SAND2022-7504C

Sandia National Laboratories

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Analysis of Element Size on Failure Model Performance

Introduction

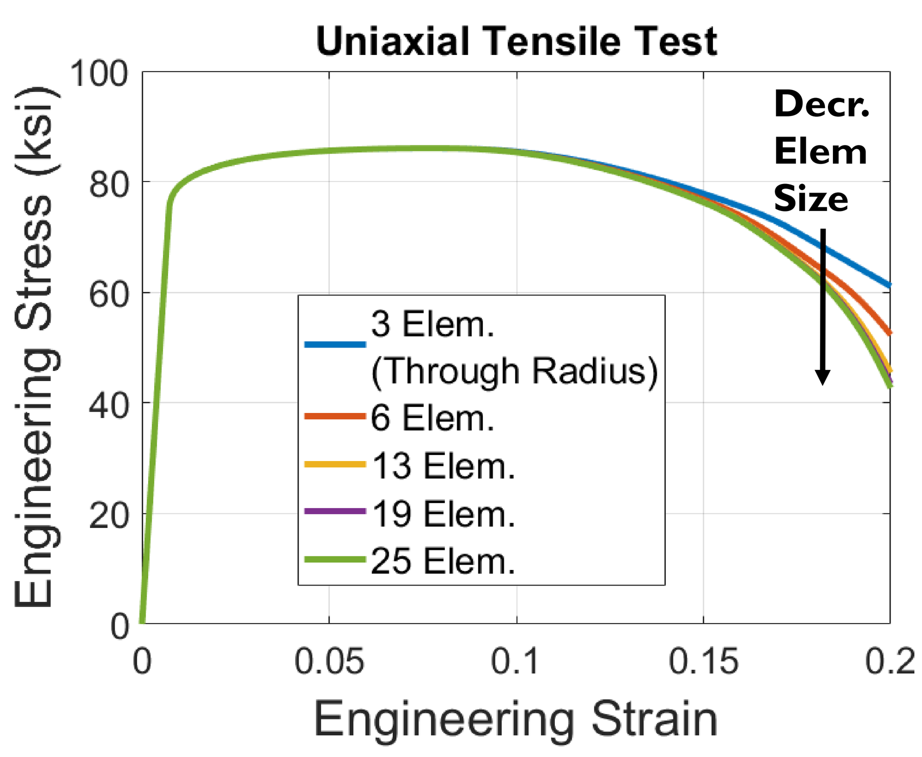
- For finite element simulations, minimum element size is often dictated by considerations like computation time, which makes very fine meshes impractical.
- **Predictions of failure models are highly sensitive to element size.**
- 3 models of increasing complexity were studied to understand the effect of element size on failure predictions
- All models were constructed using 8 node hexahedral elements and used a J_2 plasticity constitutive model with power-law hardening, and Wilkins failure model.

