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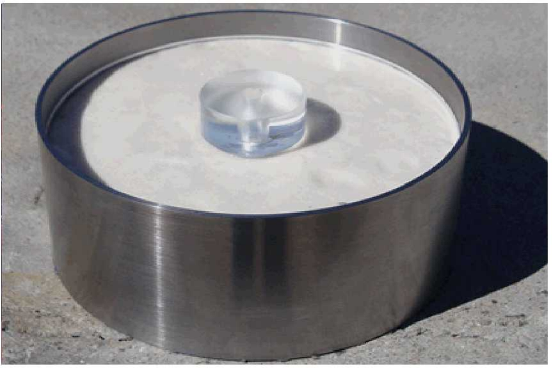


Fragmentation of an Explosively Driven Plate Using Zapotec

Russ Teeter

1555: Computational Shock Physics
Sandia National Laboratory

Presented April 16 2019

Outline

- Experiment Overview
- Material Calibration
- ¼" Plate Results
- 3/16" Plate Results
- First Order Parameter Effects
- Conclusions

Major Collaborators

- Jason Wilke
- Steve Attaway
- Mark Anderson
- Phil Reu

The work by the personnel at Thunder Range is greatly appreciate, without which the work would not have been completed

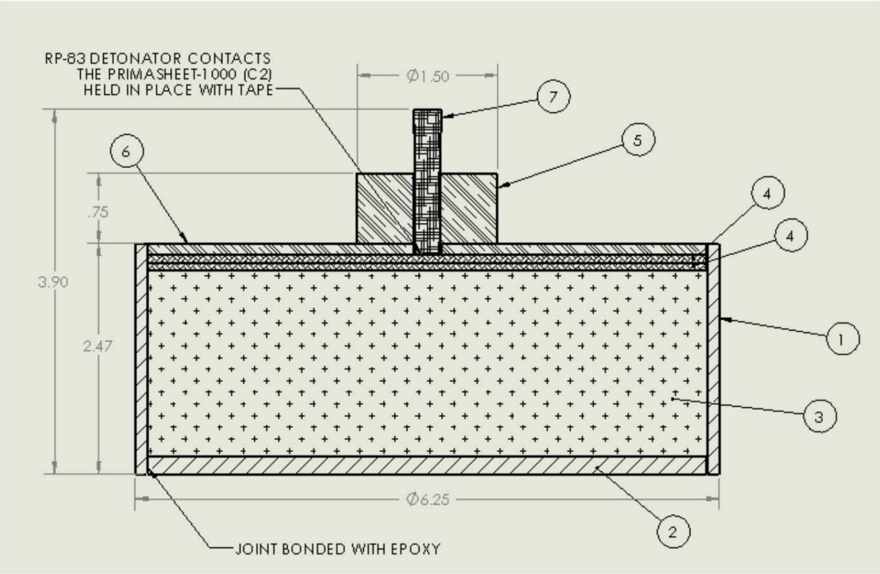
Test Details

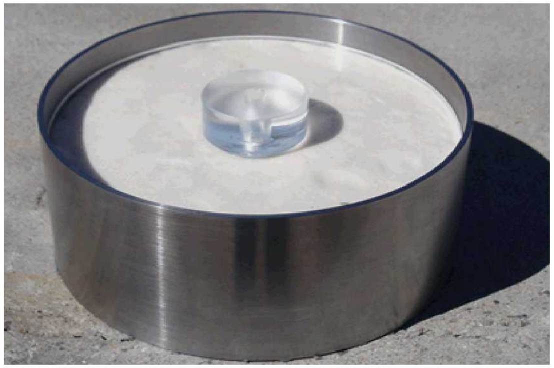
Test 1: ¼” Thick Disk

Test 2: 3/16” Thick Disk, milled down
from ¼”

Both tests used A572 Grade 50 Steel, with a 6” diameter disk

1492 grams C4 (3.29 lbs) total explosive

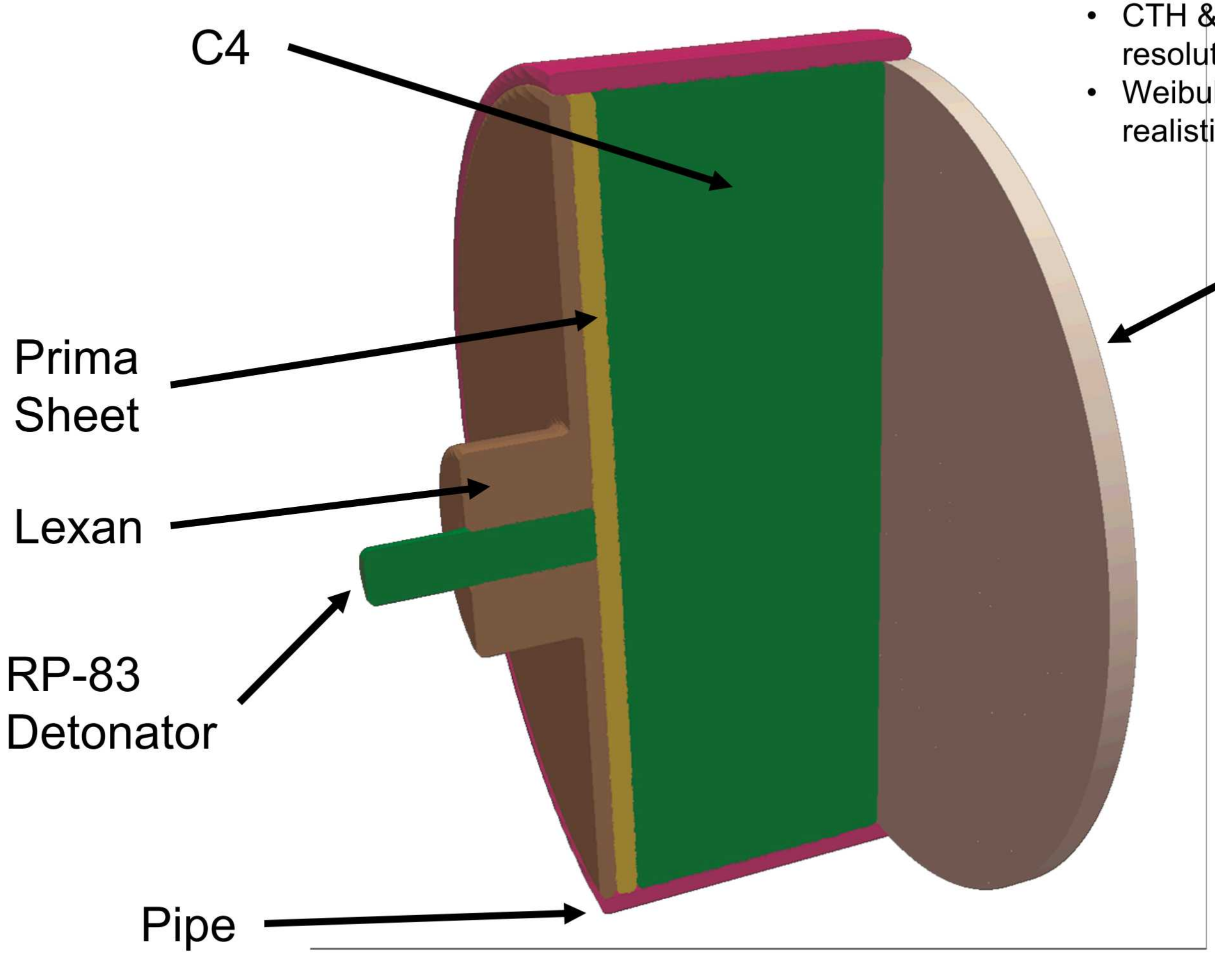




ITEM NO.	DESCRIPTION	WEIGHT	QTY.
1	6.25 INCH DOM PIPE	930 GRAMS	1
2	0.1875x5.98 STEEL DISK	3/16" - 678 GRAMS, 1/4" - 904 GRAMS	1
3	COMPOSITION C4 MAINCHARGE	1441 GRAMS	1
4	2mm PRIMASHEET 1000	51.3 GRAMS (EACH)	2
5	ACRYLLIC DETONATOR HOLDER		1
6	ACRYLLIC BACKING PLATE		1
7	RISI RP-83 Detonator		1

Test Object Designed By Jason Wilke

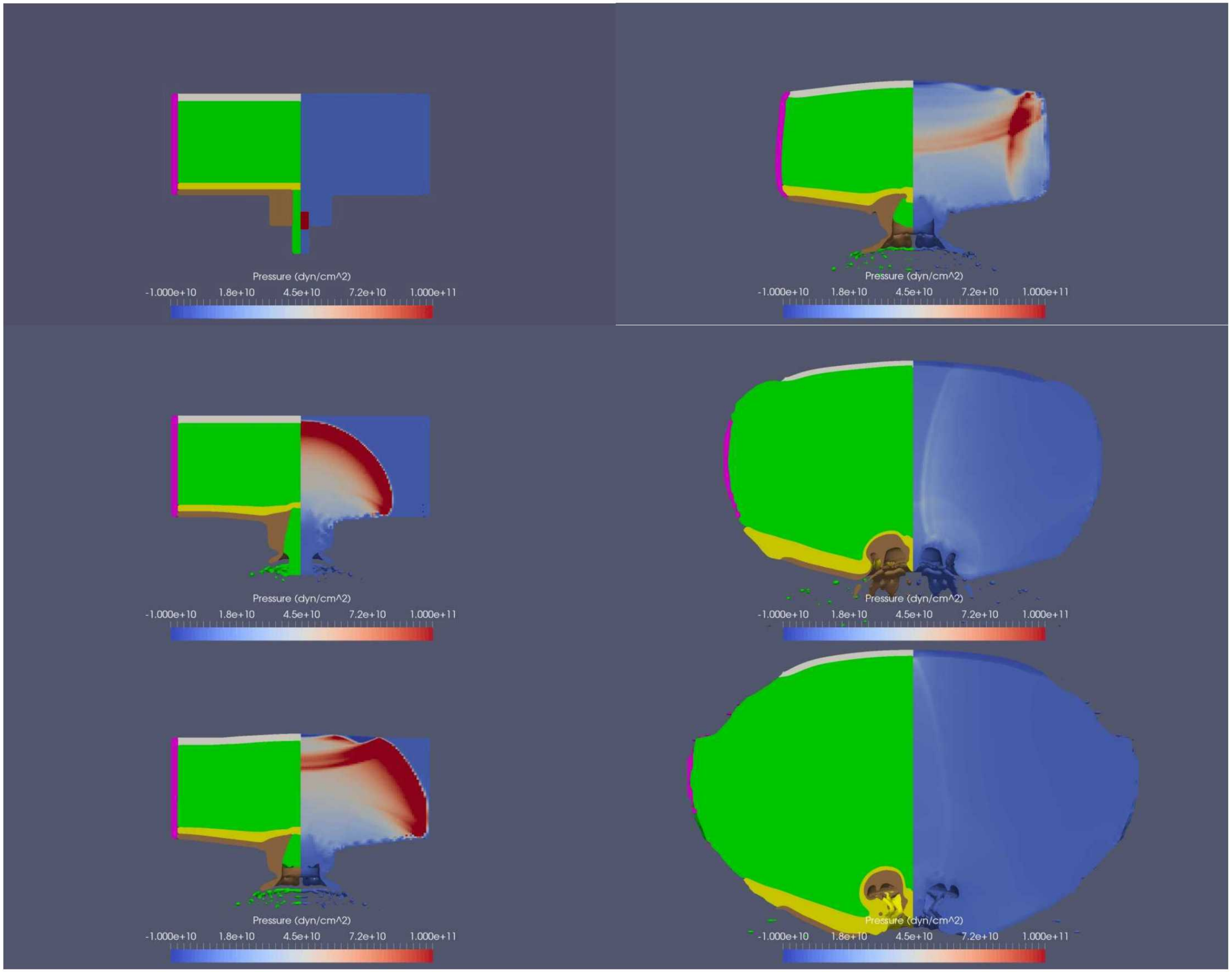
Model Description



Plate

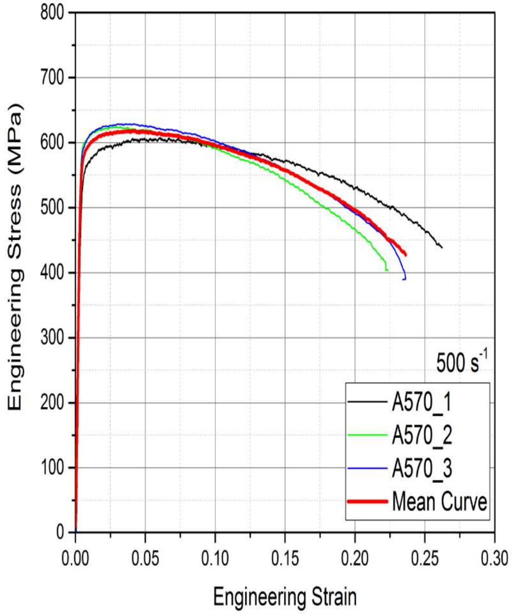
- CTH & Sierra/SM ~2mm mesh resolution
- Weibull distribution on disk to create realistic fracture propagation

