LS-DYNA & LS-PrePost Application in Bulk Metal Forging

- 2023 LS-DYNA User’s Forum, Novi, Michigan

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Ansys

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❑ Introduction

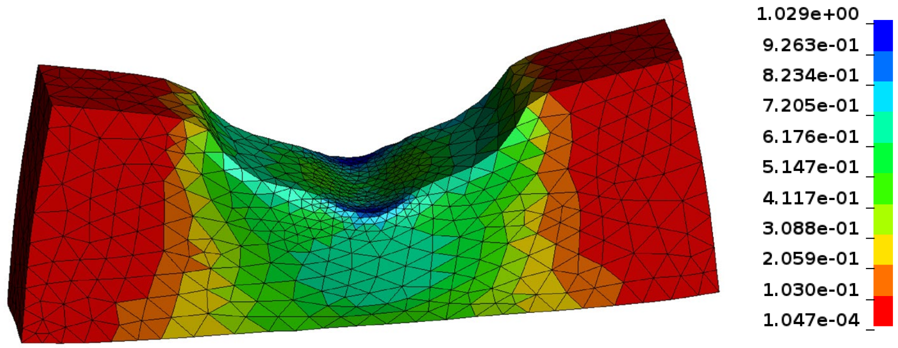
- Ansys LS-DYNA application areas: structural mechanics (including crash/safety), fluid dynamics, thermomechanical problems, and various manufacturing processes.
- Ansys LS-DYNA application industry: automotive, aerospace, defense, precision consumer product and electronics manufacturing industries.
- Simulate in the virtual world to optimize product designs and improve manufacturing processes efficiency, reduce physical DOEs, reduce waste, energy consumption and green house emissions.
- Forging is energy consumption intensive
  - Create virtual models of the forging process, various light weight materials.
  - Analyze materials under different temperatures, strain rates and tool design geometries.
  - Optimize:
    - Initial workpiece size and shape, tools' shape, # passes.
    - Assess and minimize defects.
    - Under-filled areas.
    - Predict forging tonnage (press capacity/allocation).
    - Reduce or eliminate physical DOEs.
    - Has the potential to drastically shorten product development and engineering cycles, and maximally increase manufacturing efficiency and productivity

❑ 3D Adaptive Remeshing Features

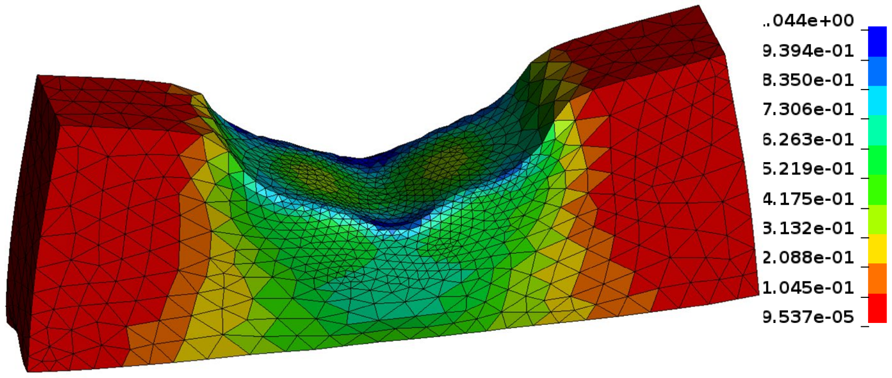
- Tool curvature based; trigger: minimum time step size (DTMIN)
- Max, min element size specified
- ADPFREQ
  - Equal interval, one segment
  - Equal interval, multiple segments
- Explicit dynamic: mass scaling (DT2MS/DTMIN)
- Mesh refinement region: ADPENE
- Monotonic increased adaptive remeshing
- Explicit dynamic: Tool velocity scaling

❑ 3D Adaptive Remeshing Features

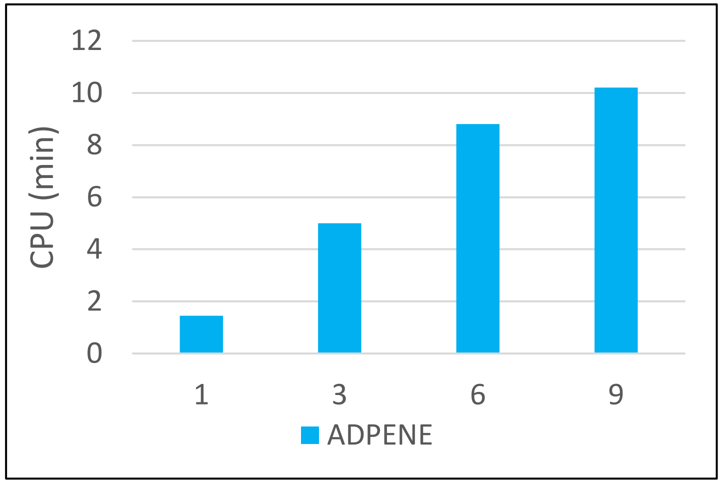
- ➢Effect of ADPENE on mesh refinement and effective plastic strain (EPS).
- ➢Initial element number: 7680

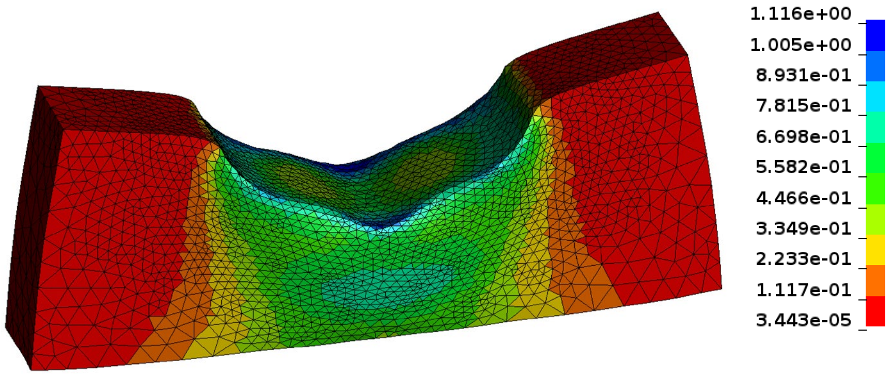


ADPENE=1, final element: 10851

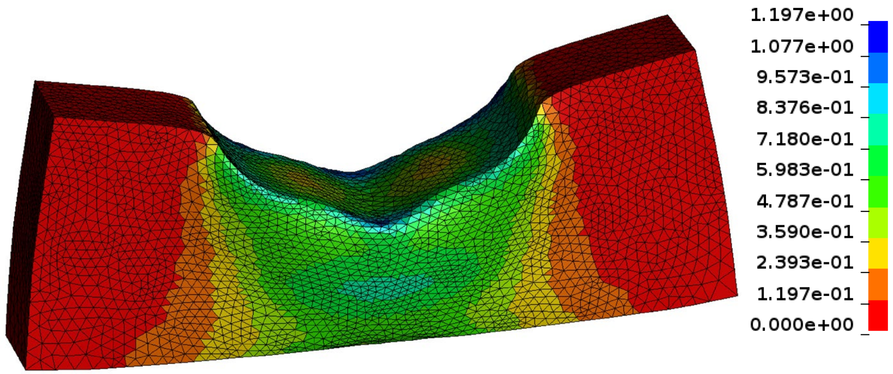


ADPENE=3, final element: 22667





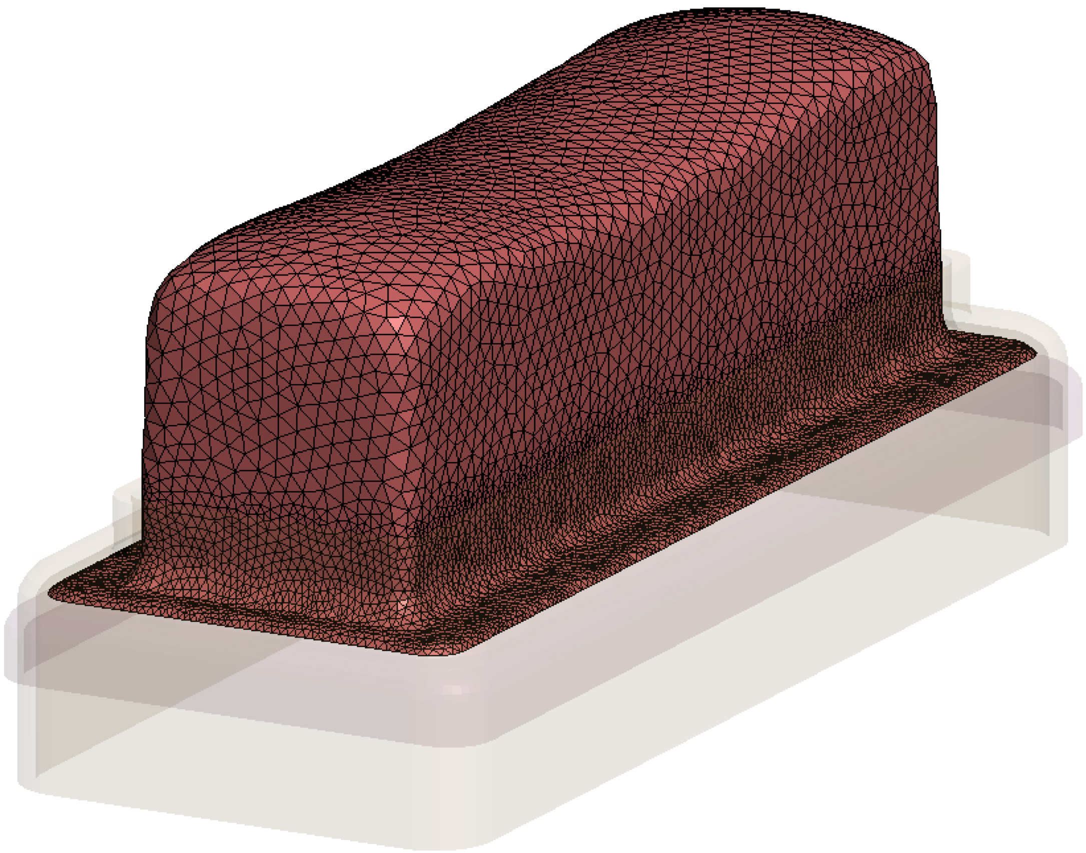
ADPENE=6, final element: 96838



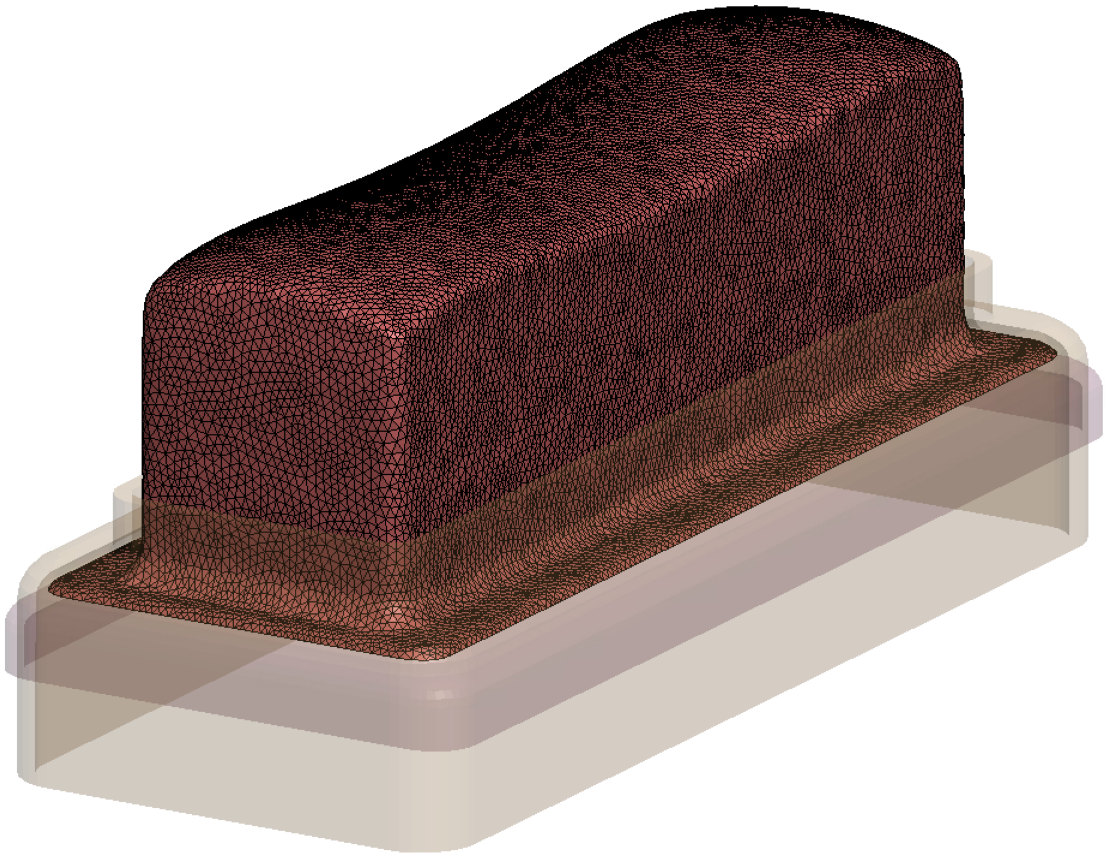
ADPENE=9, final element: 161891

❑ 3D Adaptive Remeshing Features

➢ monotonic resizing: adaptive remeshing cannot coarsen a mesh during the simulation. This feature is critical in maintaining the feature lines of the forged parts.