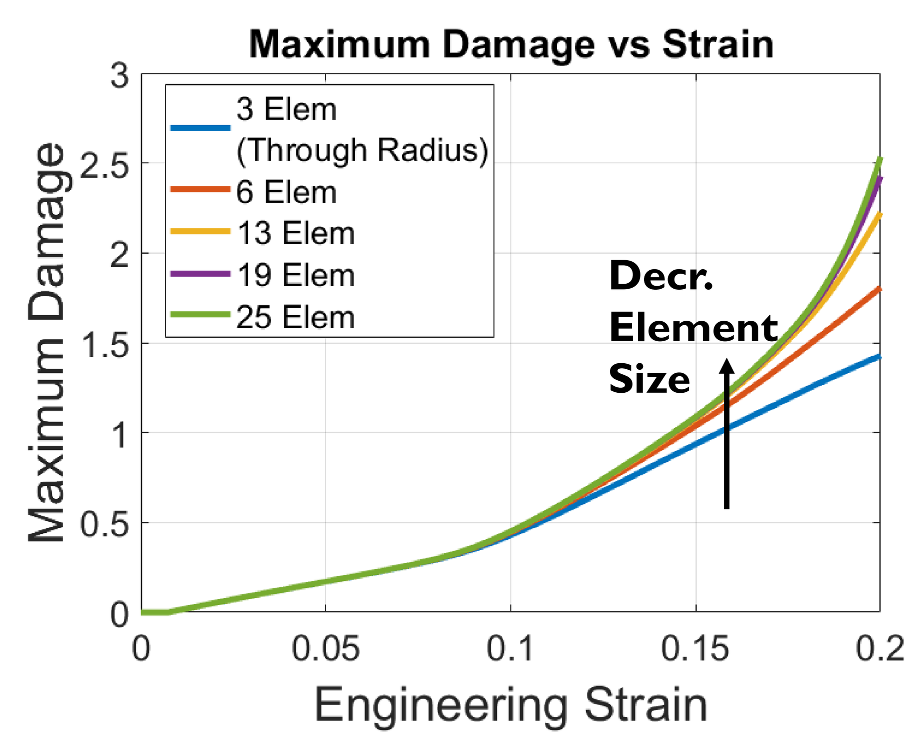
$$\bar{\sigma} = \left(A(T) + B(T)\varepsilon_{pl}^{n(t)}\right)\left(1 + C(T)\ln\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)\right)$$

$$D = \frac{1}{D_{crit}}\int_0^t \frac{(2-A)^{\beta} * \dot{\bar{\varepsilon}}^P}{\left(1-\frac{P}{B}\right)^{\alpha}(1 + D_4 \ln \dot{\varepsilon}^*)(1 + D_5 T^*)} dt$$

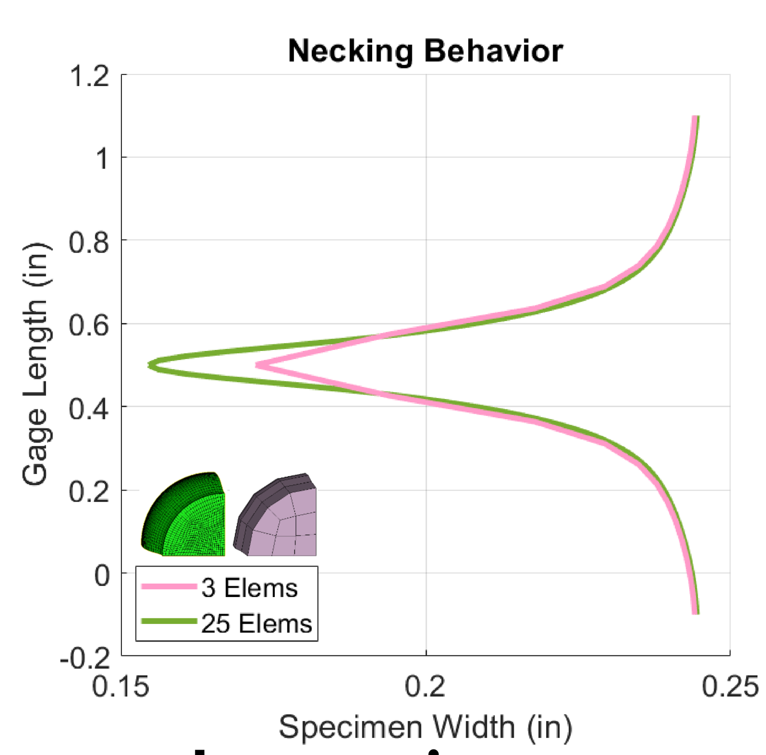
Example 1: Tensile Test (Quasi-static isothermal)

- Tensile specimens of varying element sizes were simulated to quantify the trend of damage for a simple stress state.





- Prior to ultimate, all perform the same
- Beyond ultimate, as element size decreases ↓:
  - Stress post-peak decreases ↓
  - Maximum damage increases ↑
- Necking phenomenon is captured better with smaller elements.



