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Characterization of Dynamic Strength of Alumina-Epoxy Formulations Under Shock Loading

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About Me

- B.S. in Aerospace Engineering at Embry-Riddle Aeronautical University (2021)
    - Concentration in Jet Propulsion
- 3rd Year Ph.D. Student in Aerospace Engineering at Texas A&M University
    - Detonation Physics Lab
- Research Interests include Shock and Detonation Physics, Energetics, and Propulsion

The Dynamic Strength of Composites and Polymers are not well characterized

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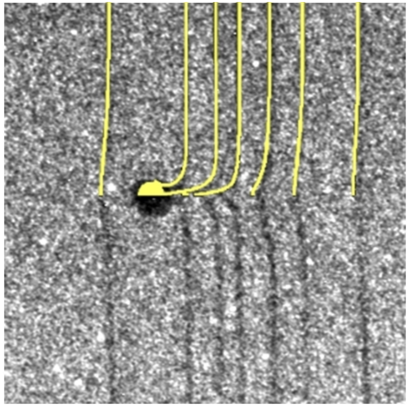
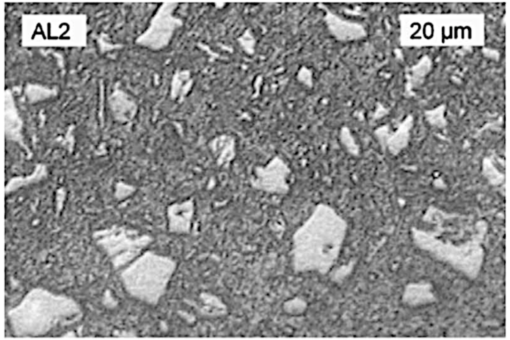
- Little work done regarding strength in the shock regime
- Previously polymers have been modeled as having no strength
- Recent particle tracking experiments performed by Bober et al indicated that silicone has a flow strength of 500 to 750 MPa, stronger than some metals
  - Found that the simulations of the silicone composites could only match experiments if the silicone strength was added



Particle Tracking Experiments in Silicone
[Bober et al (2019)]



Al_2O_3-Epoxy composite matrix
[Setchell et al (2007)]

Richtmyer-Meshkov Instability (RMI)

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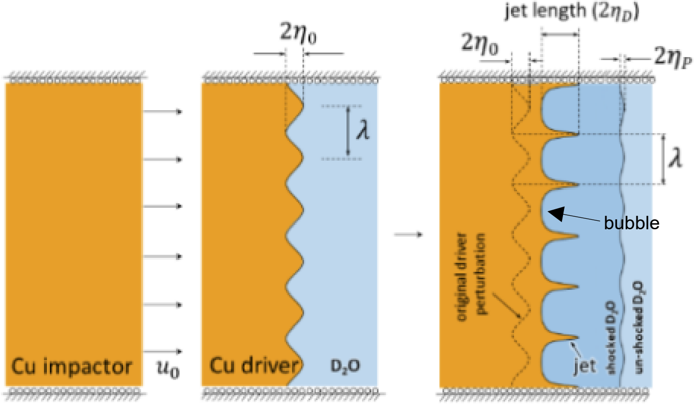
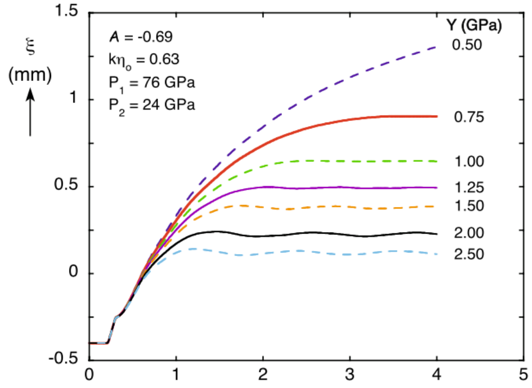
- RMI occurs when two materials of different densities are subjected to shock loading
- Tamped RMI experiments can be used for constitutive model calibration
- RMI inversion behavior is affected by
  - Driver strength, Y_p
  - Tamper strength, Y_T
  - Shock stress, σ
  - Atwood Number, $A = \frac{\rho_T - \rho_D}{\rho_T + \rho_D}$
  - Corrugation aspect ratio $k\eta_0$
    - $k\eta_0 = \frac{2\pi}{\lambda}\eta_0$