Detonation Progression is Complex

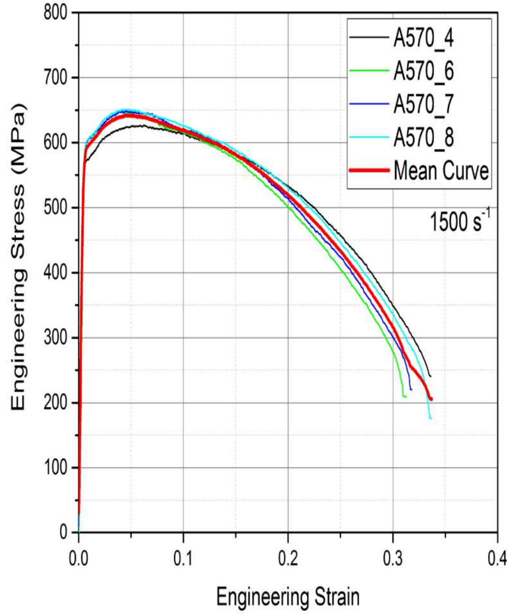


Material Calibration is an Art

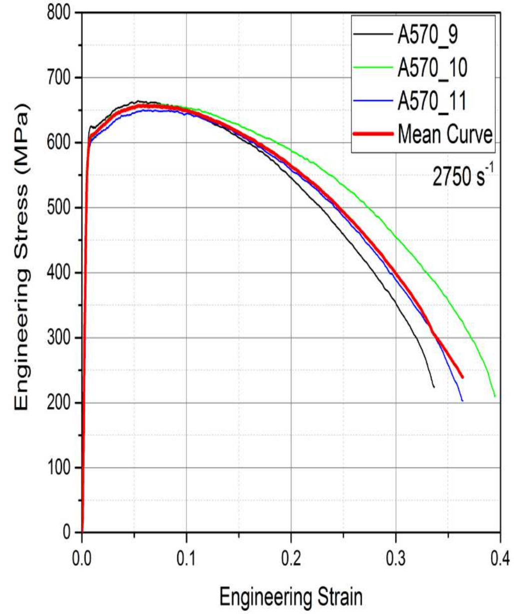
A570 SPHB Data



Engineering
Strain to failure
~Did Not Fail



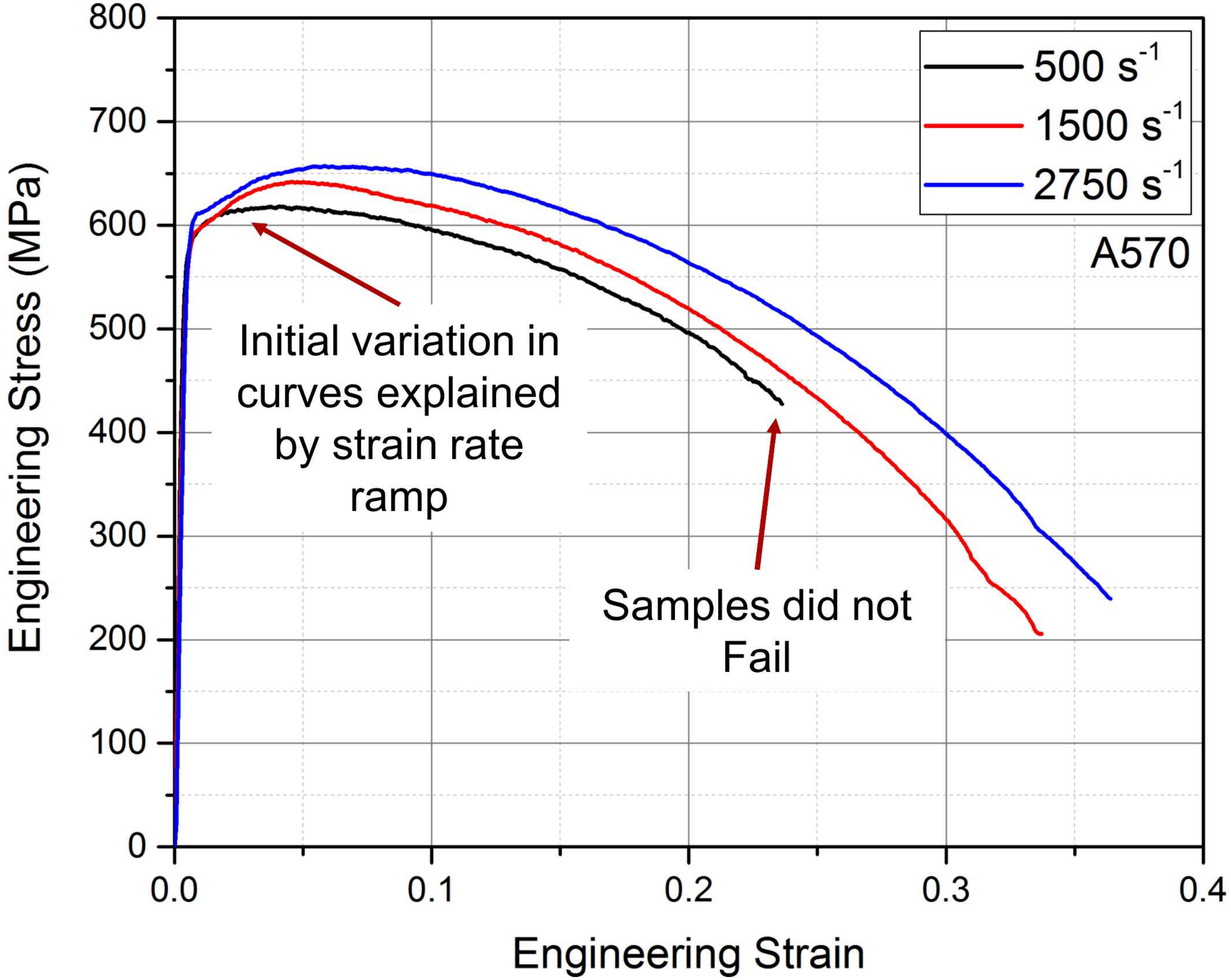
Engineering
Strain to failure
~0.35



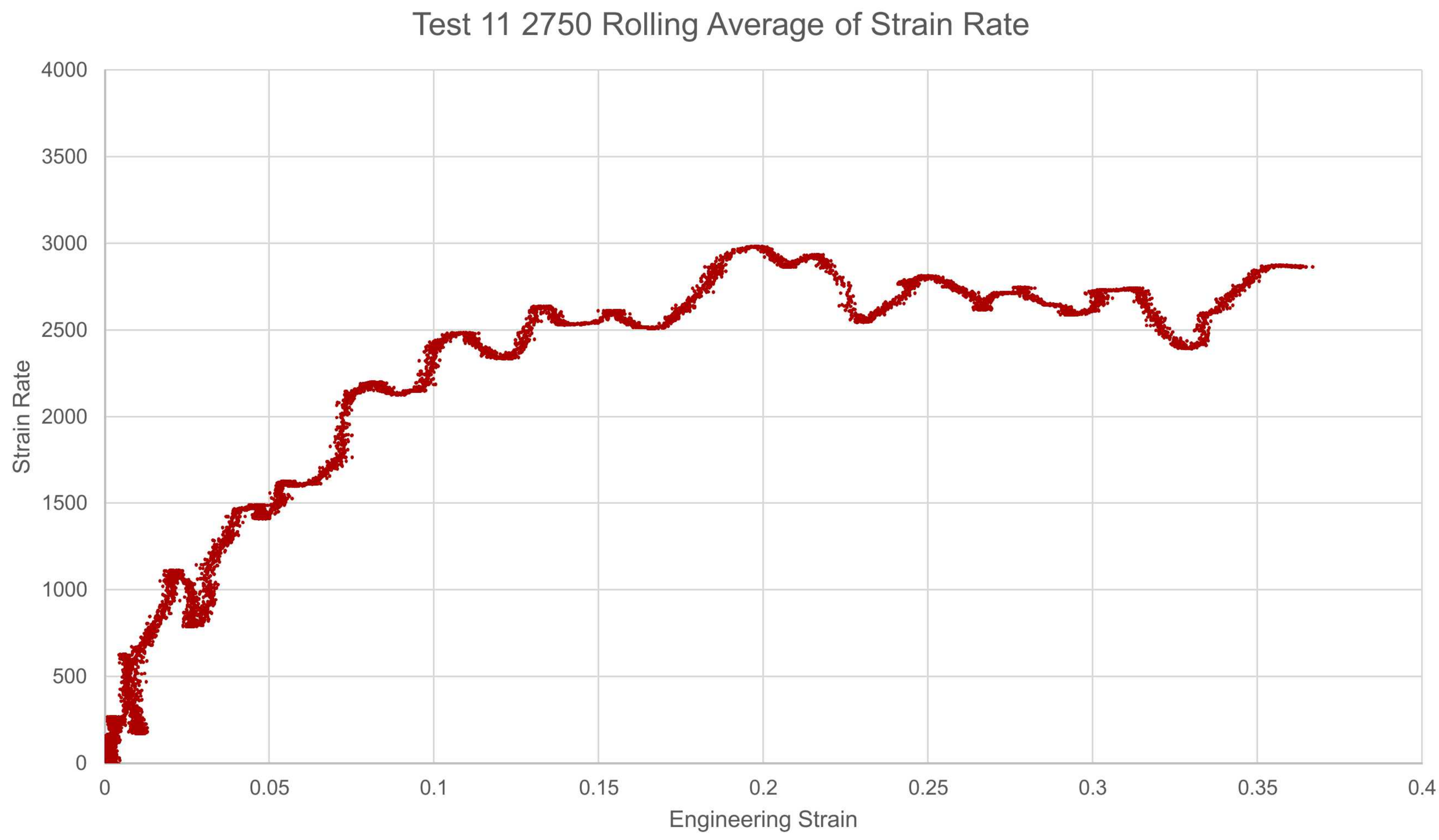
Engineering
Strain to failure
~0.36

SPHB Conduced by Bo Song: 1528

Dynamic Tensile Stress-Strain Curves of A570 Alloy

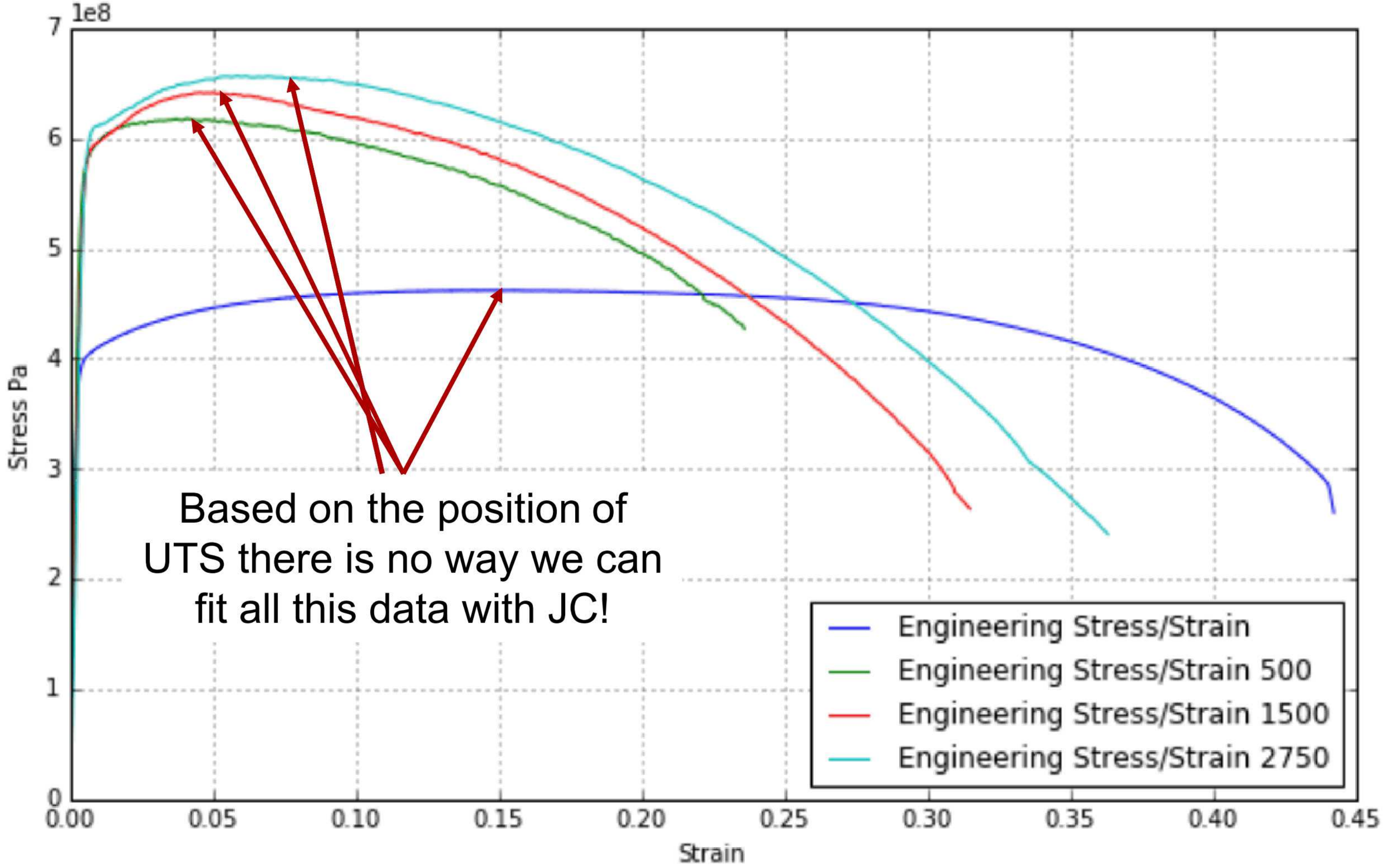


Strain Rate



Test 11 2750 Rolling Average of Strain Rate
Strain Rate
Engineering Strain
0
500
1000
1500
2000
2500
3000
3500
4000
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4

Combined Data Set



Johnson-Cook Model

Stress Strain Curve

Strain Rate Scale

Temperature Scale

$$\sigma = [A + B\epsilon_p^n][1 + C\, ln\, \dot{\epsilon}^*][1 - T^{*m}] + \alpha P$$

Strain to Failure

Triaxiality

Strain Rate

