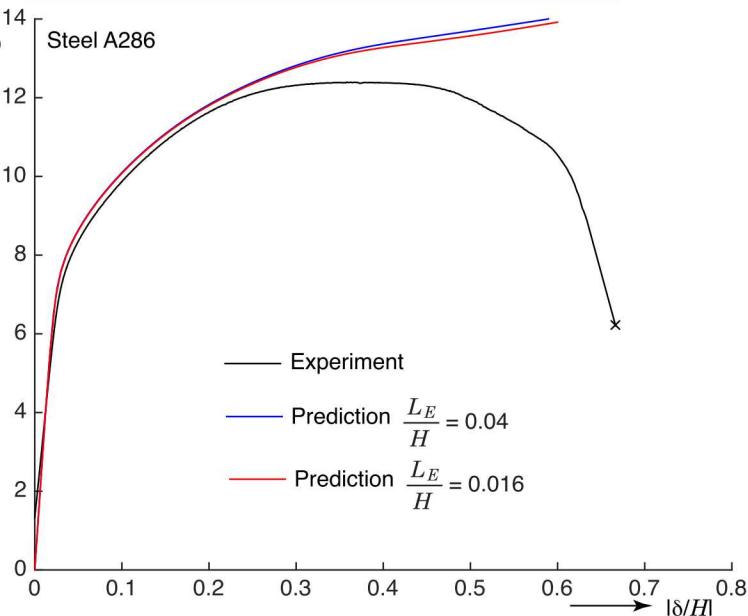
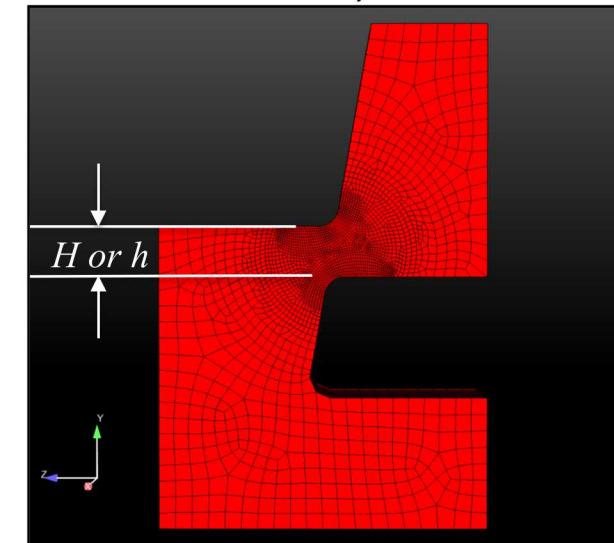
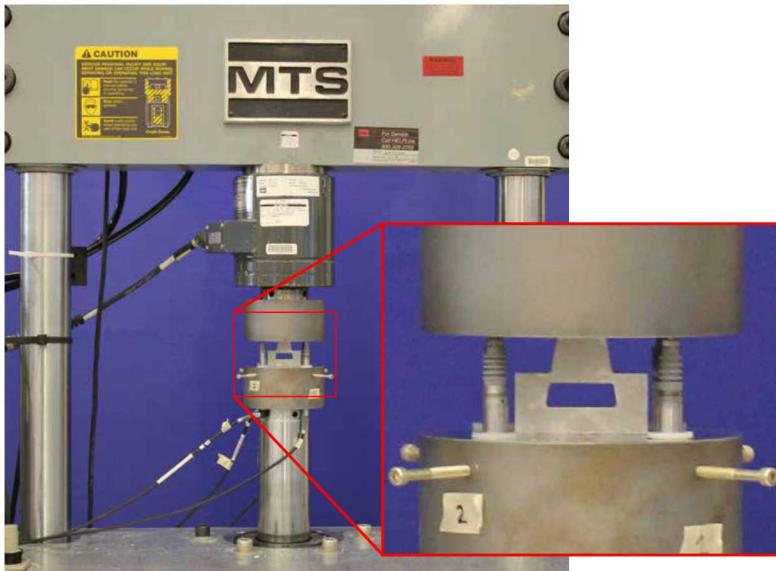


Calibration of Ductile Failure Models Accounting for Triaxiality and Lode Angle Effects

Edmundo Corona, Charlotte Kramer and
Amanda Jones

Motivation

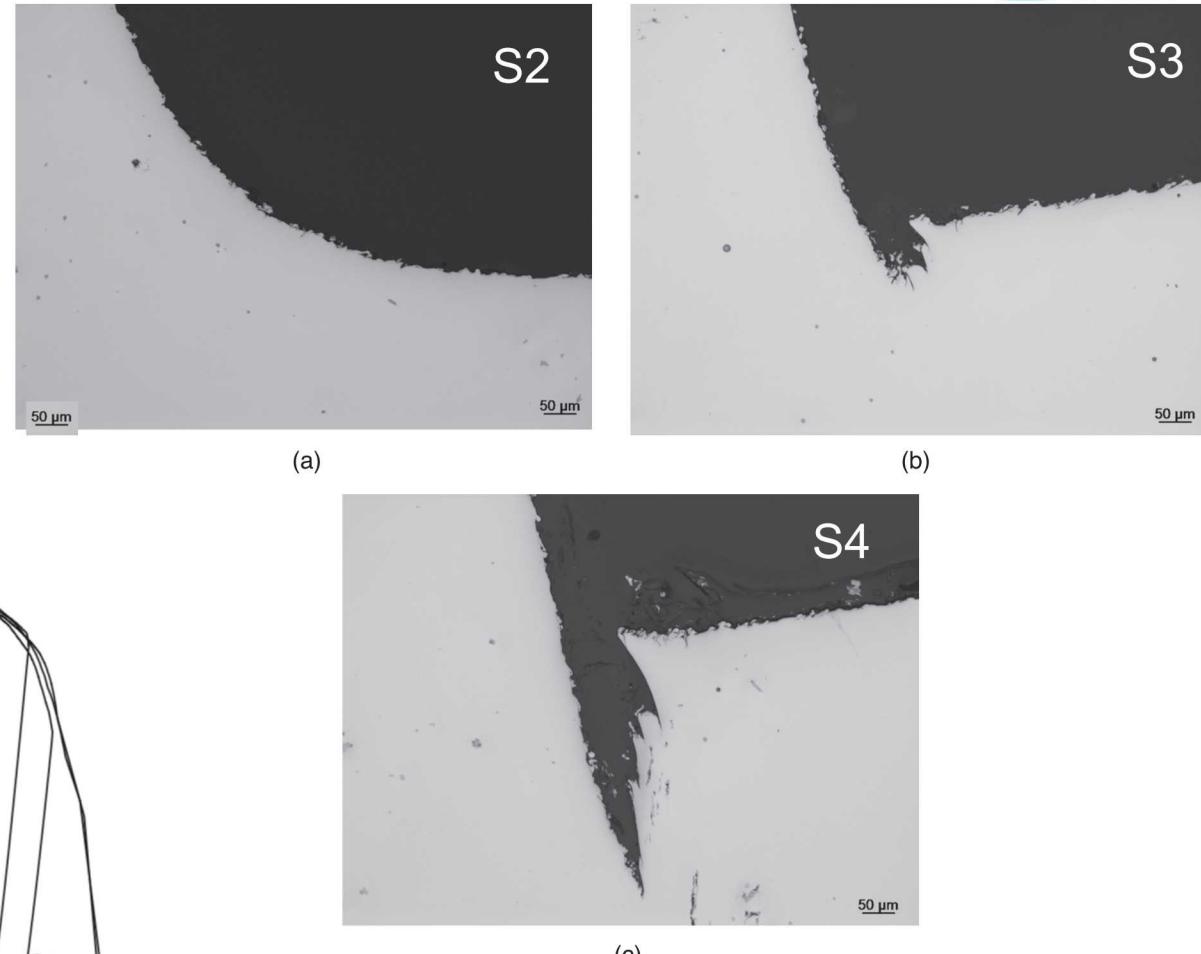
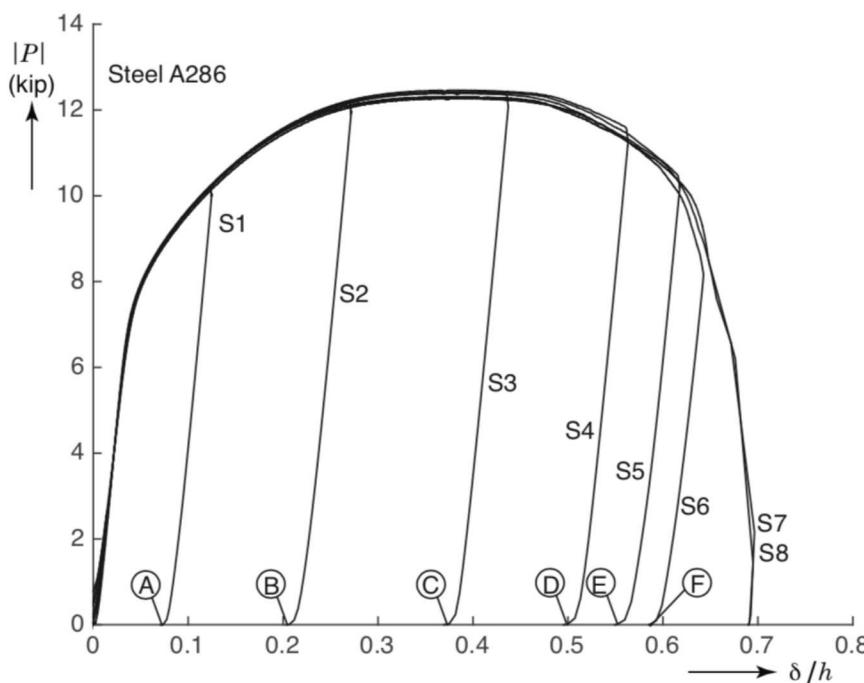
Shear failure fracture challenge (SFC 2013-Internal)