Final element #: 148583

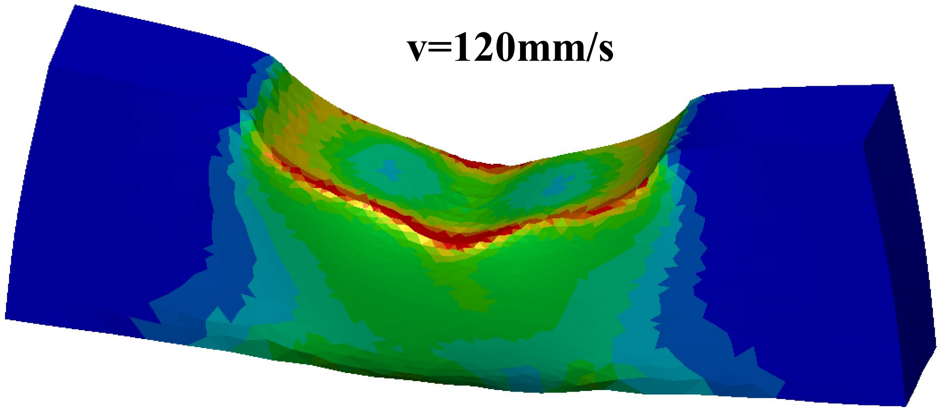


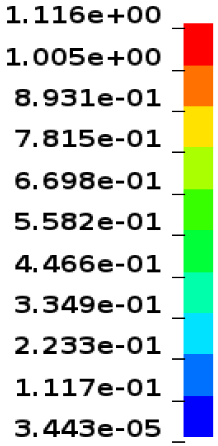
Final element #: 1123000

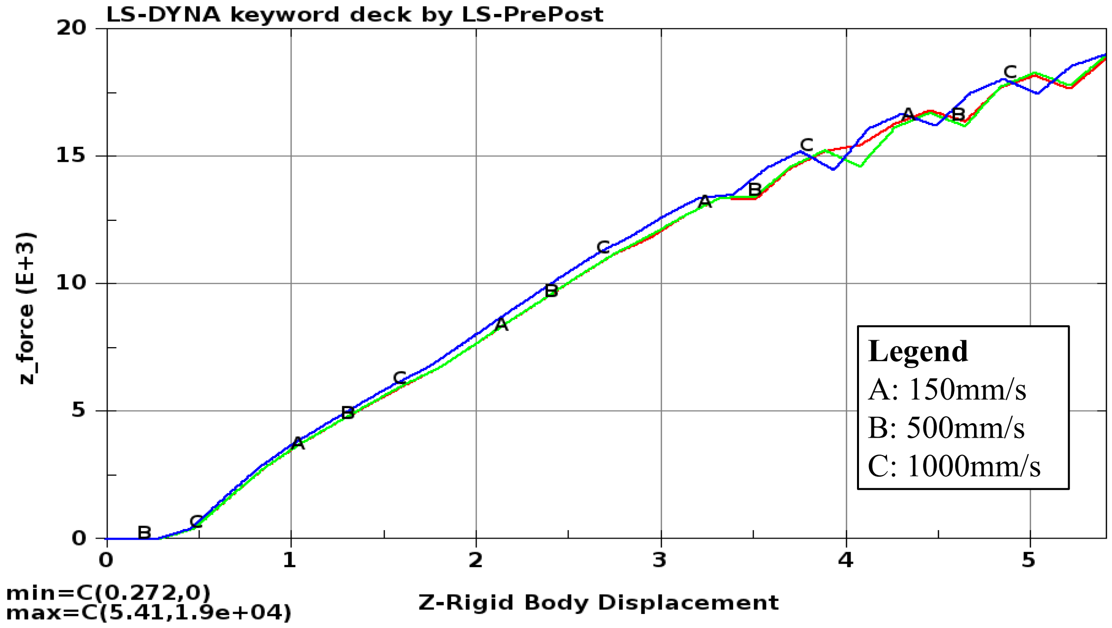
Initial element number: 516150

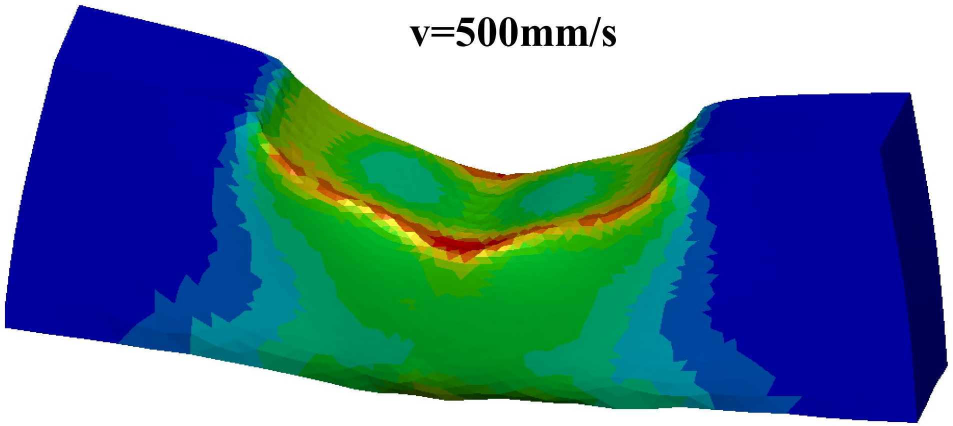
❑ Tool velocity scaling

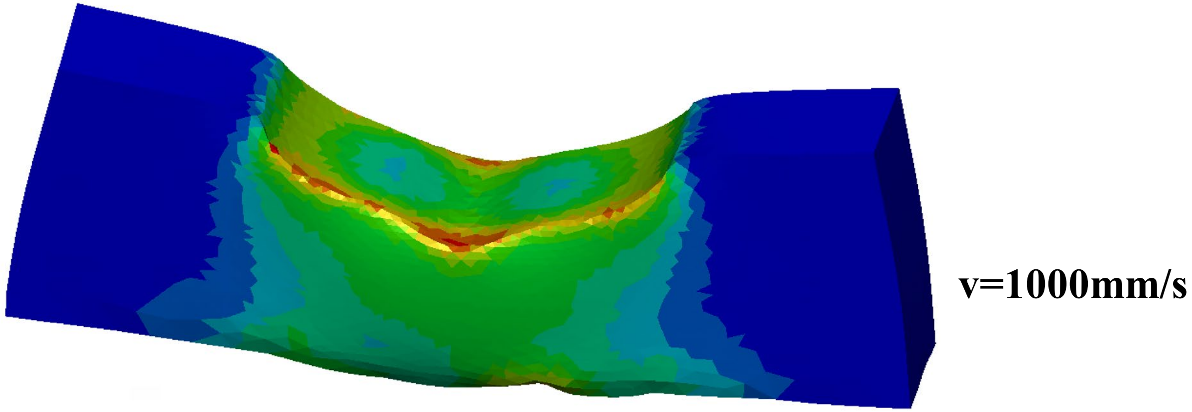
- ➢ Tonnage estimate and EPS for different tool speeds.
- ➢ For strain rate insensitive materials.





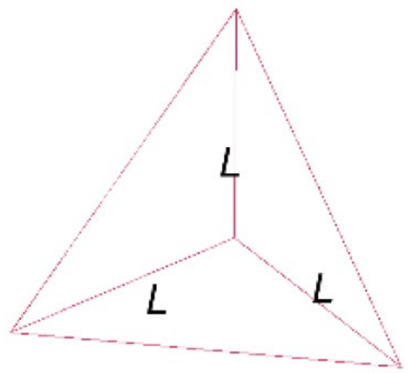






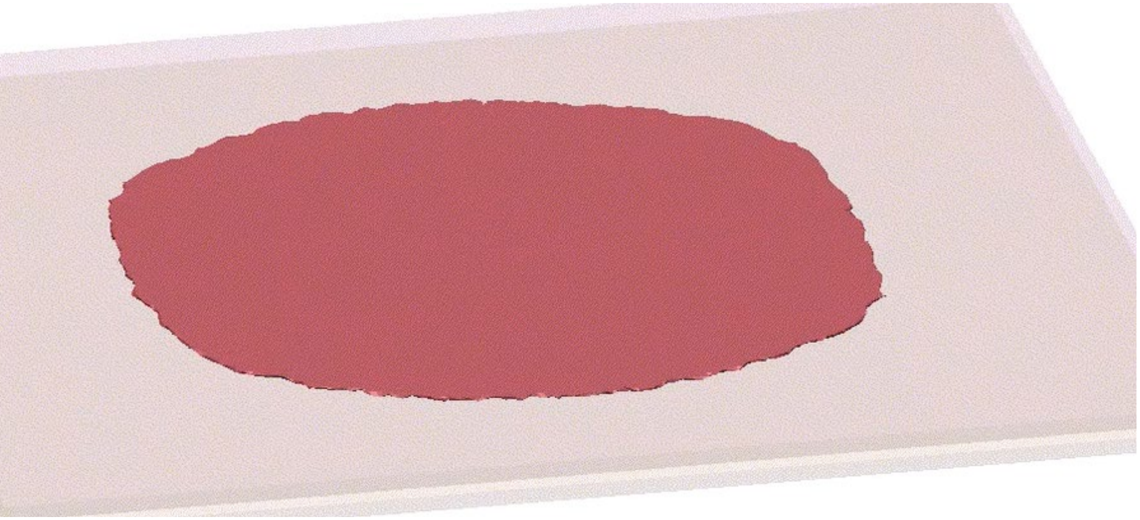
❑Elements

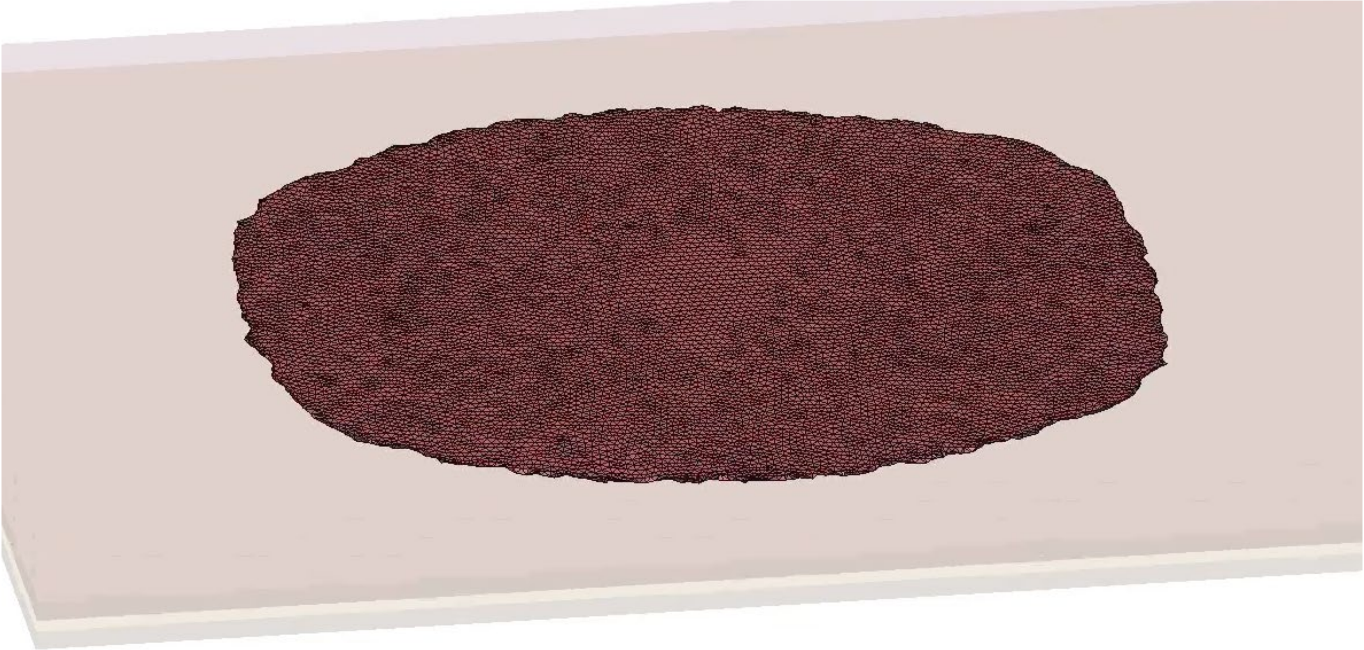
- **Workpiece:** Element type 13, Adaptive, 1 point nodal pressure tetrahedron to reduce volumetric locking.
  - Workhorse for many application w/ severe deformation
    - Good for rubber, specifically for ductile elastoplastic metals bulk forming
    - Very stable, takes severe/extreme mesh distortion (rubbers/metal, etc.), nearly collapsed shape.
    - No kinematic modes: no hourglass control needed.
  - Averge the volumetric strain over neighboring elements to smooth the pressure response
  - Prevent volumetric locking with nodal volumes and evaluating average nodal pressures in terms of these volumes.
- **Tools:**
  - Rigid: Element type 1 solid (1 point integration).
  - Deformable: -1 (8 point integration, poor aspect ratio).

