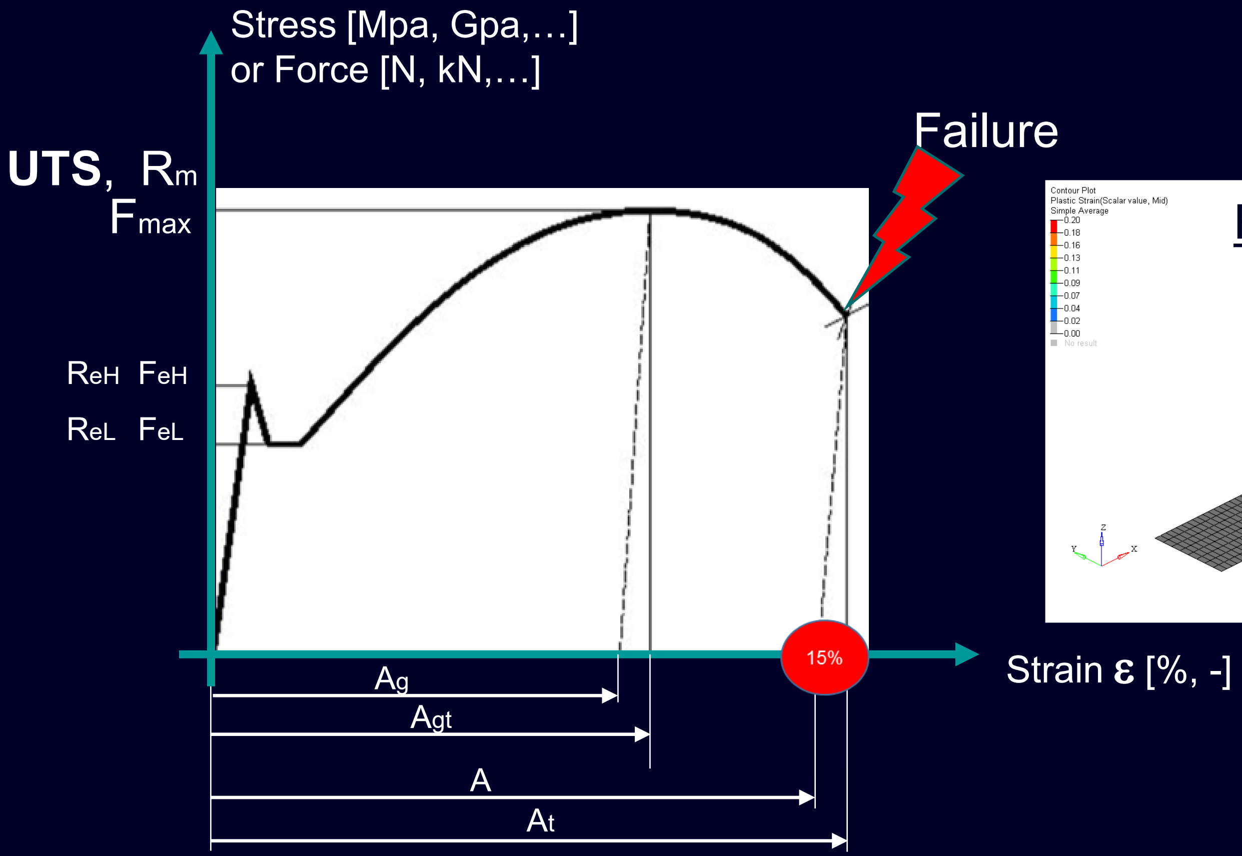
# Challenge: Modeling Failure criteria

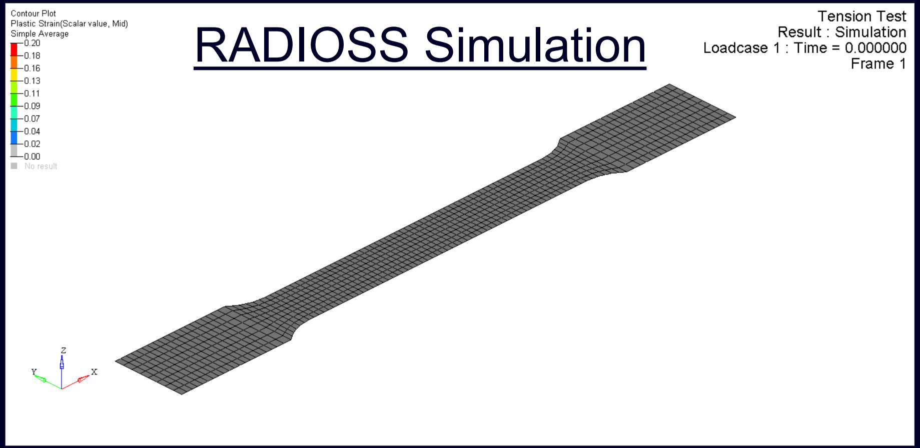
## More clear in 3-point-bending, where stress and strain and damage are visible



# Challenge: Modeling Failure criteria

**- Material tests**




| | |
|---|---|
| Ag | = Uniform elongation (before necking) |
| Agt | = Total uniform elongation |
| A | = Strain at failure |
| At | = Total strain at failure |



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# Challenge: Modeling Failure criteria

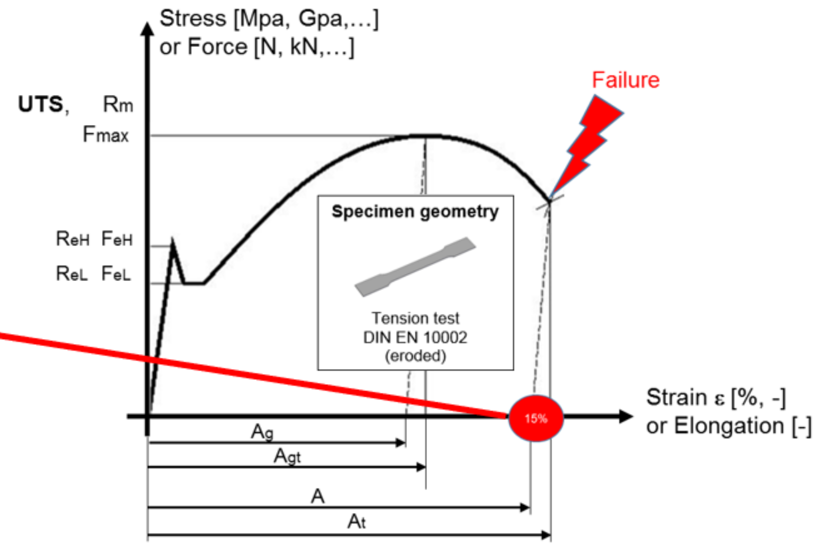
Correct treatment of failure, in non-linear simulations, plays an important role, for failure and damage prediction and post-failure strategies.

Classic (old) failure model: Element rupture at maximum equivalent plastic strain

\+ **Simple input**: Direct input of failure strain from uniaxial tensile test (no parameter fit needed)

\- **Bad results**: Flat line in the failure-strain-vs.-triaxiality diagram = not physical !

```
#---1----|----2----|----3----|----4----|----5----|----6----|----7----|----8----|----9----|---10----|
#-   2. MATERIALS:
#---1----|----2----|----3----|----4----|----5----|----6----|----7----|----8----|----9----|---10----|
#---1----|----2----|----3----|----4----|----5----|----6----|----7----|----8----|----9----|---10----|
/MAT/PLAS_TAB/2
DP600 from SSAB Homepage
#        Init. dens.          Ref. dens.
              7.8E-6                   0
#                  E                  Nu           Eps_p_max                Eps_t1              Eps_t2
                 210                  .3                 .15                     0                   0
#    Nfunc   Fsmooth               Chard                Fcut                 Eps_f
         1         1                   0                  10                     0
#    Ipfun             Fpscale
         0                   0
# Funtions
        14
# Scale factors
                   1
# Strain rates
                   0
#---1----|----2----|----3----|----4----|----5----|----6----|----7----|----8----|----9----|---10----|
```



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# Challenge: Modeling Failure criteria

## Theoretical background

**NEW** advanced failure criteria (BiQuad)

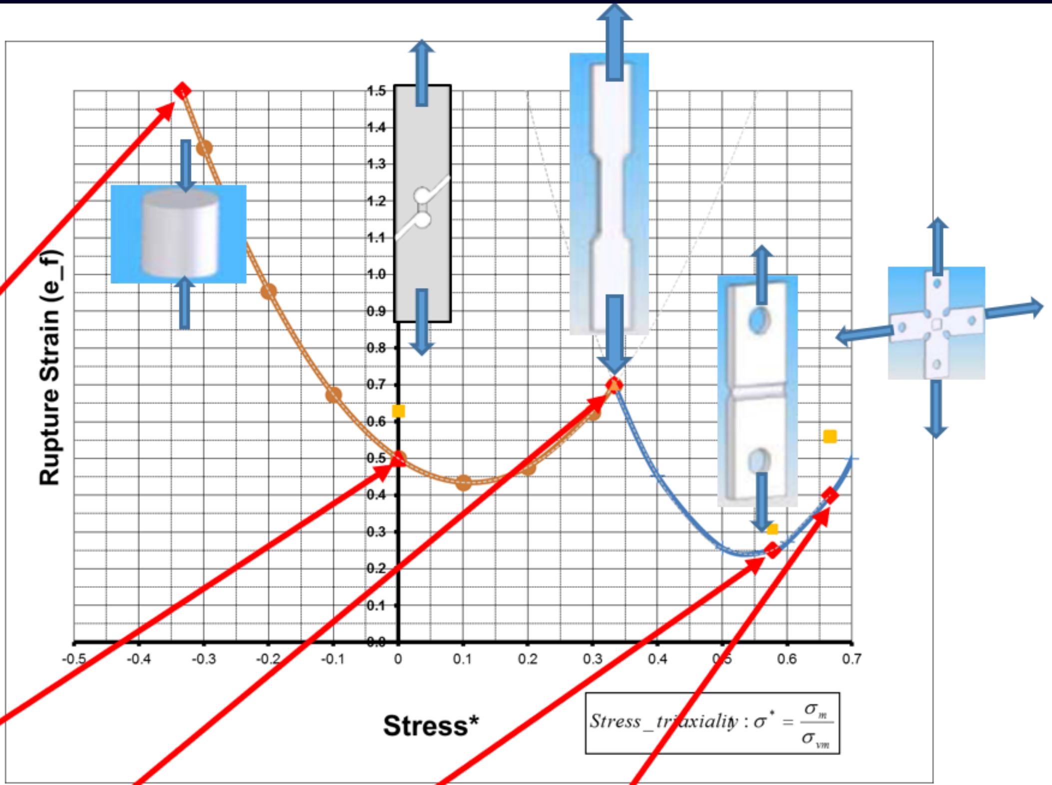
At least: **0 fitting parameters !**

**➔ Input of 5 physical values.**

**Input is directly done by failure strain at:**

- **Uniaxial Compression**
- **Pure Shear**
- **Uniaxial Tension**
- **Plain Strain**
- **Biaxial Tension**

**The parameter fit is done inside RADIOSS !**




```
#---1----|----2----|----3----|----4----|----5----|----6----|----7----|----8----|----9----|---10----|
/FAIL/BIQUAD/1
# New failure criteria: BIQUAD
#                  c1                  c2                  c3                  c4                  c5
                  1.5                 0.5                 0.7                0.25                 0.4
#        P_thickfail    Select    S_Flag
                  .0         1         0
#---1----|----2----|----3----|----4----|----5----|----6----|----7----|----8----|----9----|---10----|
```