- Experimental results were very repeatable (>10 tests)
- Simulations match experiment up to $\delta/H=0.25$
- After that, the test exhibits a maximum load and an extended regime where the load decreases. The analysis does not.

Source of Load Maximum

- Conduct interrupted tests
- Slice thickness in half and image the corners



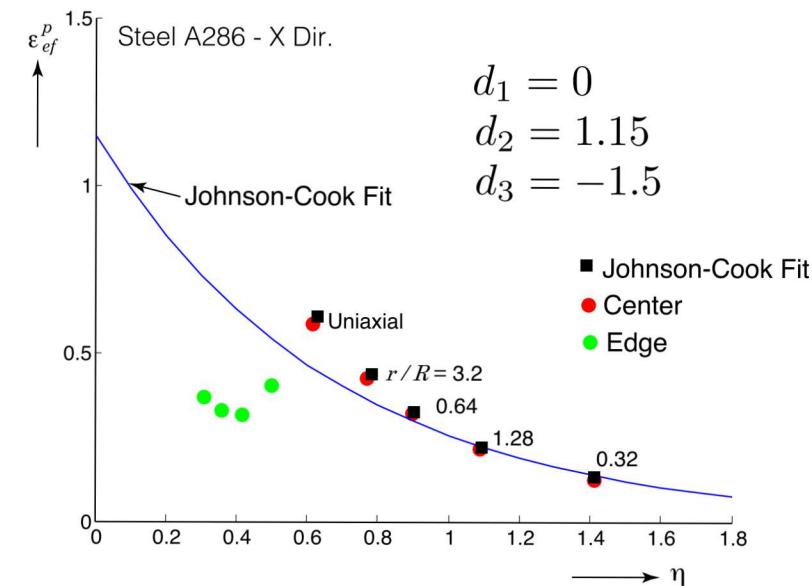
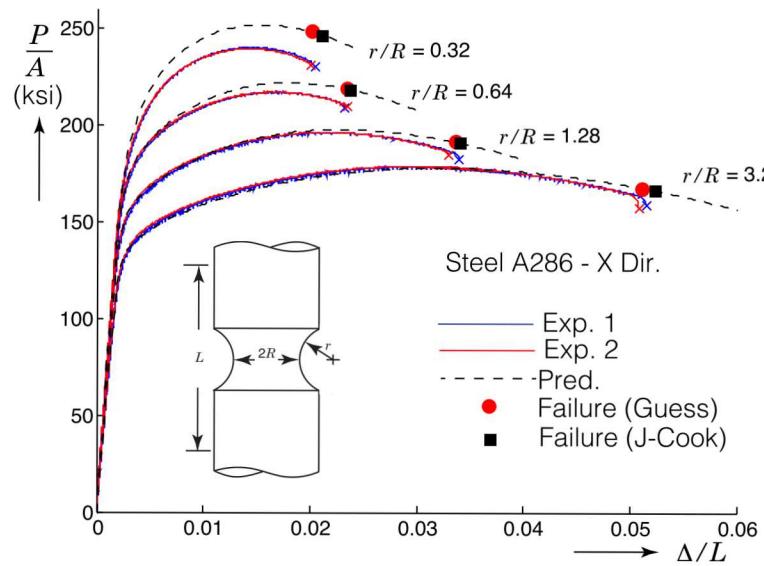
- Load maximum and drop are due to progressive fracturing of the specimen
- The concern in this work is fracture initiation, which occurs between S2 and S3

Calibration of Johnson-Cook Model

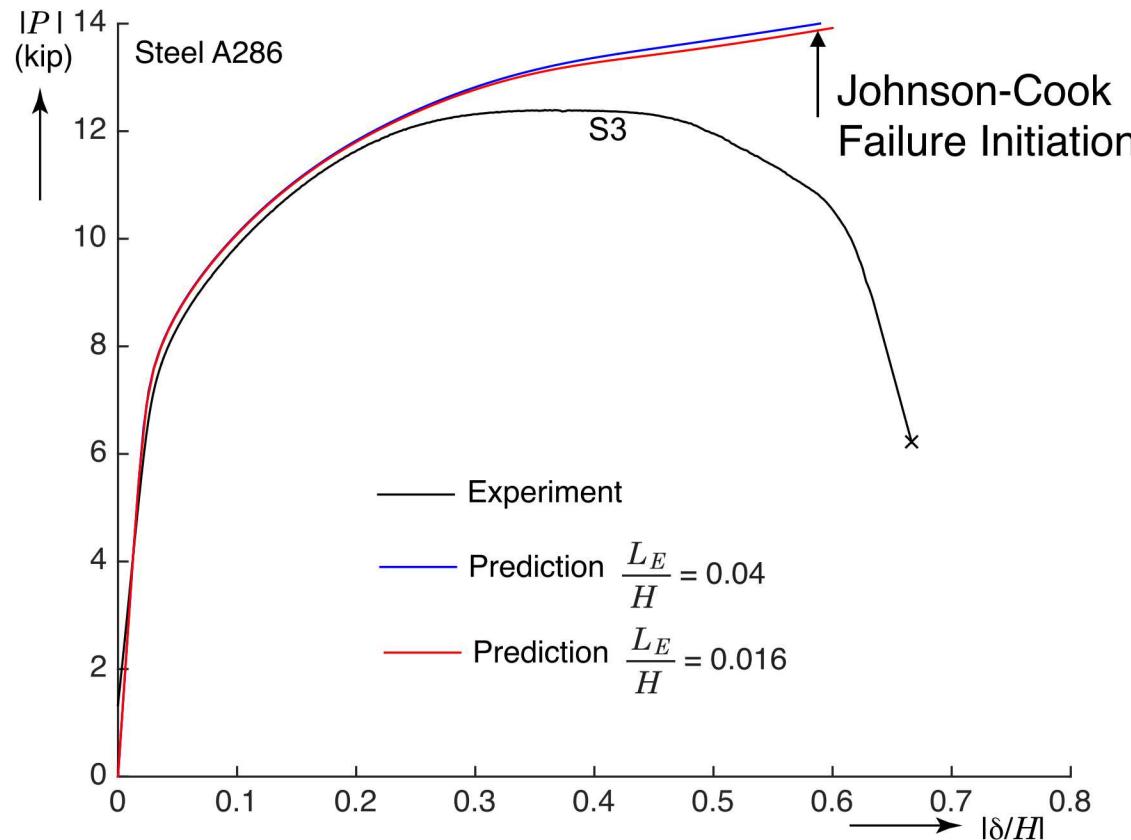
$$\varepsilon_{ef}^p = d_1 + d_2 e^{d_3 \eta}, \quad \eta = \sigma_m / \sigma_e$$

$$\bar{D} = \int_0^{\varepsilon_e^p} \frac{d\varepsilon_e^p}{\varepsilon_{ef}^p(\eta, \hat{T}, \dot{\varepsilon}_e^p)}$$

Notched Tension Tests:



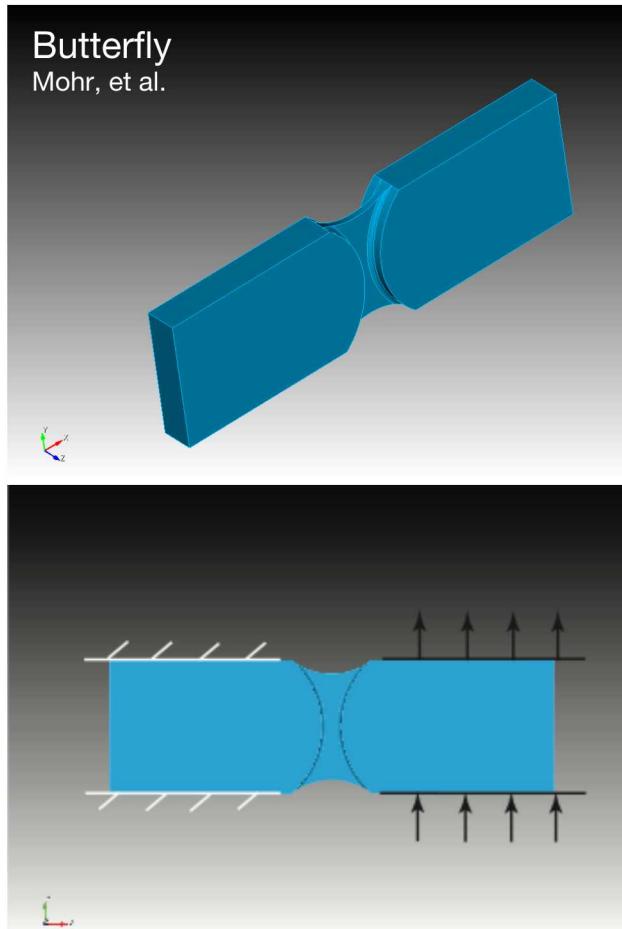
Results with Calibrated Johnson-Cook Model



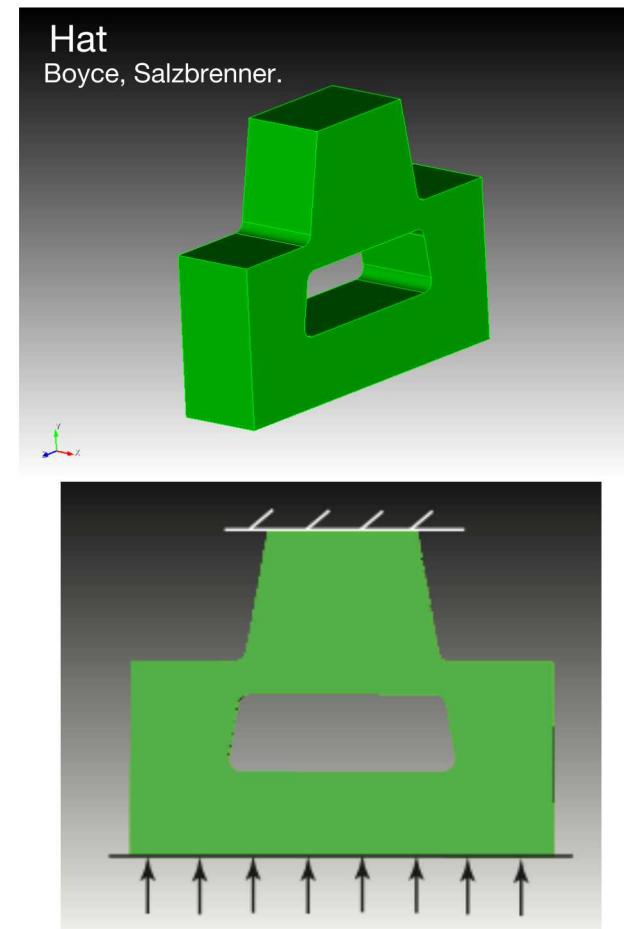
- Model predicts failure initiation at displacement 146% larger than point S3
- Calibration of Johnson-Cook model based on notched tension tests is not sufficient
- Need to address calibration methods and failure models that can accommodate failure in shear-dominated domains

Calibration Methods – Shear Dominated Experiments

- Must not have significant positive triaxiality in areas with high equivalent plastic strain
- Should enhance equivalent plastic strain in areas of low triaxiality

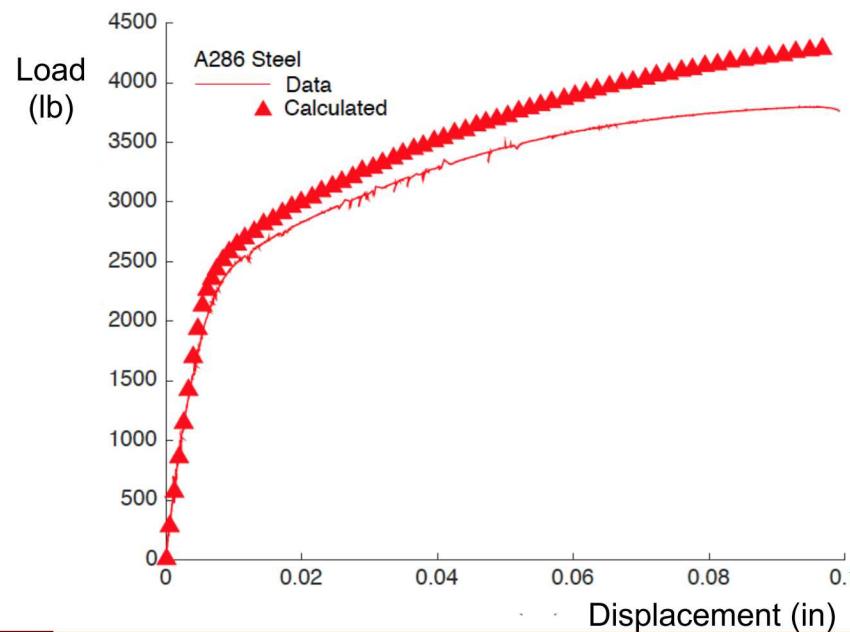
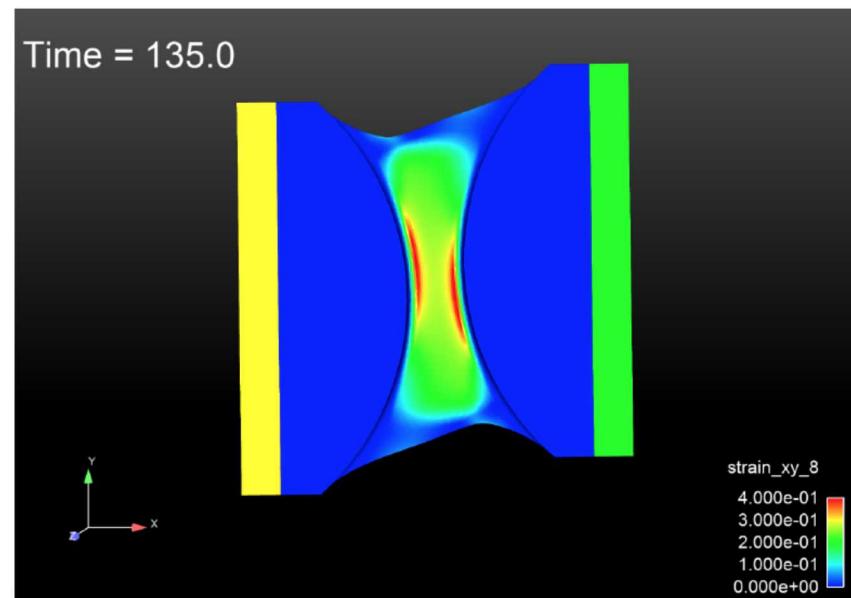
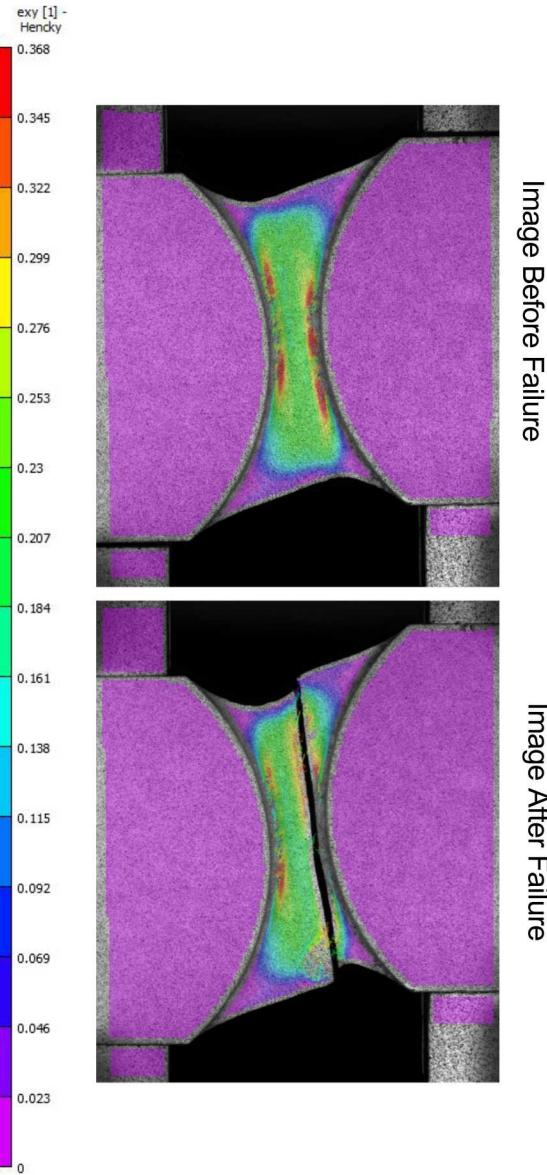