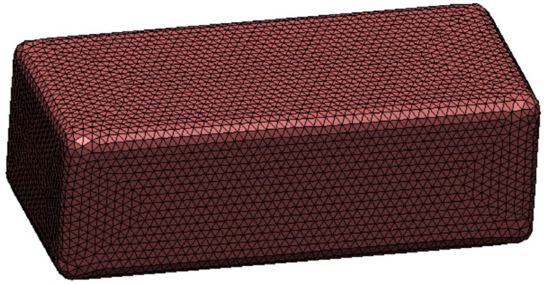


❑ Element type

- Element type 13 pancake crushing test





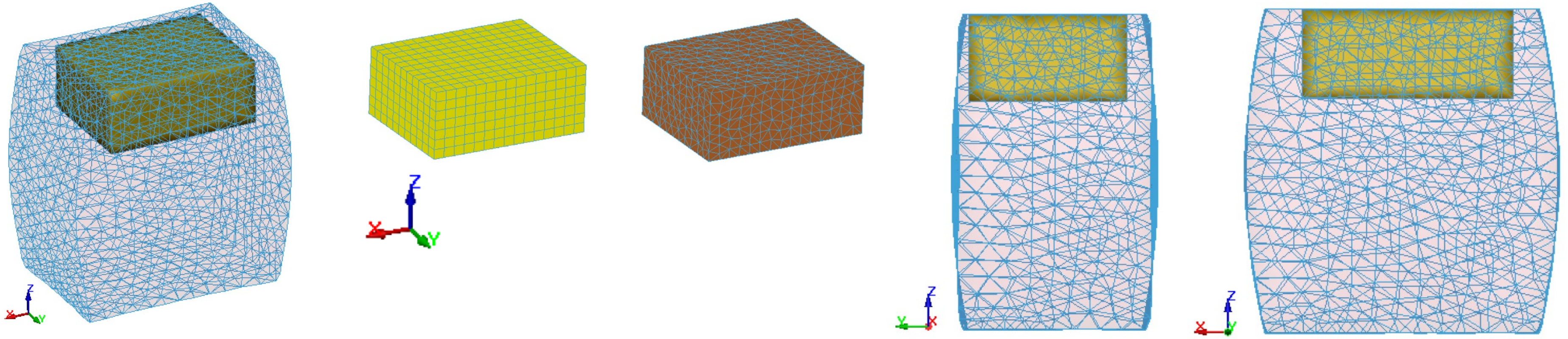


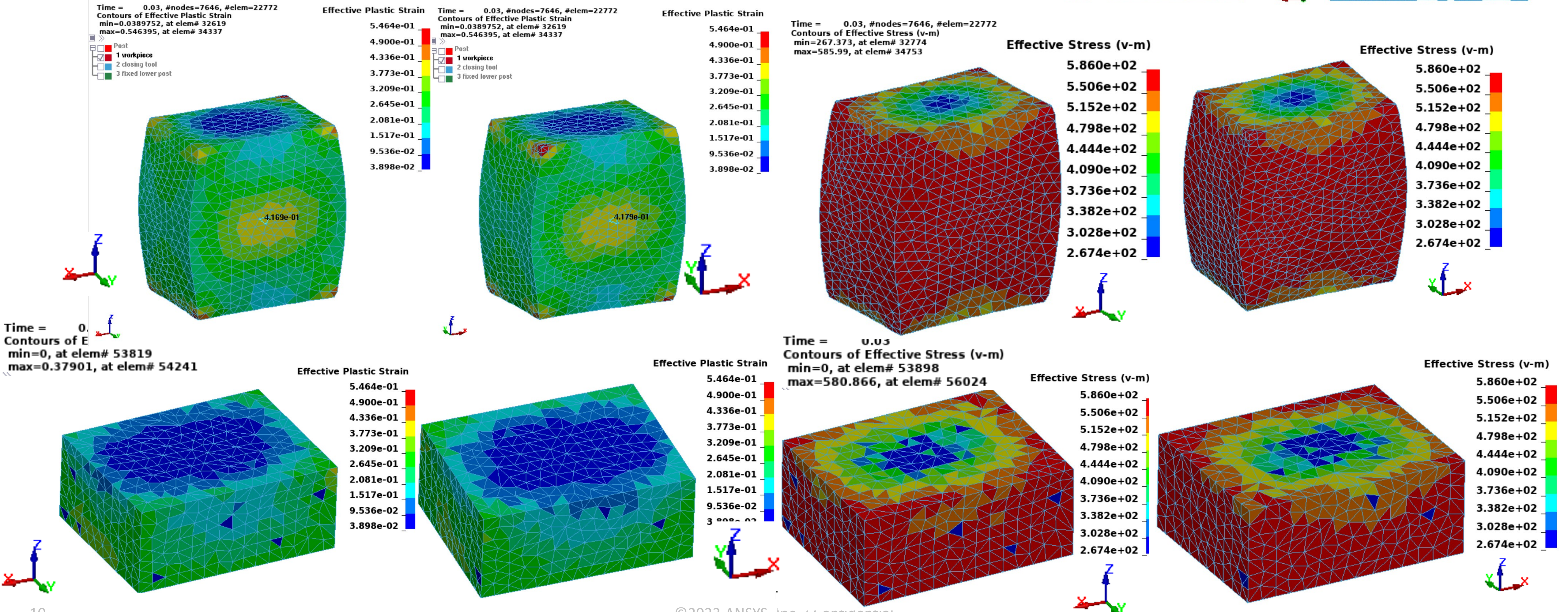
14.8 x 6.6 x 5 (mm)

Final thickness: 0.18 mm thick

❑ Trimming

➢ *INITIAL_LAG_MAPPING





❑Contact/Thermal Contact

- Explicit: *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE, _THERMAL.
- Implicit: *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE, _THERMAL
- Explicit and Implicit: *CONTACT_AUTOMATIC_SINGLE_SURFACE
    - Penalty contact, two way.
    - Gaps for heat transfer conductance.
    - Temperature dependent friction.
    - Pressure dependent thermal contact conductance.

❑Material Models

- Ansys LS-DYNA has 300+ different material models covering a wide range of different engineering materials.
  - *MAT_024: arbitrary piecewise linear plasticity, strain rates, cold/hot (thermal only) forging.
  - *MAT_106: elastic viscoplastic thermal, strain rates, temperature, workhorse for thermomechanical forging.
  - *MAT_107: Johnson-Cook, strain rates, material softening, Cockcroft-Latham damage
  - *MAT_224: Tabulated Johnson-Cook, strain rates, material softening, Cockcroft-Latham damage
- ***MAT_224**

$$\sigma_y = \left\{A + Br^n + \sum_{i=1}^{2} Q_i[1-\exp(-C_i r)]\right\}\left(1+\frac{\dot{r}}{\dot{\varepsilon}_0}\right)^C\left[1-\left(\frac{T-T_r}{T_m-T_r}\right)^m\right]$$

r: damage-equivalent plastic strain defined as $\varepsilon_p = \frac{r}{1-\beta D}$

β: equal to one for coupled damage and equal to zero for uncoupled damage.

Tabulated flow stress:

$$\sigma_y = k_1(\varepsilon_p, \dot{\varepsilon}_p)\frac{k_t(\varepsilon_p, T)}{k_t(\varepsilon_p, T_R)}$$

Cockcroft-Latham damage:

$$D = \frac{D_C}{W_C}\int_0^{\varepsilon_p}\langle\sigma_1\rangle d\varepsilon_p$$

σ_1: first principal stress.

D_C: critical damage value. For most materials D_C is 1.0.

W_C: critical plastic work, user input.

ε_f : critical failure strain.

$$W_c = \int_0^{\varepsilon_f}\langle\sigma_1\rangle d\varepsilon_p$$

No coupling is assumed between ductile damage and the constitutive relation.

▪Adiabatic heating:

$$\dot{T} = \chi\frac{\sigma : \mathrm{d}^p}{\rho C_p} = \chi\frac{\tilde{\sigma}_{eq}\dot{r}}{\rho C_p}$$