❖ **Higher geometric fidelity captures more localization.**

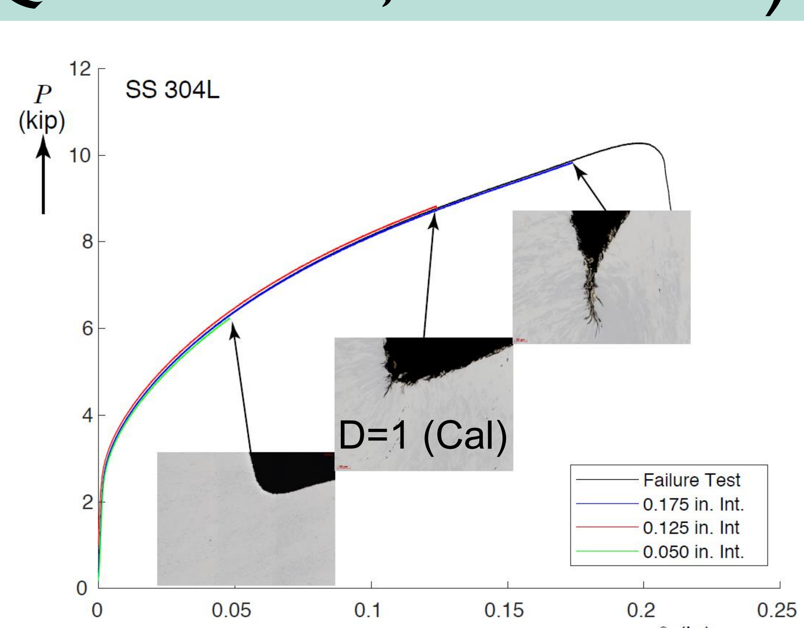
❖ **As element size decreases, maximum damage increases.**

Example 2: Compression Hat (Quasi-static, isothermal)

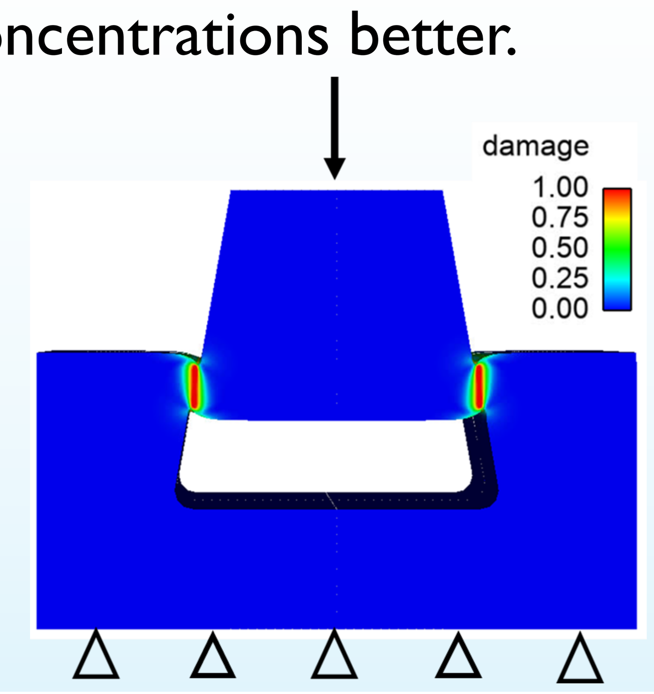
- Interrupted shear failure test where crack growth was imaged at different displacements.
- Simulations of varying element size were conducted to understand the trend of damage for a model with large stress concentrators.