Temp

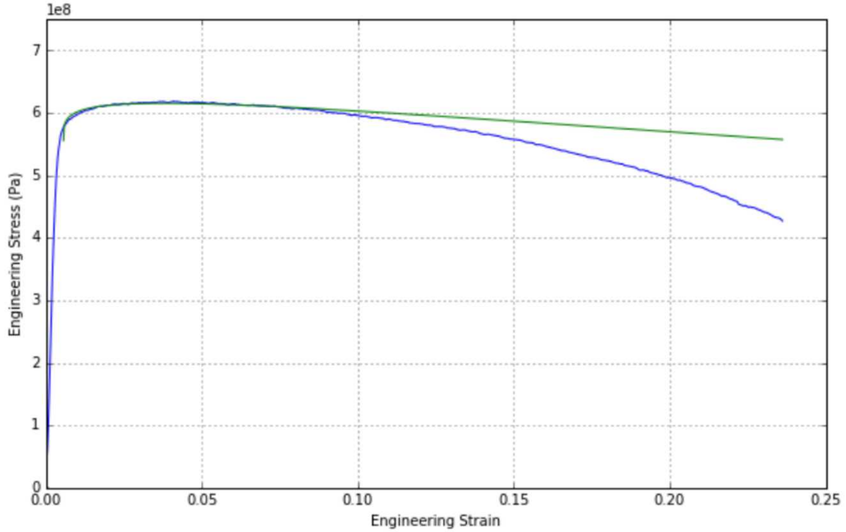
$$\epsilon_p^f = [D_1 + D_2 exp(D_3\sigma^*)][1 + D_4\, ln\, \dot{\epsilon}_p][1 + D_5 T^*]$$

Plasticity Fit

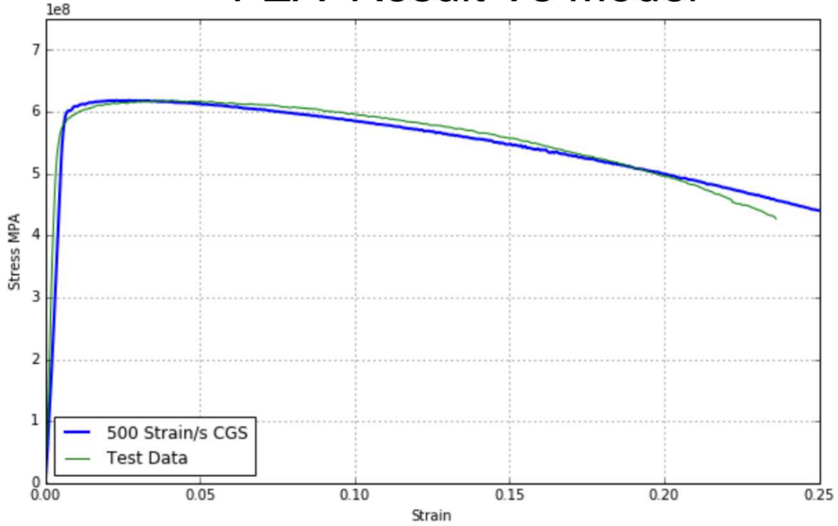
- Initial Approach
  - Import data and use a least squares minimization to fit the properties up to UTS.
  - This produced ok fits but necking was incorrect upon simulating results
- Current Approach
  - Fit 500 in/in ignoring rate effects. Ensure that the fit produced a UTS similar to the data. Check with FEA that post UTS response matched data.
  - Determine a rate term that scaled the 500 in/in curve to be close to the 1500 and 2750 curves
- Future Approach
  - Inverse FEA to dial in post neck behavior

Fitting 500 in/in data

Hand Calculation Vs Model



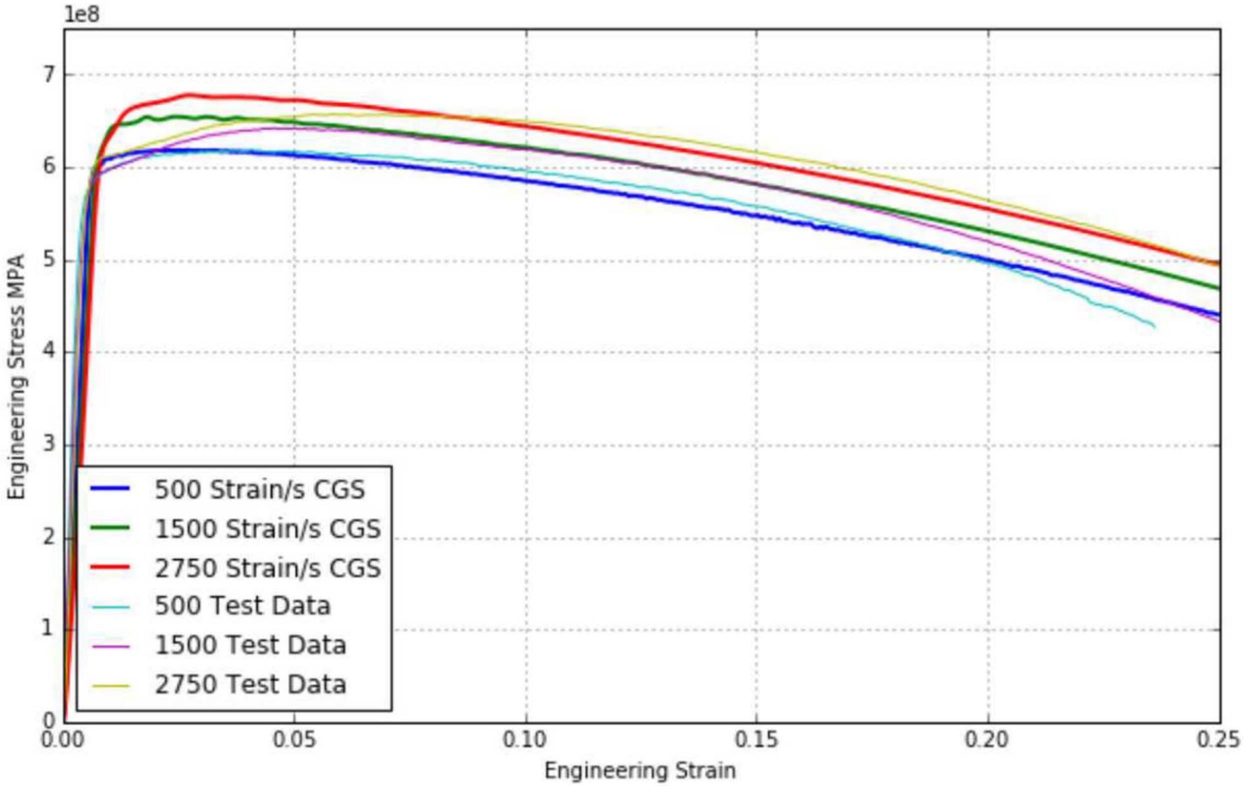
FEA Result Vs Model



$$\sigma = [A + B\epsilon_p^n][1 + C \, ln \, \dot{\epsilon}^*][1 - T^{*m}]$$

Found A, B, and n.