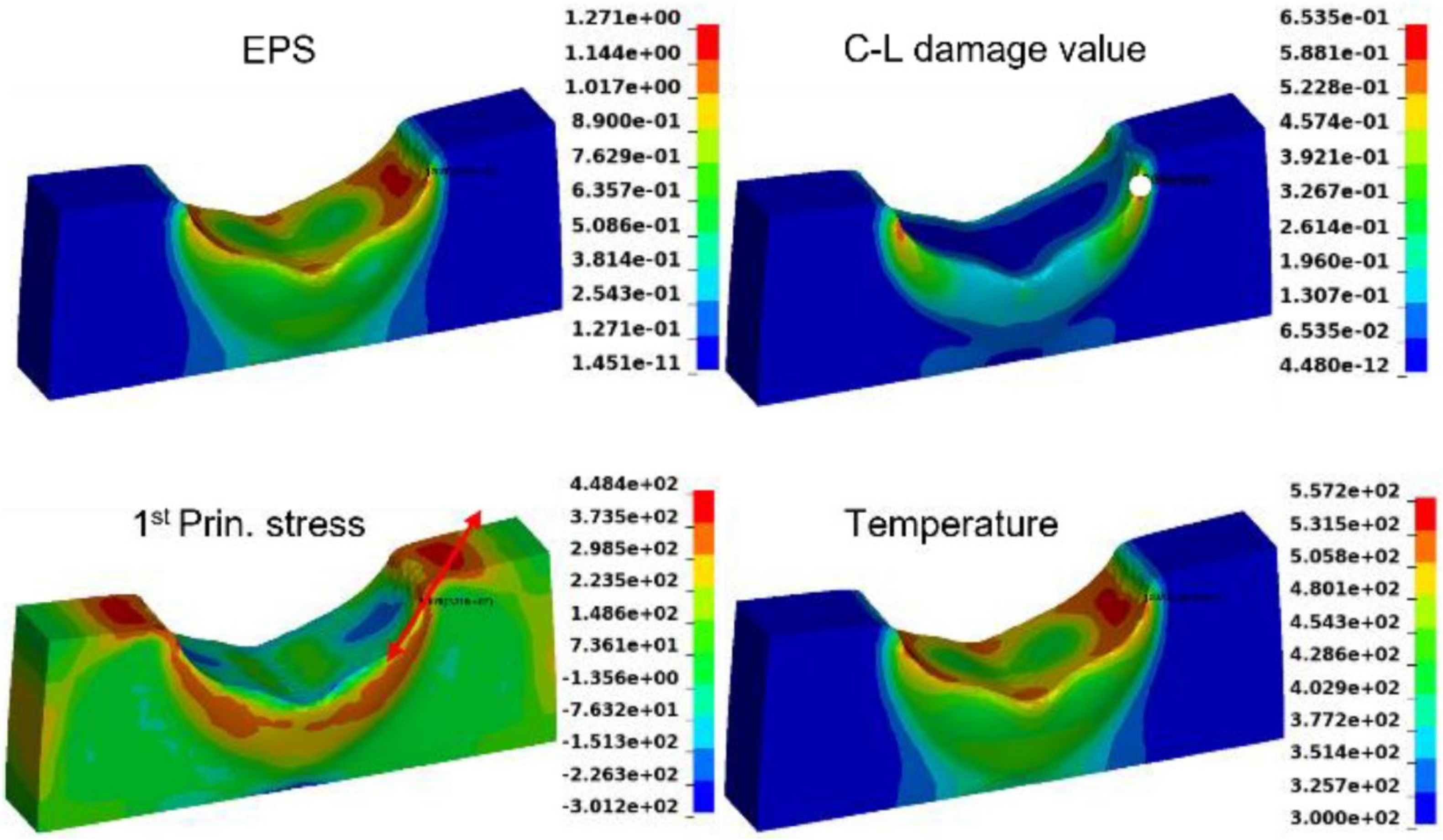
ρ: density

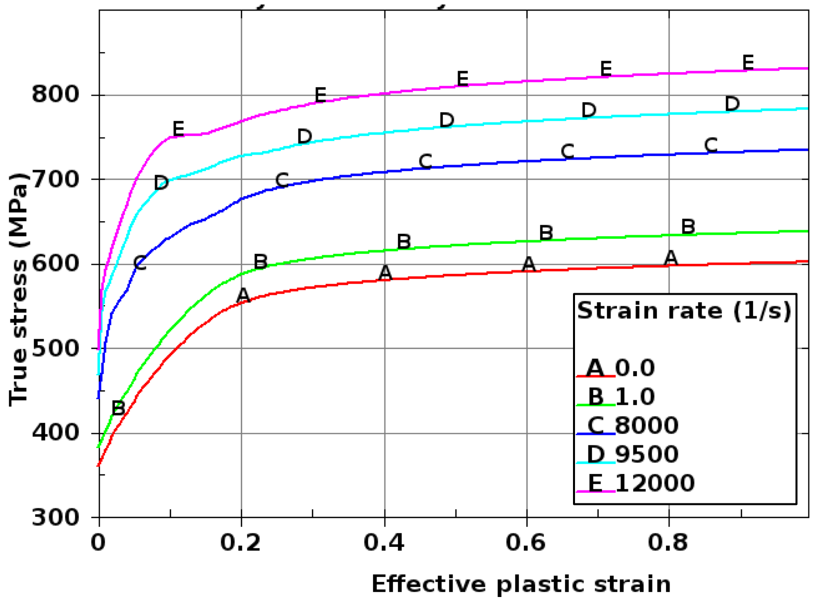
C_p: specific heat

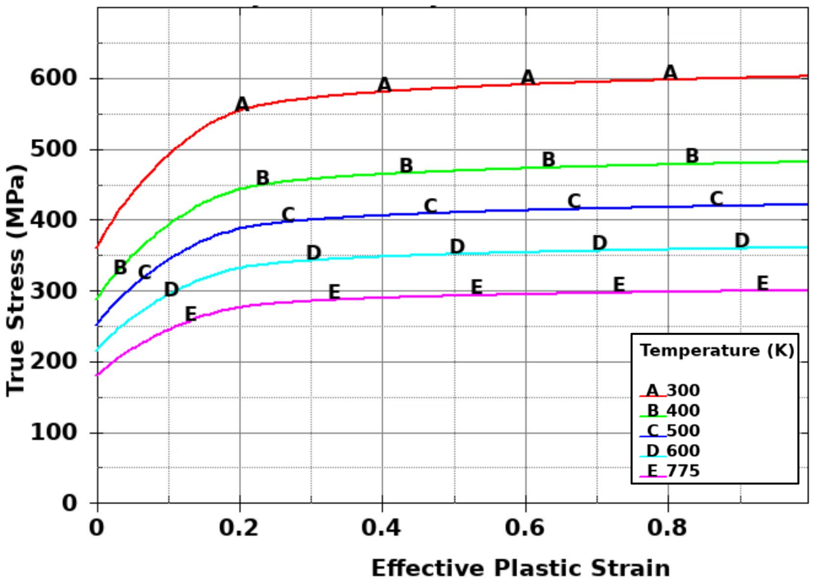
X: Taylor-Quinney parameter

❑Material Models

- *MAT_224, damage model, mechanical only simulation.
- The maximum C-L damage accumulation value: high levels of σ1 (tension) and EPS.
- Plastic heating induced temperature: EPS, work, C-L/σ1.

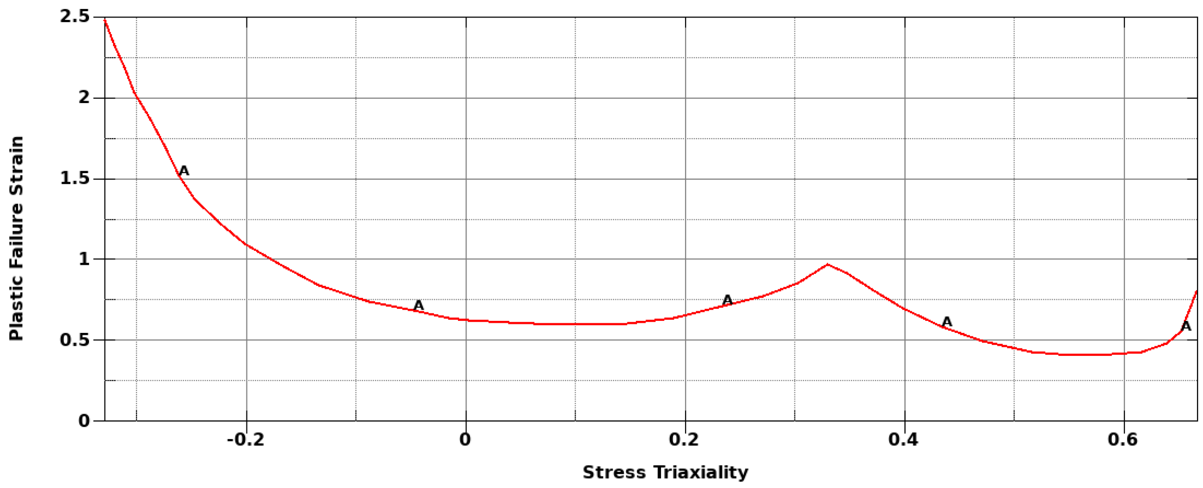


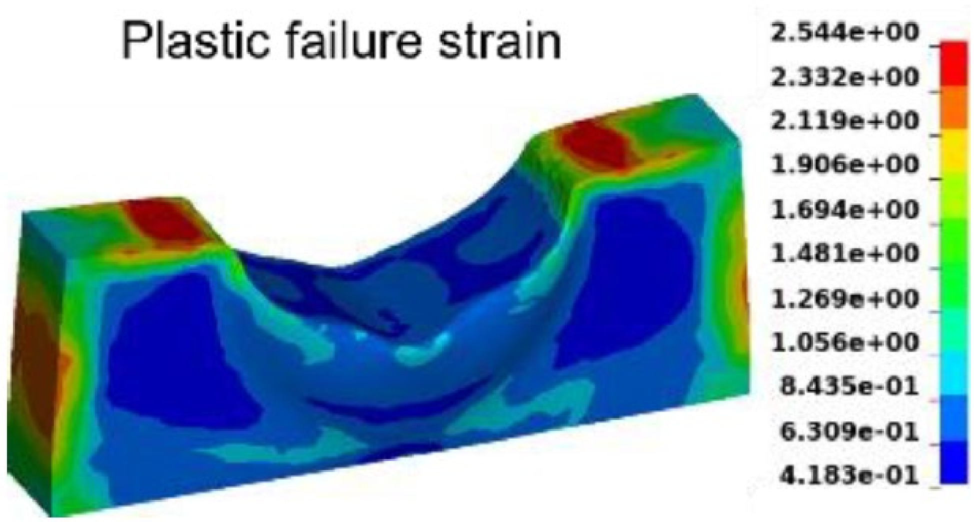


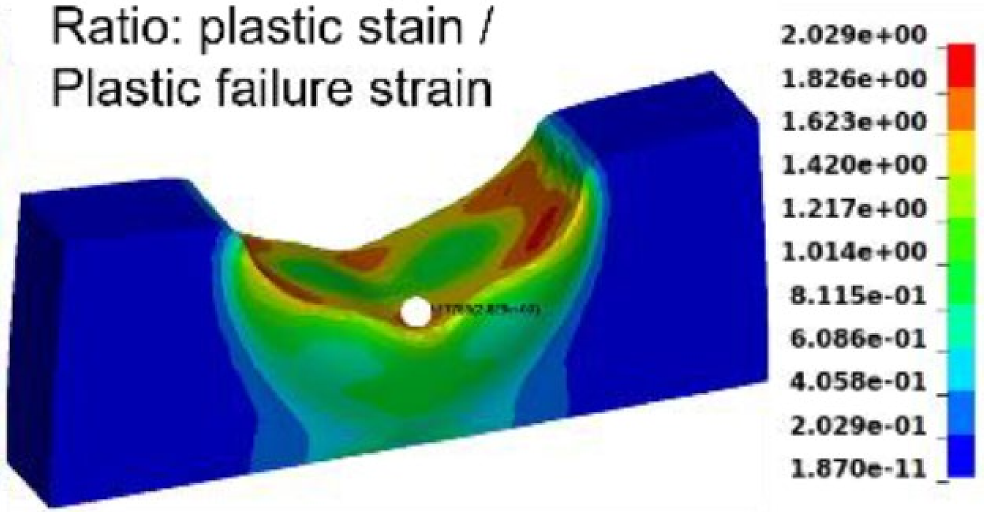


❑Material Models

- *MAT_224, damage model, mechanical only simulation.
- Max ratio in negative σ1 area.



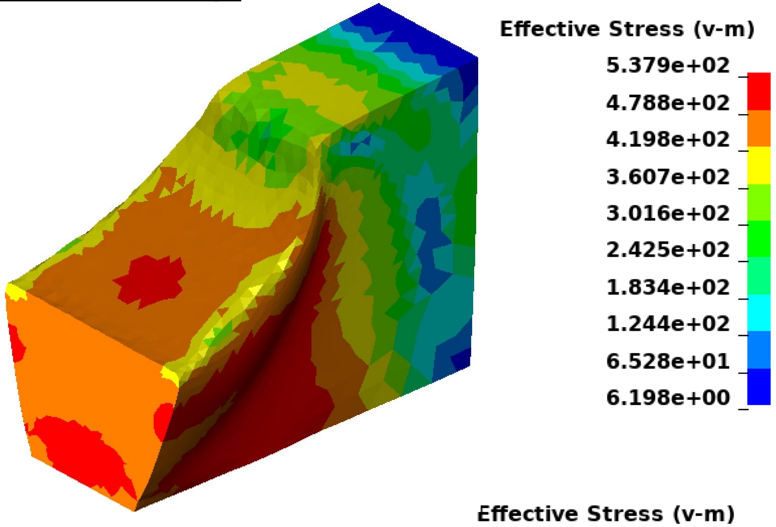


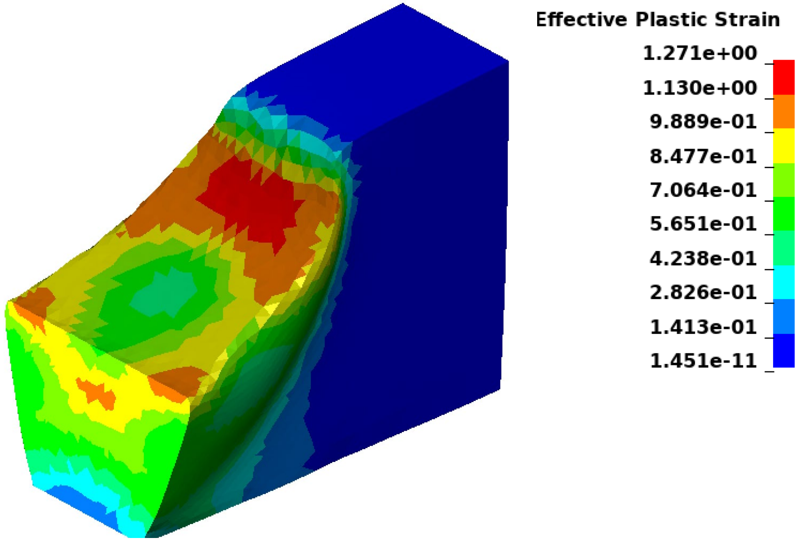


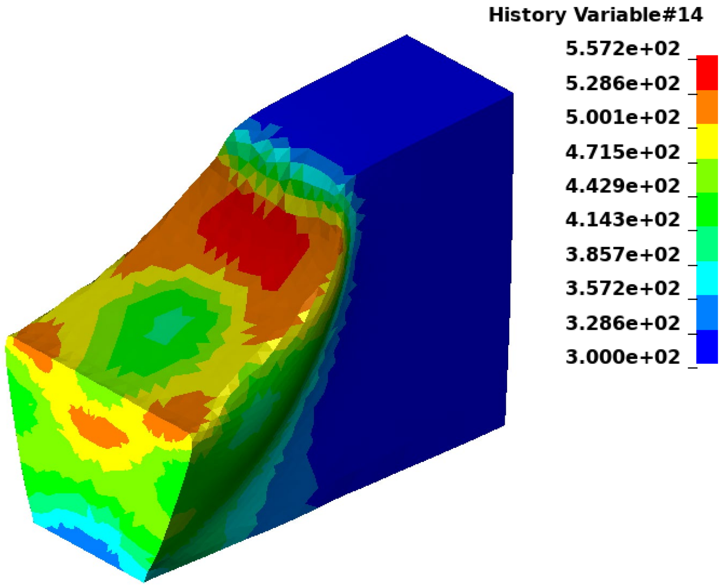
- ***MAT_224, plastic heating**

causes temperature to increase adiabatically and material softening. Mechanical only.