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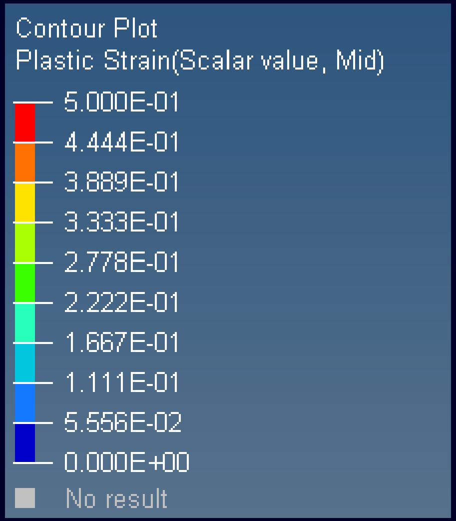
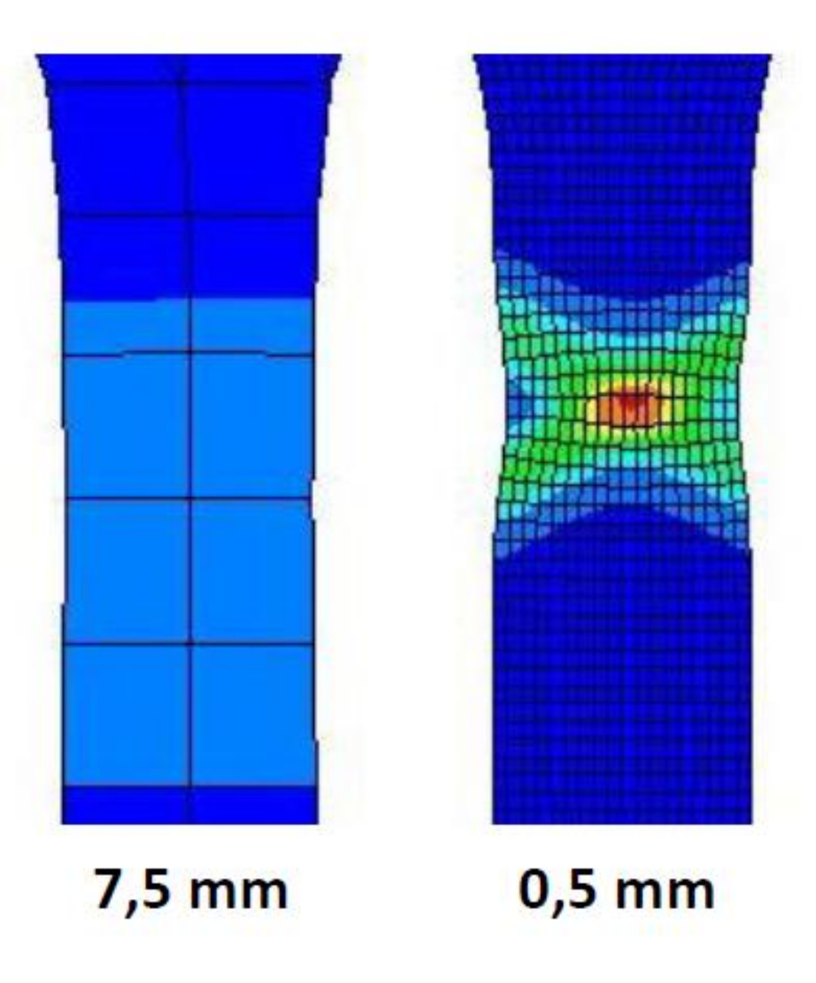
# Challenge: Modeling Failure criteria – Advanced Regularization



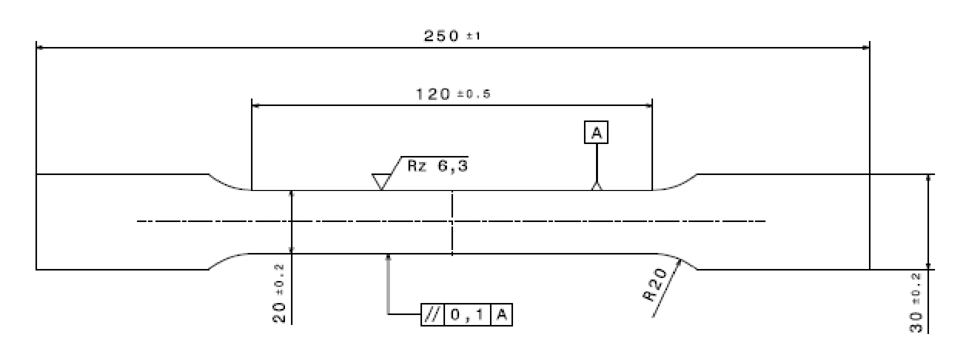



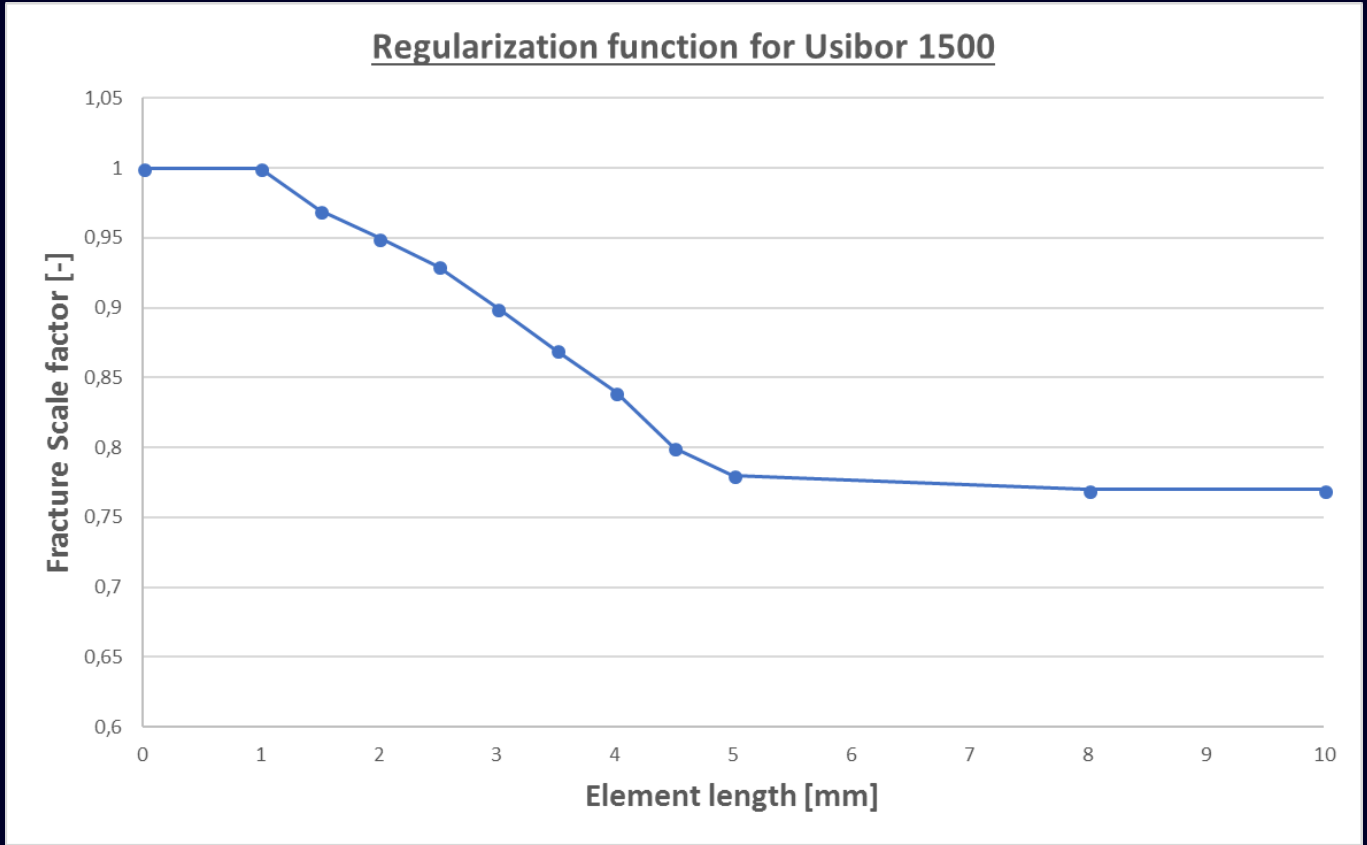

Bigger elements show
less strain at same global
Tension of the specimen,

Or: ***Smaller elements fail first !***

➔ Scaling needed

# Challenge: Modeling Failure criteria – Advanced Regularization




/FAIL/BiQUAD + Different mesh size: Regularization
1mm (used for material validation), 2mm, **5mm and 10mm element length**



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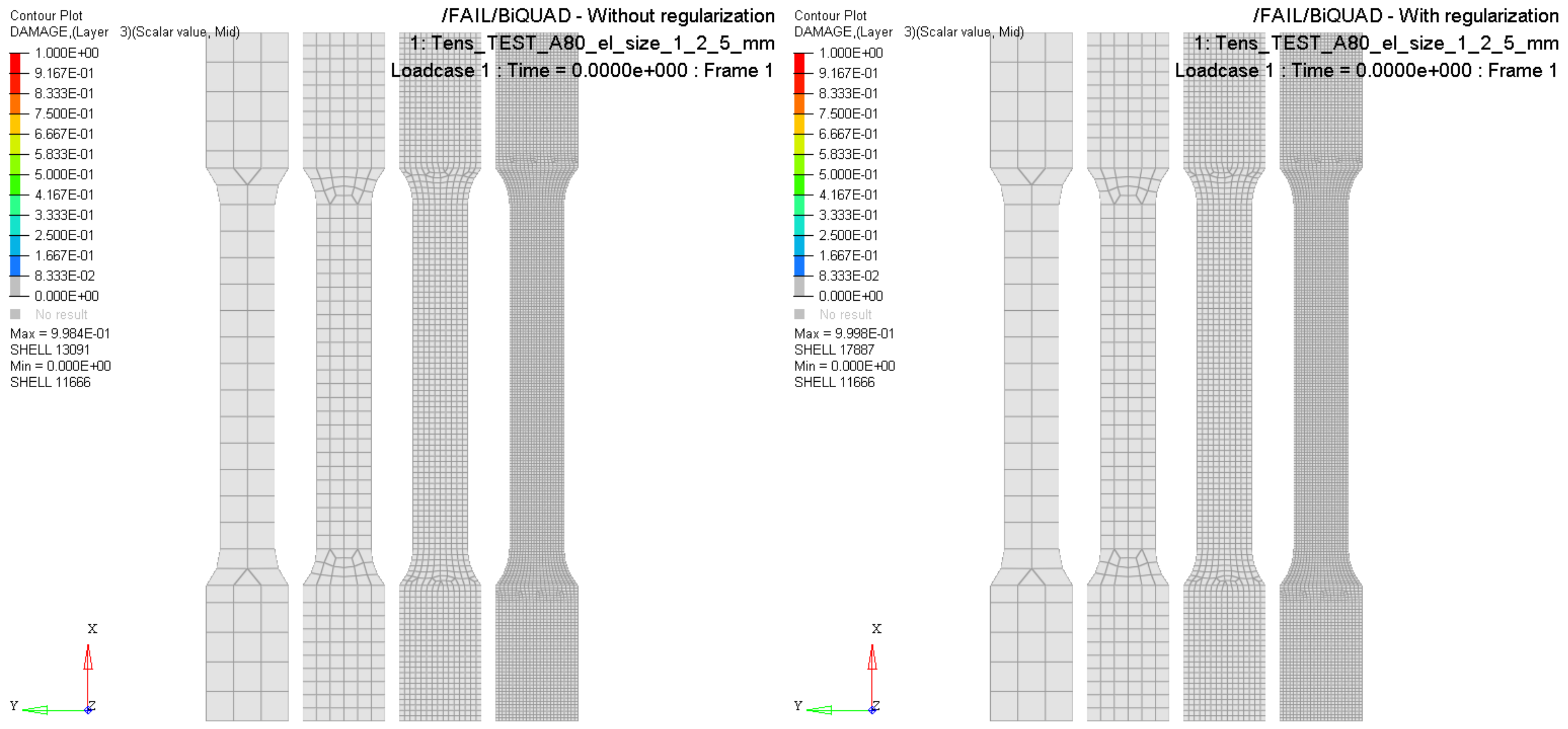
# Challenge: Modeling Failure criteria – Advanced Regularization

Results with /FAIL/BiQUAD + Different mesh size:

1mm, 2mm, **5mm an 10mm element length**




➔ Regularization works for tension ! But how about other load-cases (shear, compression,…) ?