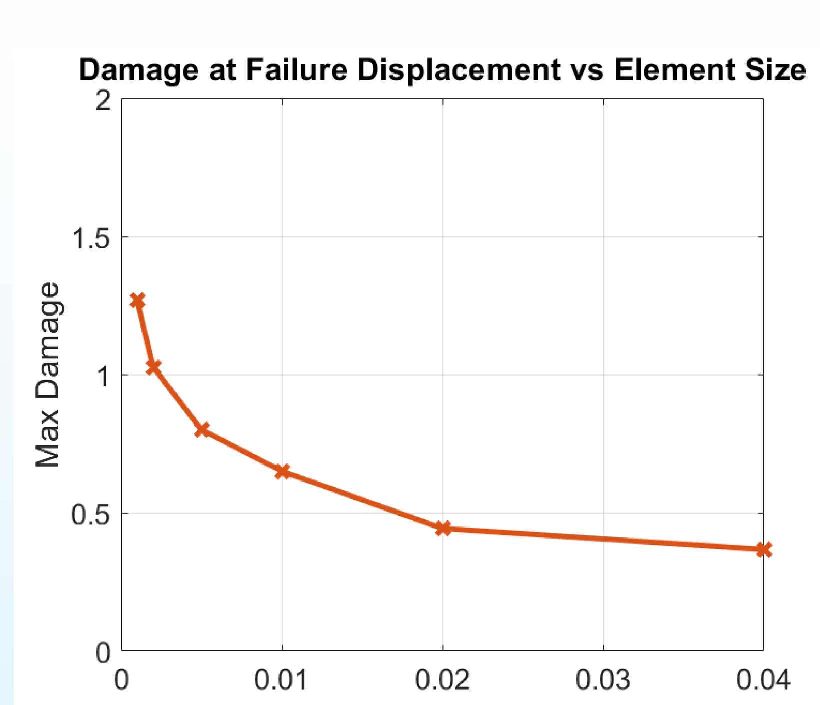
❖ Maximum damage decreases with increasing element size

❖ Smaller elements capture stress concentrations better.



*Experiments performed by Amanda Jones [SNL]

