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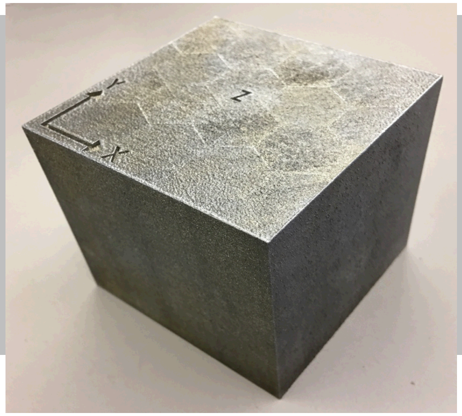

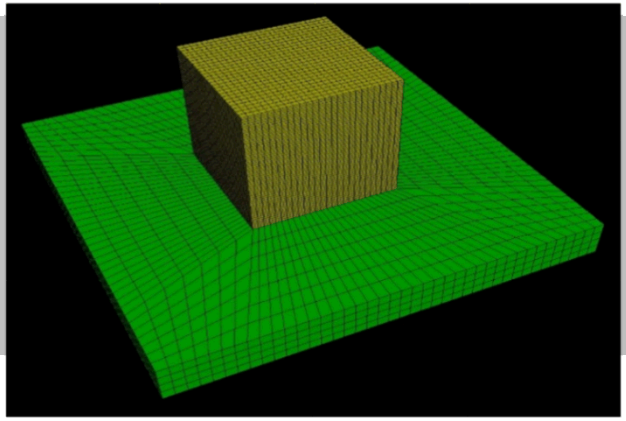

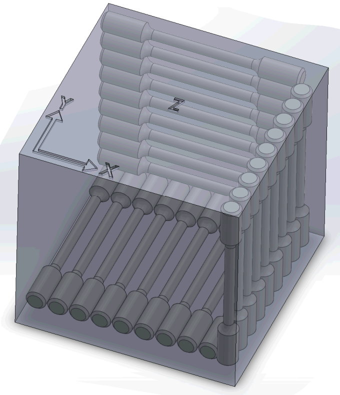

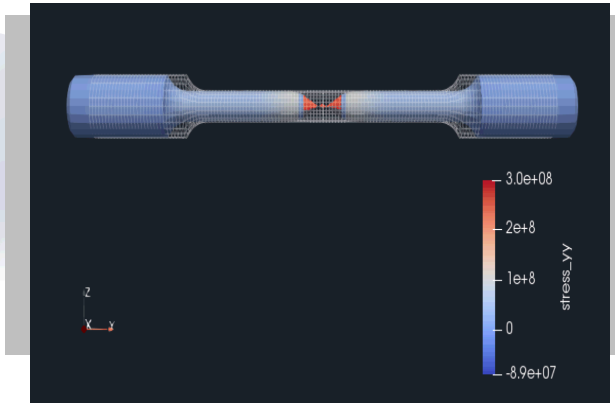

Investigation of Dynamic Strain Aging Behavior of Stainless Steel for Additive Manufacturing Applications

Phi Nguyen | University of California, San Diego
Mentors: Coleman Alleman & Michael Stender
Sandia Summer Intern | Sept 14, 2017

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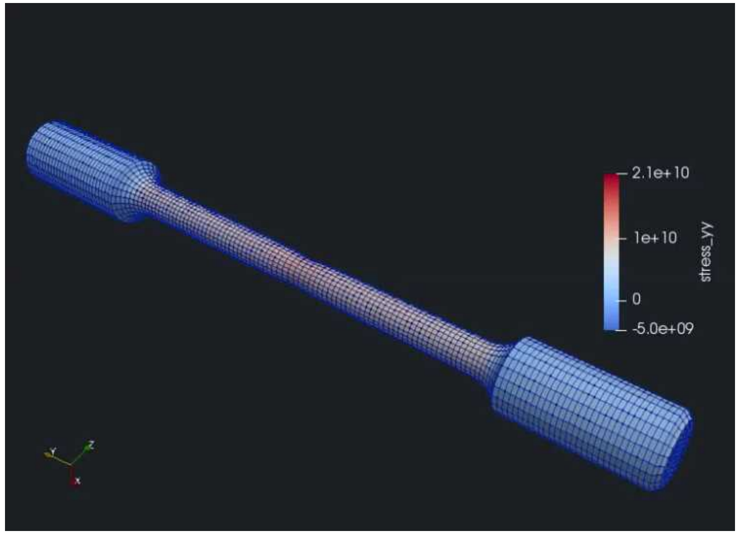
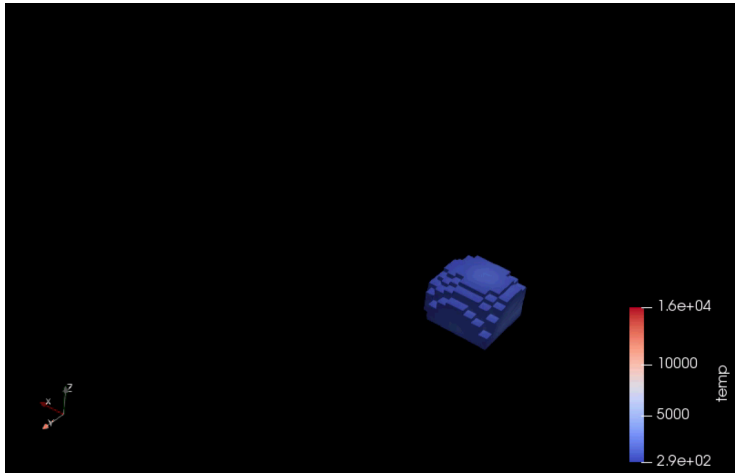
Motivations

- Understand the behavior of the current dynamic strain aging model with higher temperatures
- Calibrate a physically-based constitutive model with experimental data
- Test the constitutive model fit on a tensile specimen to predict localization leading to failure
- Map the result from the processing simulation including residual stress and internal state variables onto the experimental specimen





F. Lin 2017

Constitutive Material Model (DSA/BCJ_MEM)

The hypoelastic constitutive material model

$$\dot{\sigma} = E\left(\dot{\varepsilon} - \dot{\varepsilon}_p\right)$$

With the evolution of the plastic flow rule

$$\dot{\varepsilon}^p = f(\theta)\sinh\left\langle\frac{\sigma}{\kappa+Y(\theta)} - 1\right\rangle^{n(\theta)}$$

Evolution of the isotropic hardening variable

$$\dot{\kappa} = [H(\theta) - R_d(\theta)\kappa]\dot{\epsilon}_p - \boxed{R_s(\theta)\kappa\sinh(Q_s(\theta)\kappa)}$$