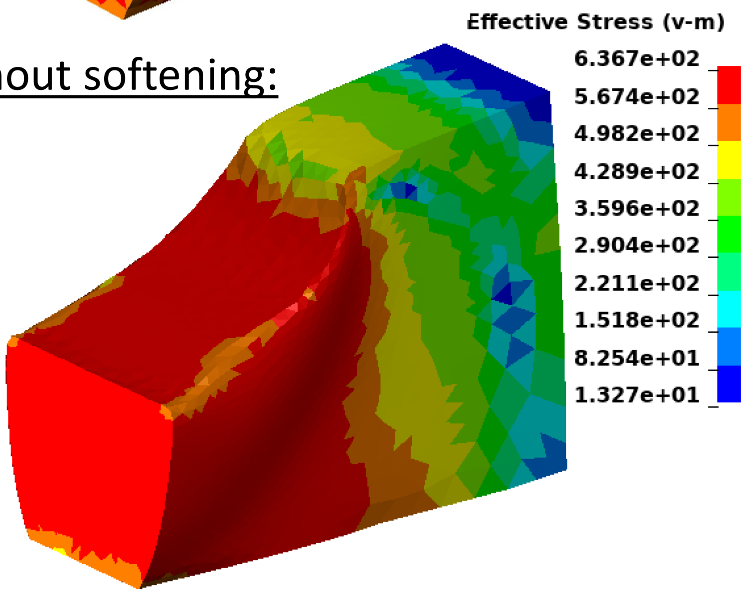
With softening:

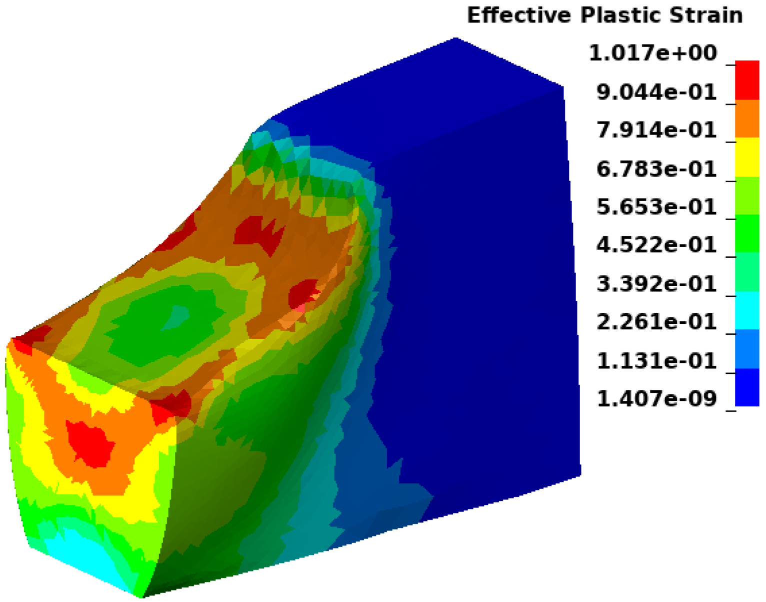


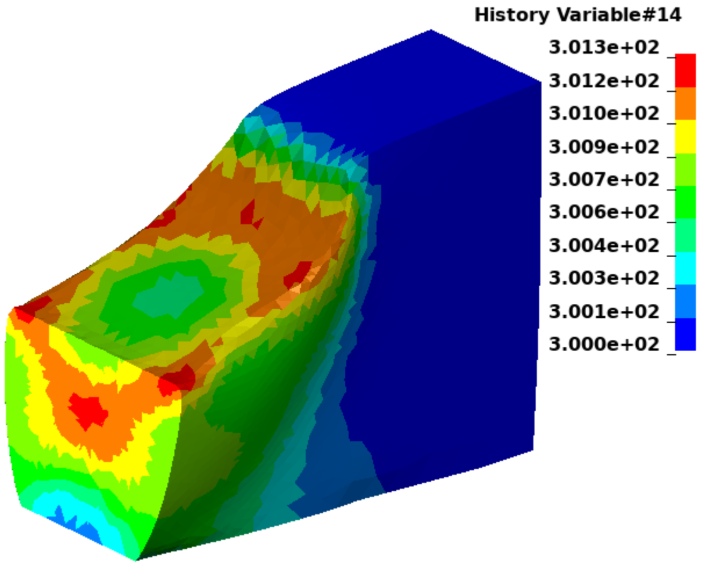




Without softening:







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❑Material Models

- *MAT_224, plastic heating

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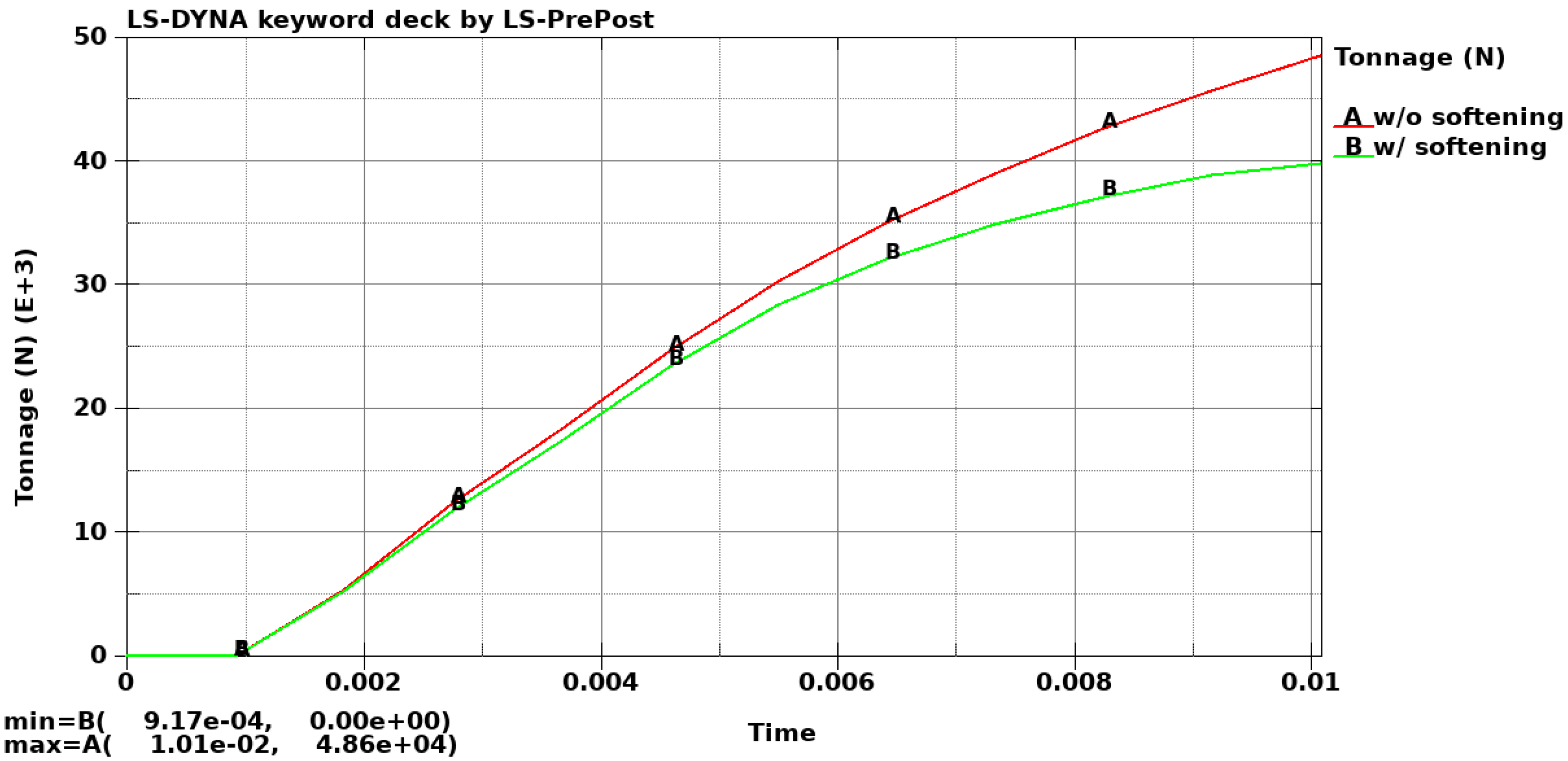
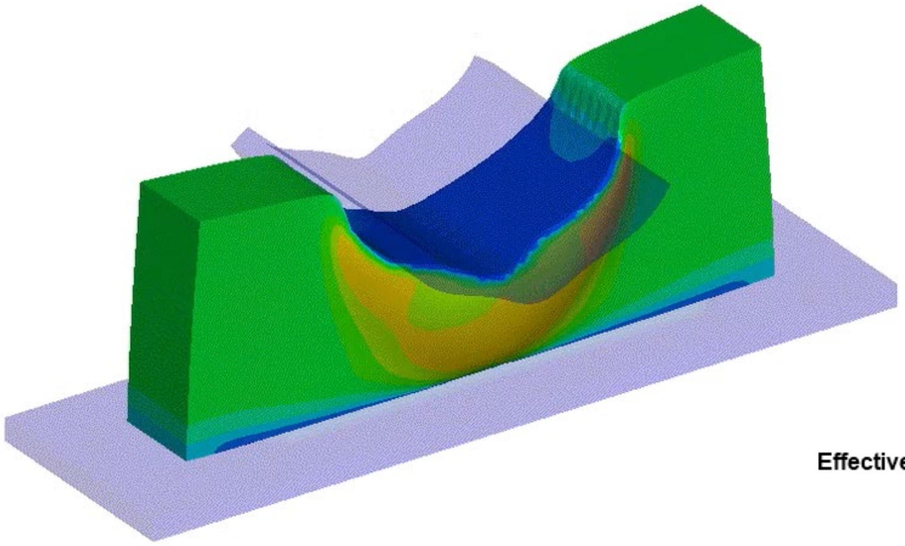
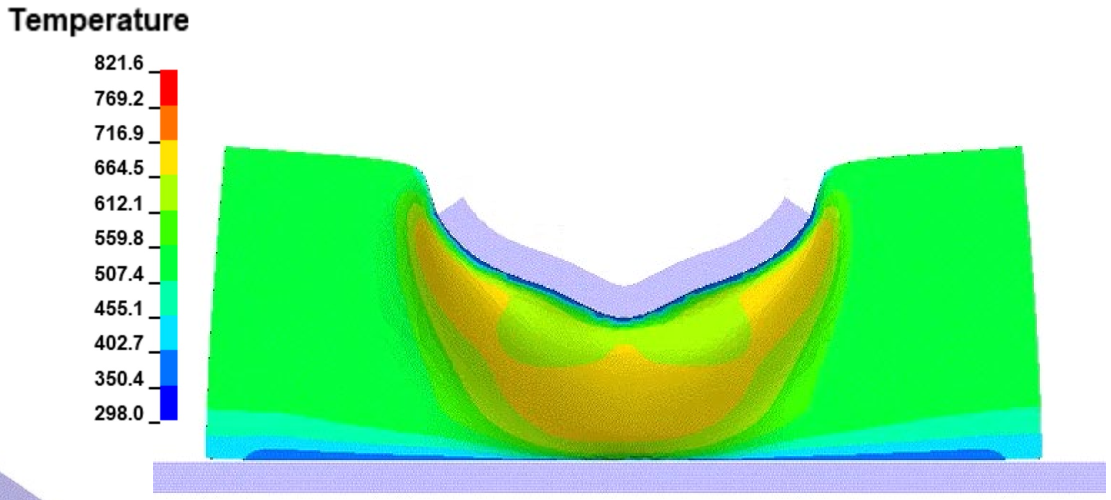
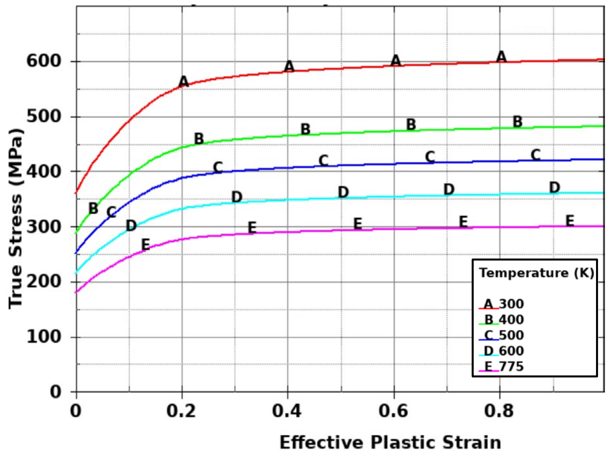