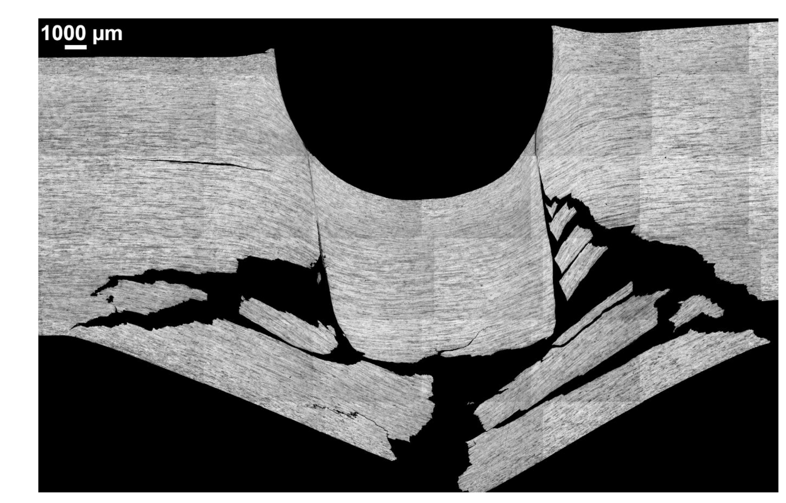




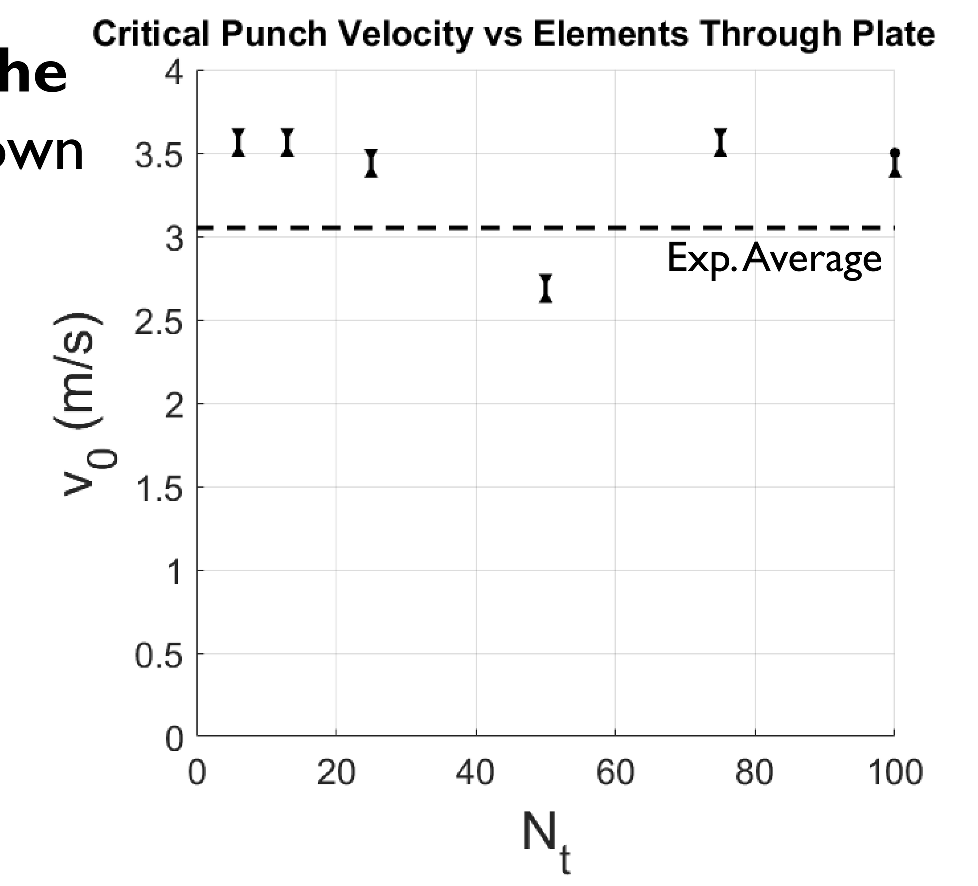
Example 3: Puncture Problem (Dynamic, adiabatic)

- ½ inch hemispherical punch attached to a falling mass, which contacts a ½ inch aluminum plate. Failure propagation was modeled by element death although the model was not calibrated for this.