High strains at center
of reduced section



All corners reduce in
radius when loaded

Butterfly Test Specimen



Wilkins Ductile Failure Model



$$D = \int w_1 w_2 d\bar{\varepsilon}^p$$

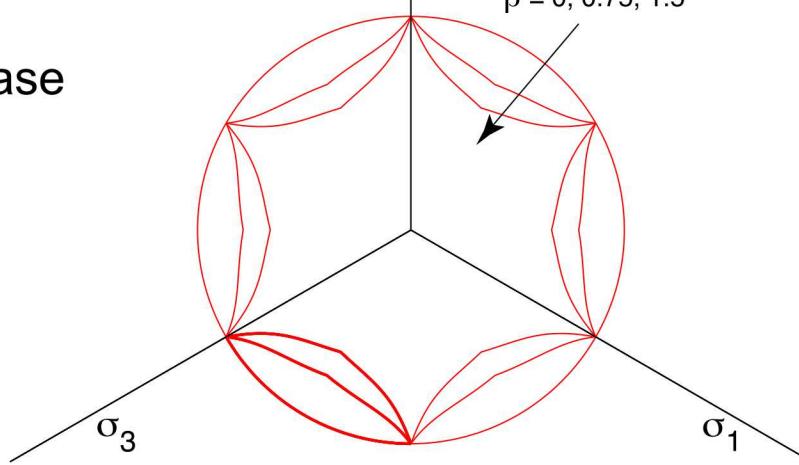
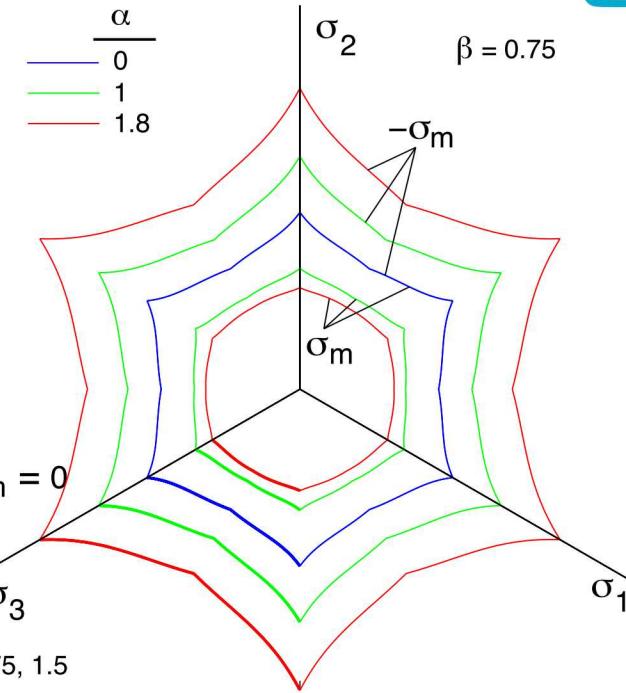
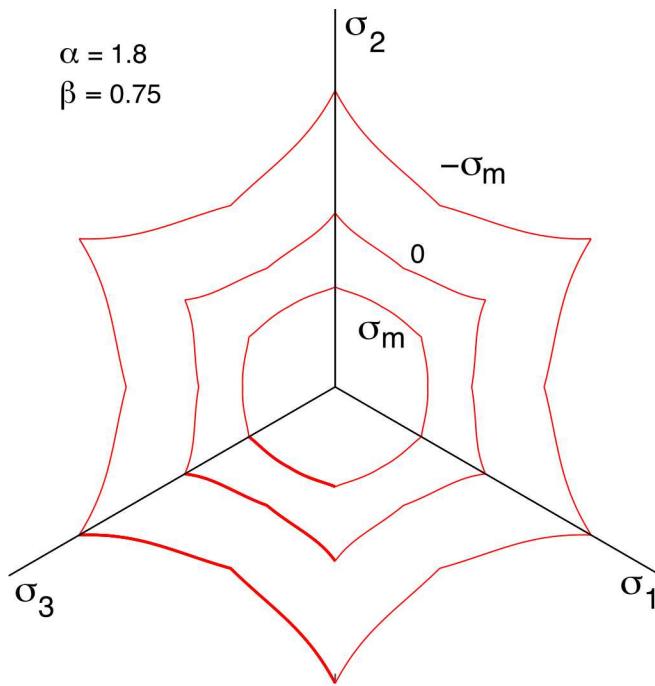
$$w_1 = \left(\frac{1}{1 - a\sigma_m} \right)^\alpha \quad w_2 = (2 - A)^\beta$$

$$A = \text{Max} \left(\frac{s_2}{s_3}, \frac{s_2}{s_1} \right), s_1 > s_2 > s_3$$

Examples: Radial path from constant mean stress

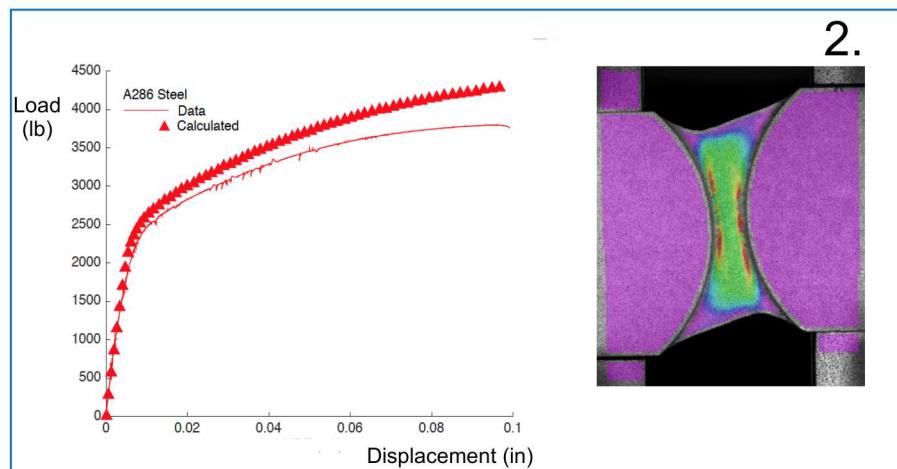
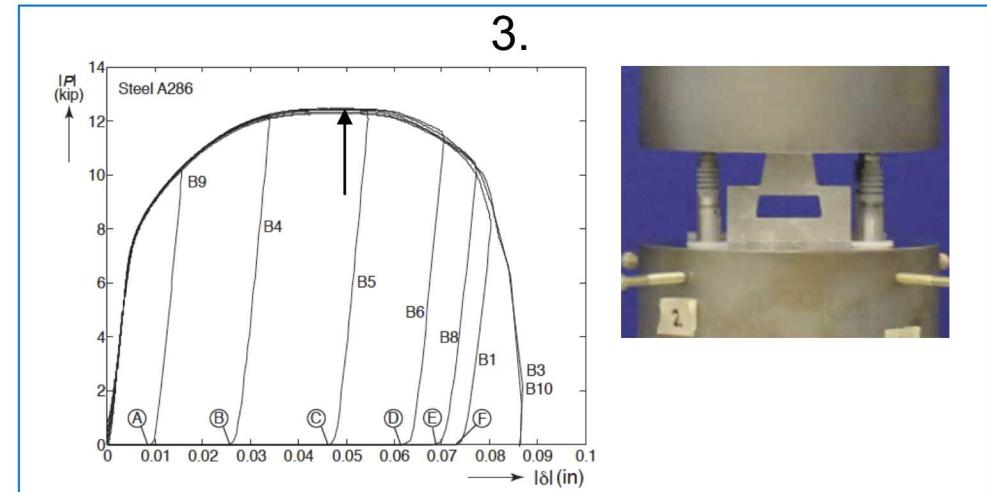
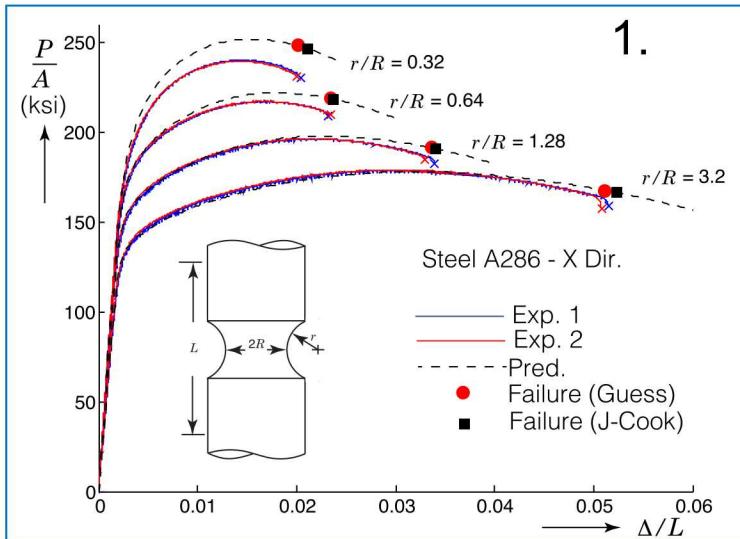
$$D_c = 0.67, \frac{1}{a} = 100 \text{ ksi}, \alpha = 1.8, \beta = 0.75$$