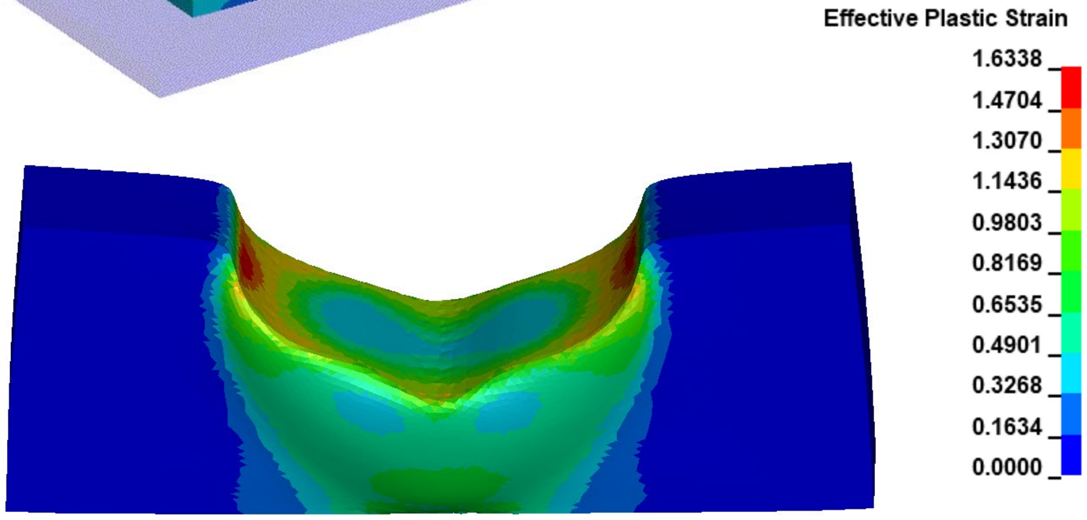
❑Material Models

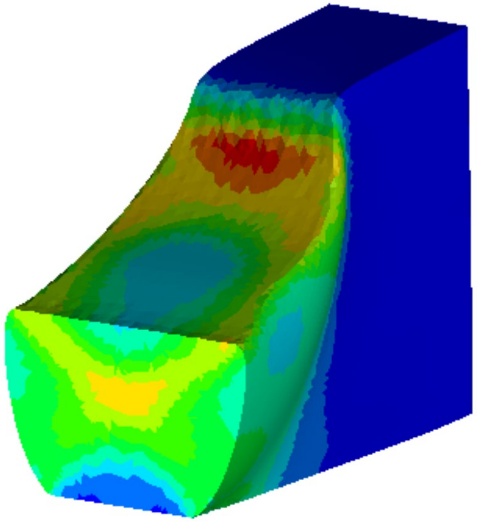
- *MAT_106, Thermomechanical
- Temperature and strain rate

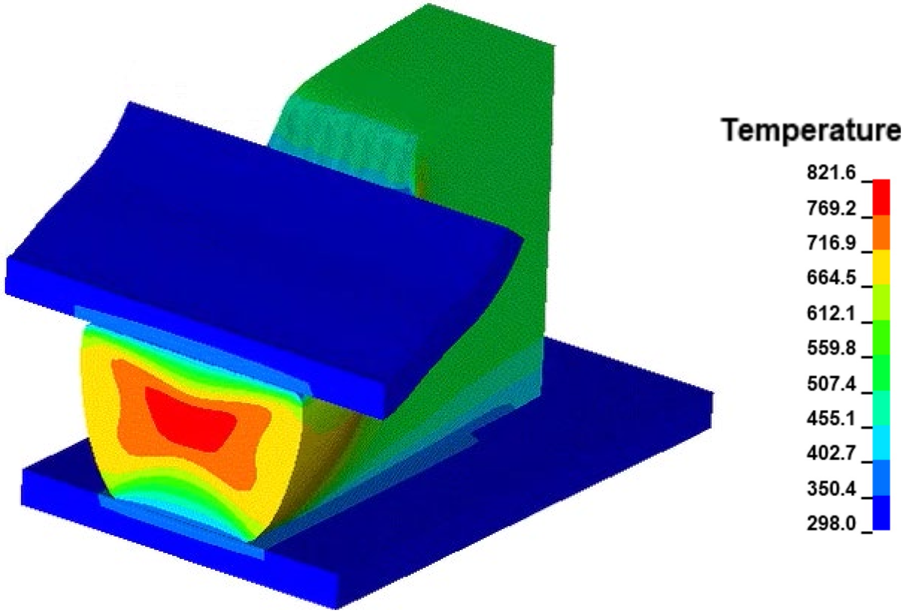












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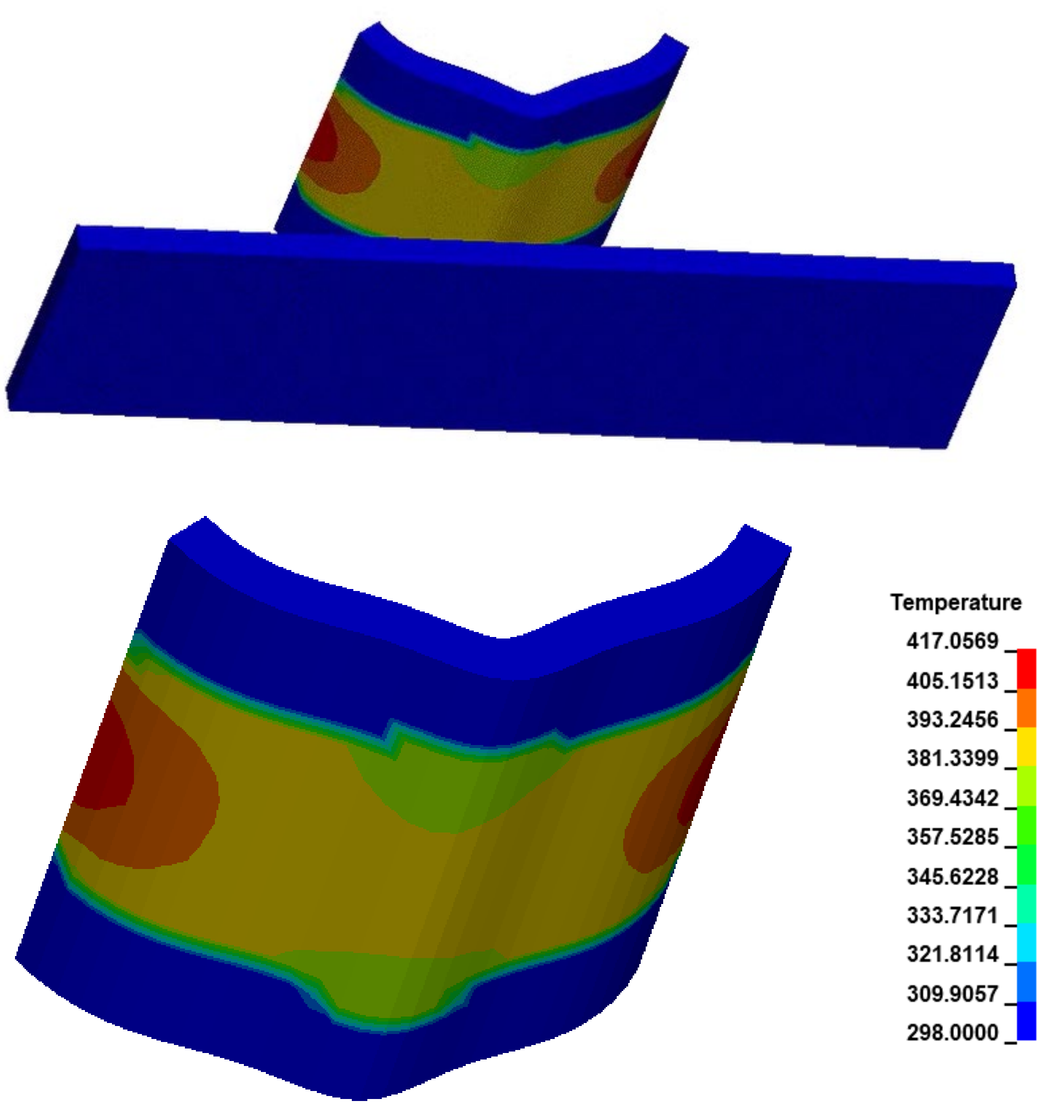
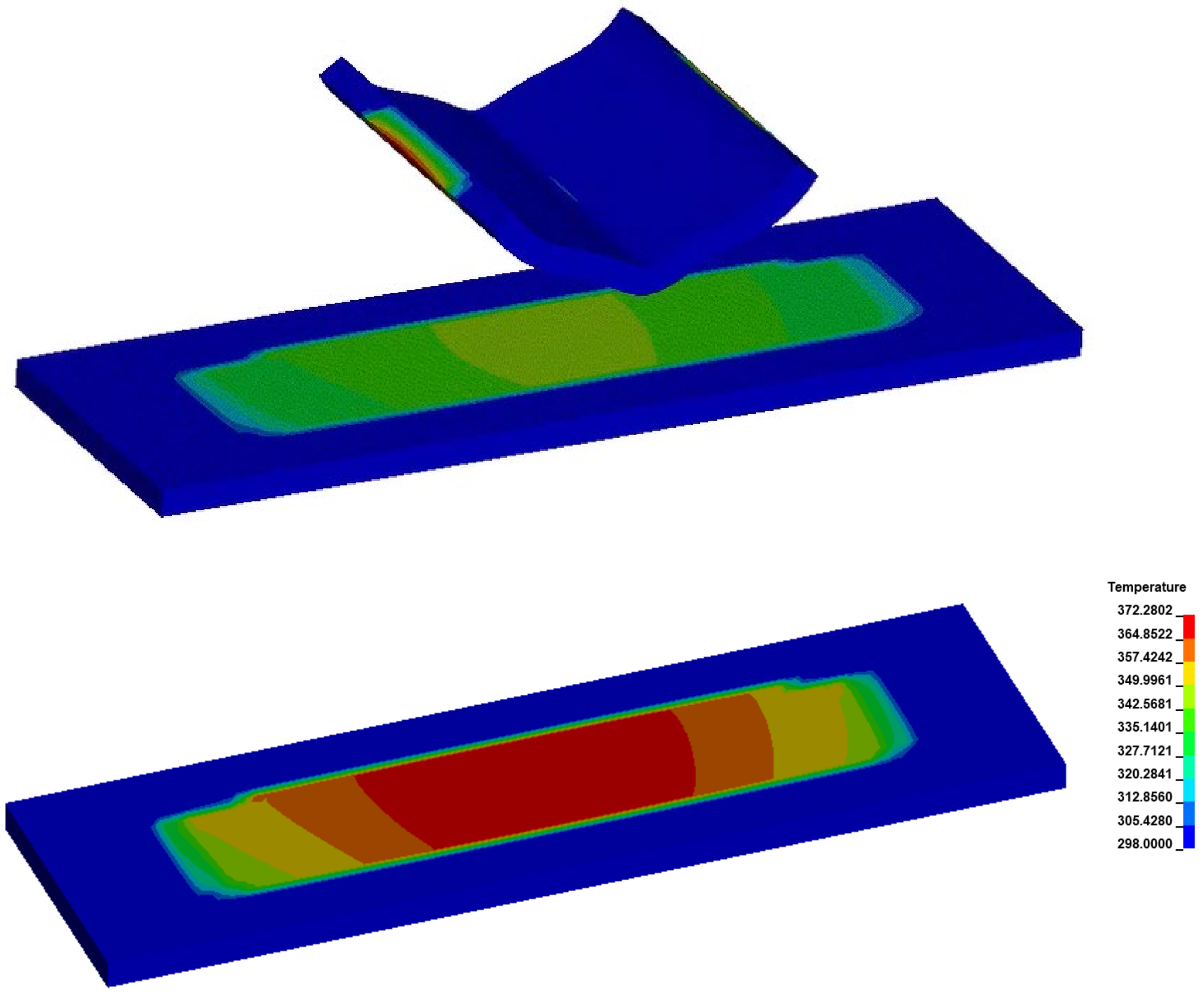
❑ Material Models