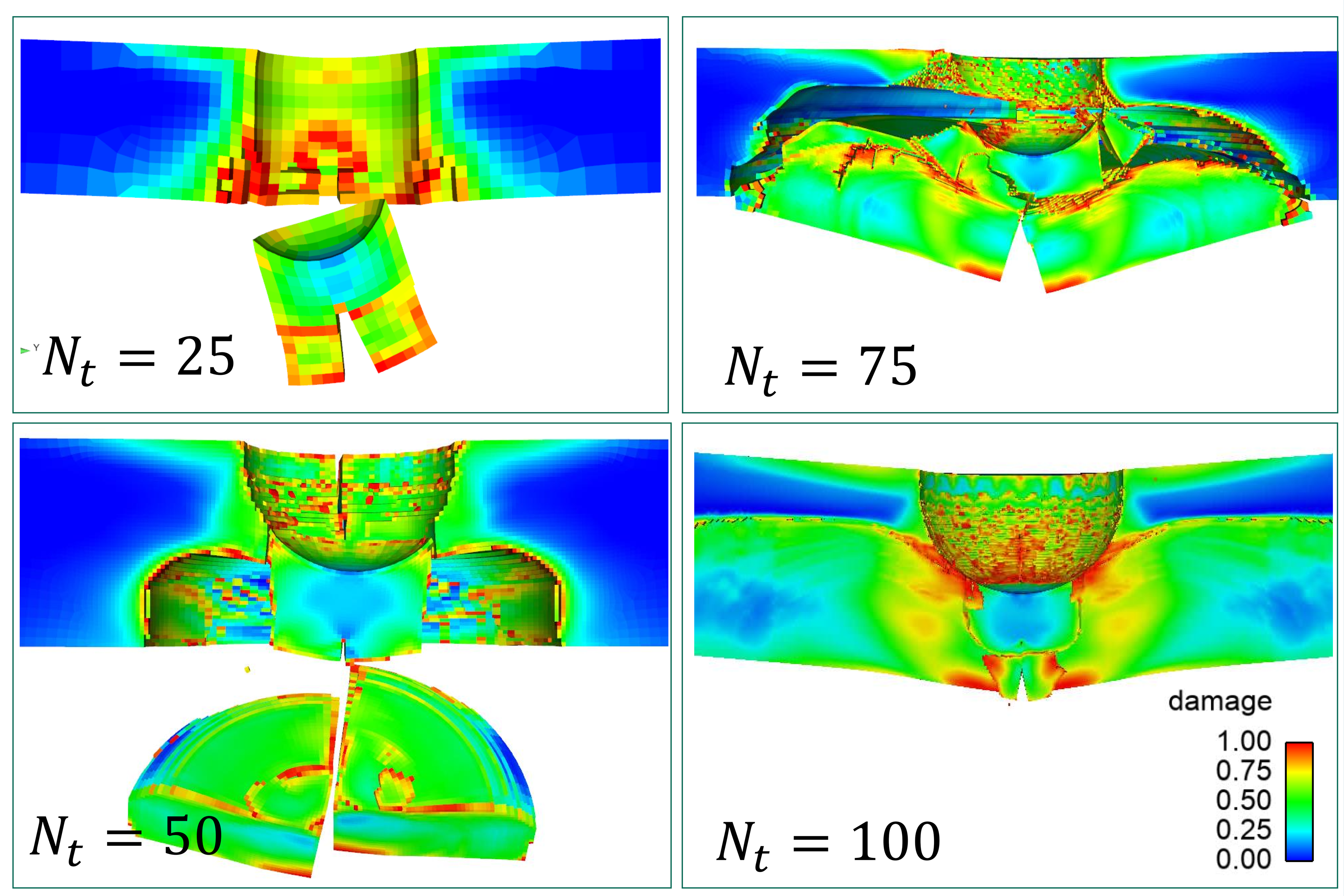
- Critical punch velocity is the minimum velocity needed for breach where a bracket between breach and no breach was measured.
- Critical punch velocity was relatively mesh insensitive but not convergent.
- Experiments showed plugging failure with scabbing.
- **As element size decreases the mode of failure changes** (shown below)
  - 25 Elements, no scabbing occurred
  - 50 elements, matches test.
  - 75 elements mostly scabbing occurred.
  - 100 elements, nonphysical behavior on contact.



*Experiments performed by Matt Spletzer [formerly SNL]



❖ **Problems requiring damage propagation may require fracture propagation calibrations that account for element size.**



Conclusions

- For failure initiation as element size decreases maximum damage increases.
- Using failure initiation criteria can lead to difficulties if failure propagation plays a role.
- Failure propagation likely requires further investigation.
- Analysists should use caution when modeling failure and making associated design decisions.

References

[1] Johnson, G. R., and W. H. Cook. "Fracture Characteristics of Three Metals Subjected to Various Strains, Strain Rates, Temperatures and Pressures." *Eng. Fract. Mech.* 21, no. 1 (1985): 31–48.

[2] Wilkins, M.L., R.D. Streit, and J.E. Reaugh. "Cumulative-Strain-Damage Model of Ductile Fracture," *LLNL* (1980). UCRL-53058

[3] Corona, E., and C. Fietek. "Effects of Finite Element Discretization and Model Simplification on Calculations of Ductile Failure Initiation." *SNL* (2021). SAND2021-10905R

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