Rate Constant C



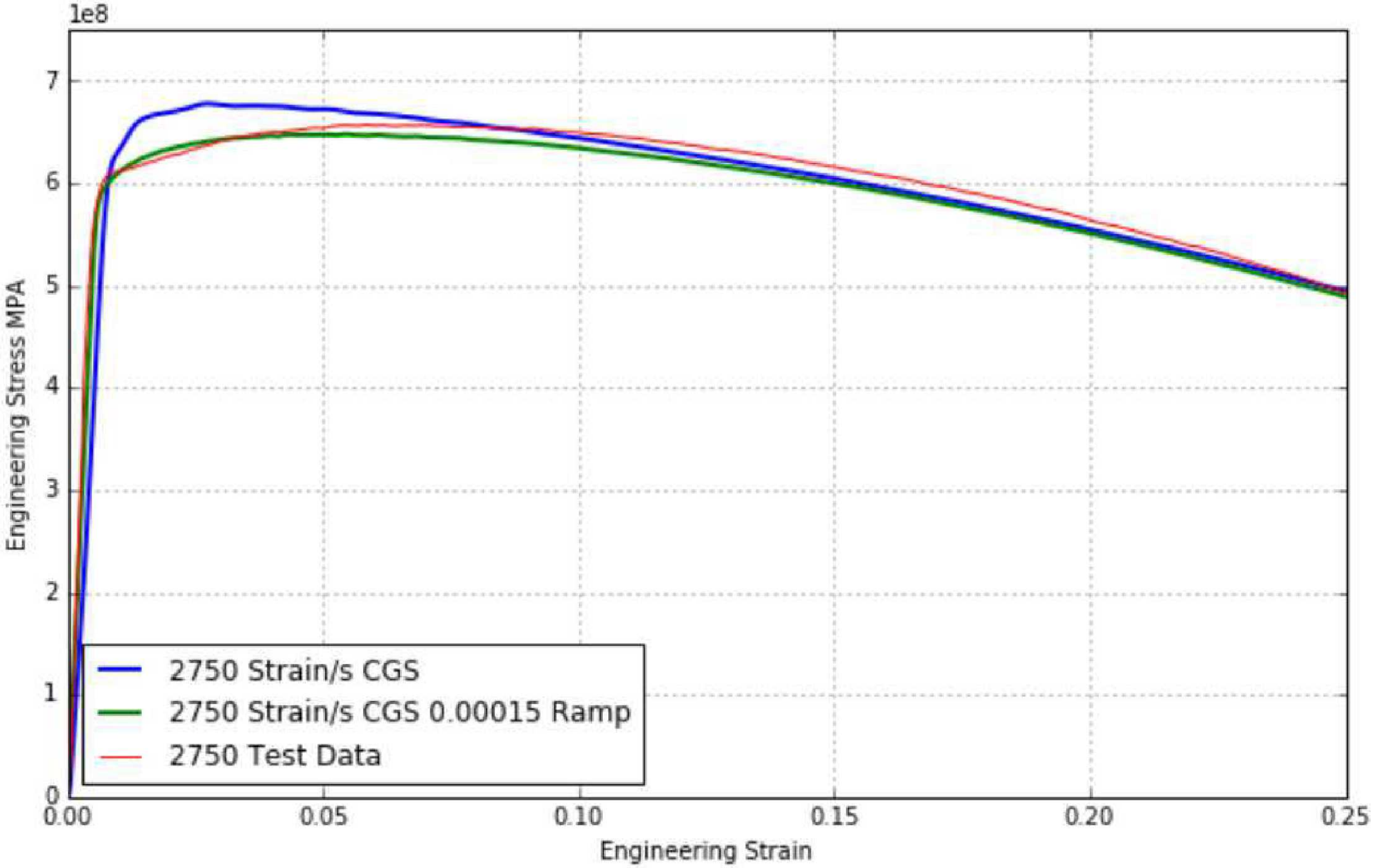
High Rates are poorly matched early on!

$$\sigma = [A + B\epsilon_p^n][1 + C\, ln\, \dot{\epsilon}^*][1 - T^{*m}] + \alpha P$$

Found C

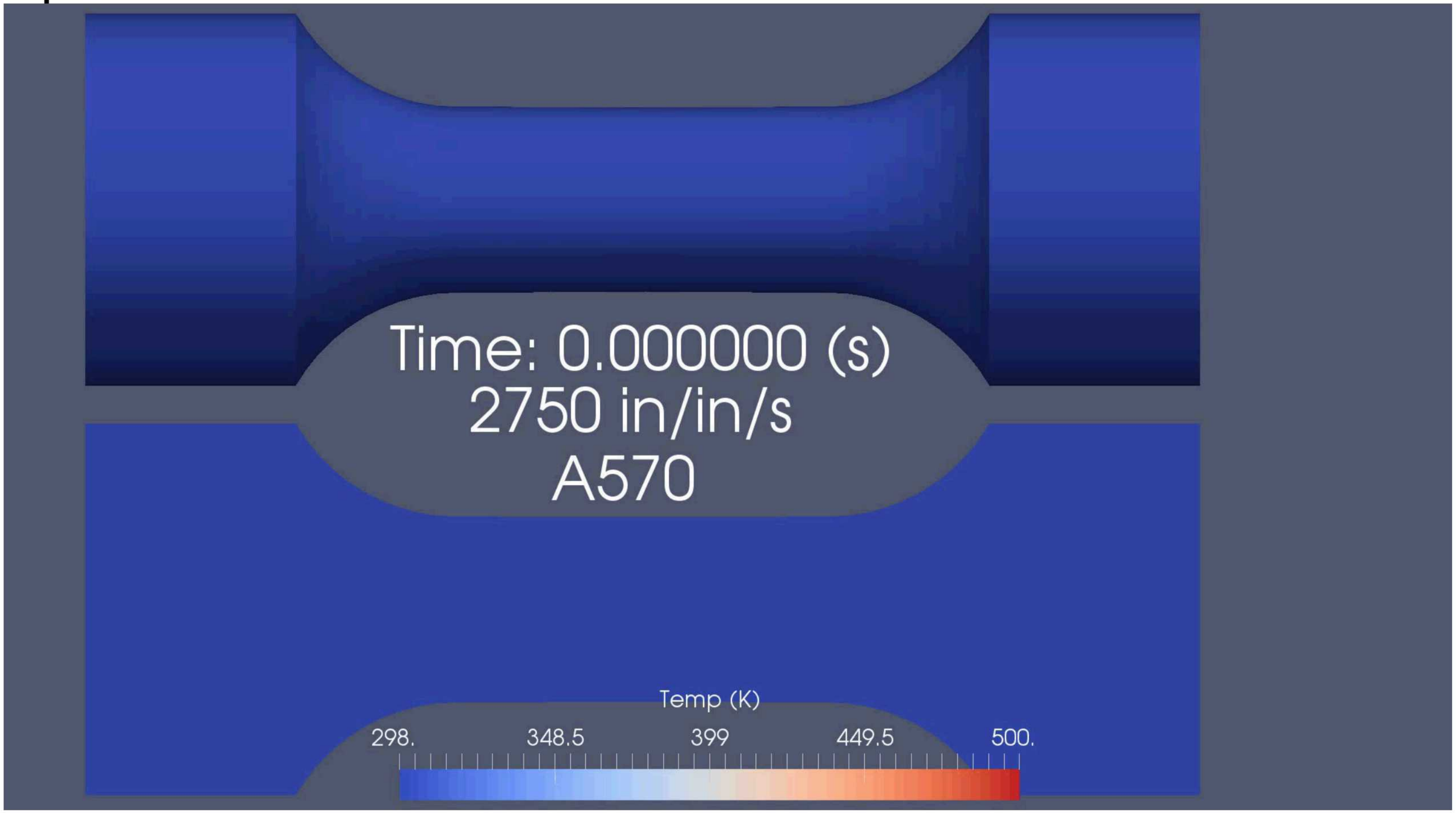
Effect of Ramping the Data

- 150μs cosine ramp fits the data nicely



Temperature Effects

- Temperature effects completely ignored in calibration but are present!



Damage Variable

- Based on a shifted version of 4340 Steel from Ref 1
- Compute damage weighted triaxiality at central element in tensile bar
- Arbitrarily shift values until failure strains match tensile bar failure data.
- We need additional states of triaxiality to fit damage model

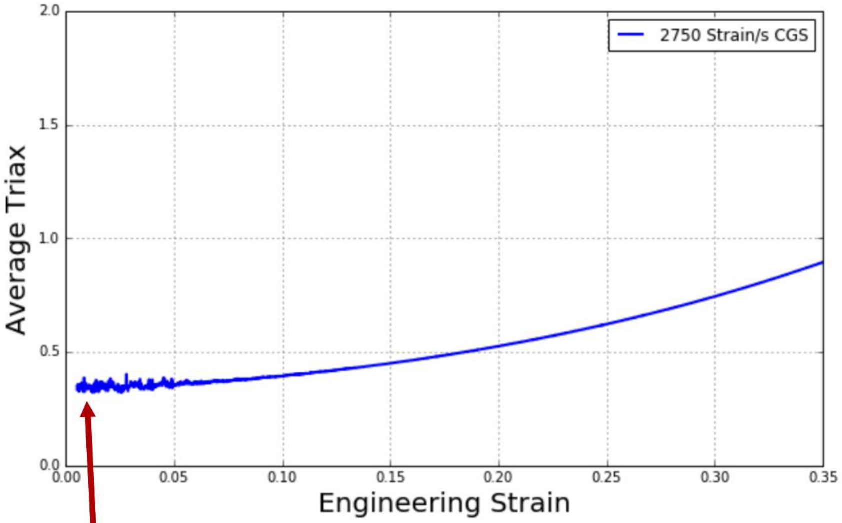
Triaxiality = $\frac{\sigma_m}{\sigma_{vm}}$

- Large Positive Value, High State of tensile pressure, Lower failure strain
- Large Negative Value, High State of compressive pressure, higher failure strain, may fail in shear banding

1. G.R. Johnson, W.H. Cook “A Constitutive Model and Data for Metals Subjected to Large Strains, High Strain Rates and High Temperatures”

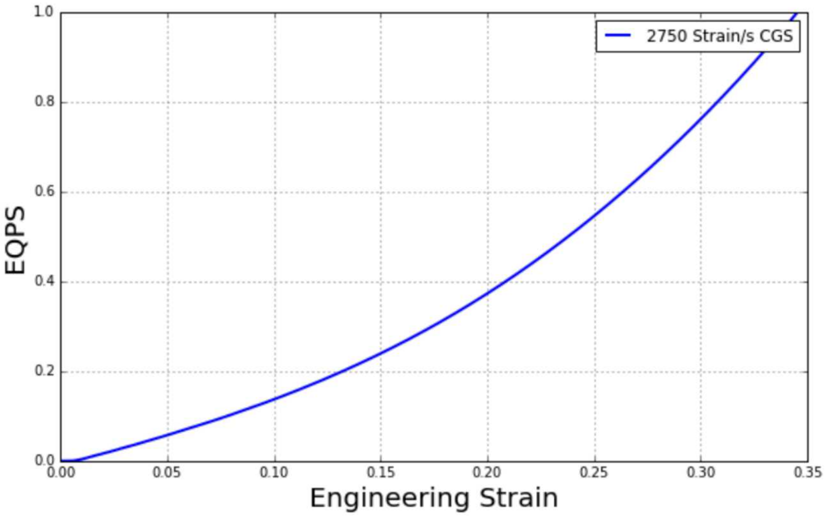
Average Triaxiality at center of bar

Damage weighted average of triaxiality of center element



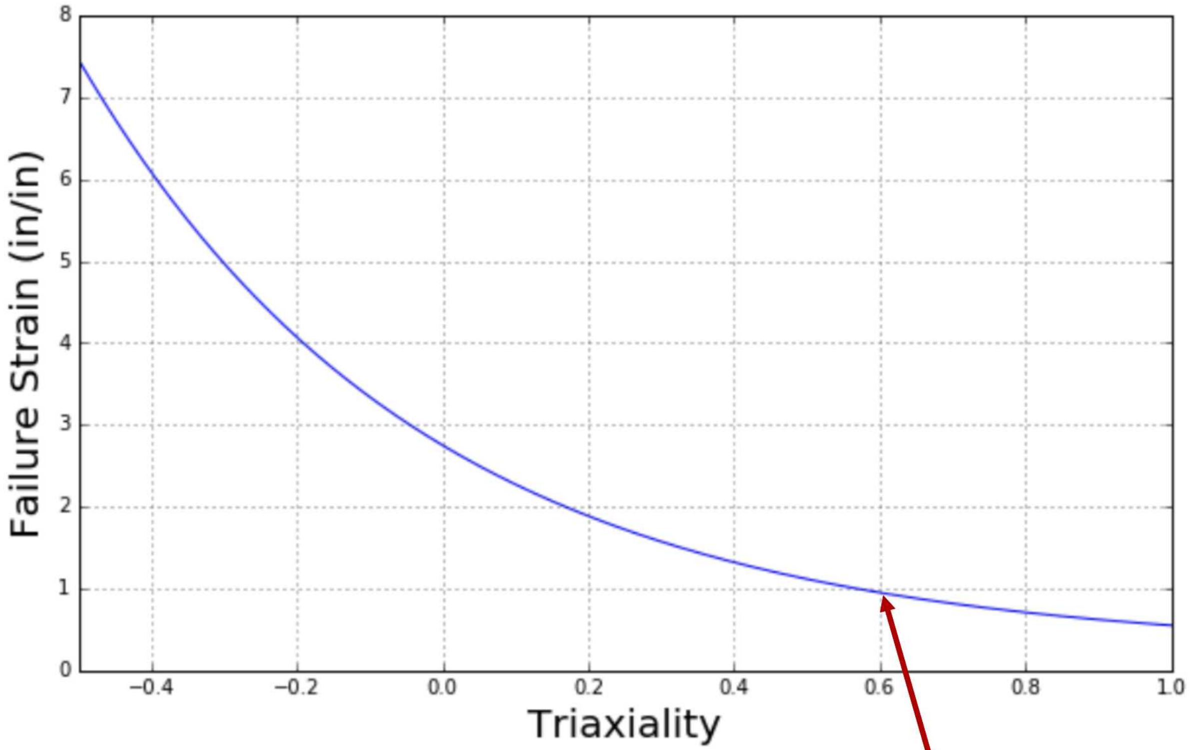
As expected, In a round bar, triaxiality starts at 0.33 and climes as necking increases