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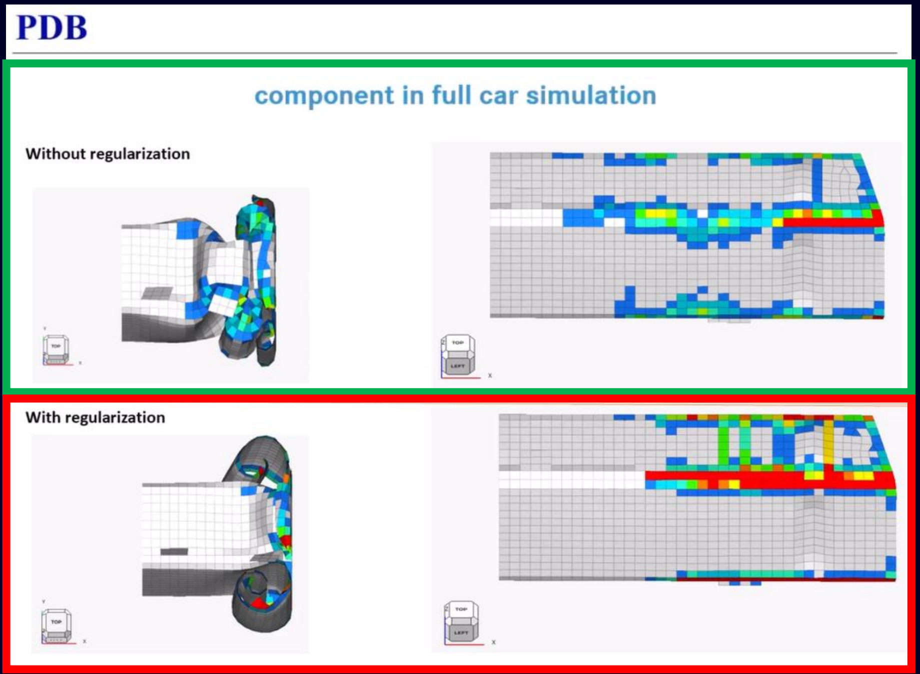
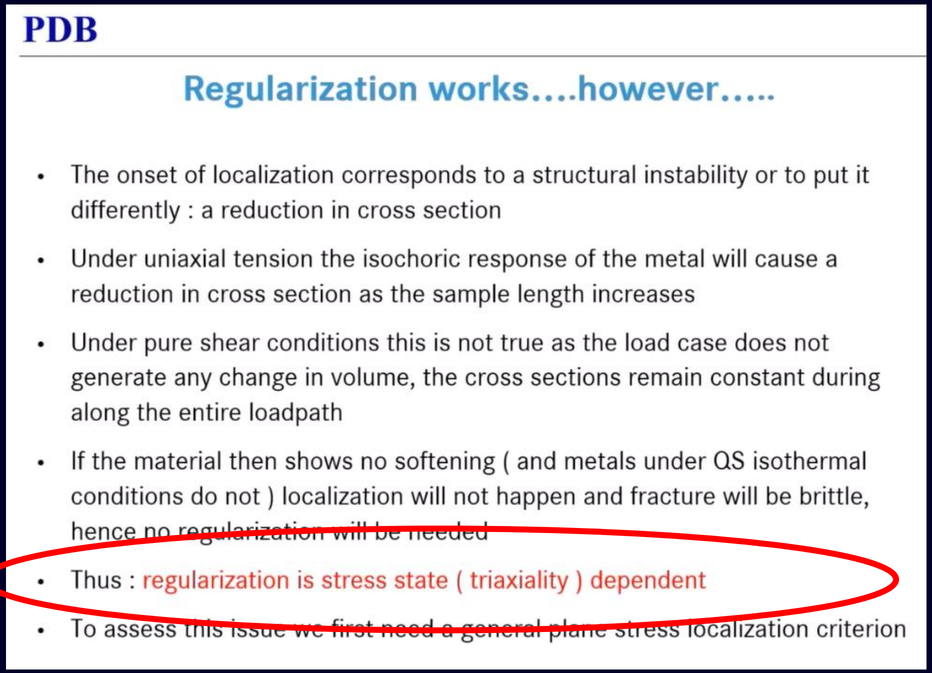
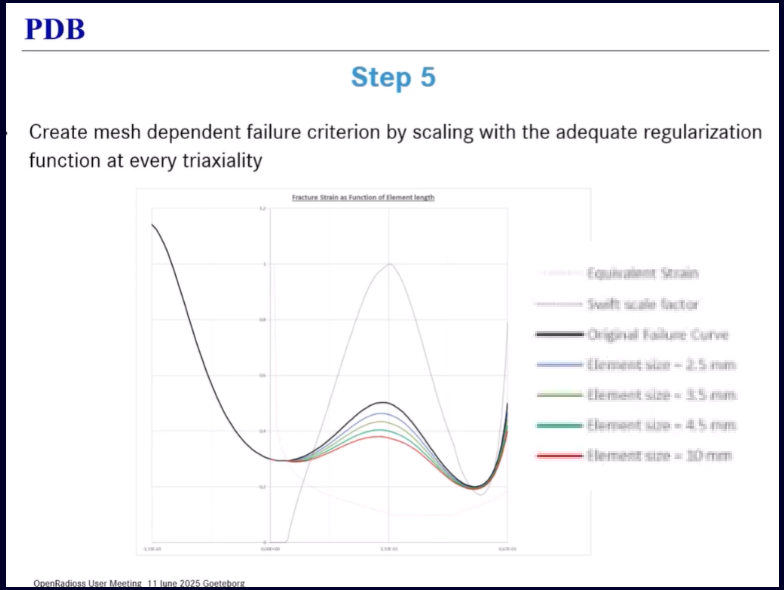
# Challenge: Modeling Failure criteria – Advanced Regularization

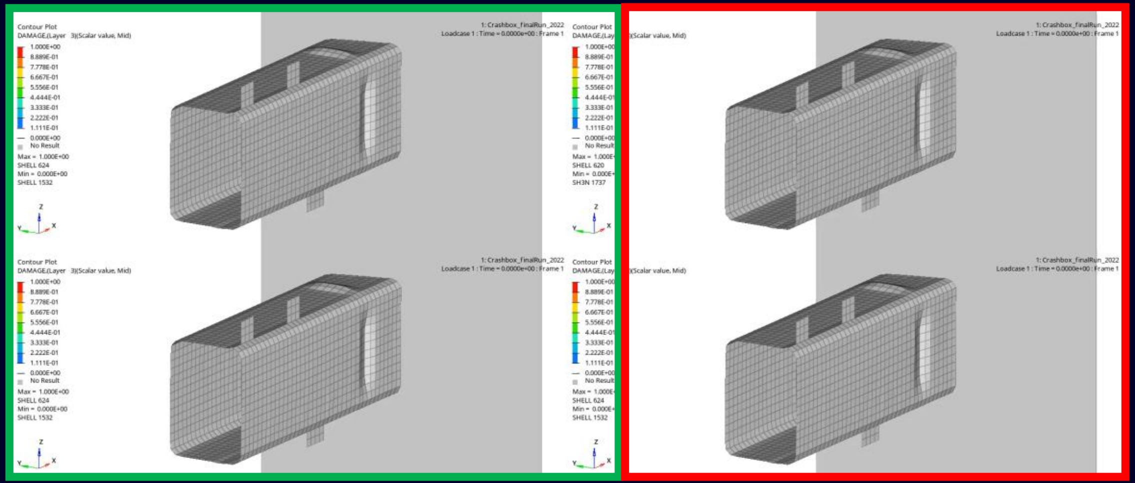




Source: https://openradioss.org/presentations-gothenburg110625/

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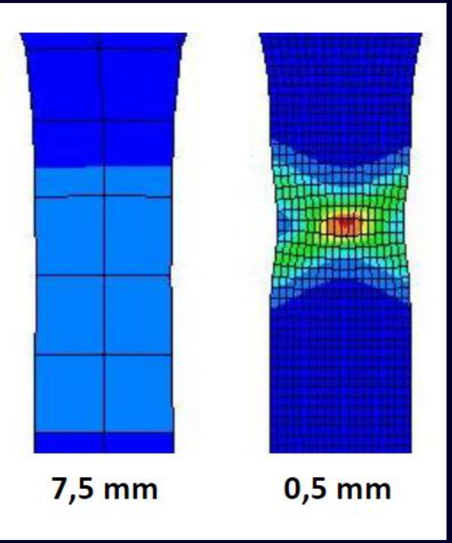
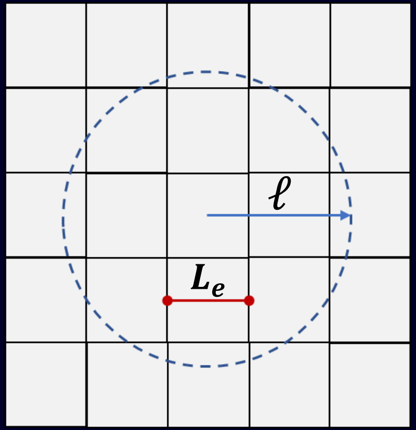
# Challenge: Modeling Failure criteria – Advanced Regularization + Non-Local

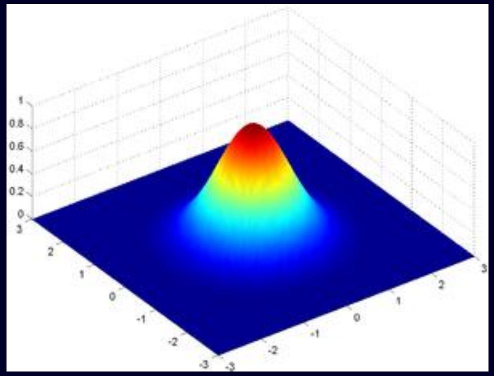
- **Non-local approach based on gradient in space,**
- **<u>Compatible with parallel computing and modular,</u>**
- **Automatic computation of internal length based on a geometric assumption:**



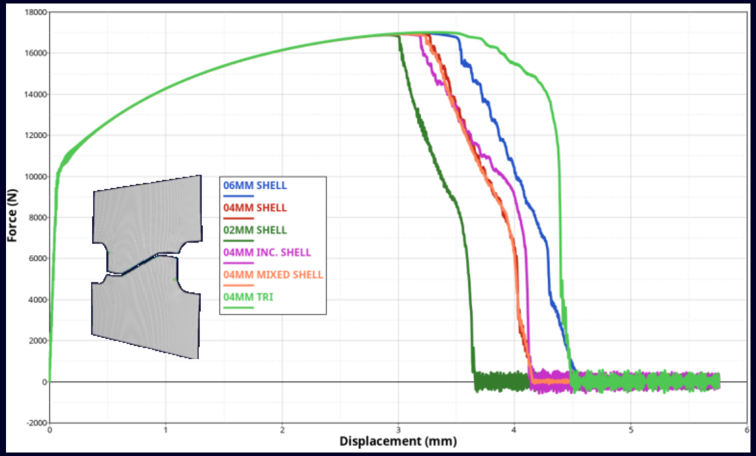

$$\ell = \frac{3L_e^{MAX}}{\sqrt{\pi}}$$



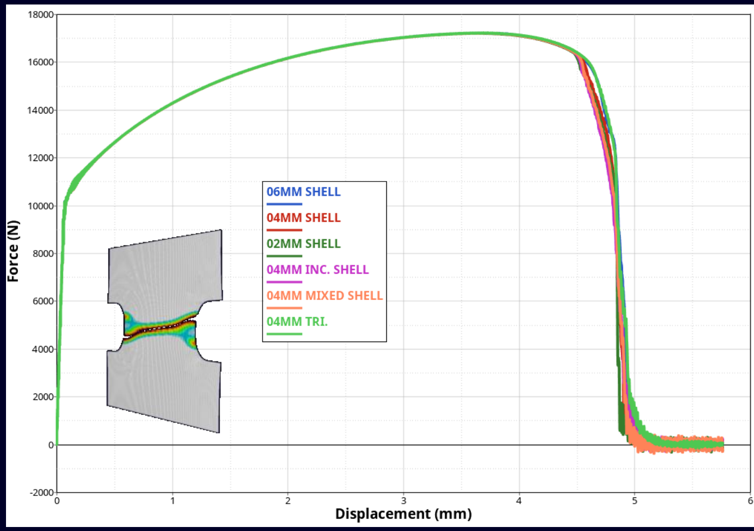

*Non-local regularization.*



*Non-local gaussian function.*




*Force – displacement curves <u>without</u> regularization.*




*Force – displacement curves <u>with</u> non-local regularization.*

Bigger elements show less strain at same global the same extension of the specimen !
Or: **Small elements fail first !**

Implemented in: Simcenter Radioss and **OpenRadioss**

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# Challenge: Modeling Failure criteria – Non-Local

## THREE POINTS STARTER CRACK TEST

Same parameters,

Two different mesh sizes : 0.5mm and 2mm.

- ✓ Same failure that occurs at the same time.