- *MAT_106, Thermomechanical





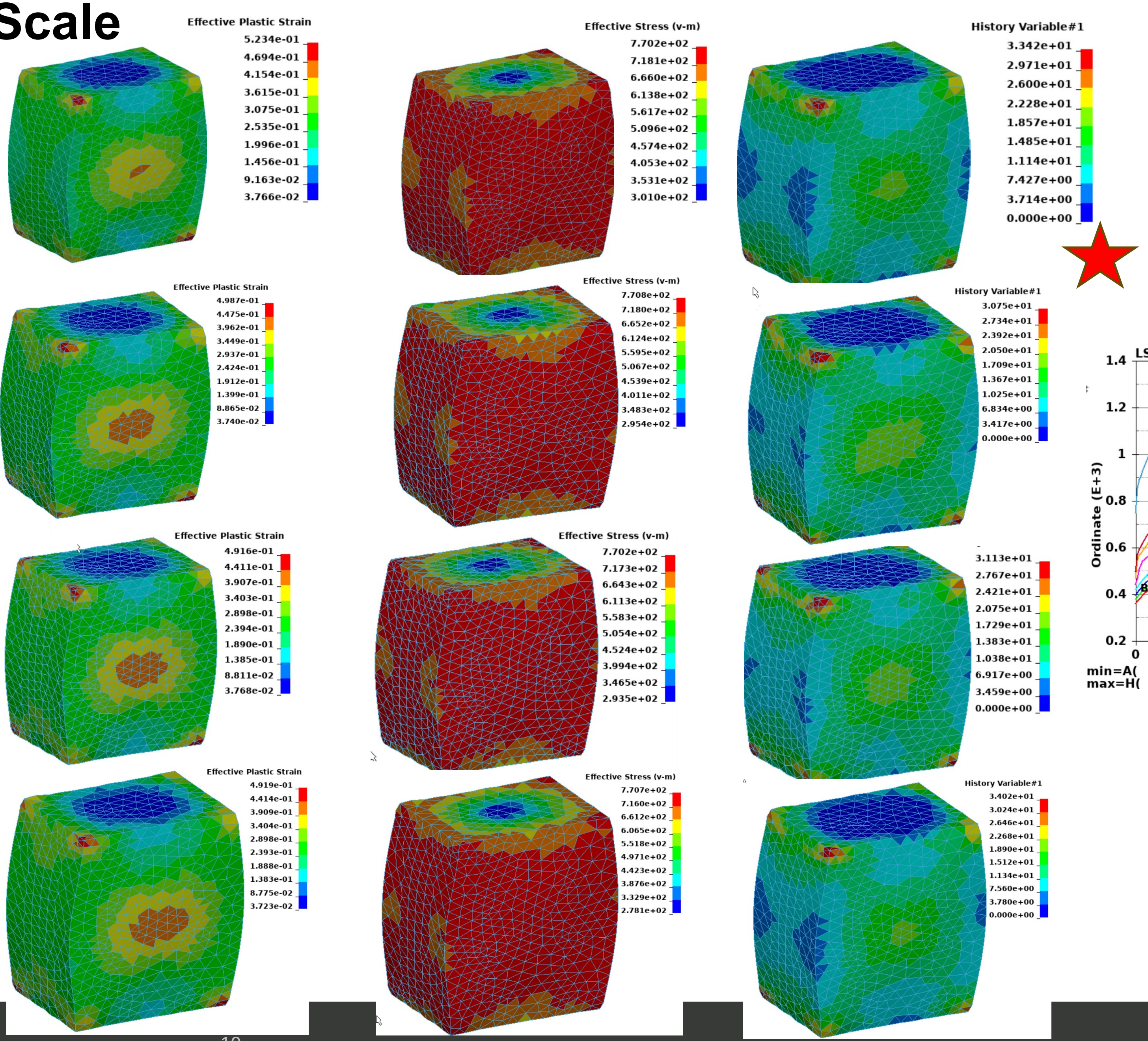
❑ Strain Rate Scale

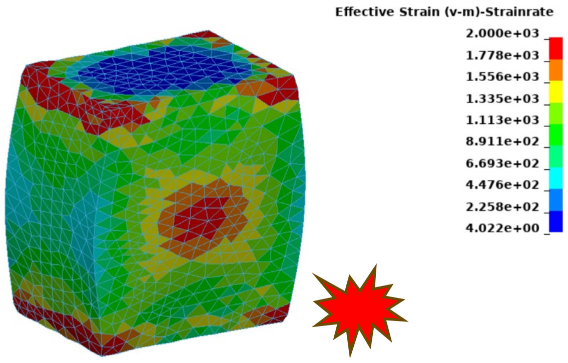
V=10000mm/s — Adpsize(rate scale=100

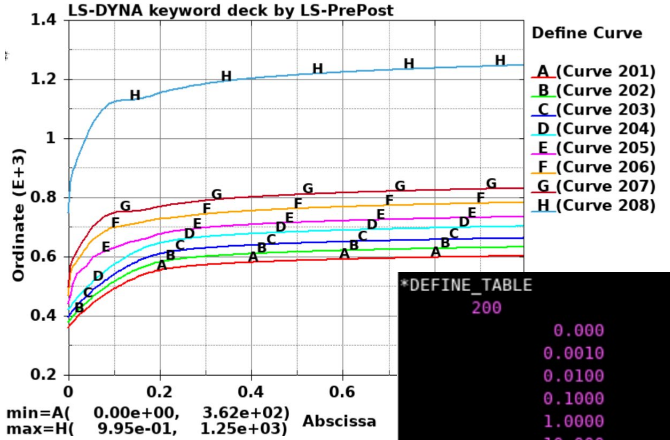
V=5000mm/s — Adpsize(rate scale=50

V=500mm/s — Adpsize(rate scale=5

V=100mm/s — Adpsize(rate scale=1








```
*DEFINE_TABLE
     200
   0.000     201
   0.0010    202
   0.0100    203
   0.1000    204
   1.0000    205
   10.000    206
   100.00    207
   1000.00   208
```

CPU comparison (32 cores):

v10K, rscale 100, 50 sec.

V5k, rscale 50, 1 min

V500, rscale 5, 5 min7sec

V100, rscale 1, 22.5 min

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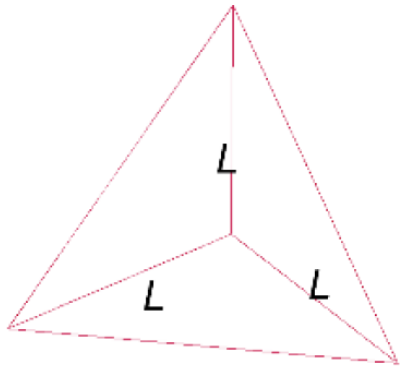
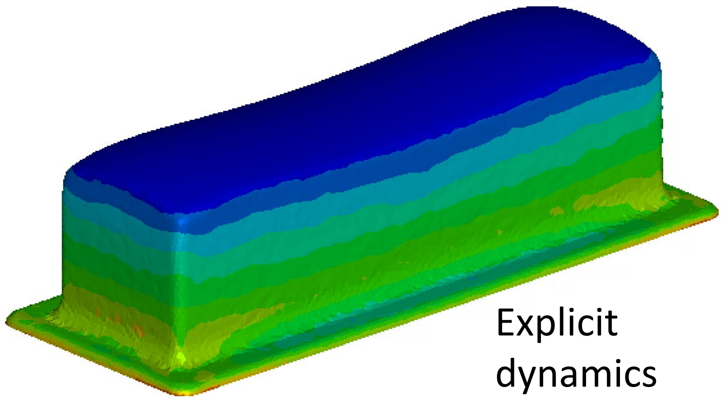
❑ Solvers: Explicit and Implicit

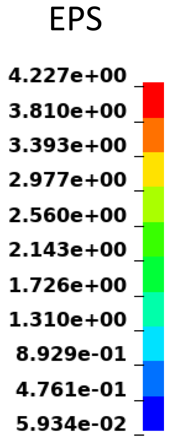


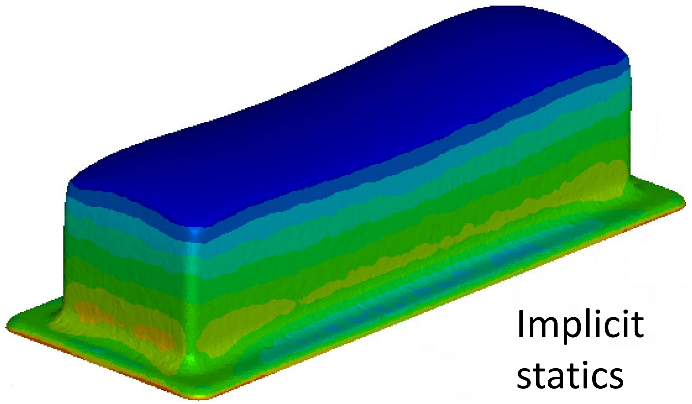
Tetra element edge length L x L x L (mm)	Characteristic length (mm)	CFL time step size (sec.)
1 x 1 x 1	0.577	8.6E-8
0.5 x 0.5 x 0.5	0.289	4.3E-8
0.25 x 0.25 x 0.25	0.144	2.2E-8
0.01 x 0.01 x 0.01	0.00577	8.6E-10

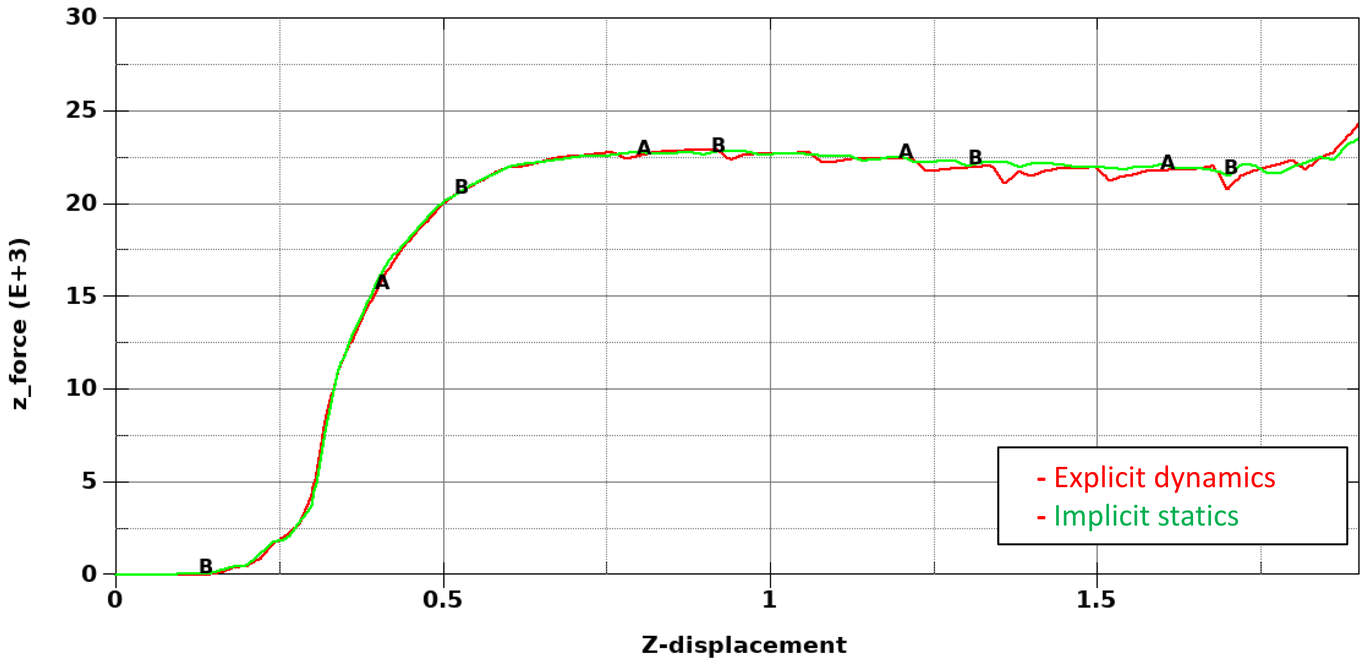
Table 1. CFL time step size of a trirectangular tetrahedron of an aluminum alloy.