Examples



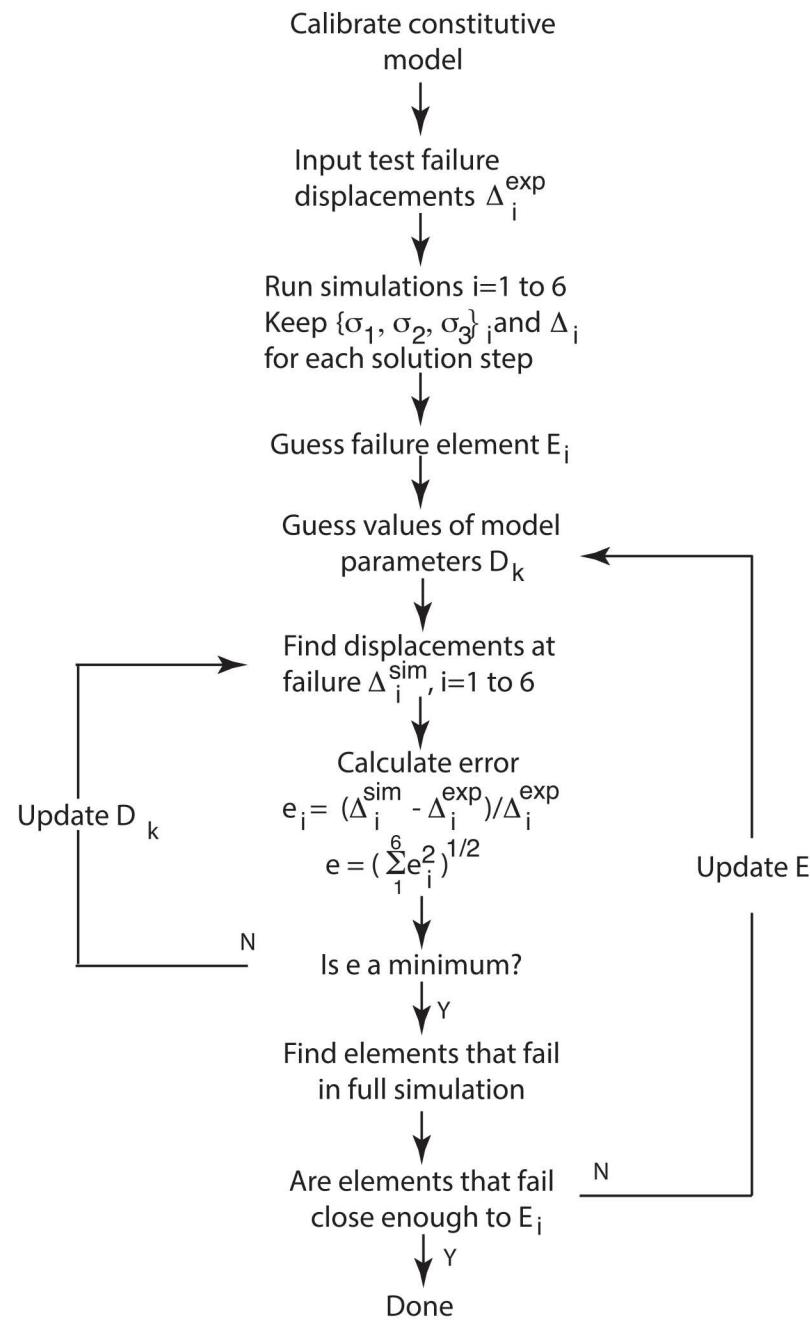
Summary of Calibration Tests

1. Four Notched Tension Tests
2. One butterfly shear test
3. One compression hat specimen

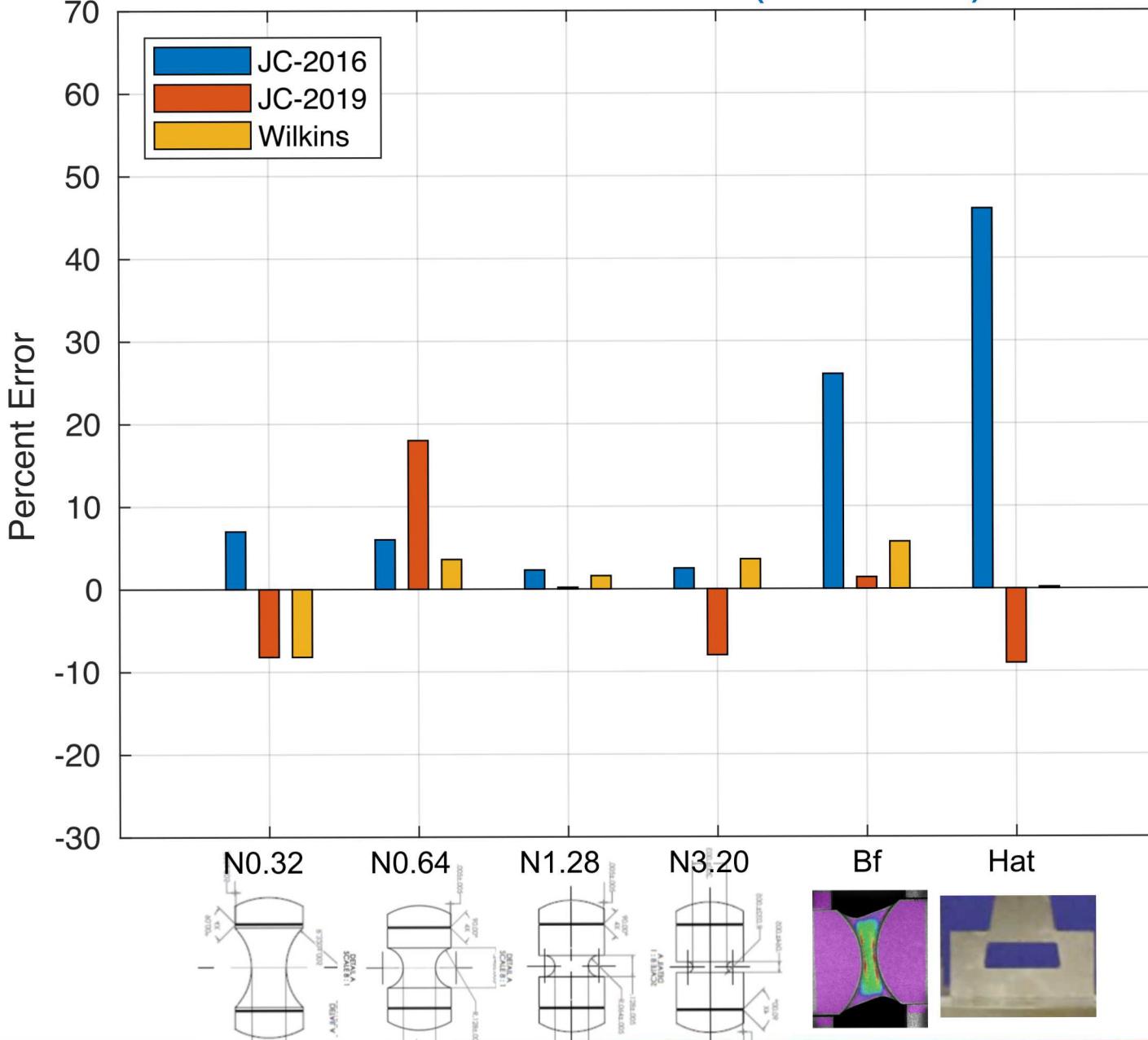


- Extract global displacement at failure
- Observe location of failure

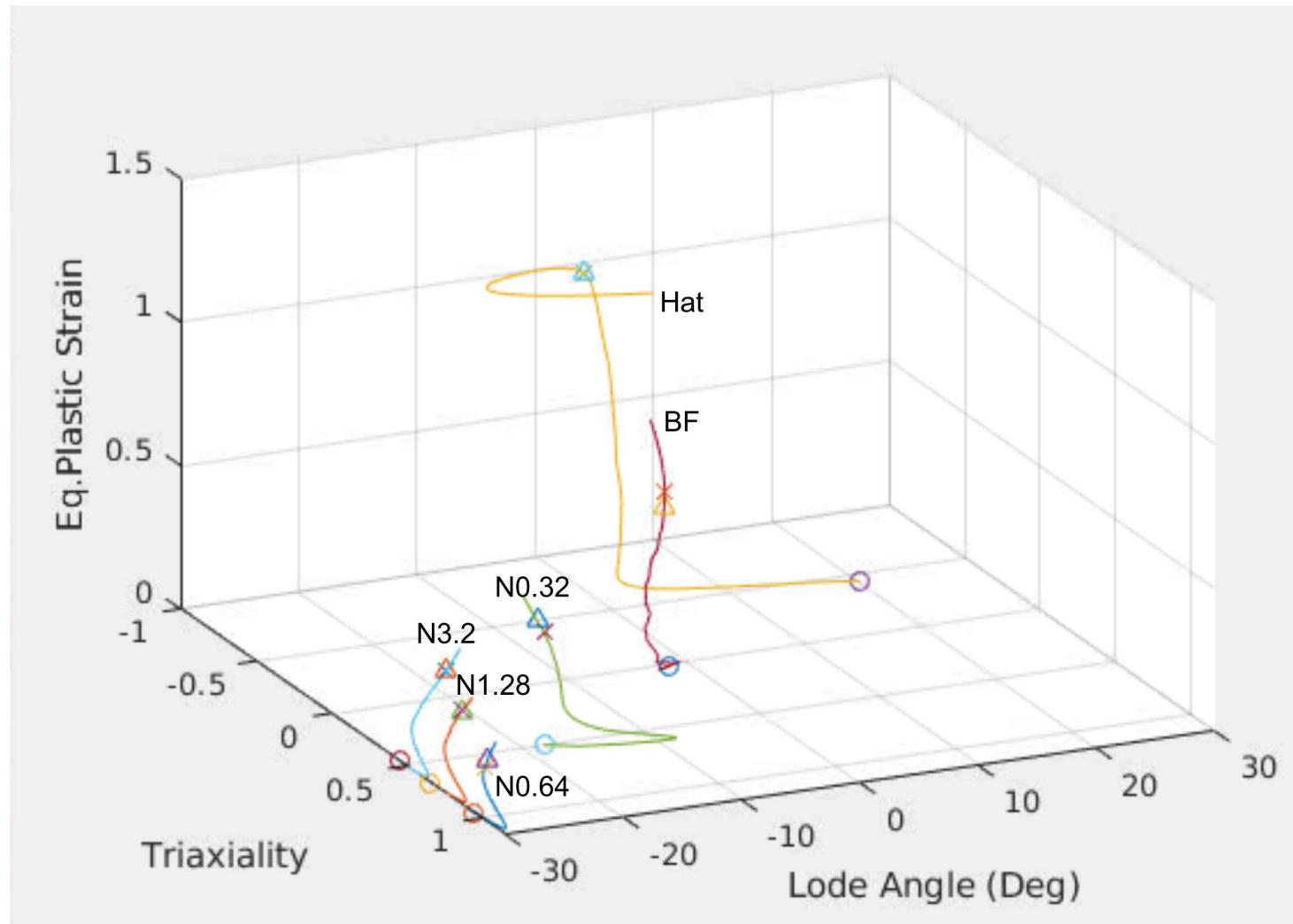
Calibration Process



Calibration Results (Error – e)



Calibration Results - Space Explored at Calibration Point



Conclusions



1. Conclusions are specific to material tested.
2. Developed a “first draft” calibration procedure using results from notched tension tests, shear dominated tests combined with FE simulations of material tests
3. Selected promising experiments to generate shear-dominated failure data