EQPS of center element



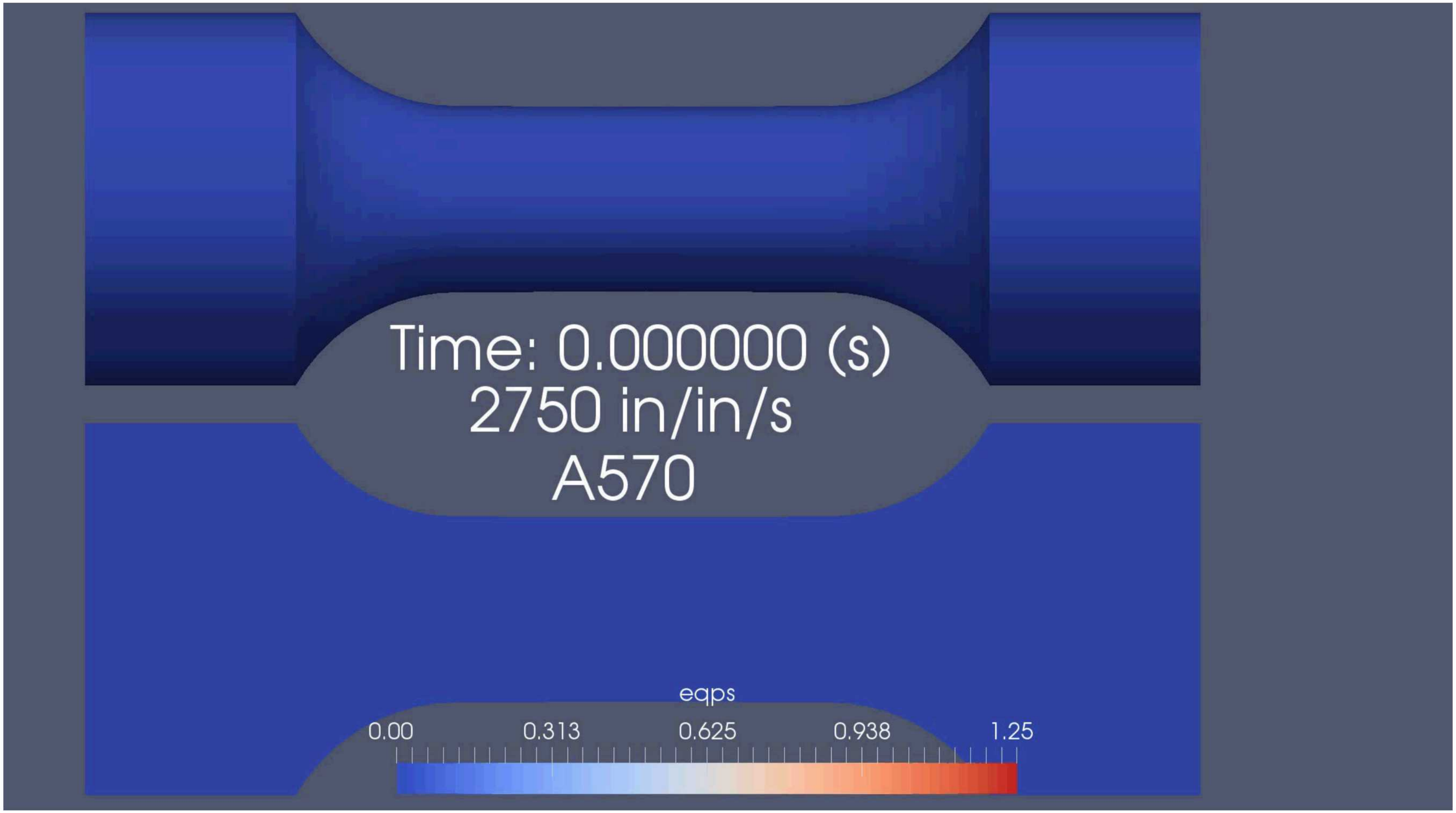
Find EQPS at failure Strain:
500 in/in: (did not fail)
1500 in/in: ~0.90
2750 in/in: ~1.0

Failure Strain Vs EQPS

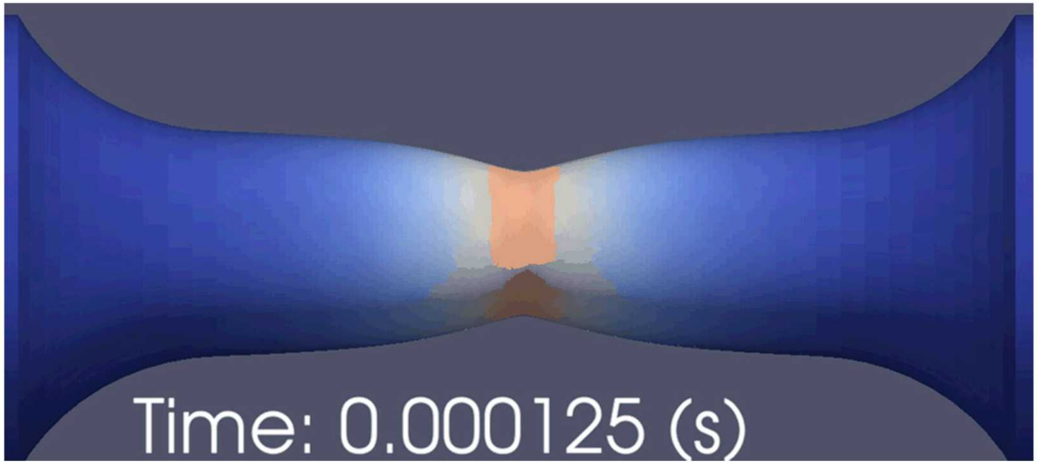


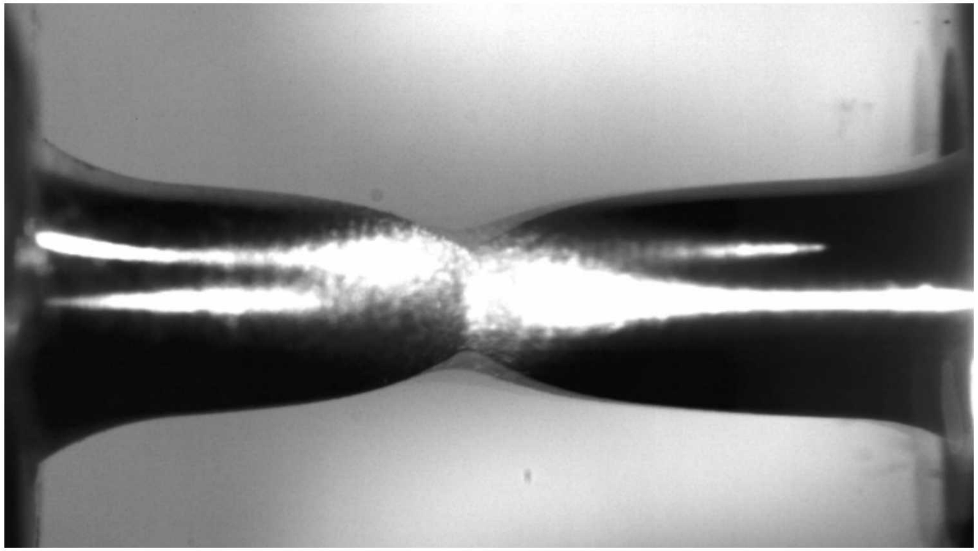
Avg Triaxiality in necked tensile bar

Simulated Tensile Bar



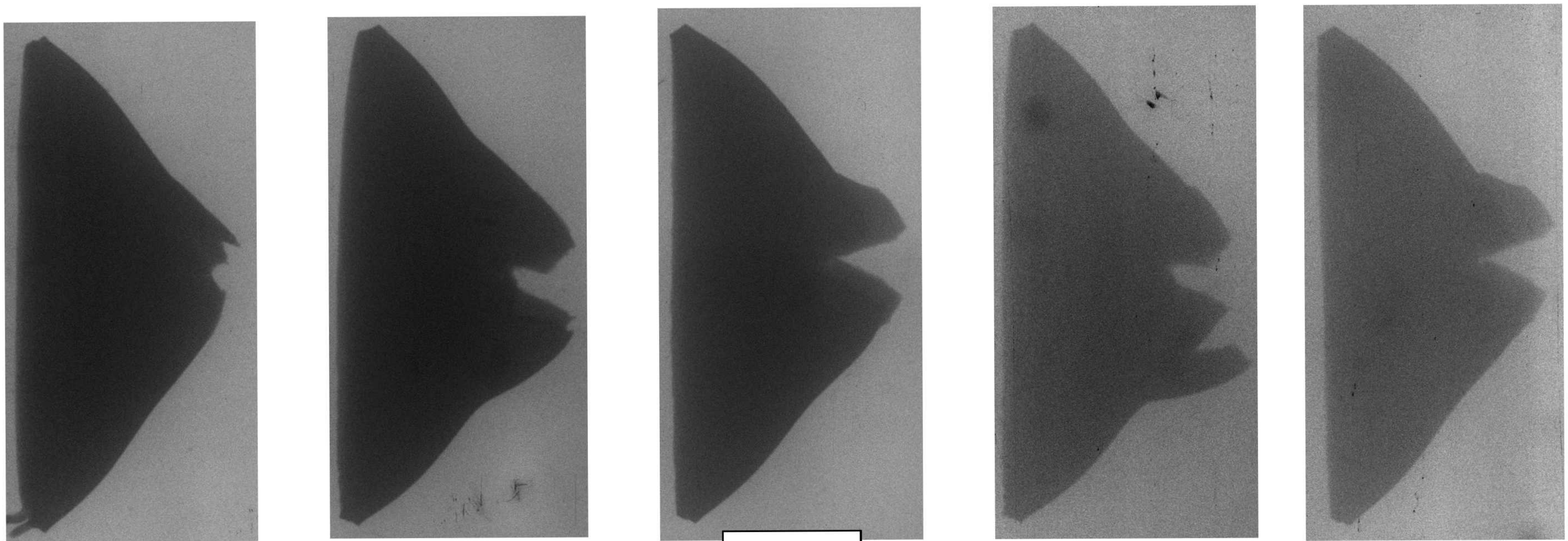
Necking





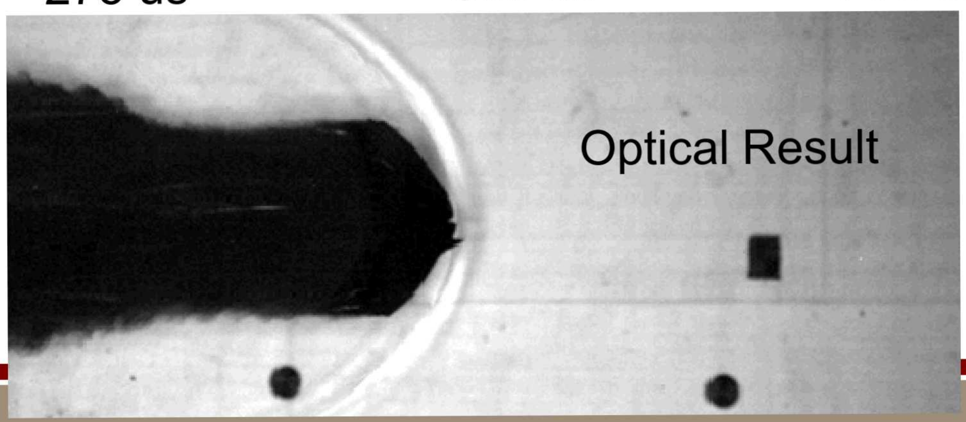
Back to the Test!