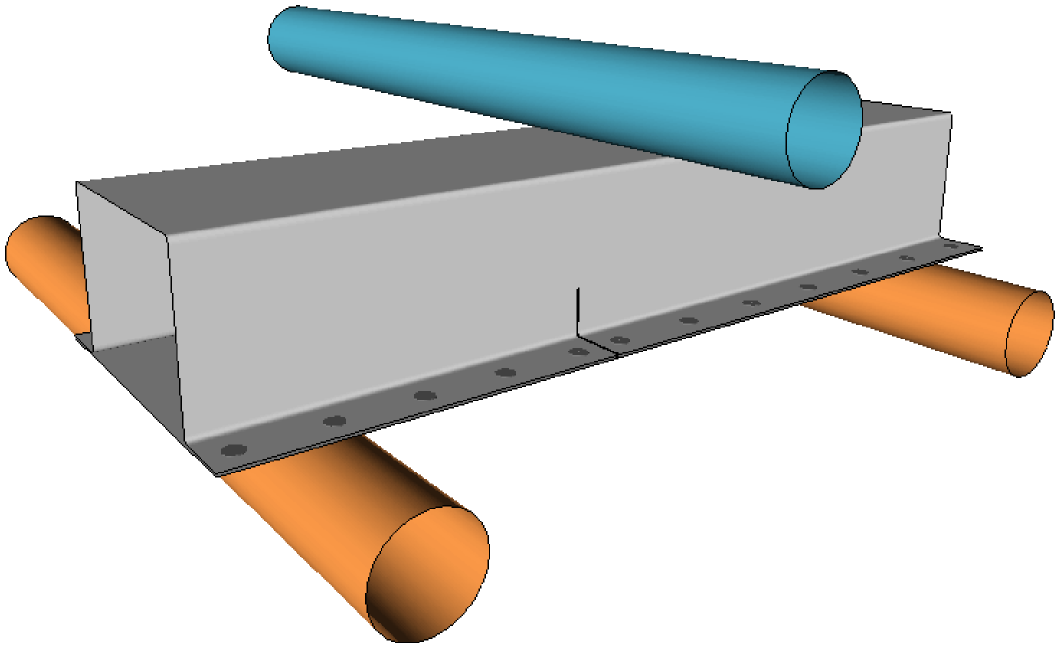

*Fig. 0.5mm mesh.*

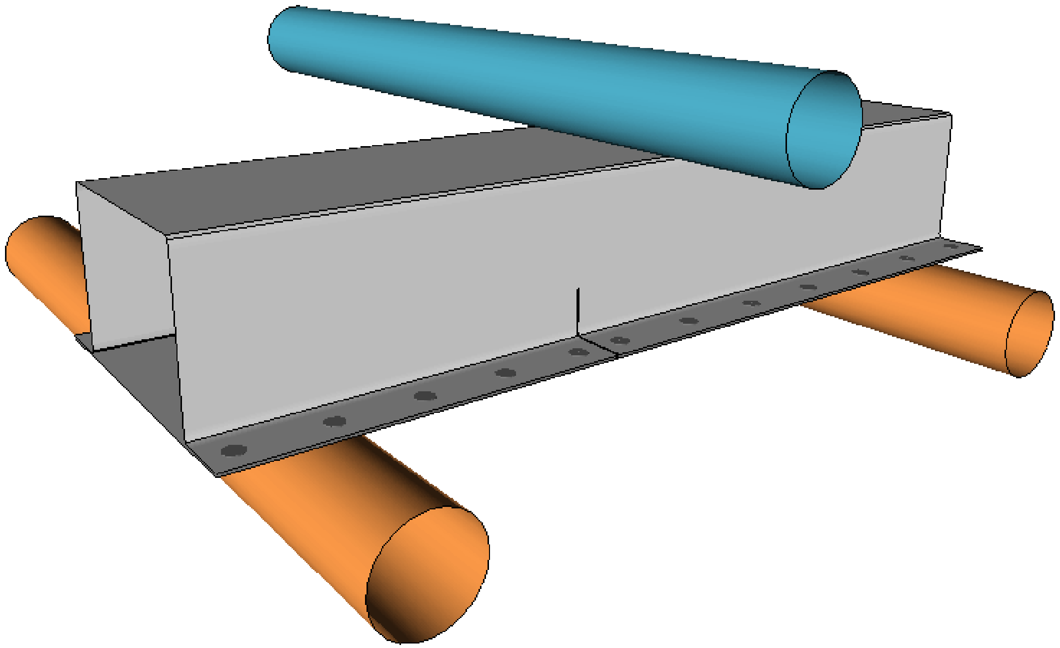

*Fig. 2mm mesh.*



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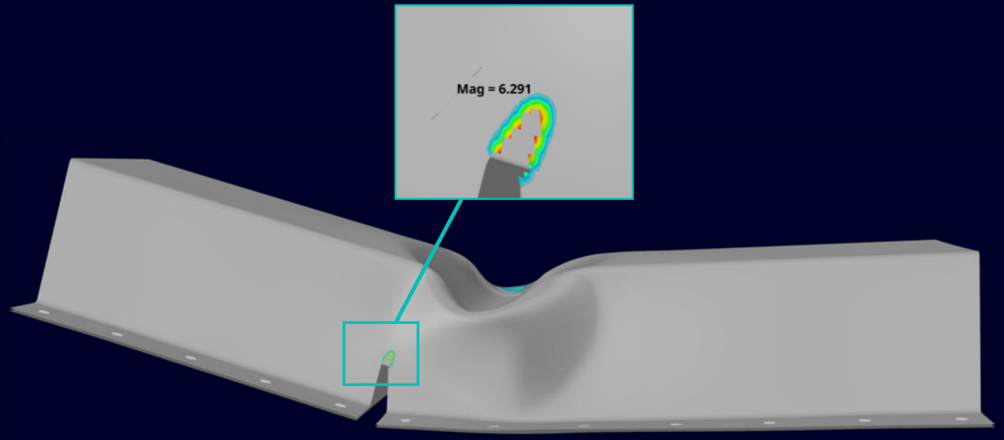
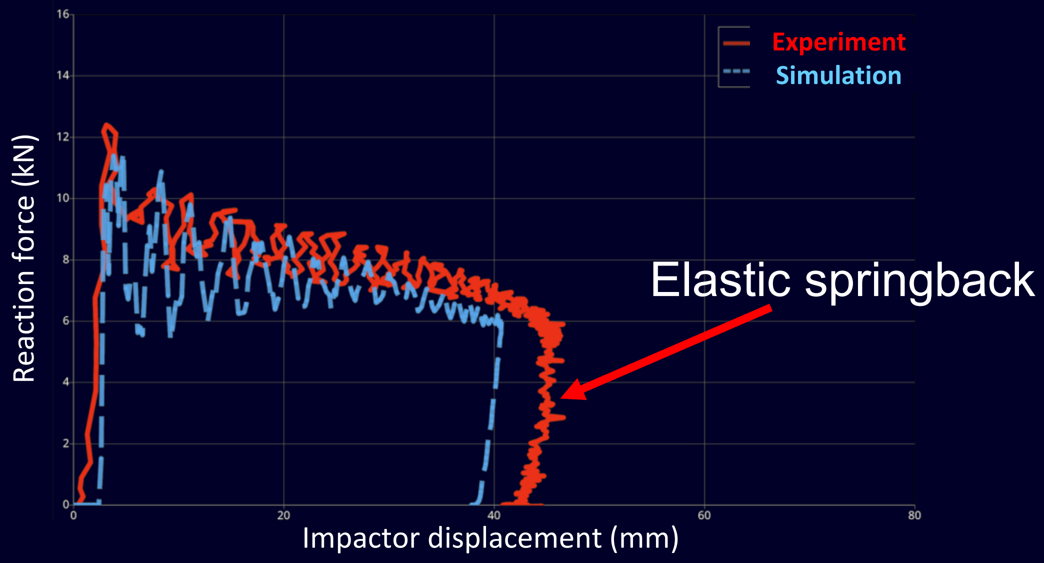
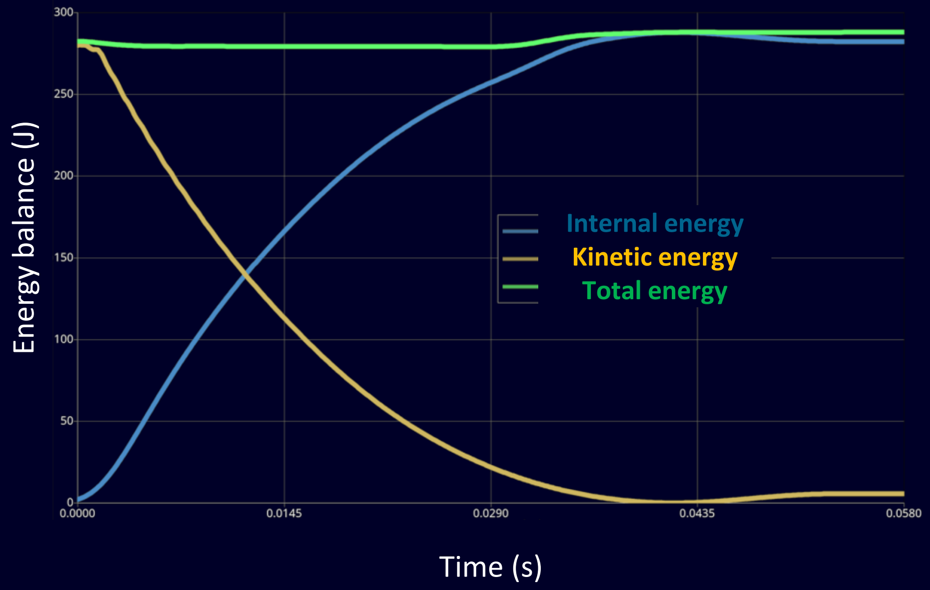
# Challenge: Modeling Failure criteria

- *Impact velocity 2.0 m/s – 282 J*

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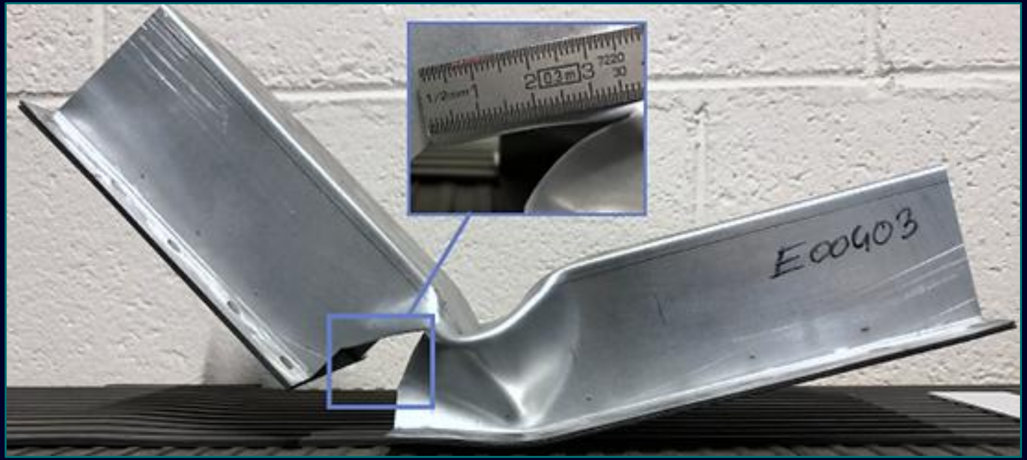
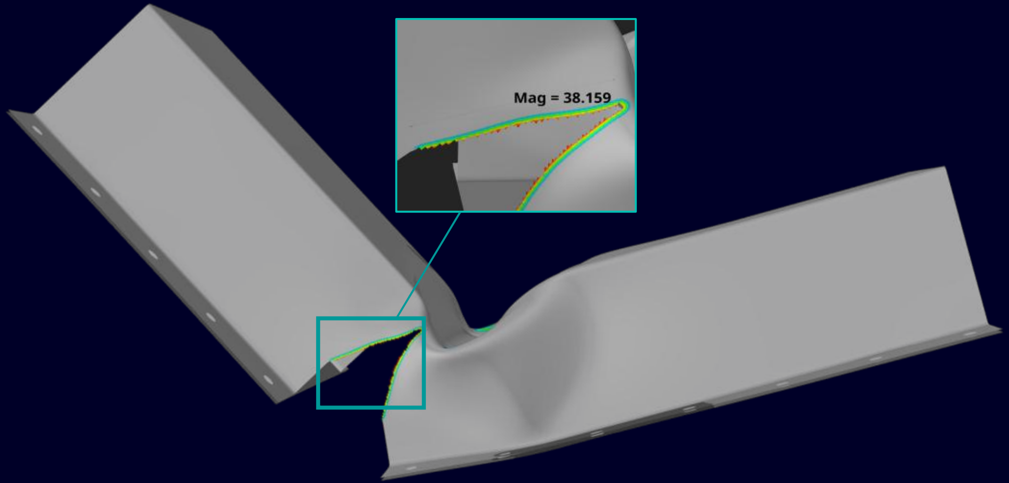
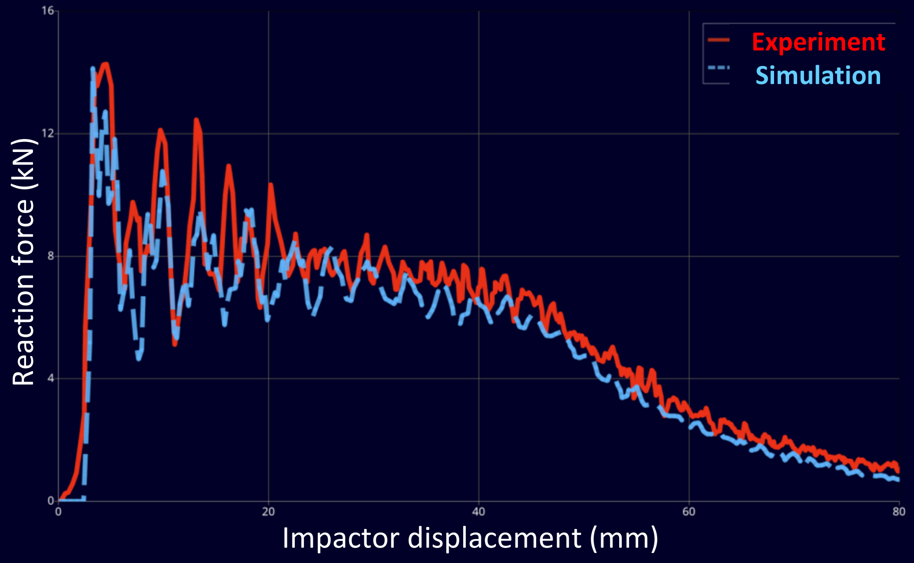
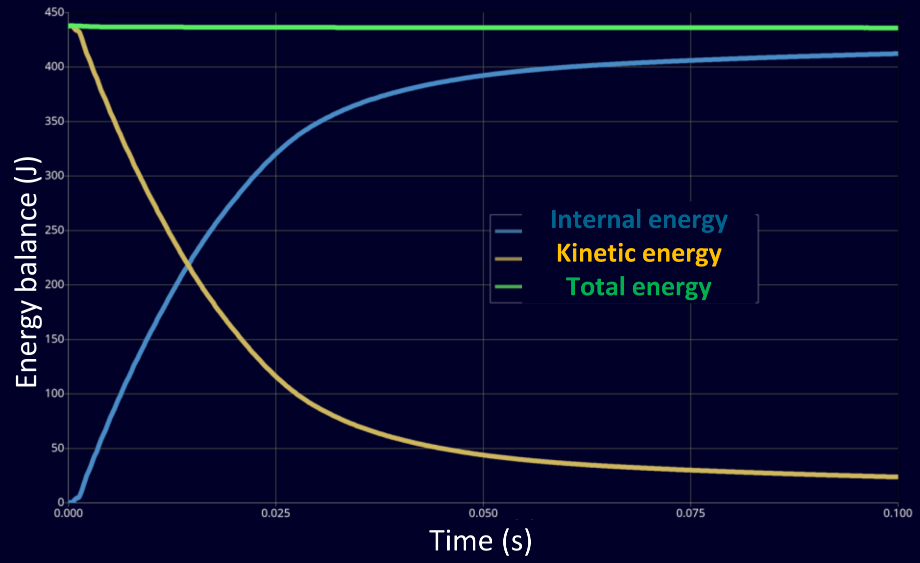
# Challenge: Modeling Failure criteria

- *Impact velocity 2.5 m/s – 441 J*





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# Challenge: Modeling Failure criteria

## THREE POINTS STARTER CRACK TEST

- Same parameters
- Two different mesh sizes : 0.5mm and 2mm.
  - ✓ Consistent with experimental results.