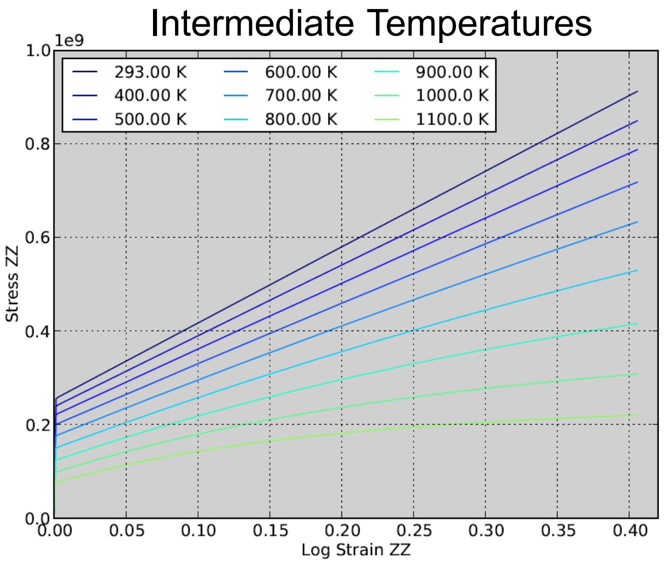
Evolution of the kinematic hardening variable

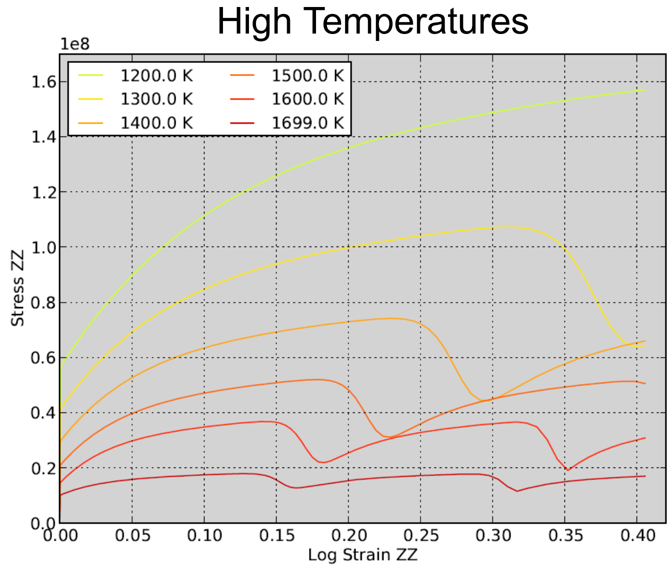
$$\dot{\alpha} = \boxed{h(\theta)}\|D^p\| - \sqrt{\frac{3}{2}}\dot{\varepsilon}_p R_d(\theta)\alpha\|\alpha\|$$

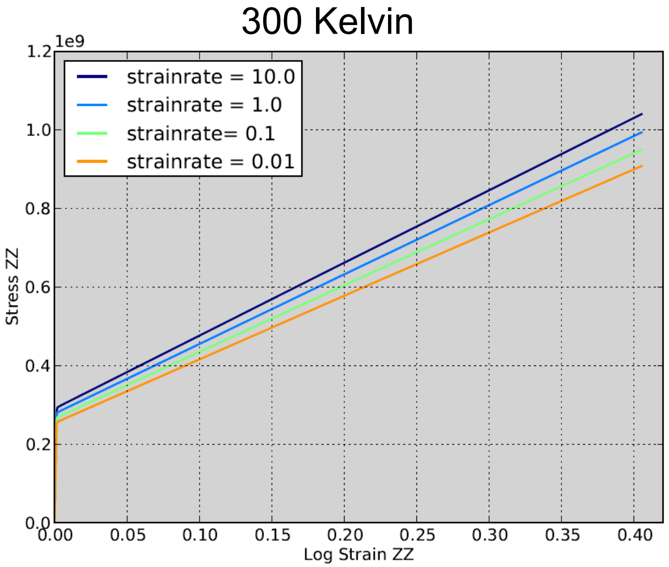
Nomenclature	
$f(\theta)$	Flow Rule Coefficient
$n(\theta)$	Flow Rule Exponent
$Y(\theta)$	Temp Dependent Initial Yield Strength
$H(\theta)$	Hardening Parameter
$R_d(\theta)$	Dynamic Recovery
$R_s(\theta)$	Static Recovery
$Q_s(\theta)$	Sinh Static Recovery
$h(\theta)$	Backstress Hardening

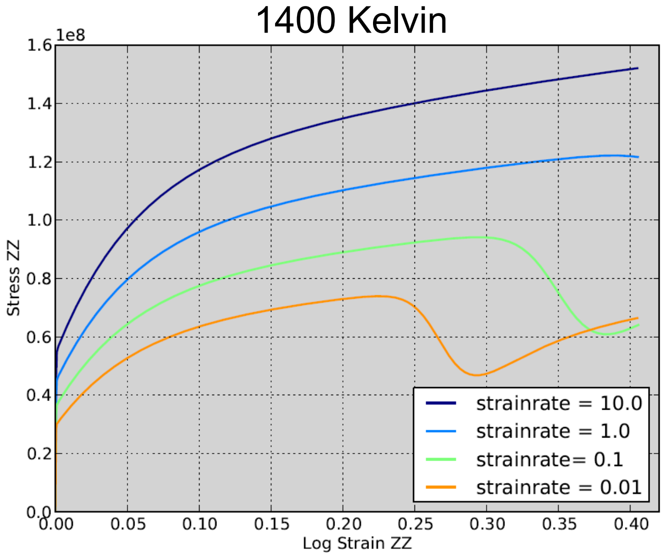
Single Element Uniaxial Tension Test for Baseline DSA Parameters with Varying Temperatures & Strain Rate

Baseline DSA Parameters	
f_1	9.178e-02
n_2	5.699e+03
Y_0	5.264e+09
Y_1	2.688e+05
Y_2	1.87e-03
Y_3	8.683e+02
Y_4	3.316e+01
H_μ	0.01
Rd_1	8.565e+02
Rd_2	5.419e+03