1/4" Plate Multi-Shot X-Rays



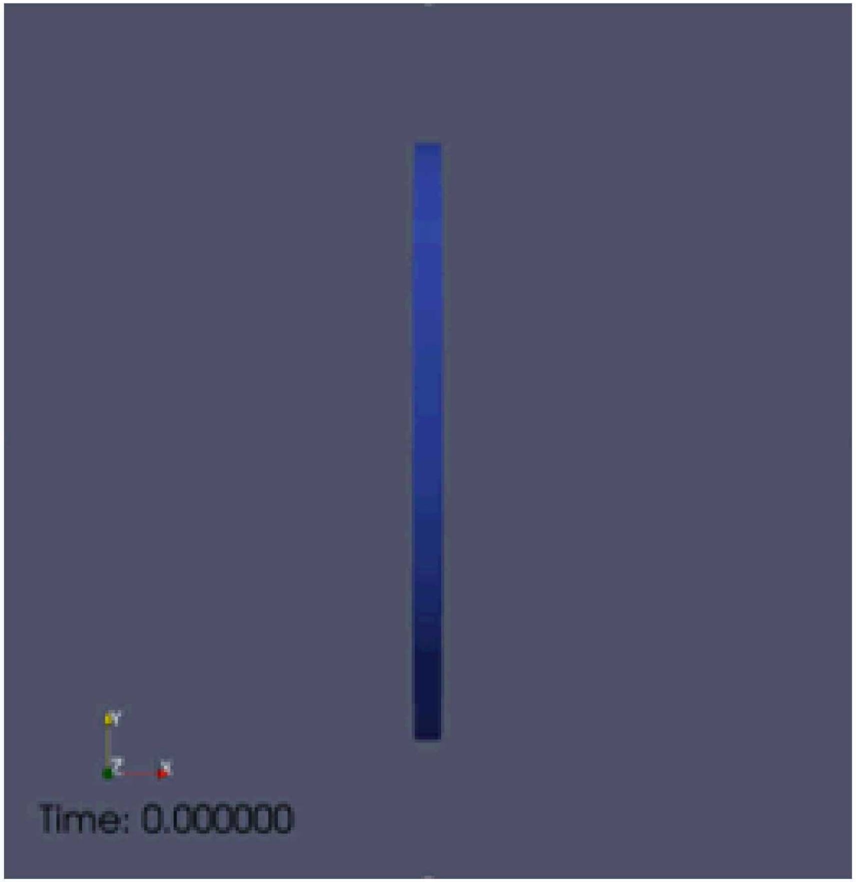
Flight

Shot 1	Shot 4	Shot 5	Shot 4	Shot 5
250 us	275 us	300 us	500 us	600 us



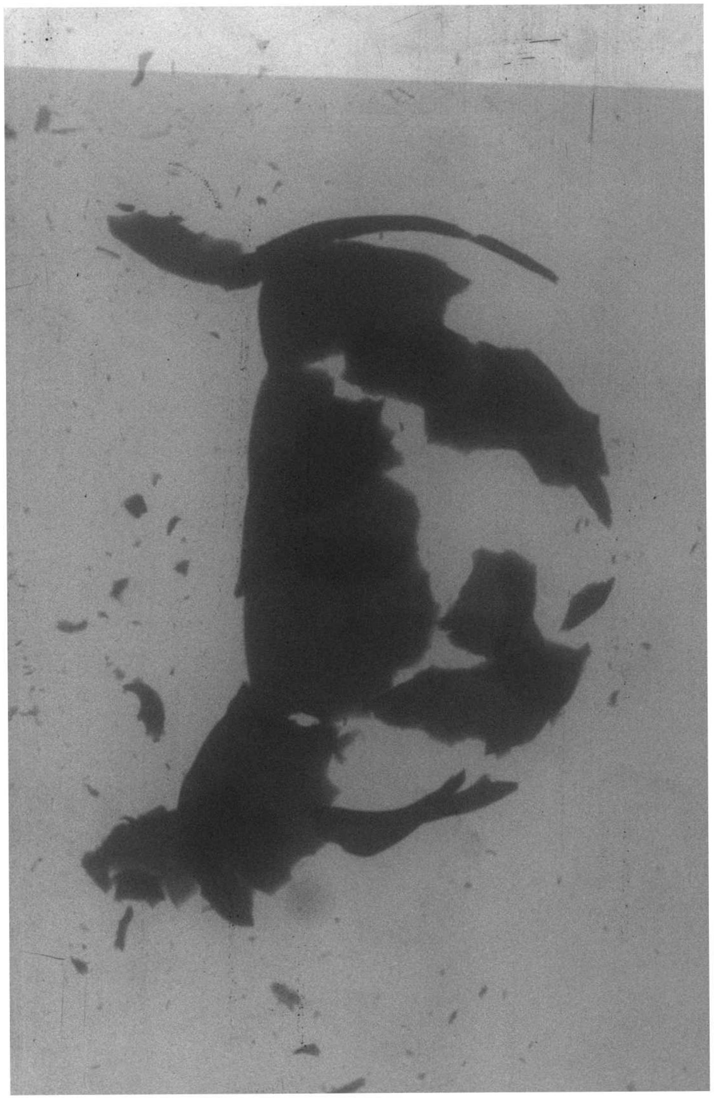
Results are Mixed

¼ Plate



1. Failure progresses to similar locations
2. Model over predicts number of petals
3. CTH matches petals better

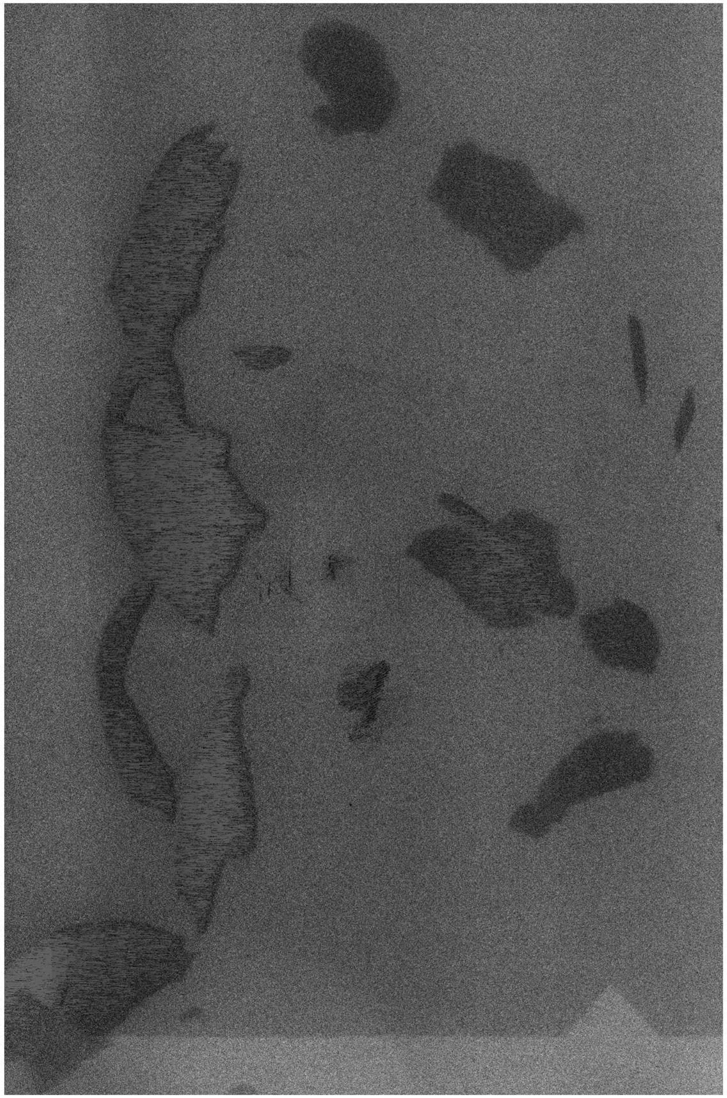
0.1875" Plate Results



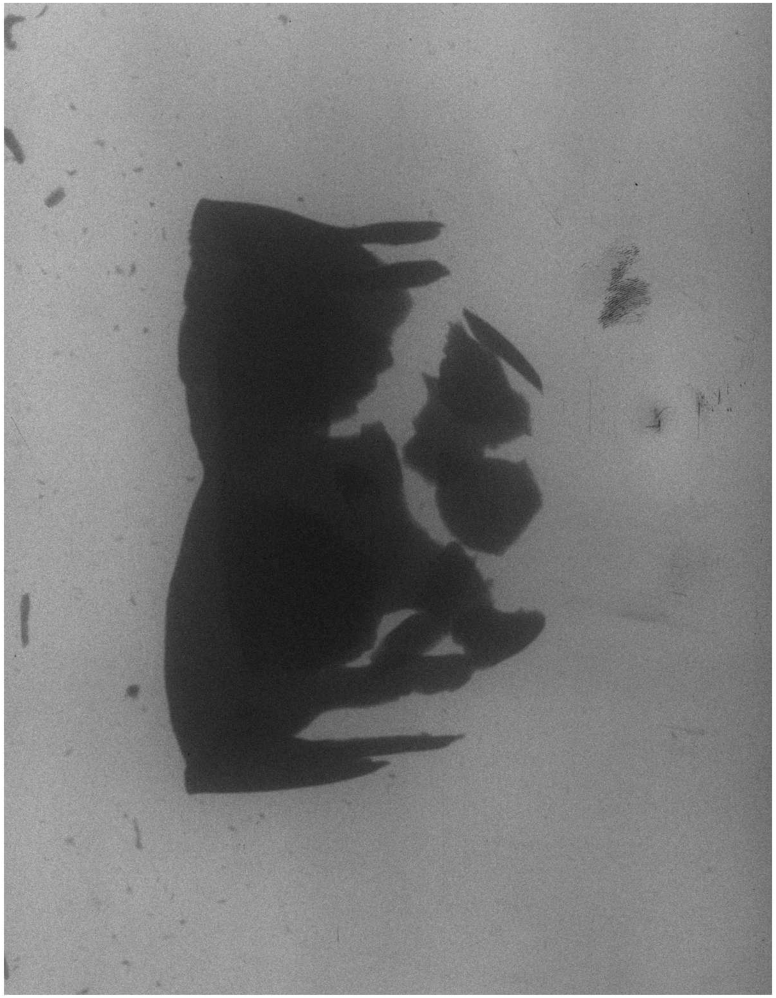
Shot 2
← 250 us
→425 us

0.1875” Plate Results

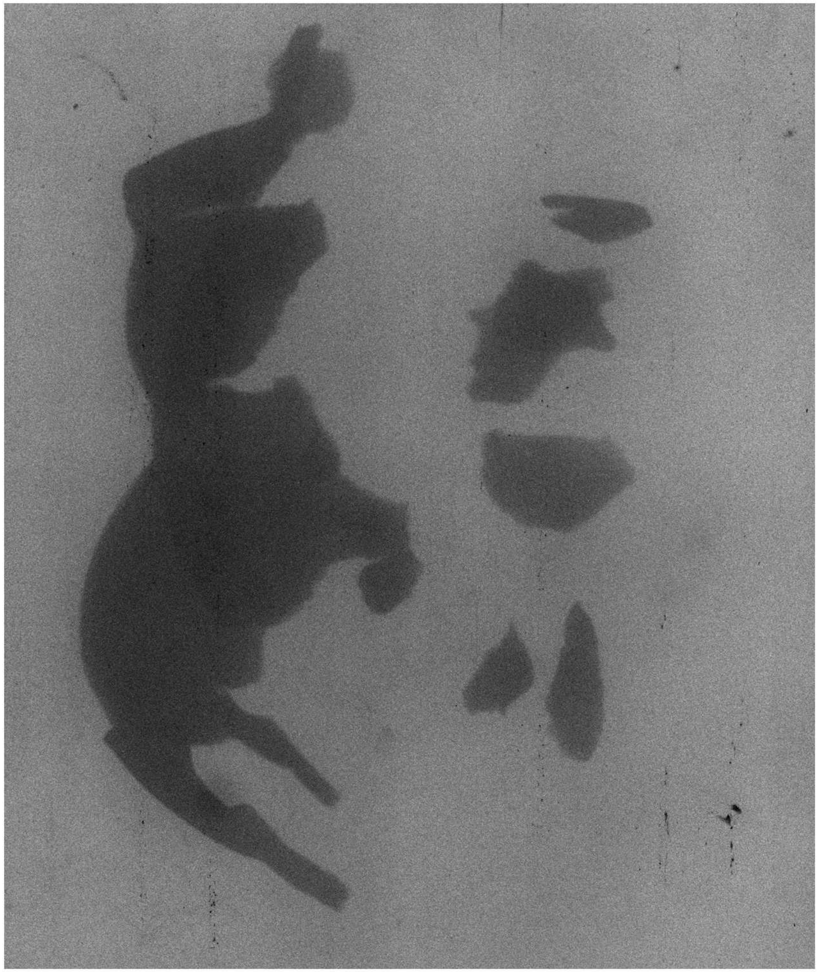
Shot 3
← 250 us
→450 us



0.1875” Plate Results

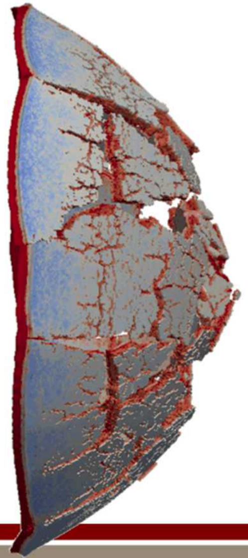


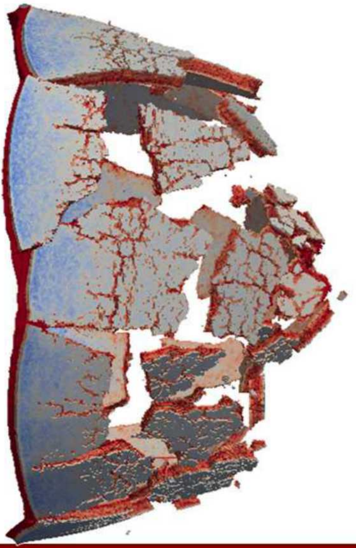
Shot 6
← 250 us