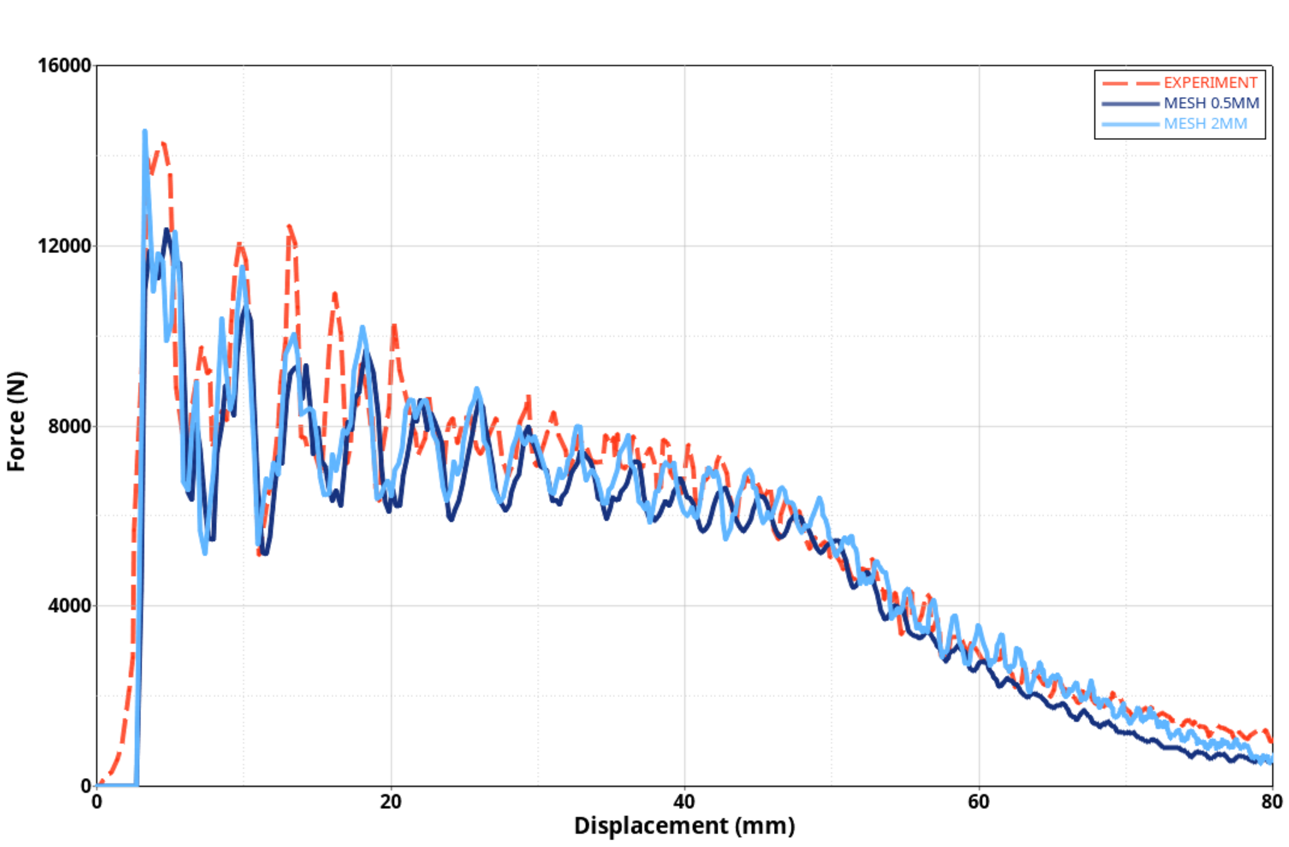
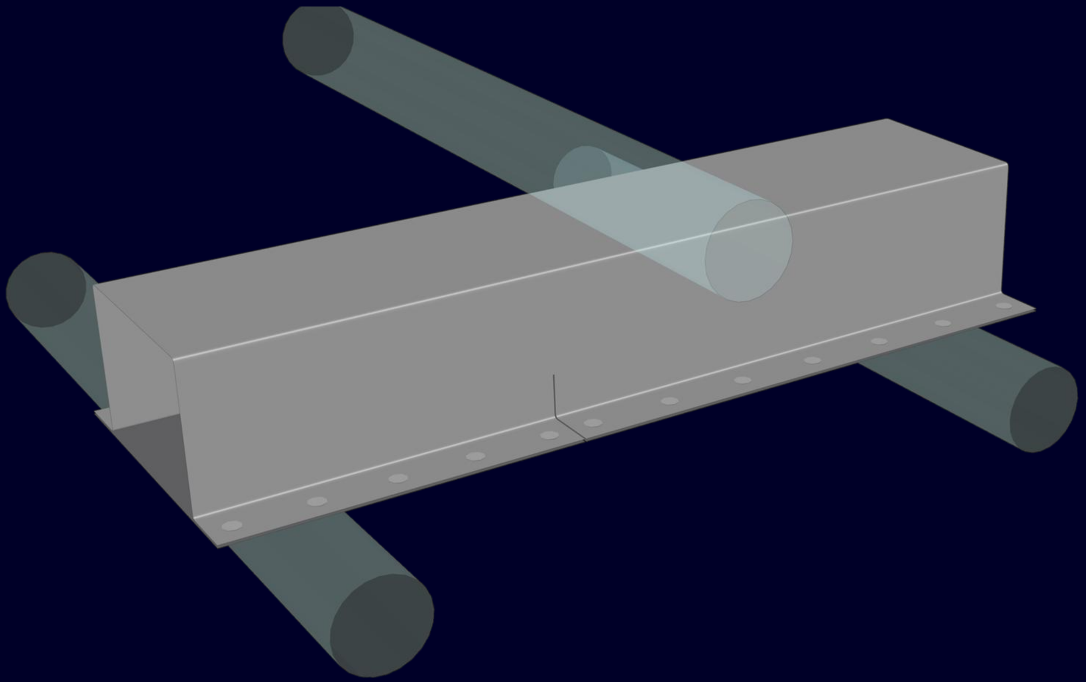



*Fig. Reaction force – impactor displacement curve.*





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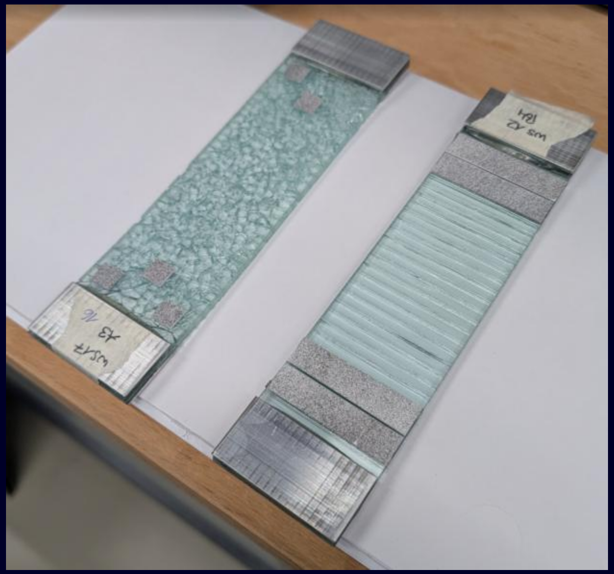
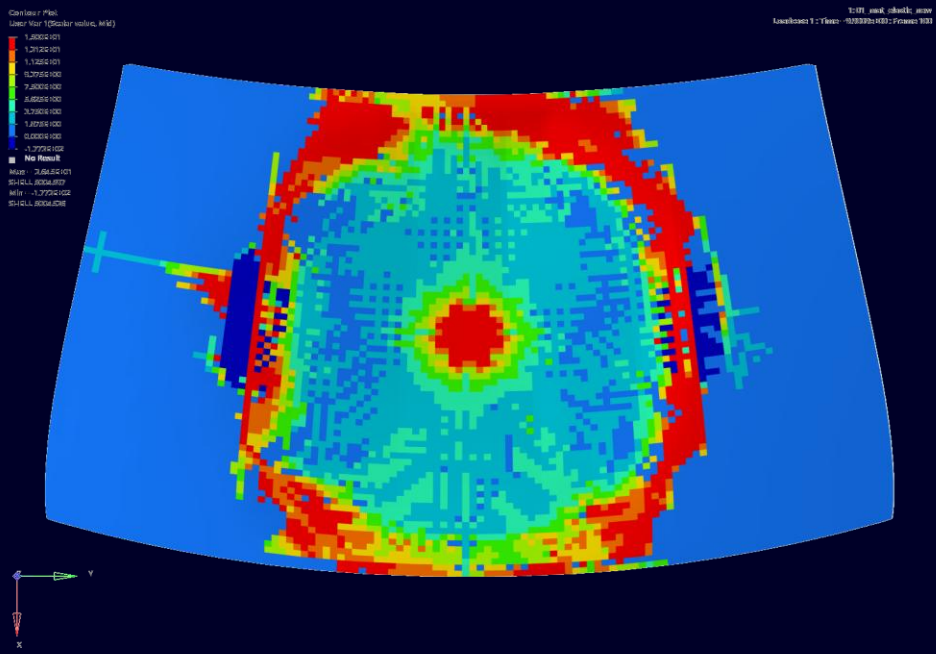
# Challenge: Modeling Failure criteria

- **Non-local modular approach compatible with industrial applications,**
- **Method used or considered at short term by several partners and customers,**
- **OpenRadioss, partnership driver:** *Institute for Mechanics and Materials, THM University of Applied Sciences*
- ➔ ***/FAIL/ALTER***





*Extension of non-local method to windshield failure with OpenRadioss (Institute for Mechanics and Materials).*