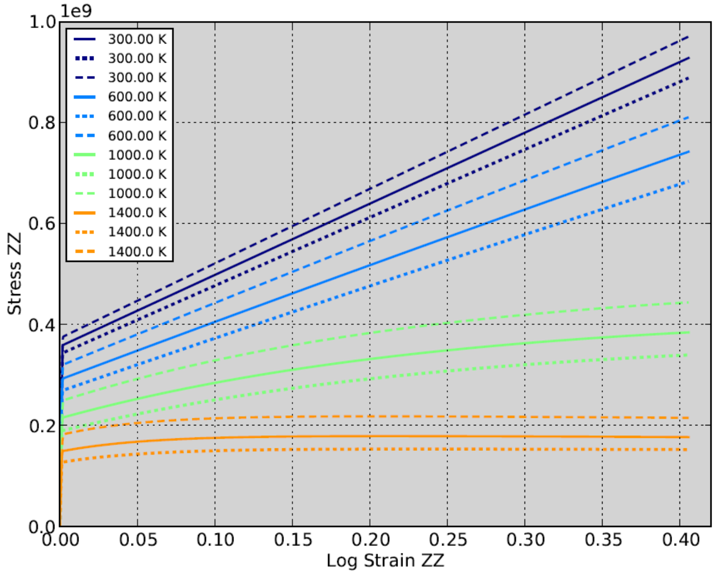


BCJ_MEM Flow Rule

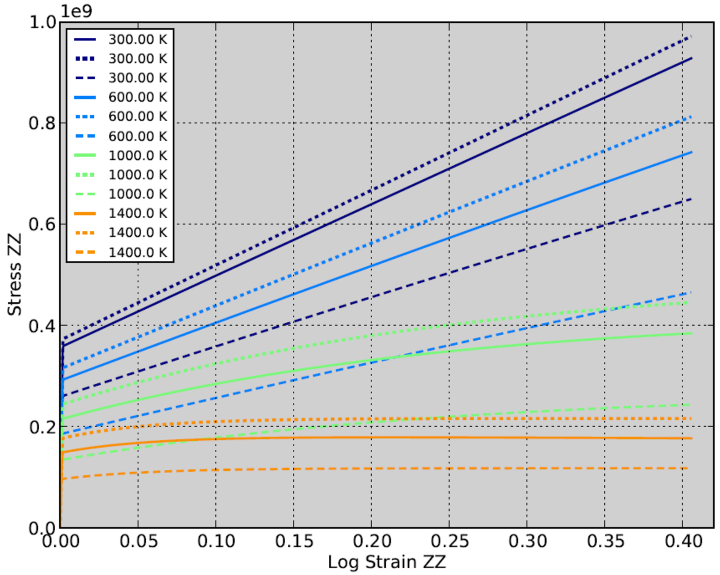
With the evolution of the plastic flow rule

$$\dot{\varepsilon}^p = f(\theta)\sinh\left\langle\frac{\sigma}{\kappa+Y(\theta)}-1\right\rangle^{n(\theta)}$$

$$Y(\theta)=\frac{Y_0}{Y_4+e^{-Y_1/\theta}}\frac{1}{2}\left[1+\tanh\big(Y_2(Y_3-\theta)\big)\right]$$



$$f(\theta)=f_1 e^{-f_2/\theta}$$



$$n(\theta)=n_1+\frac{n_2}{\theta}$$

Dynamic Recovery & Hardening Parameter

Sandia National Laboratories

Evolution of the isotropic hardening variable

$$\dot{\kappa} = [H(\theta) - R_d(\theta)\kappa]\dot{\epsilon}_p$$

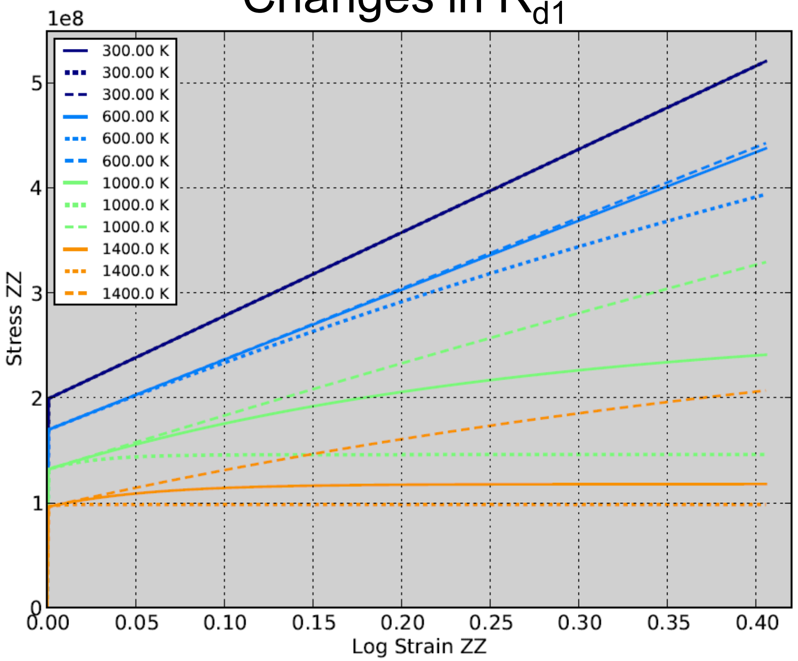
Evolution of the kinematic hardening variable

$$\dot{\alpha} = -\sqrt{\frac{3}{2}}R_d(\theta)\dot{\epsilon}_p\alpha\|\alpha\|$$

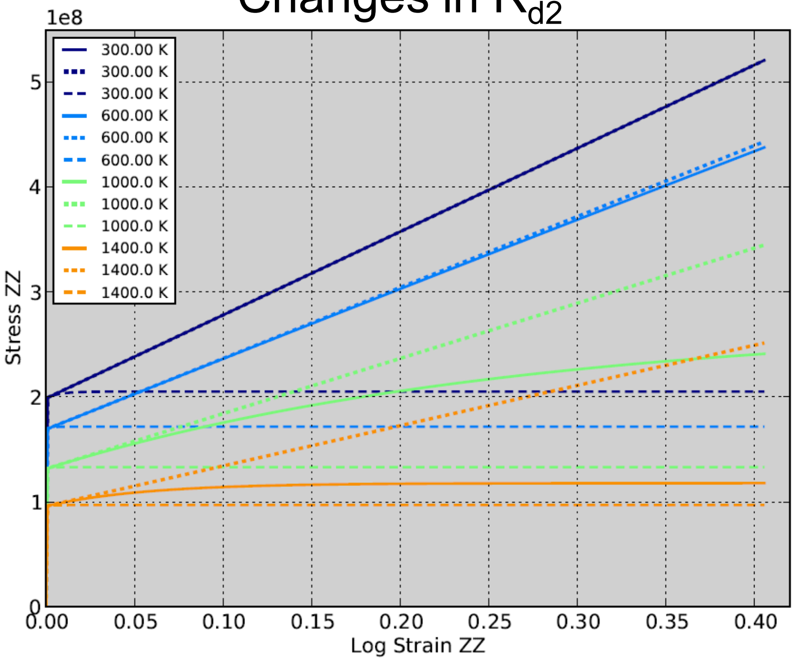
$$H(\theta) = H_1 - H_2\theta$$
$$H(\theta) = H_\mu\mu(\theta)$$