 - * Hat specimen
 - * Accessed states of stress with negative triaxiality and near zero lode angle
 - * Total failure occurred after significant load drop and required interrupted testing and sectioning
 - * Butterfly specimen
 - * Accessed states of stress with nearly zero triaxiality and lode angle
 - * Total failure occurred with little load drop
4. Wilkins model gave smallest overall calibration error
5. Results look promising and warrant further development
6. Ongoing work: What if only one shear-dominated test is available?

Specimen S3 at Center

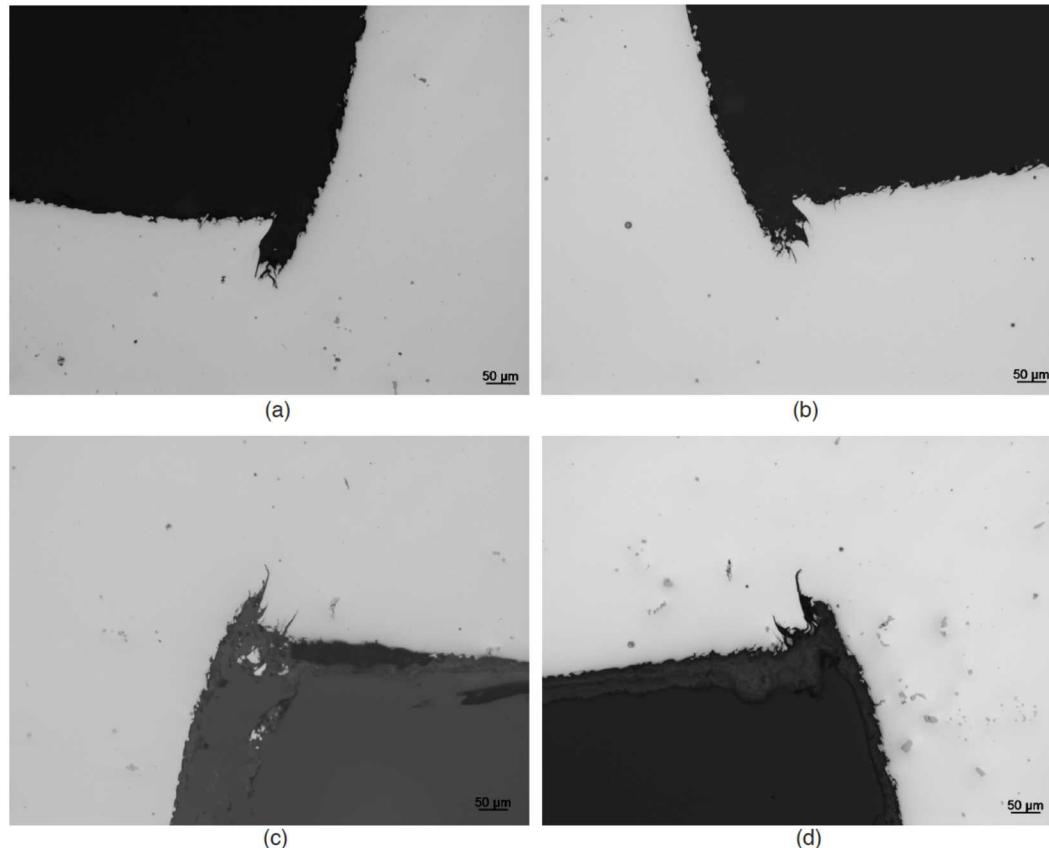


Figure 4. Comparison of the state at the four fillets where damage was first detected at the center of specimen S3.