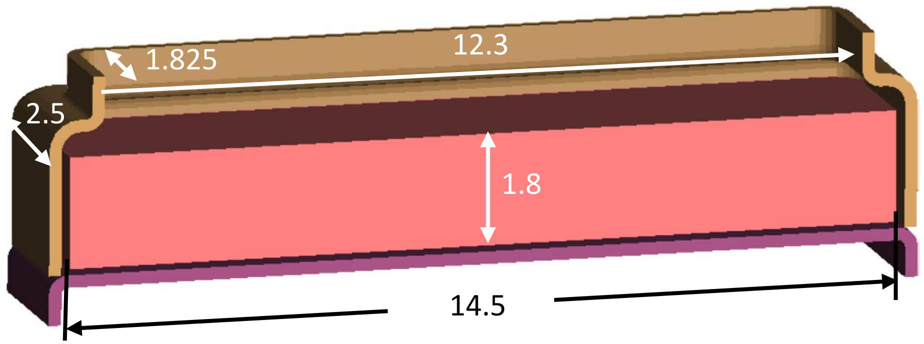
❑ Solvers: Explicit and Implicit





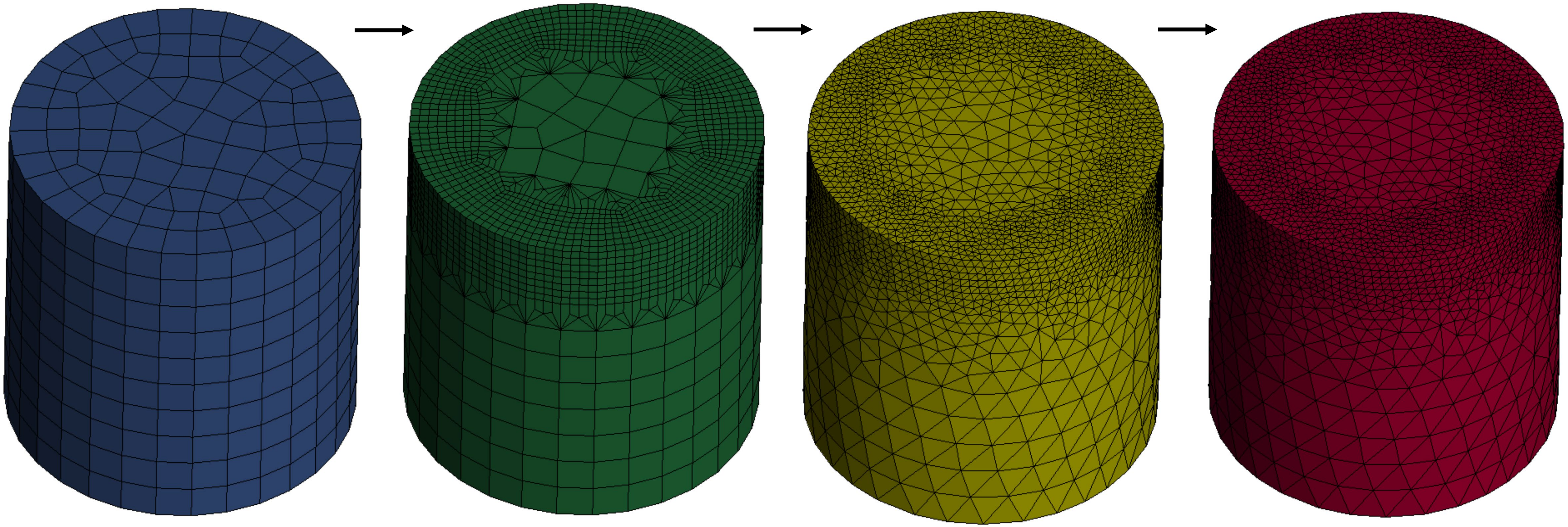




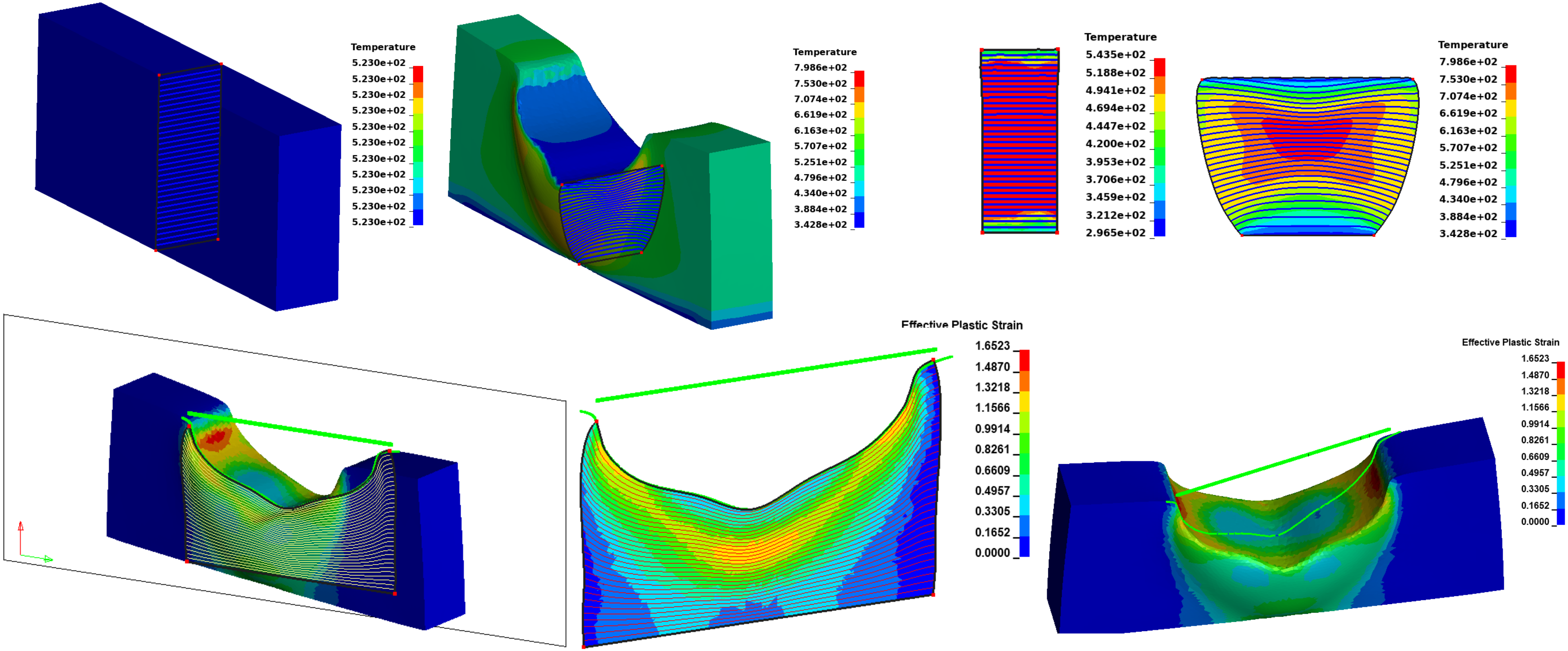


❑LS-PrePost Meshing Features: workpiece meshing

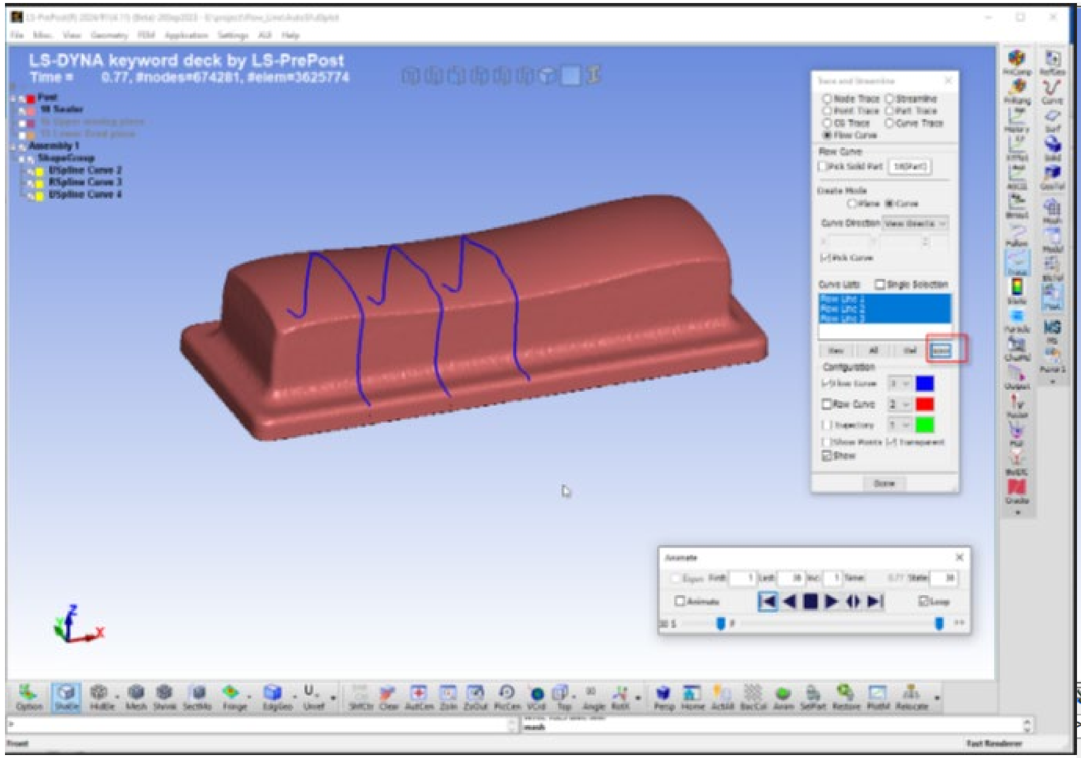
2mm QAUD | **0.5~2mm TRI/QAUD** | **0.4~2mm Remeshed TRI** | **0.4~2mm Remeshed TETRA**

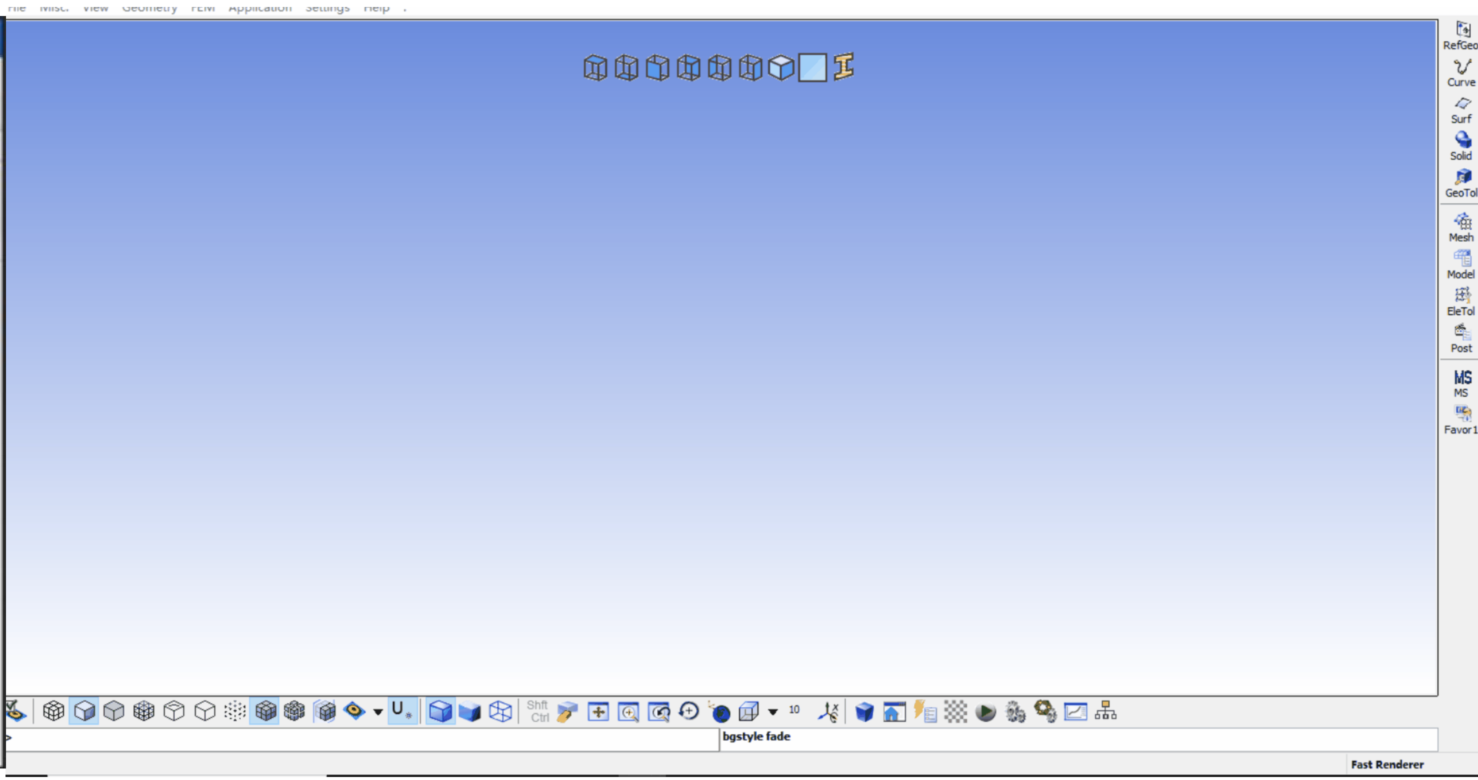


❑LS-PrePost Features: Flow Curves (Internal)



❑LS-PrePost Features: Flow Curves (Surface)





Summary

- **3D adaptive meshing**
- **Element, Trimming, Contact**
- **Material models, C-L damage/failure, strain rate scaling**
- **Explicit/implicit solvers**
- **Thermomechanical coupled forging**

Thank You For Your Attention

Ansys