$$R_d(\theta) = R_{d1}e^{-R_{d2}/\theta}$$

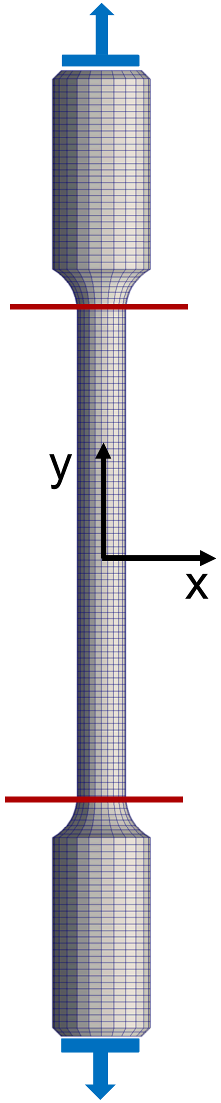
Changes in R_{d1}



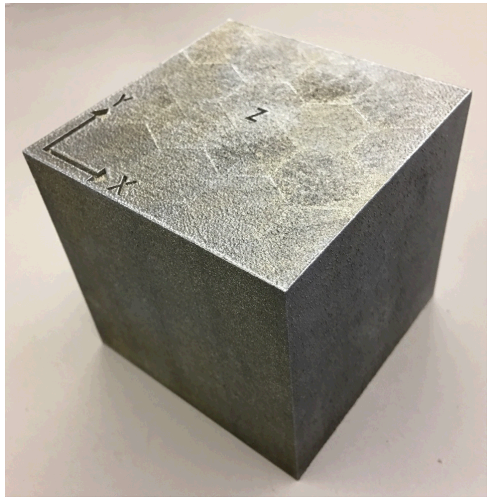
Changes in R_{d2}



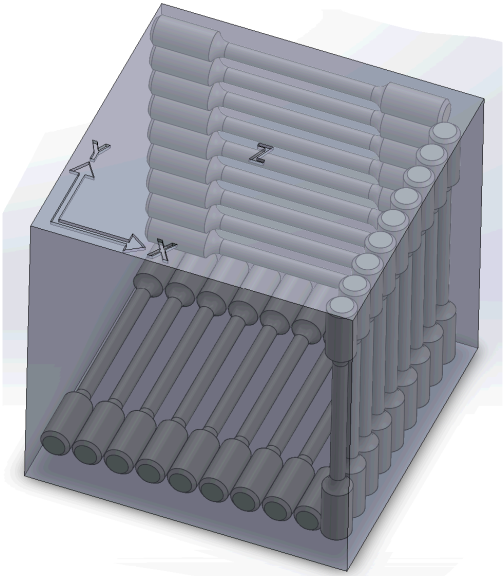
Tensile Specimen Geometry and Boundary Conditions



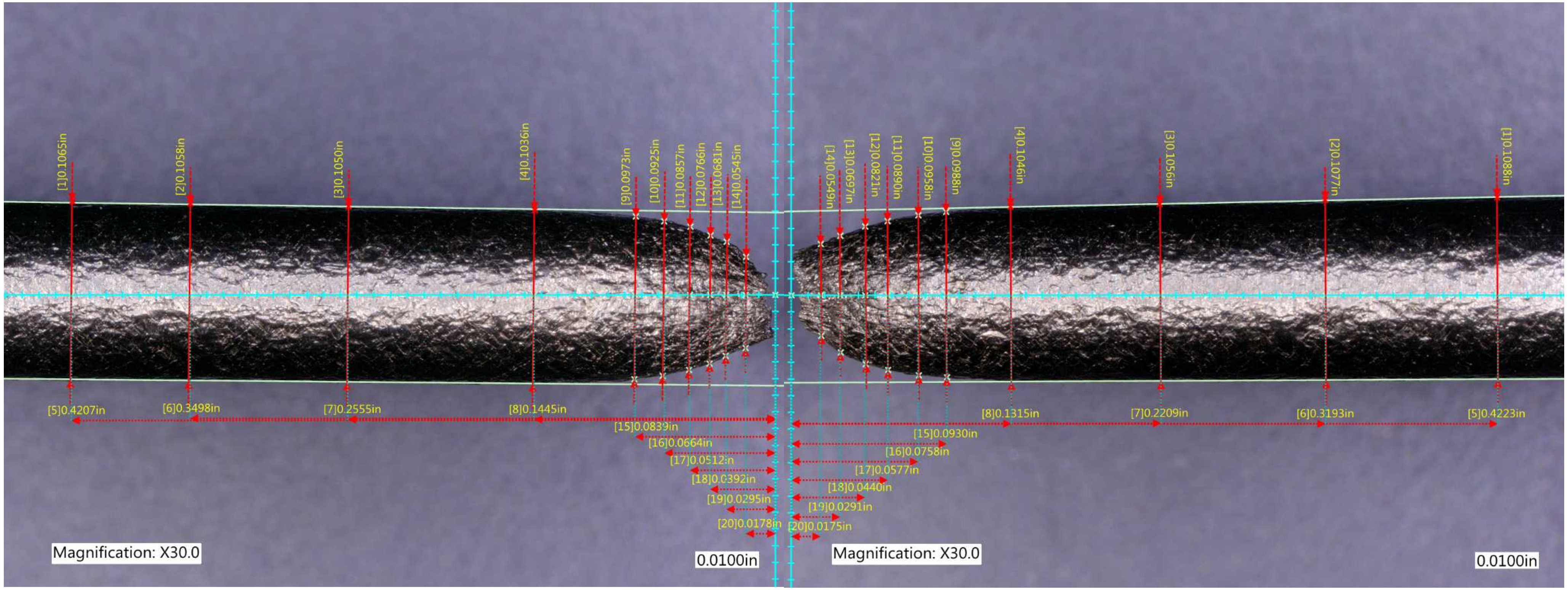
- The total length of specimen is 63.25 mm
- The center rod (gauge section, L_0) is 31.75 mm
- Center radius of the gauge section is tapered by $10^{-2} * R$
  - Where R is 1.5875 mm
- The top and bottom surfaces are fixed in the X & Z direction
- The top and bottom surfaces have an applied constant velocity of $v = \frac{1}{2}\dot{\varepsilon} * L_0$ in the Y direction