Specimen S3 at Surface

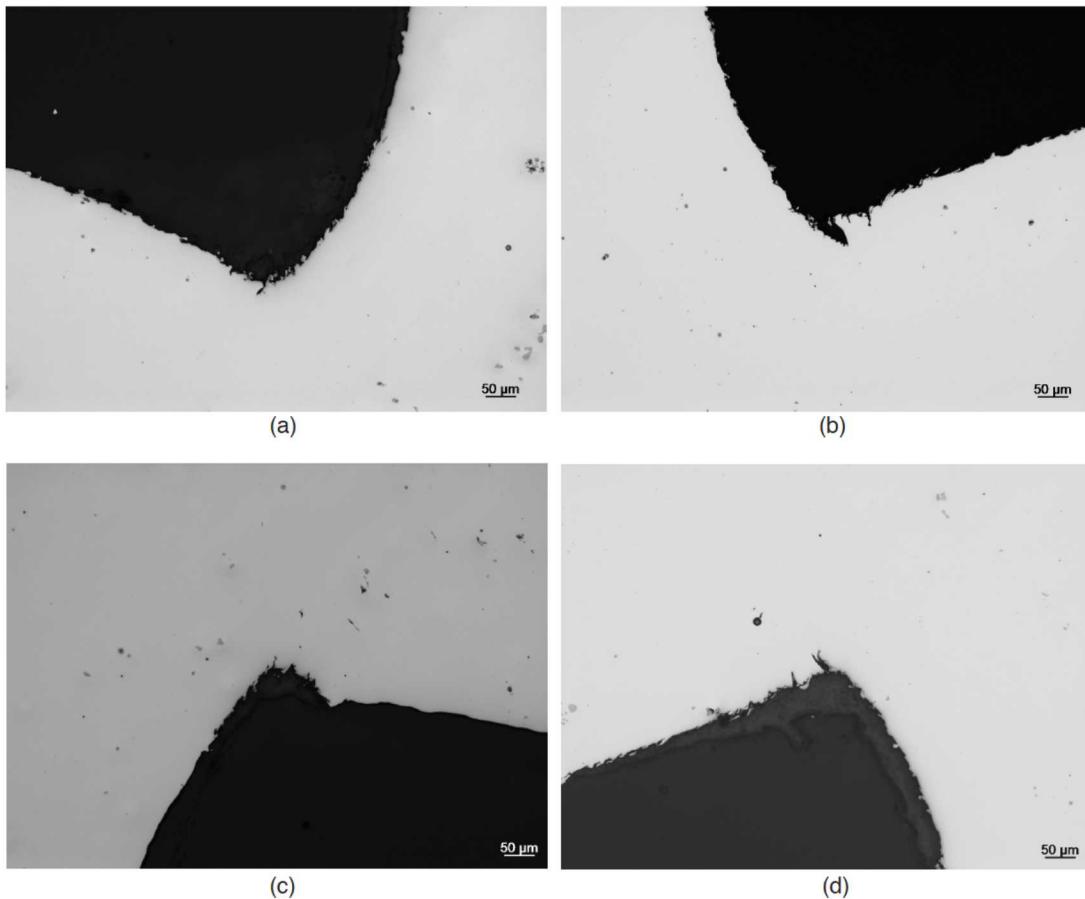
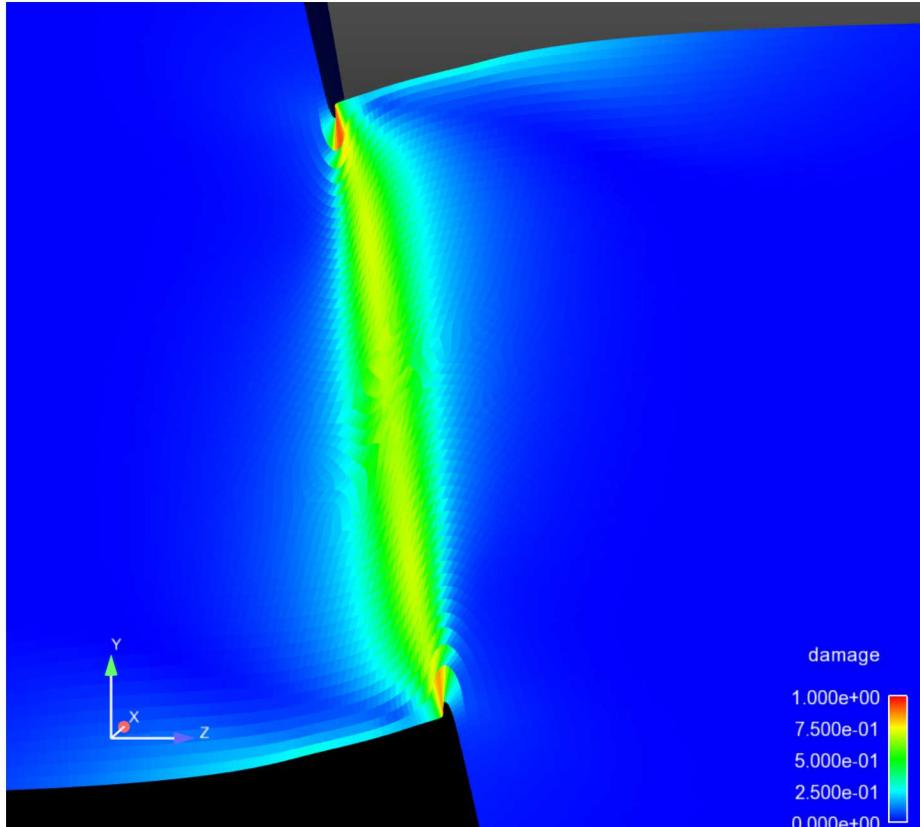


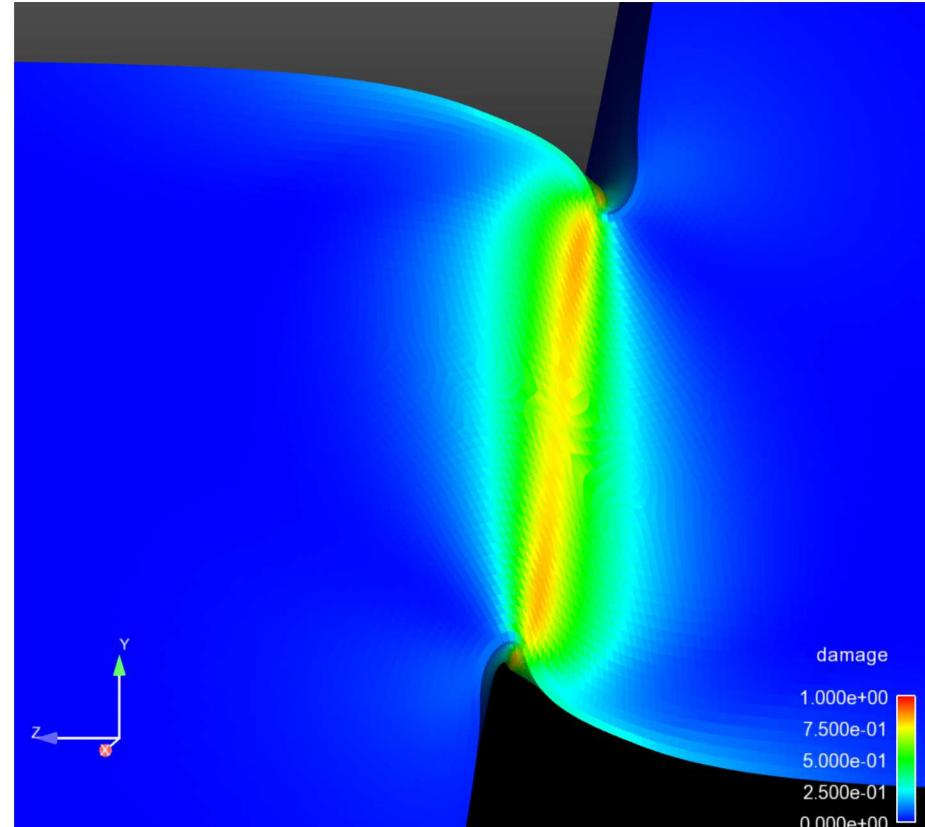
Figure 5. Comparison of the state at the four fillets at the surface of specimen S3.