→450 us

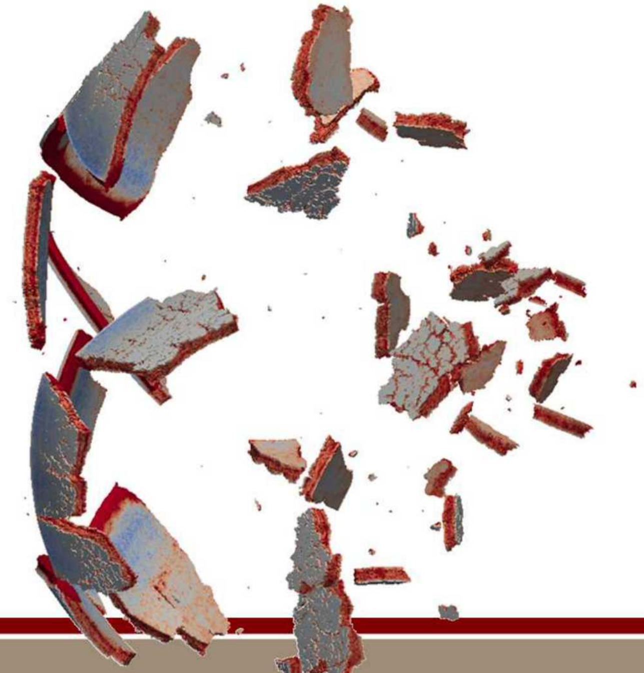


Zapotec predictions Predictions are Reasonable

1. Results seem qualitatively Similar
2. Model seems to overpredict damage at center of Disk
3. Quantitative could be made by comparing to optical test results

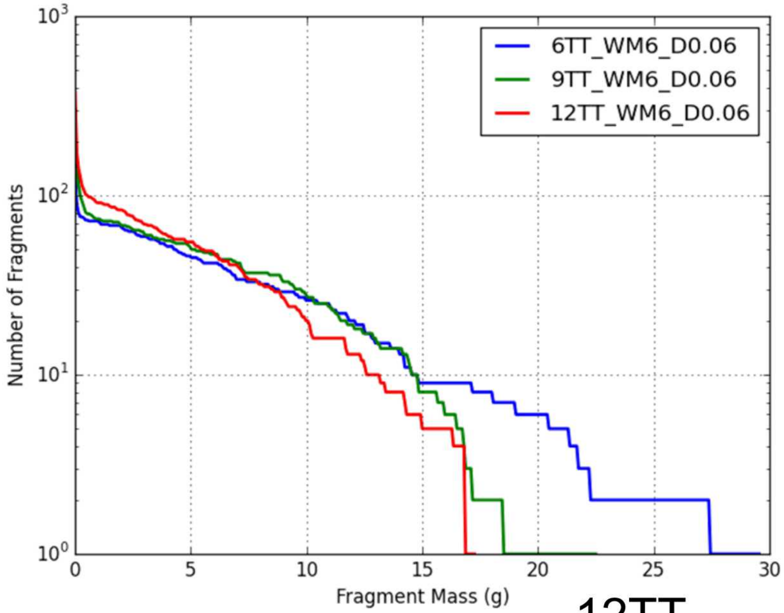




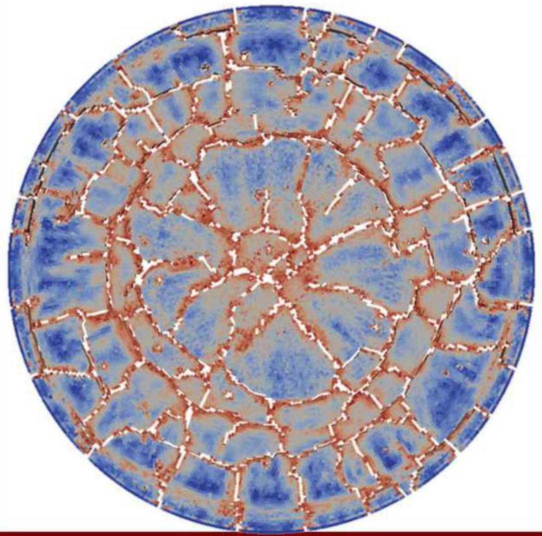


Effects of Mesh Refinement

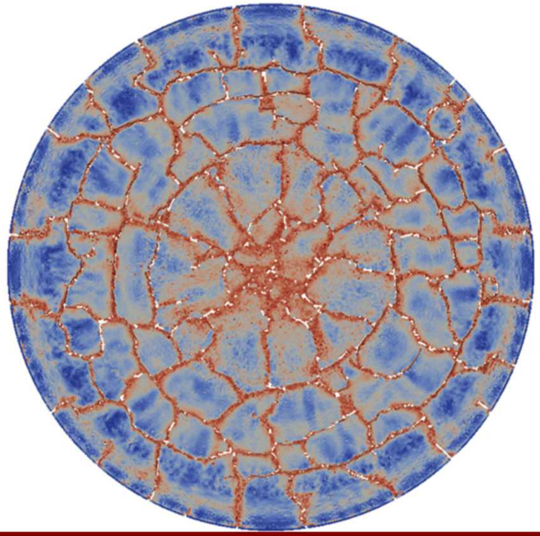
- 3 Element sizes were studies 6, 9, and 12 through the thickness. Elements were kept as cubic as possible.
- CTH grid was unchanged through out (CTH cells larger than disk elements)
- Refined meshes produced more, smaller fragments
- Results appear to be converging