Antoun, Connelly, 2017



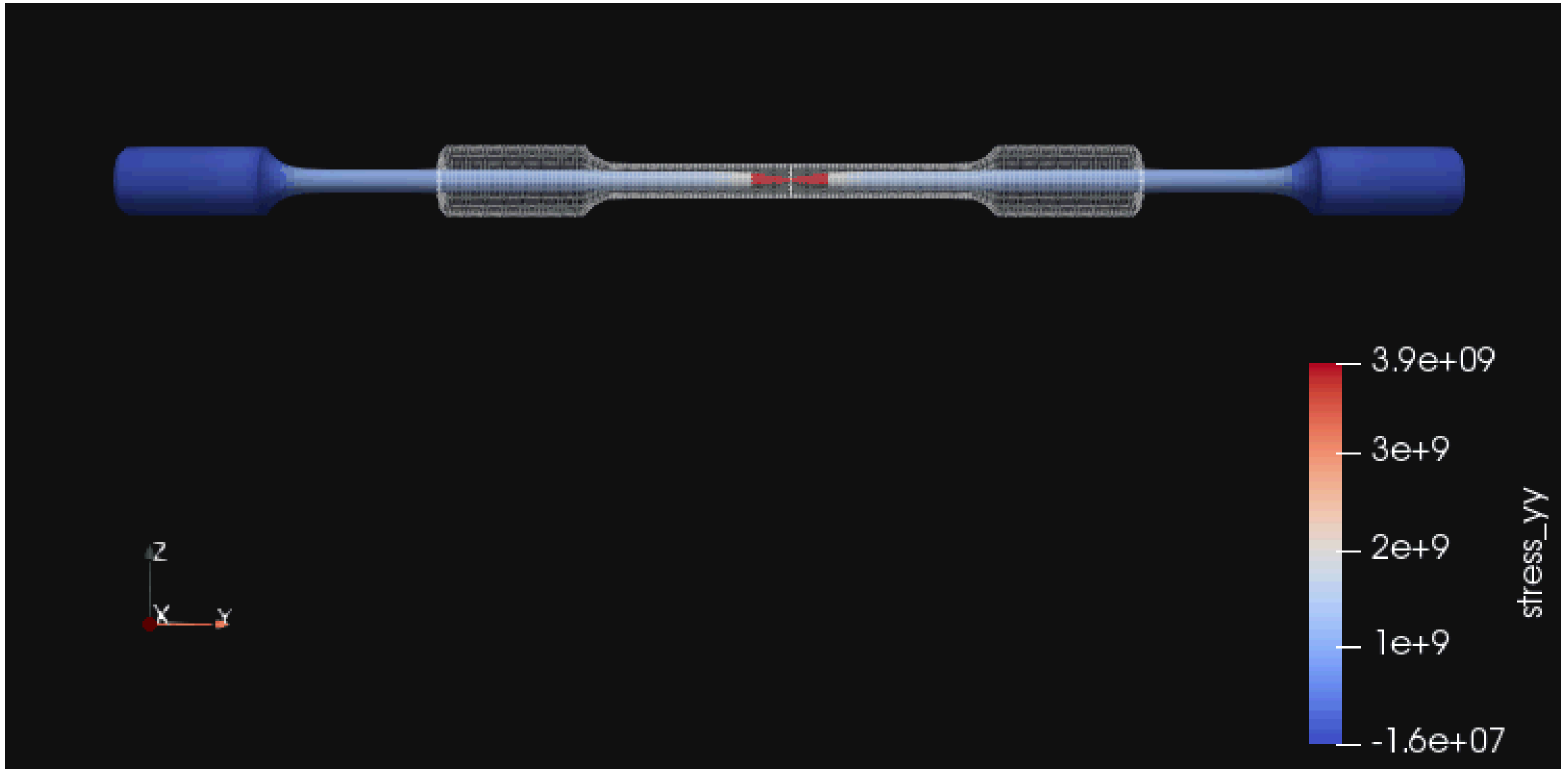
Experimental Tensile Specimen Failure



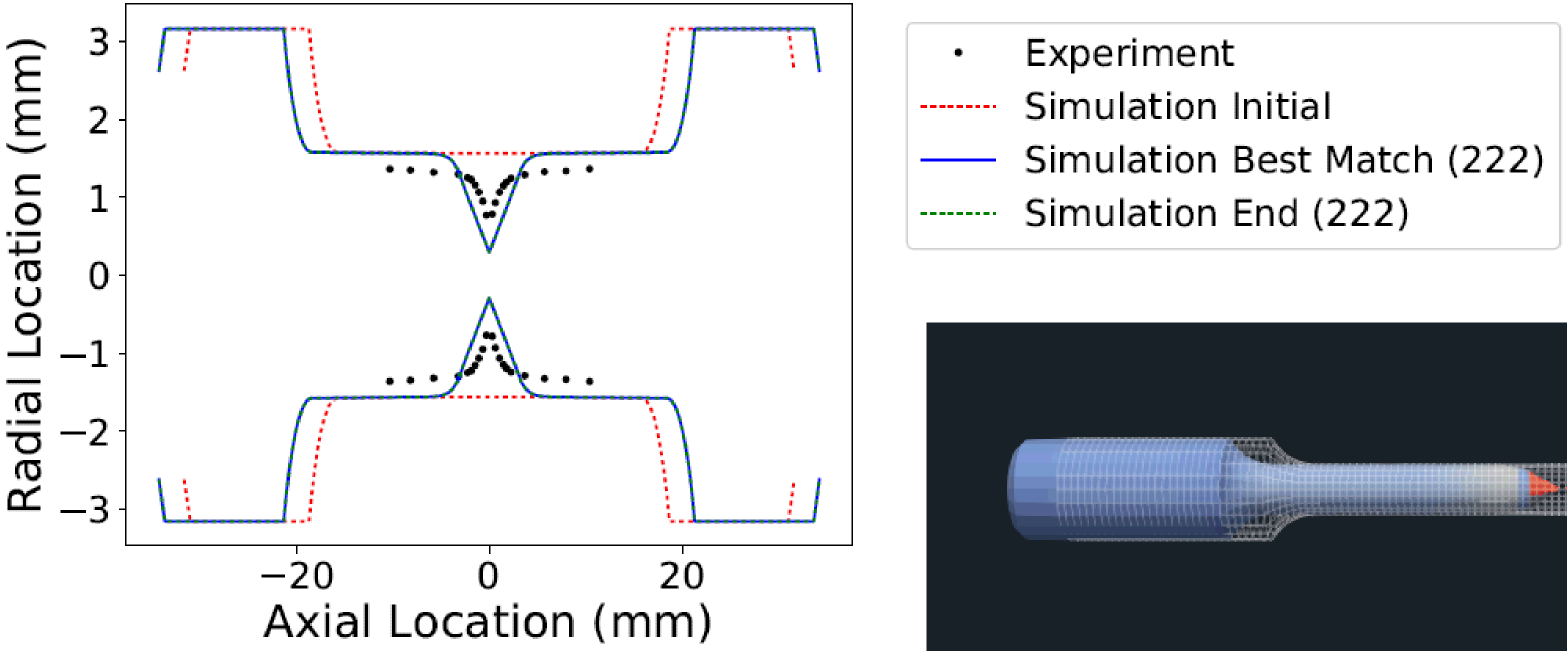
B. Antoun 2017

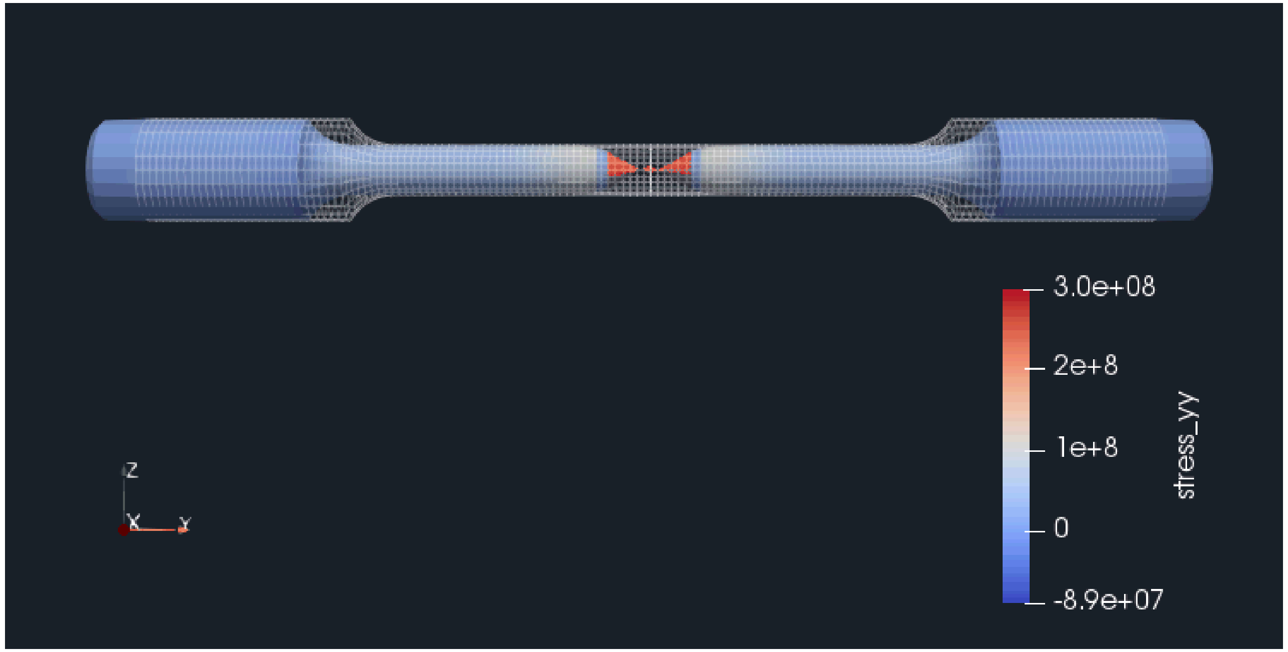
Simulation Results with Baseline DSA Parameters