Johnson-Cook Damage for Hat Specimen

End of simulation

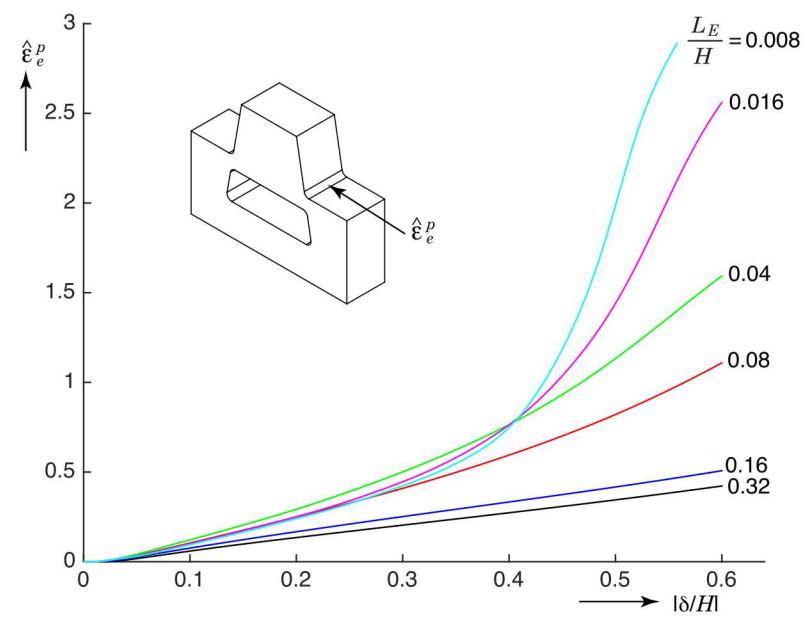
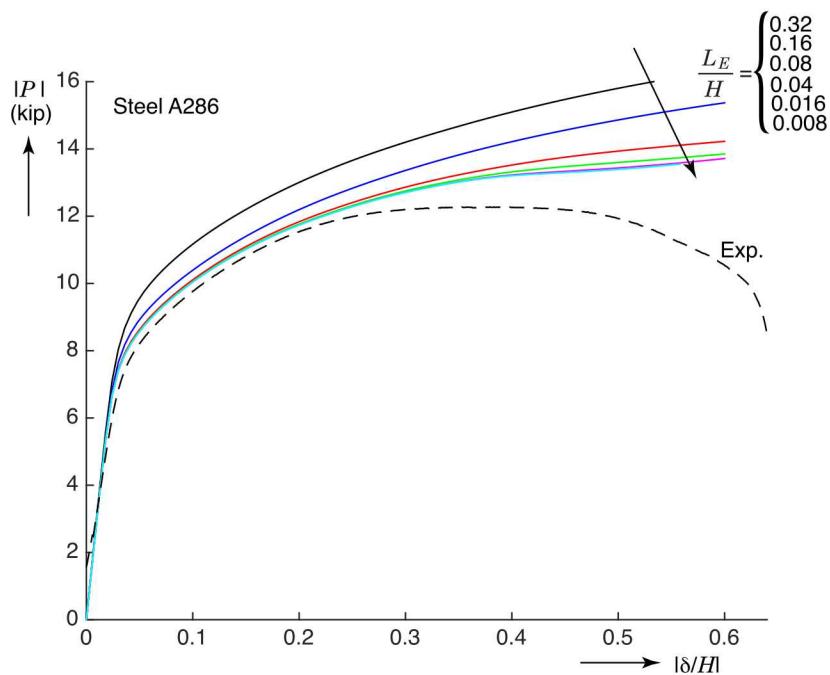


Center

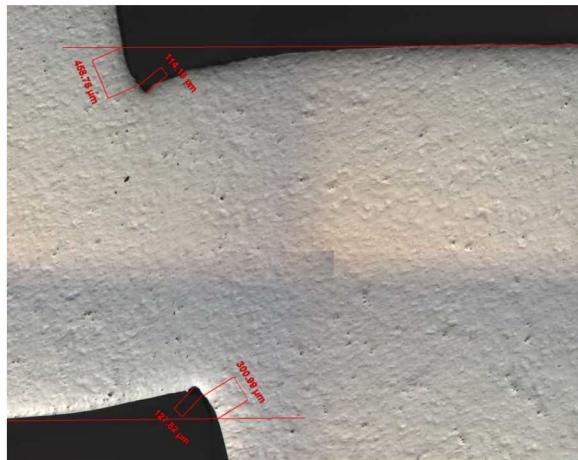
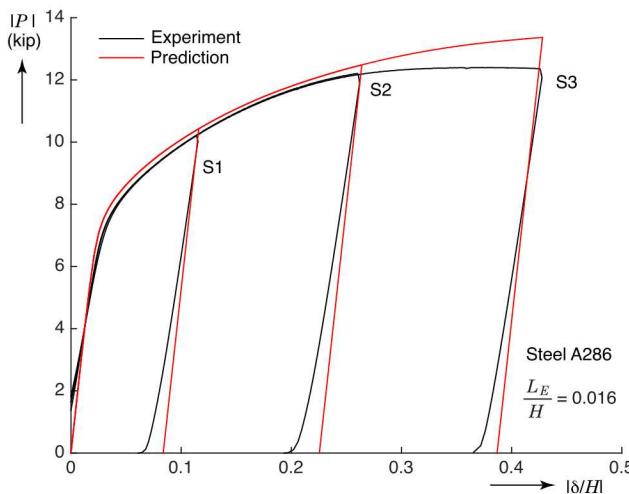


Surface

Element Size Sensitivity for Hat Specimen



Profile Comparisons for Hat Specimen



$$\frac{L_E}{H} = 0.016$$

Center

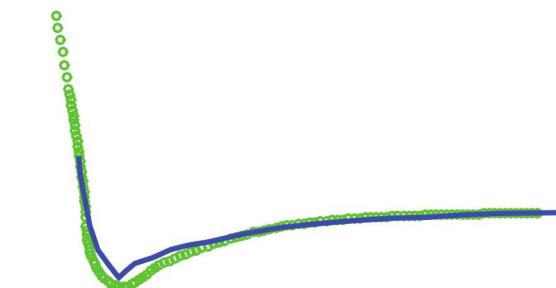
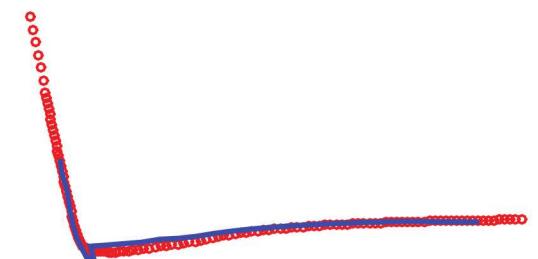
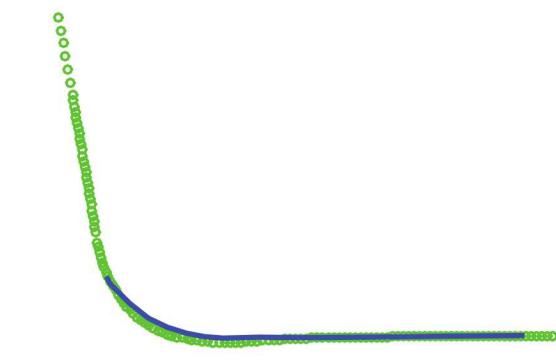
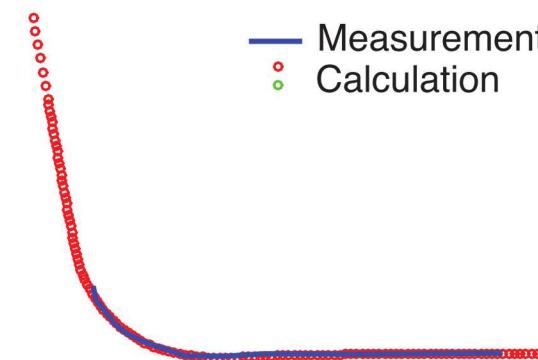
Measurement
Calculation

Surface

S1

S2

S3



“Imperfection” Model