**➔ The next BIG Challenge !**



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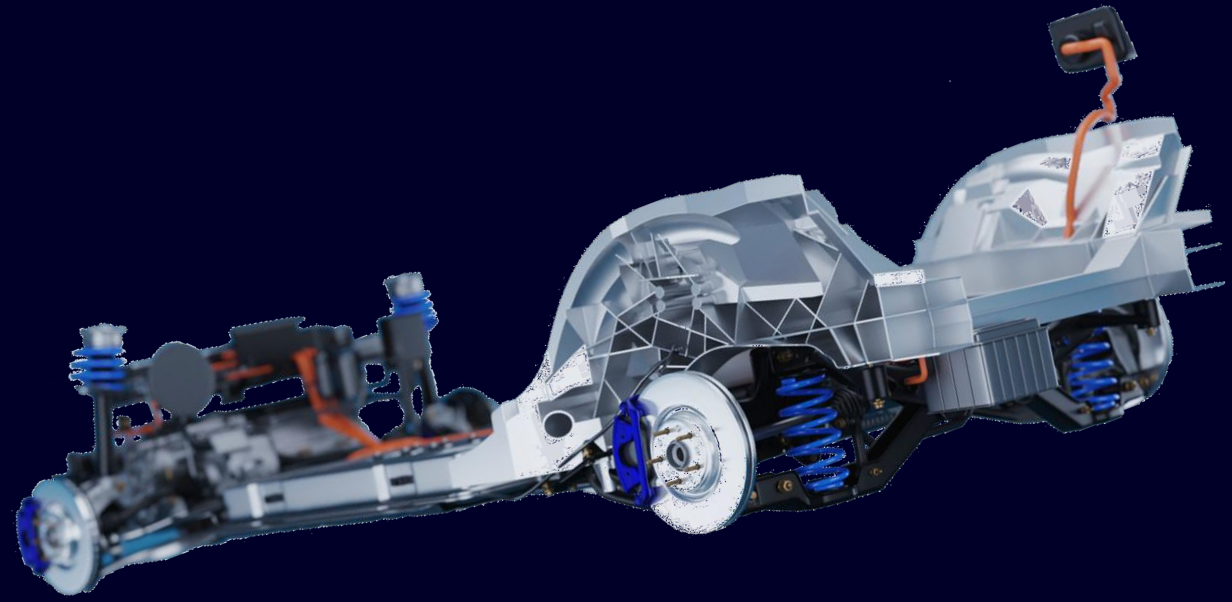
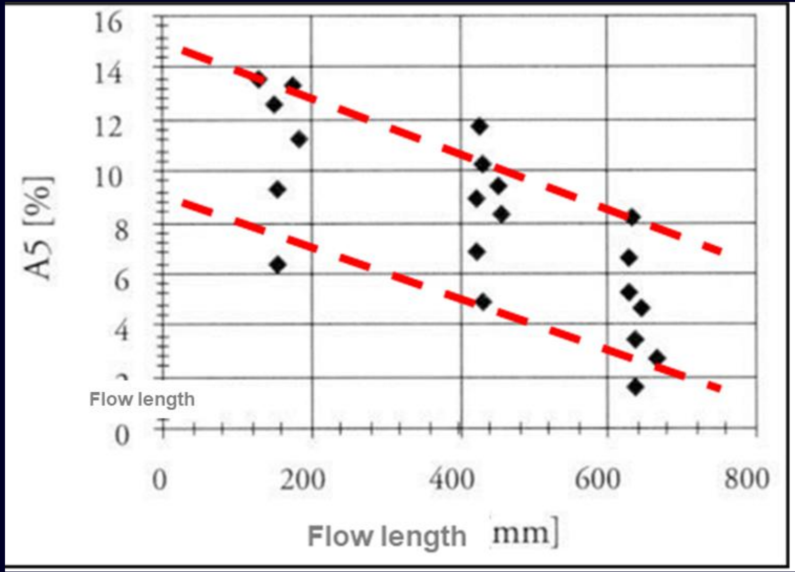
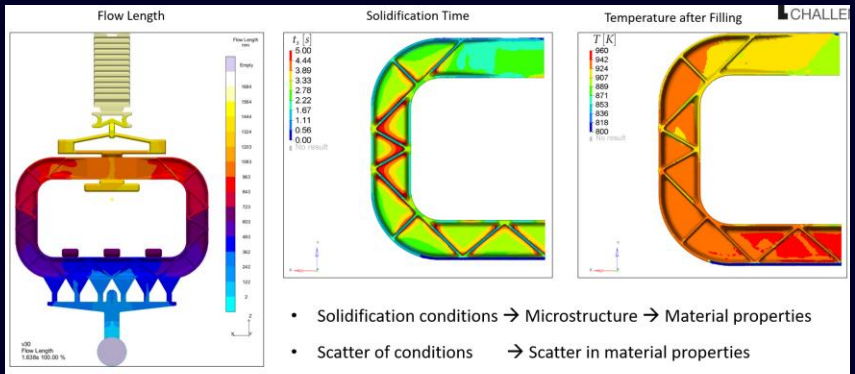
# Challenge: Modeling of cast material (Large Cast Parts)



Source: Dr.-Ing. Moritz Frenzel / Euroguss **2024**




Failure strain reduction of ~ **50%** for 200 – 600 mm flow length




- Solidification conditions → Microstructure → Material properties
- Scatter of conditions → Scatter in material properties

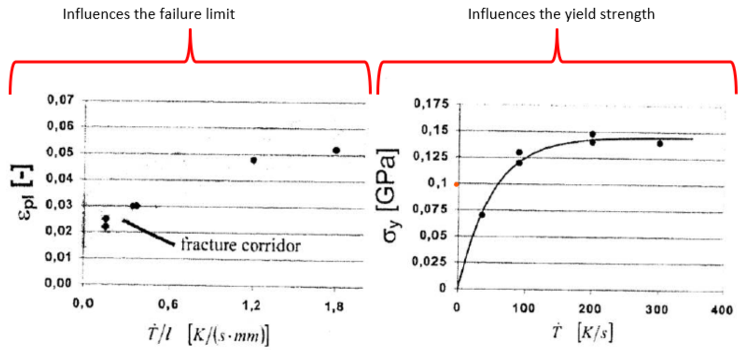



**Figure 3.** Simple correlation of casting conditions and mechanical properties

➔ Need for adjustments of the material behavior….locally at element (Integration Point) level

➔ Mapping from a casting simulation to a crash model

Source: PhD Thesis: David Funke 2023: https://publications.rwth-aachen.de/record/956682

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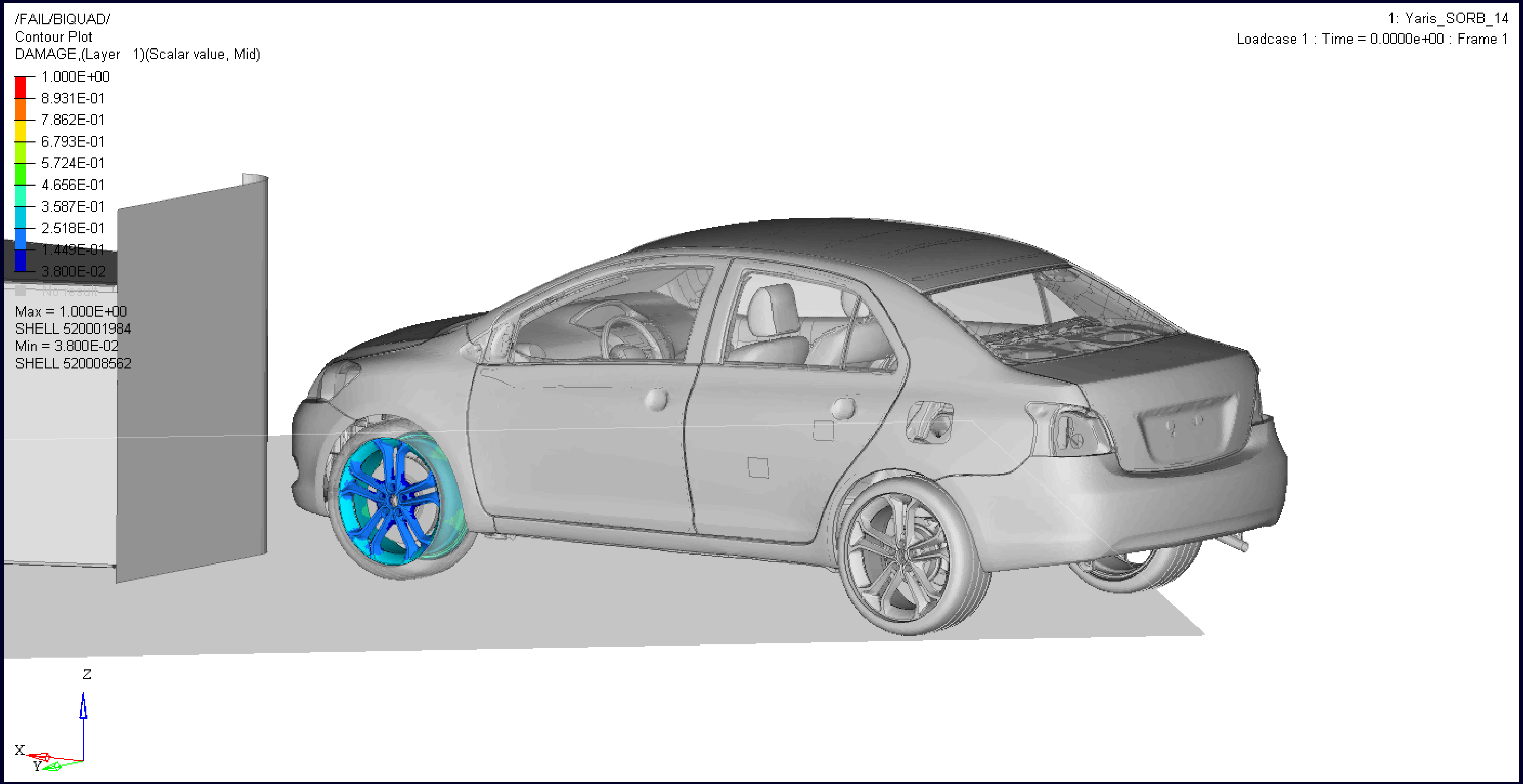
# Challenge: Mapping of casting results to crash



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# Challenge: E-Mobility – Li-Ion Battery

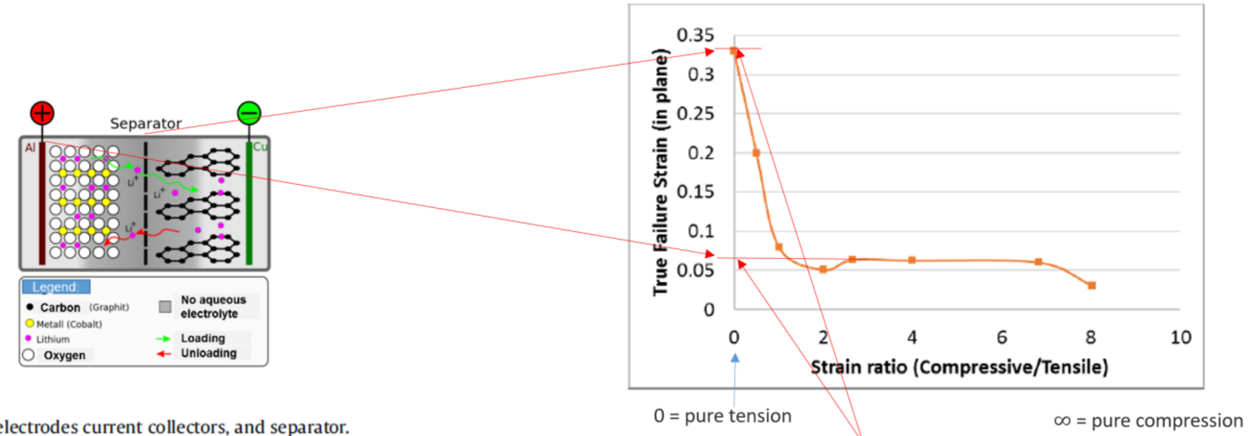
The **Sahraei failure model /FAIL/SAHRAEI** is an orthotropic failure mode, which uses the failure strain versus the strain ratio (Compression/Tension).

It is designed to be used for prediction of short circuit in electric batteries.

Developments is still ongoing by Prof. Elham Sahraei and her team at TEMPLE university in Philadelphia (USA),

Initially started at MIT.

It is available for solid elements only.




Material properties of electrodes current collectors, and separator.

| | Elastic properties | | | Material Model | Failure strain ($\varepsilon_f$) |
|---|---|---|---|---|---|
| | Mass density ($\rho$) | Young's Modulus ($E$) | Poisson's ratio ($\nu$) | | |
| Copper | 8930 $\frac{kg}{m^3}$ | 110 $GPa$ | 0.343 | J2 plasticity | 0.1899 (0.1783 after coating) |
| Aluminum | 2680 $\frac{kg}{m^3}$ | 70 $GPa$ | 0.33 | J2 plasticity | 0.067 (0.049 after coating) |
| Anode coating | 879 $\frac{kg}{m^3}$ | 2.5 $GPa$ | 0.01 | Crushable foam | Not used |
| Cathode coating | 2162 $\frac{kg}{m^3}$ | 5.9 $GPa$ | 0.01 | Crushable foam | Not used |
| Separator | 1764 $\frac{kg}{m^3}$ | 385 $MPa$ | 0.01 | Crushable foam with linear hardening | 0.33 |