- Temperature = 300K
- Strain rate = 0.01



Elastic Plastic Model



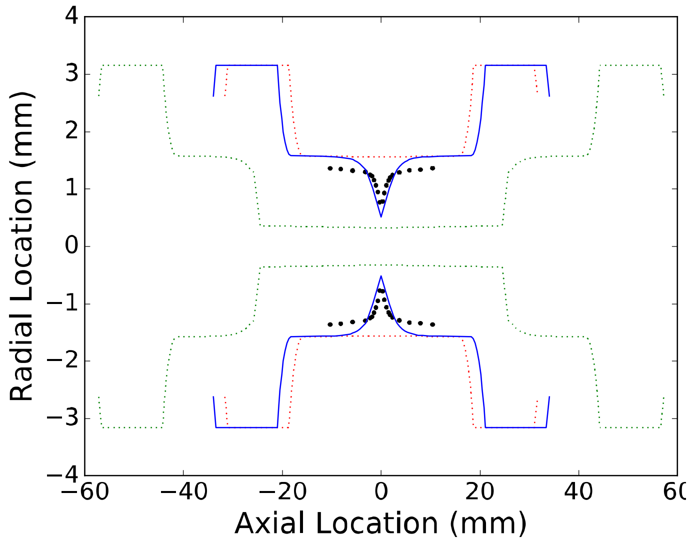


E = 200e9
nu = 0.25
Yield Stress = 200e6
Hardening Modulus = 20e6

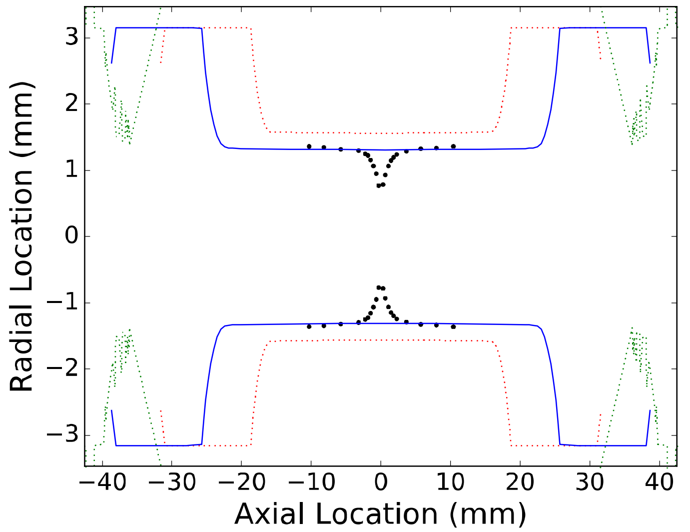
Elastic Plastic Model

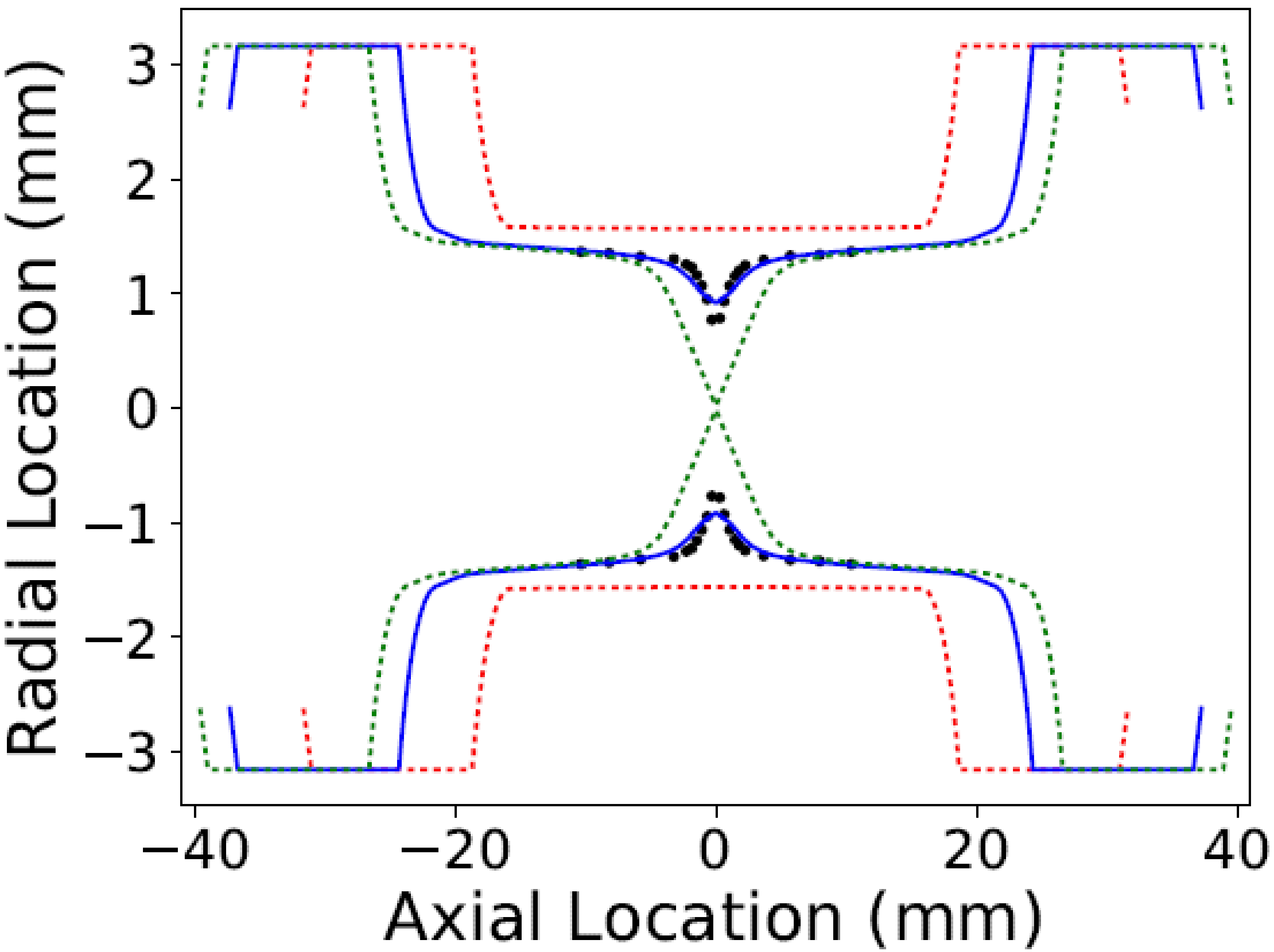