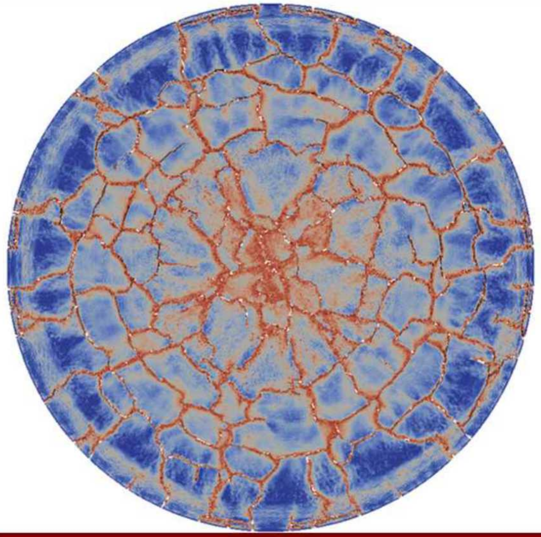
6TT



9TT

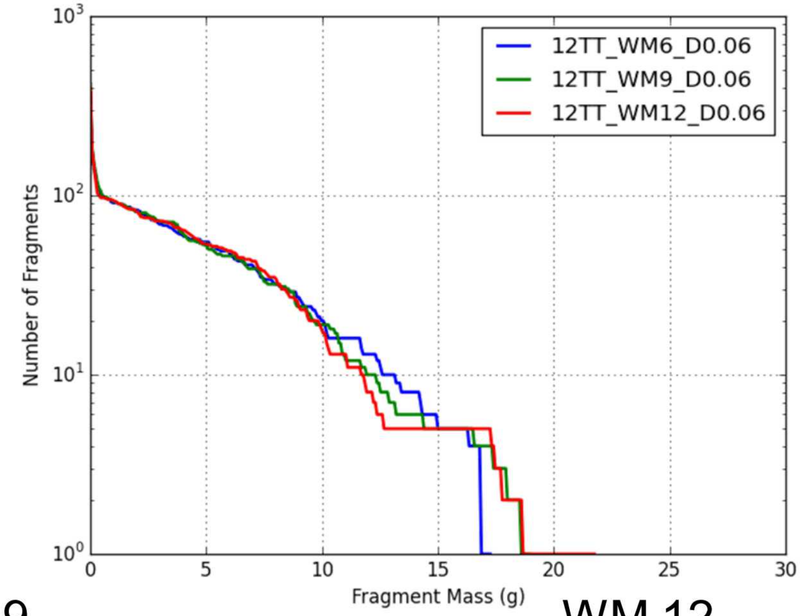


12TT

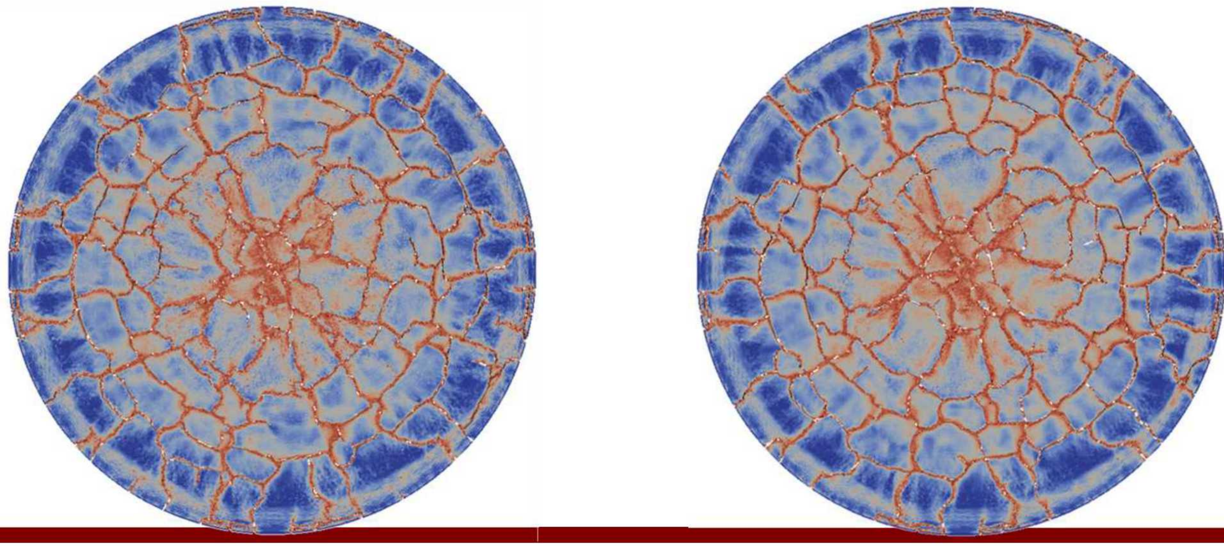


Effect of Weibull Modulus

- 3 Weibull Moduli (WM) were studied 6, 9, and 12. A higher WM means smaller variations in element yield strength. Simulations used 12TT meshes
- WM did not appear the have a significant effect of the fragment size/distribution

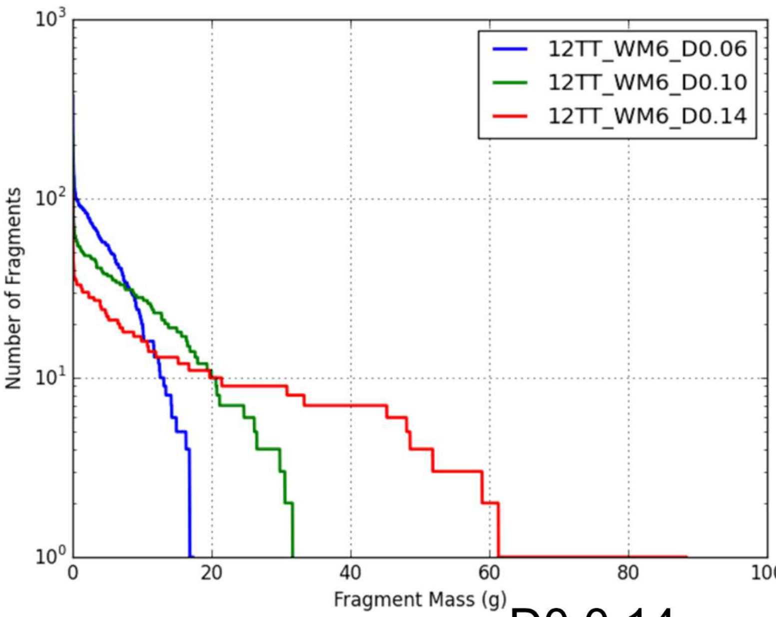


WM 6 WM 9 WM 12

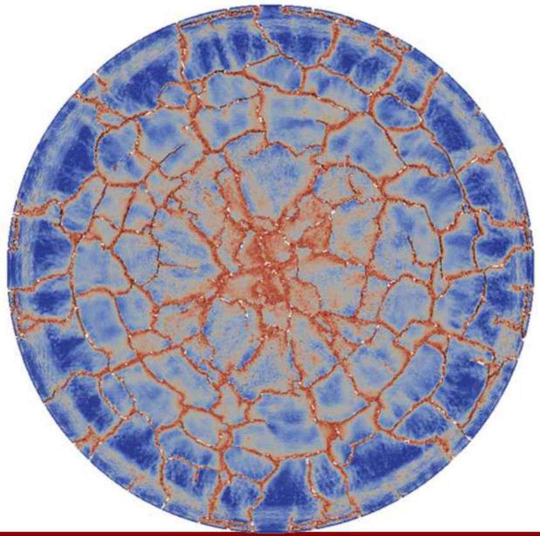


Effect of JC D0 Parameter

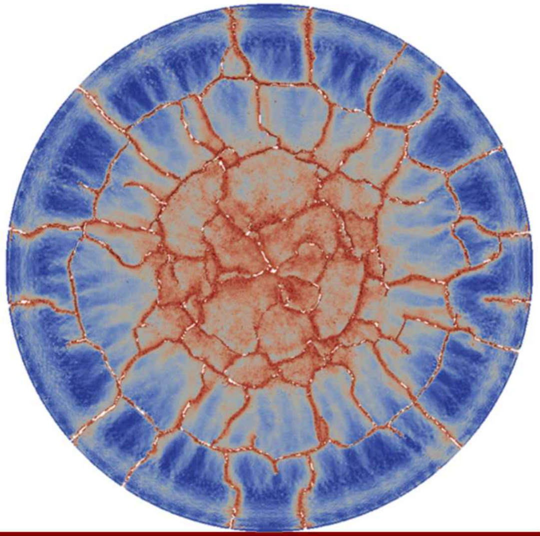
- Three initial failure strains (D0) in the Johnson-Cook damage model were used.
- D0 had a significant effect on the results,
    - Lower values of D0 (less ductile) produced small fragments
    - Higher values of D0 (more ductile) produced large fragments



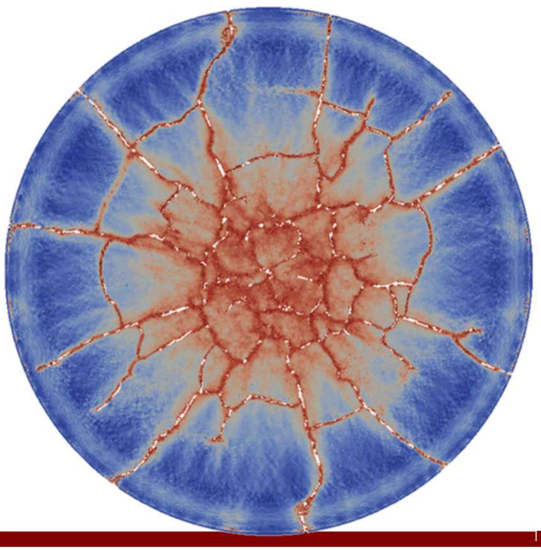
D0 0.06



D0 0.10



D0 0.14



Conclusions

- The process of model fitting using SPHB tests was discussed
- A model of two fragmenting disks driven by a C4 charge have been simulated yielding qualitatively similar results to testing
- Three parameters were varied, mesh size, Weibull modulus, and initial failure strain
  - Fragment size distributions appear to be converging with mesh resolution
  - The range of Weibull moduli studied did not appear to significantly change the results
  - Of the parameters studied, Initial failure strain in the Johnson-Cook damage model had the largest effect on fragment size distributions.
- Open Question: What material measurements and models do we need to accurately reproduce failure behavior?

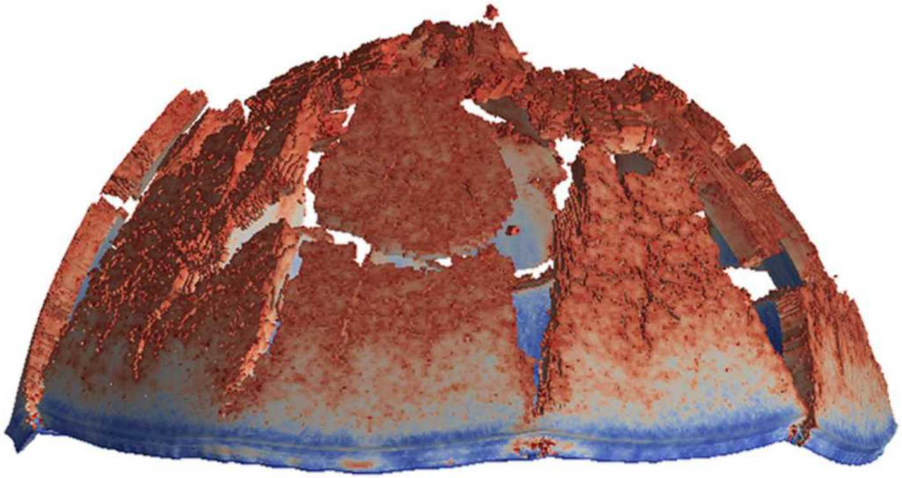
Additional Details

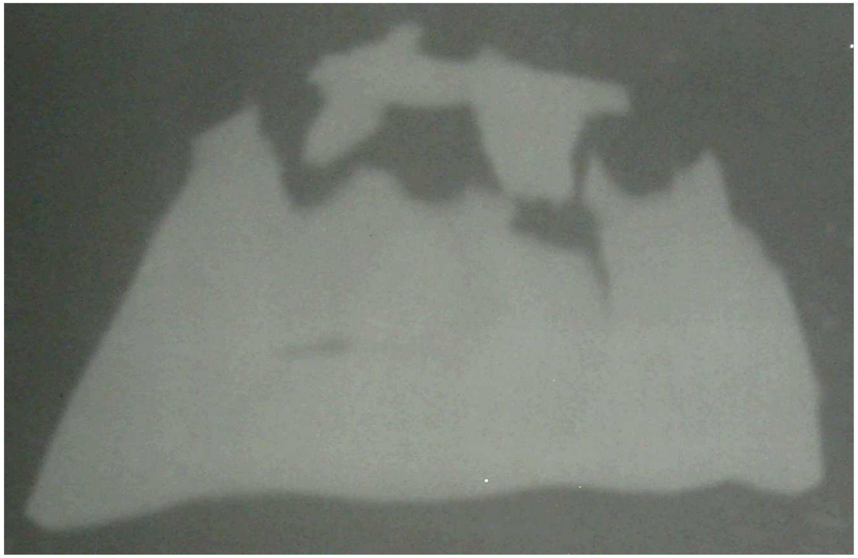
General Results

- Initial Experiments conducted years ago were not meant to characterize fragments
- Results are qualitatively similar

▲~50 Fragments swept into a pile
▼X-Ray of disk during test

▼Zapotec simulation results painted with contours of damage





Blast/Structure Code Regimes

CTH (Eulerian):

Blast Load:
Captures ***complex*** shock (pressure) behavior (detonation product equation of state, reactive flow models, etc.)

Structure Behavior:
Very large deformation (phase change/gas flow), surfaces less well defined, high resolution may be required, limited to ***early time*** structural response

Sierra/SM (Lagrangian):

Blast Load:
Simplified blast methods (e.g. ConWep); misses pressure wave reflections and complexity of near field blasts

Structure Behavior:
Large deformation, failure & fracture captured at ***longer time*** scale, non-linear (geometry and material response), multi-physics solutions (thermal/ mechanical, thermal/fluid and fluid/structure)