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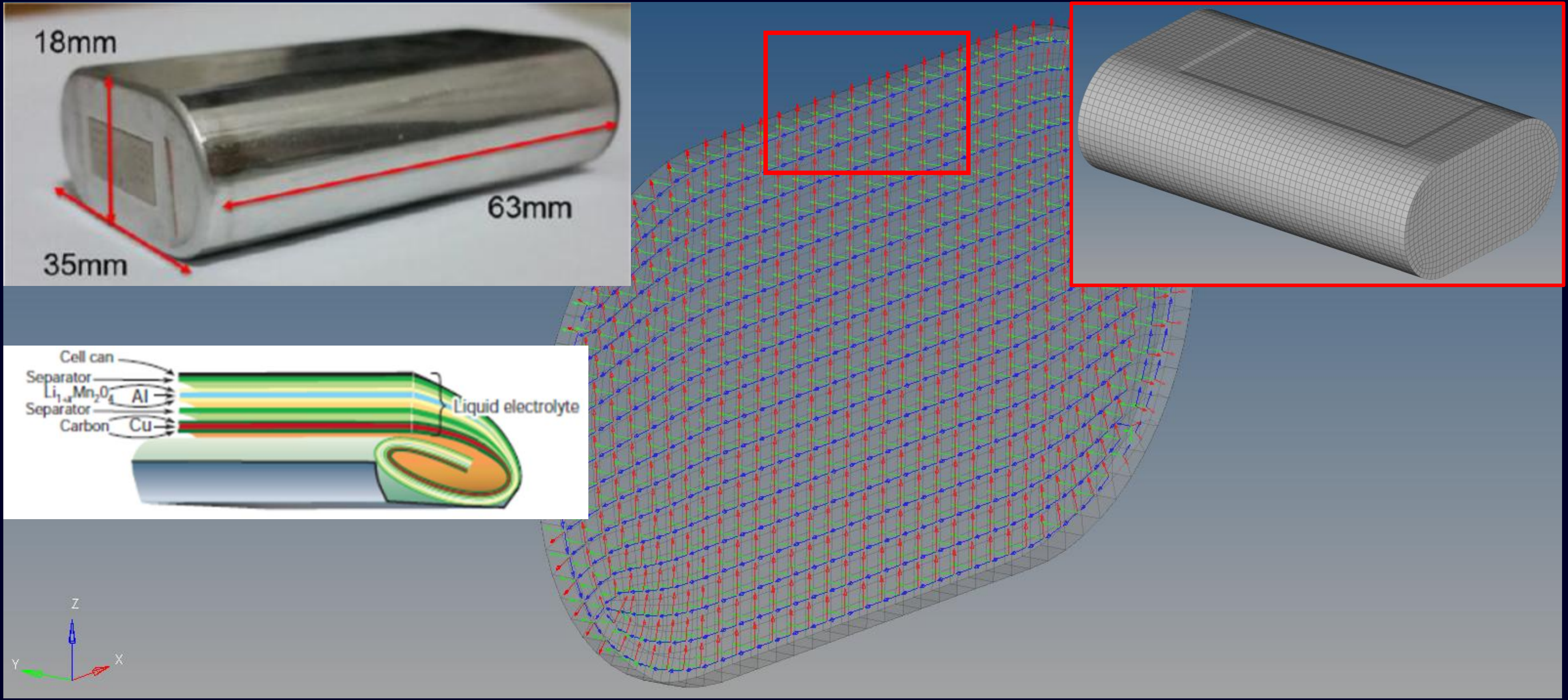
# Failure criteria: Li-Ion-Battery → /FAIL/SAHRAEI



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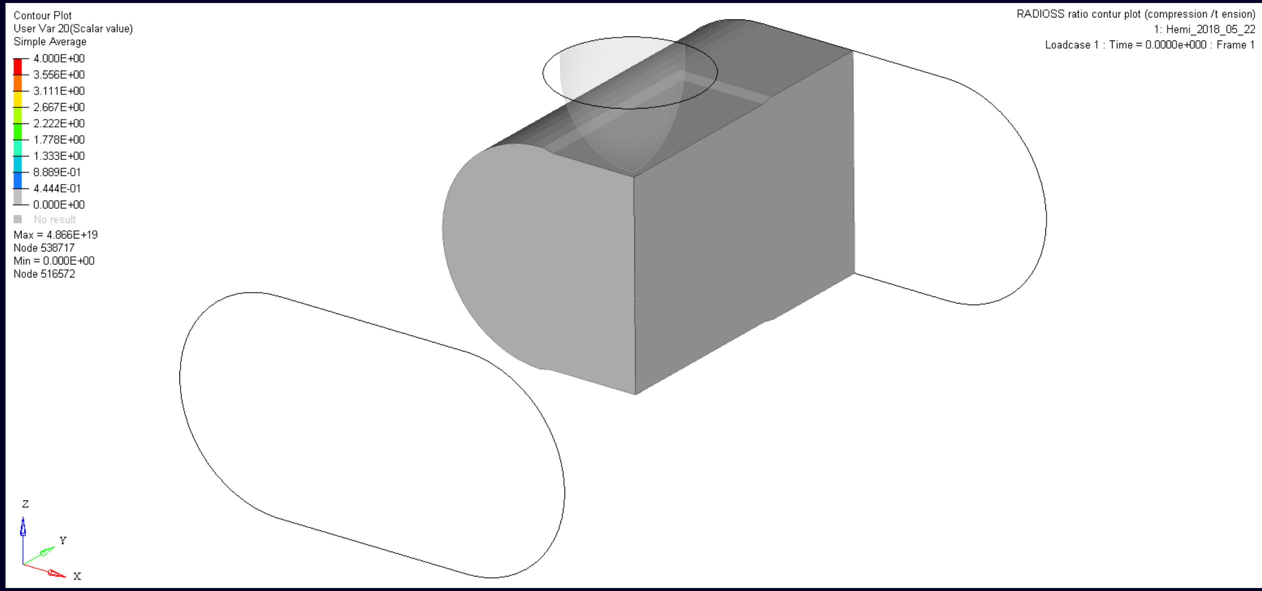
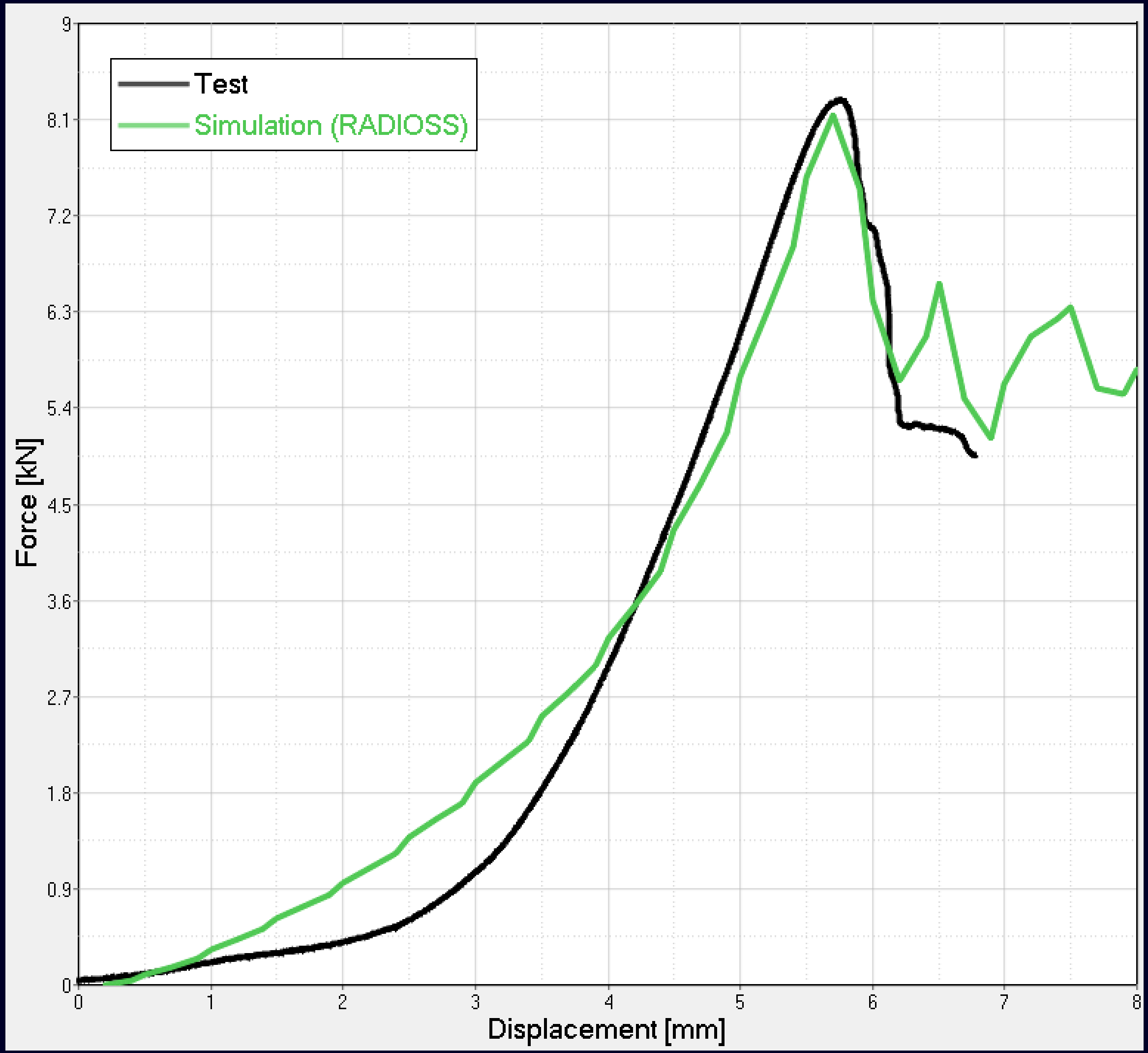
## Failure criteria

The **Sahraei failure model** /FAIL/SAHRAEI is able to predict the mechanical behavior of Li-Ion battery




Resultant curve Sphere Impact: Force vs. Time




No modification/adjustments in material and failure criteria cards

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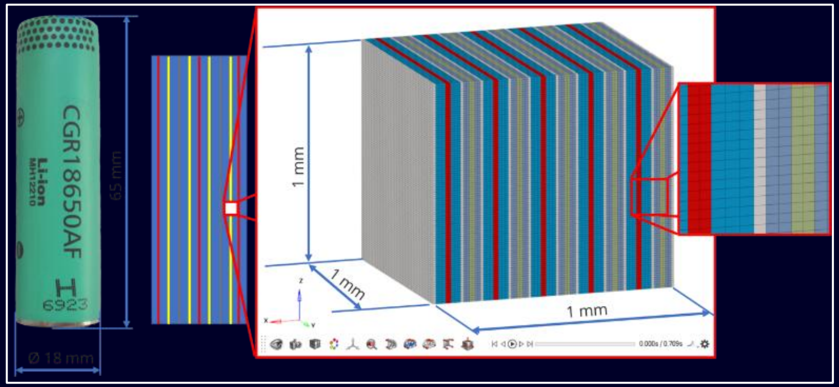
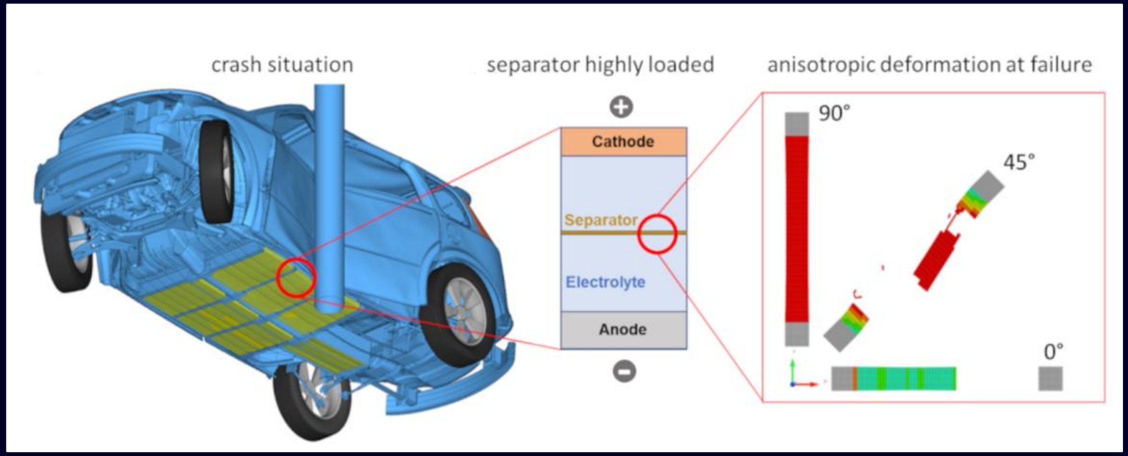
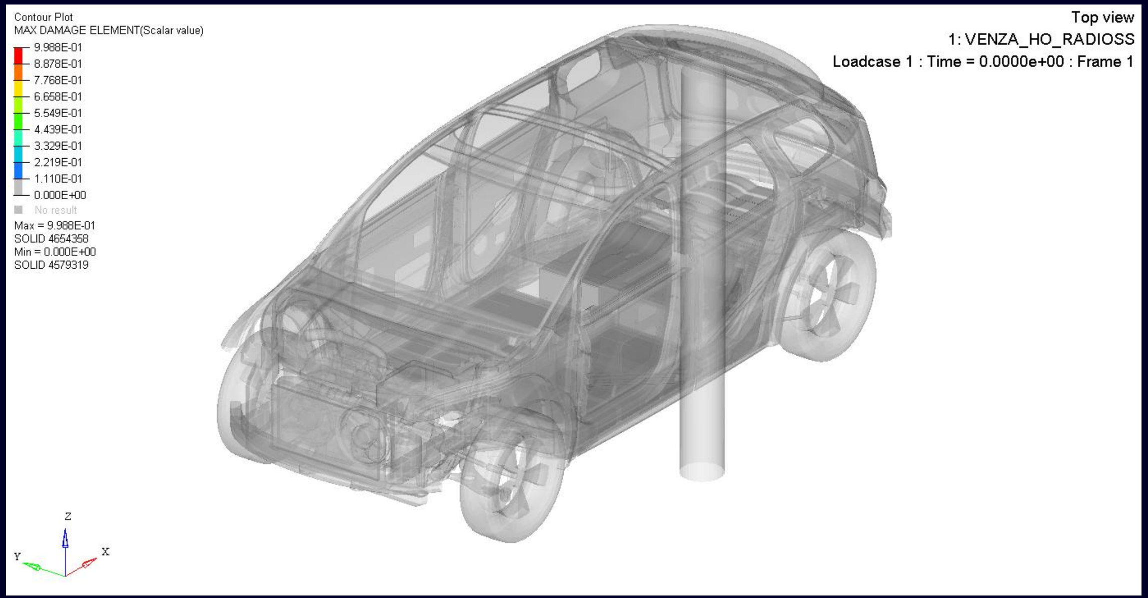
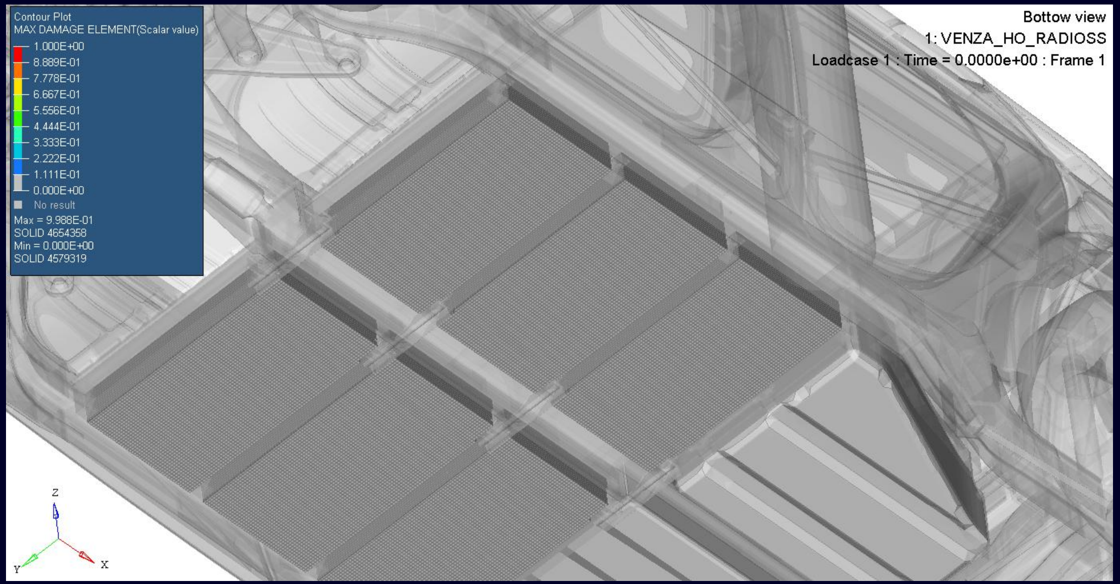
# The Goal: Virtual Testing in Full Systems