Hardening Modulus

20e7

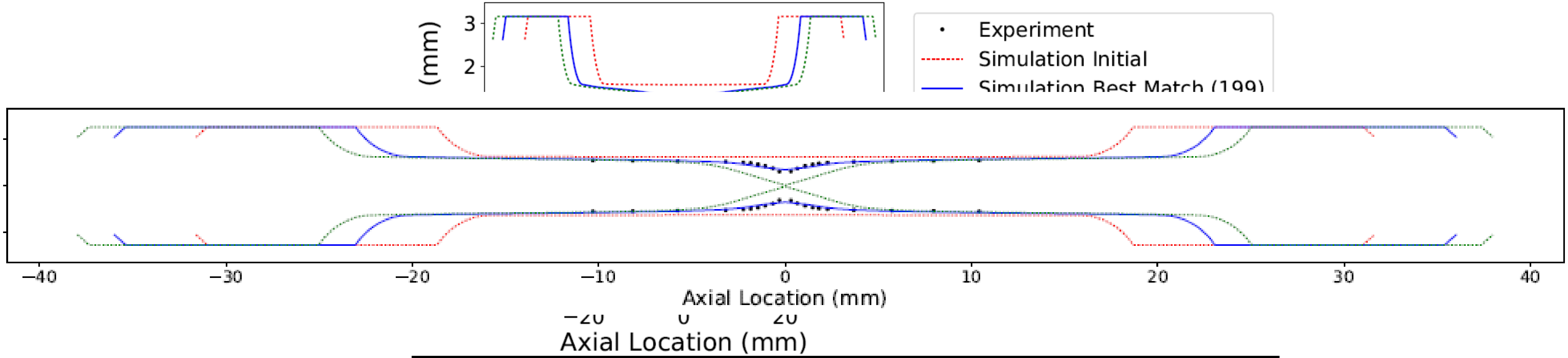


20e8

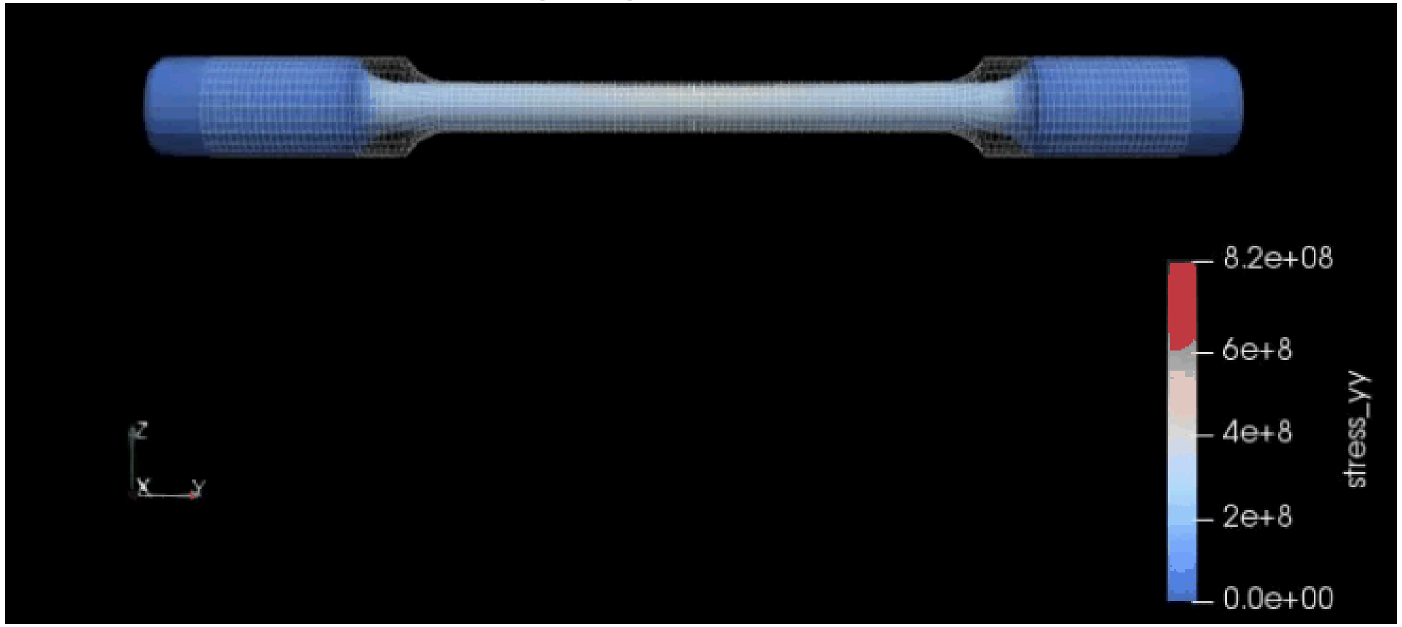




DSA/BCJ_MEM Model for Tensile Specimen



$$H_\mu^{BL} = 0.01$$
$$H_\mu = 0.00085$$
All other values are baseline parameters.

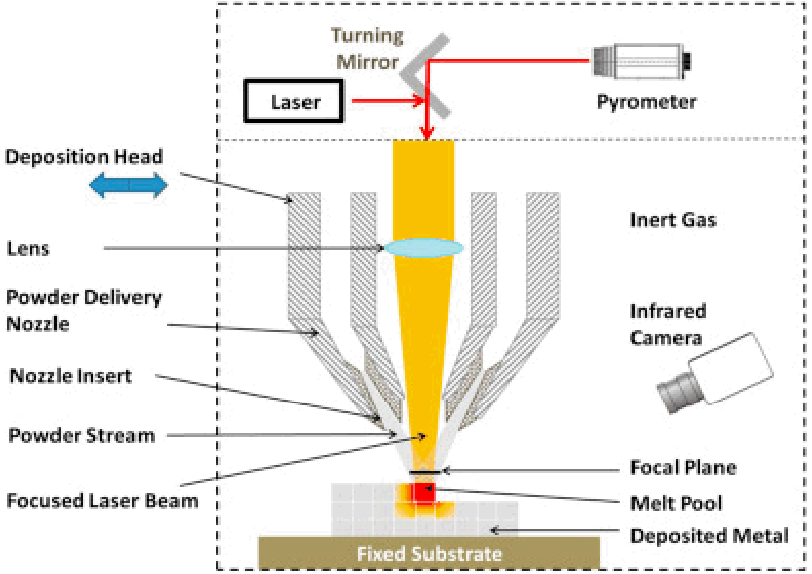


Conclusion

- Affects of Varying Model Parameters
- Recalibration of isotropic hardening shear coefficient
- Parameter sets for DSA model

Directed Energy Deposition

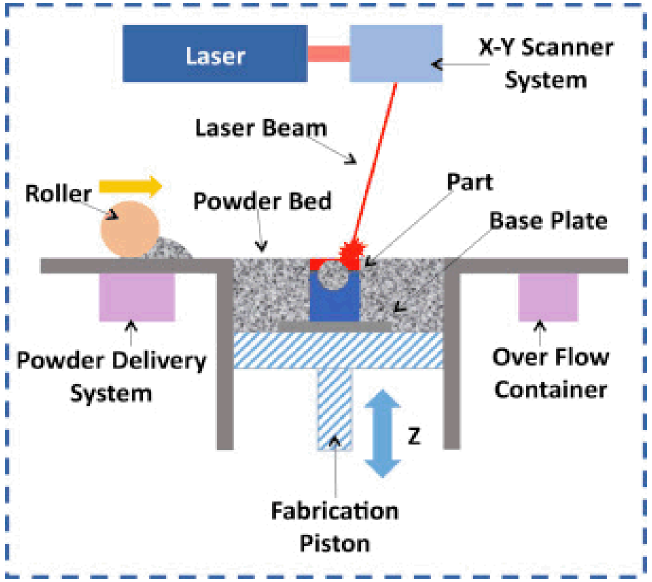
Laser Engineered Net Shaping (LENS)



https://doi.org/10.1016/j.addma.2015.07.001

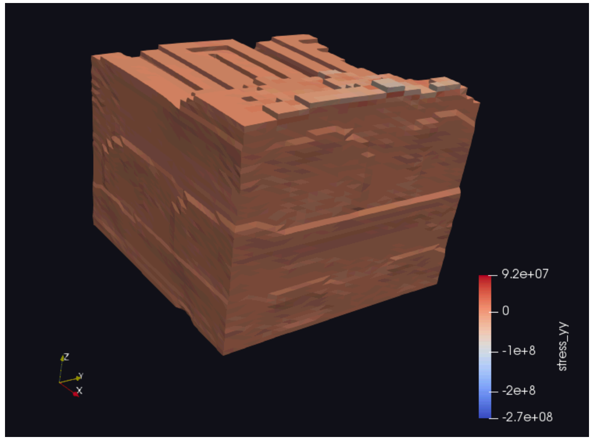
Selective Laser Melting

Powder Bed Fusion

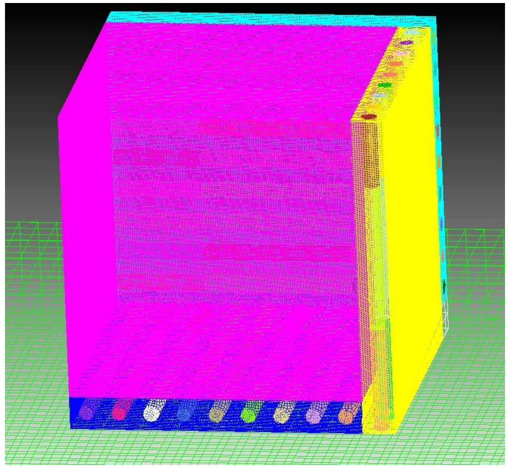


https://doi.org/10.1016/j.addma.2015.07.001

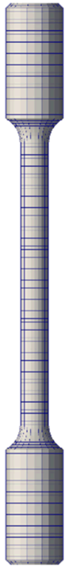
Future Work



Process Simulation

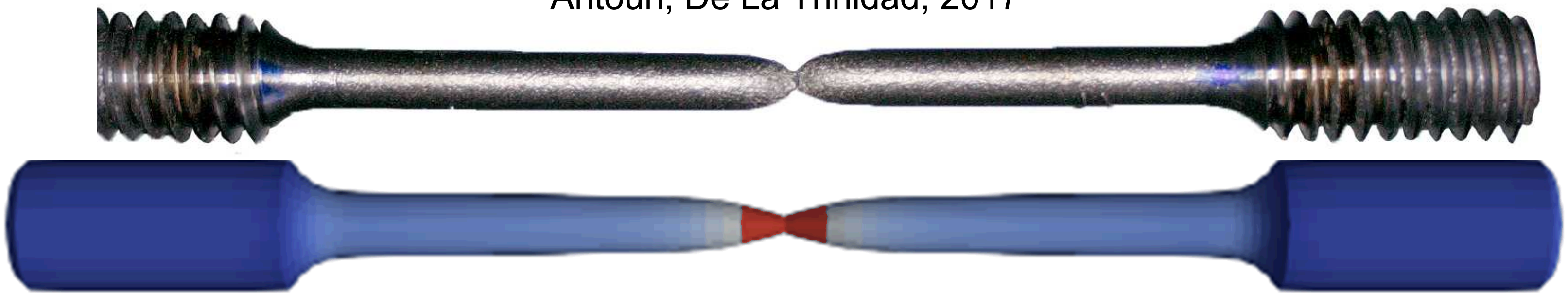


Computational Geometry



Simulation Design

Antoun, De La Trinidad, 2017



Validation Analysis