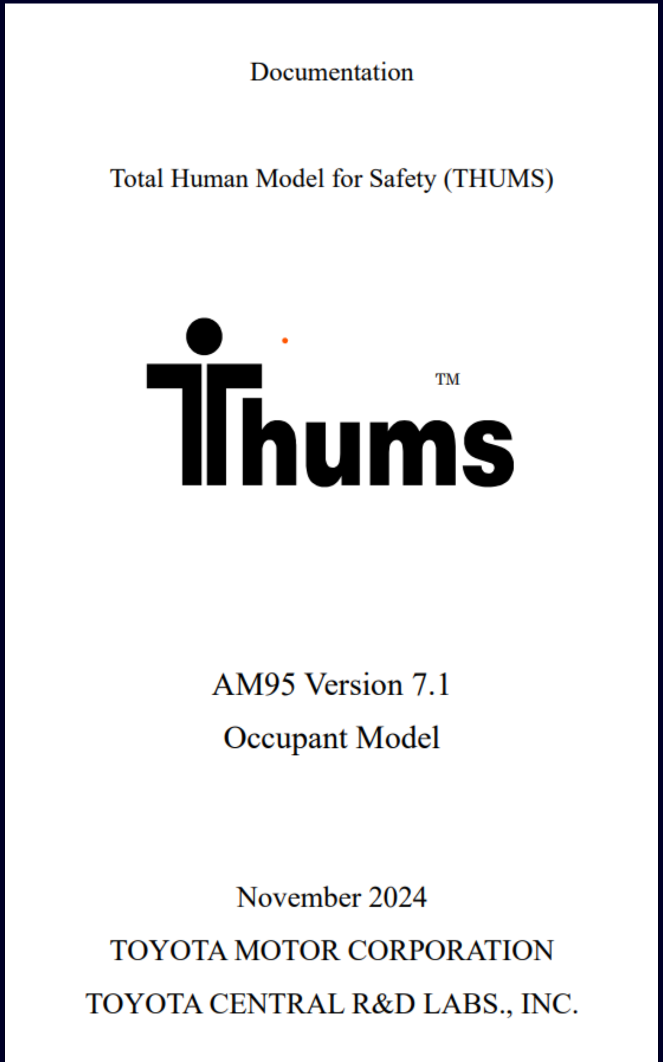


# Challenge: Virtual Testing


Documentation

Total Human Model for Safety (THUMS)

Thums™

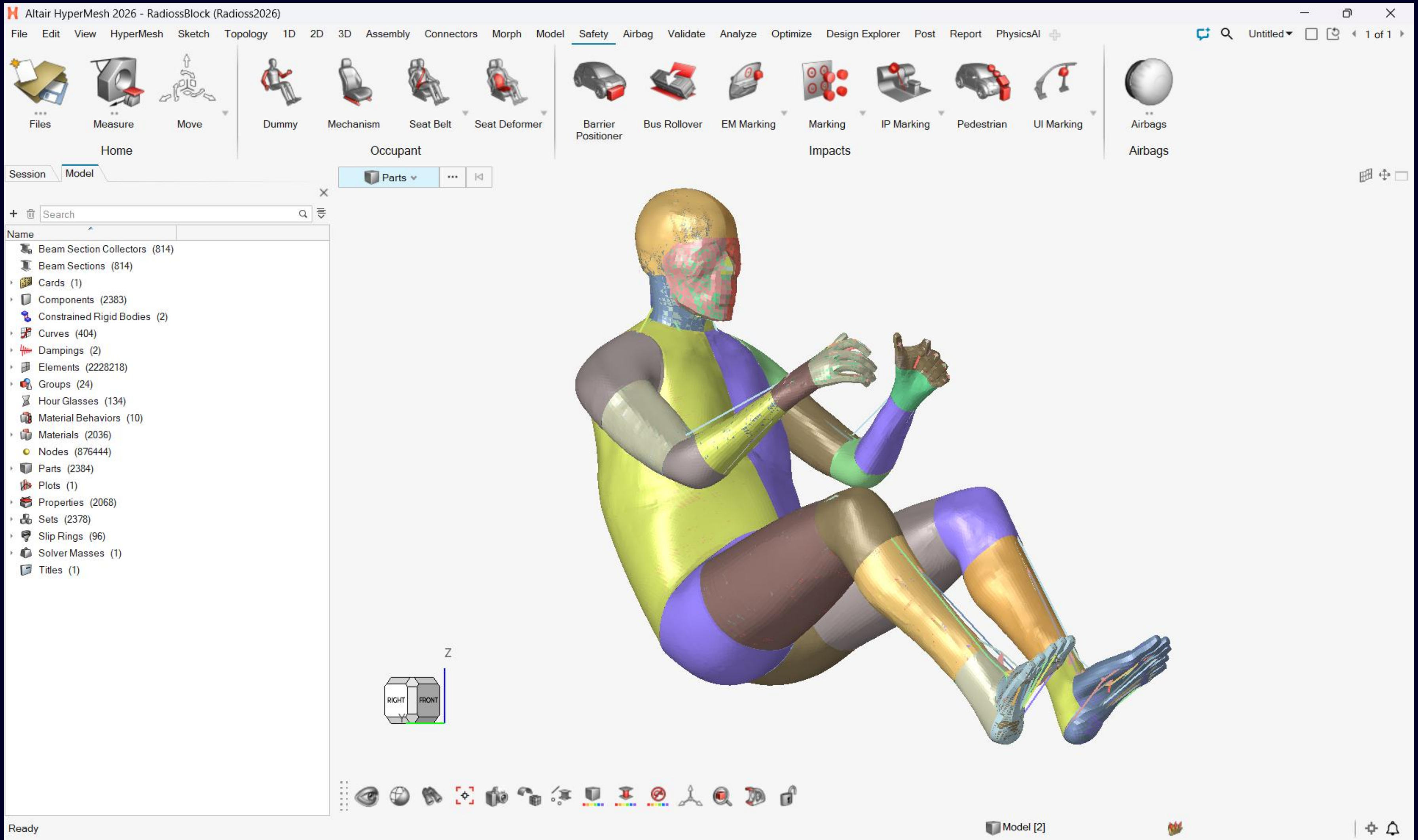
AM95 Version 7.1

Occupant Model

November 2024

TOYOTA MOTOR CORPORATION

TOYOTA CENTRAL R&D LABS., INC.



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# Virtual Testing

## Input Deck

```
#---1----|----2----|----3----|----4----|----5
#-  2. MATERIALS:
#---1----|----2----|----3----|----4----|----5
/CHECKSUM/START
Material 1
/MAT/PLAS_JOHNS/1
Steel
#              RHO_I
        .0078999996                    0
#                  E                   Nu
             199355           .30000001
#                  a                    b
          185.39999                  540
#                  c             EPS_DOT_0
                  0                    0
#                  m               T_melt
                  0                    0
#---1----|----2----|----3----|----4----|----5
/CHECKSUM/END
```

## Radioss Starter

**Compute Hash**

…of deck parts

- No comments in Hash
- Compatible with Encryption

New output file:
[ROOTNAME]_0000.checksum

```
**********************************************************************
 **                                                                 **
 **                                                                 **
 **                        Checksum Digest                          **
 **                                                                 **
 **                                                                 **
 *********************************************************************
 ** COPYRIGHT (C) 1986-2026              Altair Engineering, Inc. **
 ** All Rights Reserved.  Copyright notice does not imply publication. **
 ** Contains trade secrets of Altair Engineering Inc.              **
 ** pilation or disassembly of this software strictly prohibited. **
 *********************************************************************

 DECK ROOTNAME ............................:      CRA2V44
 EXECUTION COMPLETED ......................:      2026/04/15   17:19:56

 CHECKSUM OPTION: DECK FINGERPRINTS
 ---------------------------------
    CHECKSUM: Material_1_45461df88c5e818de9165be67b16a54a
    CHECKSUM: Materials_2_3_0fd4b3f281f48614889426418 7feba3a
    CHECKSUM: Mesh_2ac69568b991a6bab0f70420a5971324
    CHECKSUM: Time_histories_2_f15a5625d287d20c270c717ceefa93f0
    CHECKSUM: Properties_afe765d2731e1a7a26a7b56a226654d9
    CHECKSUM: Time_histories_1_f9f37045e7a2ca0ed1857547a8444ebe

 ILES: CHECKSUM DIGESTS
 ------------------------------
    FILE: CRA2V44A001 decf2b50257eef4cba1154efaef0f38a
    FILE: CRA2V44_0001.thy e5cb625e60d69a6a9ac871bf430c6473
    FILE: CRA2V44_0001.out f50aa8bff89d979f993e334a7c45165f

-----BEGIN SIGNATURE-----
P5cABAVId8xnJxDiMBarNzt+jPx1zPcFezX6Zg4EFs/0jeO+JWMlRUrKc0hbW3JWf3yUCC3ECz
7DsIUB7aFYp2OyMVp7Fu5PE8DGaQygEhexobr/AmhDyz2UVxDGYm0m+OaNe+GN5kPg0ypNUaQK
41kvjfe8+kDPFYkGnr7K8yc4XxlSdu1u1a3fLtKNCzoFIqBaLobOHd0oEIshGXiHHl1AXPl9kO
Skb7YKsqpt2MBxYNYqEtgGsuLEwqR98EB3lb0ueOqQgxEGMWcyJTQJKagk7qA5mnRsprqqsv5O
XiwNBPkBwVMuaM+0hXXI/xKTF2jTL07uuuyHZLrmVmD6Gg==
-----END SIGNATURE-----
```

## Radioss Engine

- Write checksum hash in every output file:
  Time History, Animation, H3D File, Output file (.out)
- Compute hash digest from all output files
- New output file: [ROOTNAME]_[RUNN].checksum



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## Conclusion

Today's presentation has shown advanced material models and failure criteria in **Simcenter Radioss**

By selecting and calibrating these models, increase the quality of FE-results (compared to reality)

These capabilities not only improve the **fidelity of crash simulations but** also provide valuable insight early in the design process — helping engineers evaluate risks, optimize structures, and improve faster

Ultimately, robust material modeling and failure criteria are key enablers for designing **safer, more resilient vehicles**, next-generation mobility with confidence.

For authorities involved in homologation, trusting FE models and their validated results are crucial, because it enables them to efficiently and reliably verify that products meet stringent safety, performance, and regulatory standards without the need for additional extensive physical testing!

# Thank You

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Open for discussion



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