Olles et al (2018)



Vogler et al (2021)

Study Objectives

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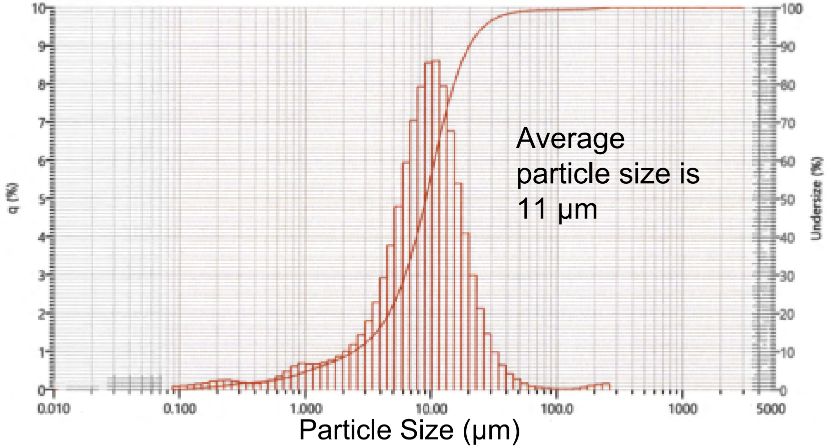
- Alumina-Epoxy matrix (ALOX)
  - Al_2O_3 Loaded Epoxy

<u>Goal</u>: Characterize the dynamic strength of the ALOX matrix at different volumetric fractions
  - 44% Al_2O_3
  - 21.5% Al_2O_3
  - 0% Al_2O_3 (Neat Epon828 epoxy resin cured with DEA)
- The corrugation aspect ratio $k\eta_0$ and impact velocity (stress) were also varied to promote jet formation



Define Geometry → Execute Experiments → Epon828/DEA Analysis → ALOX Analysis

The Dynamic Compression Sector (DCS)

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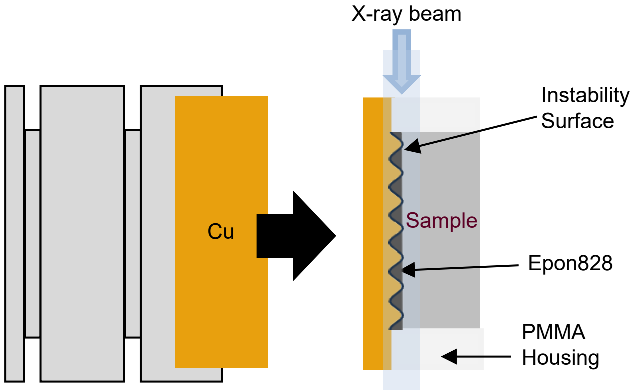
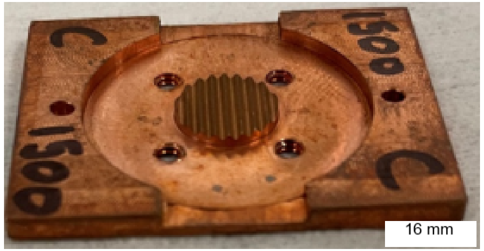
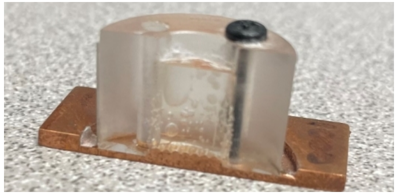
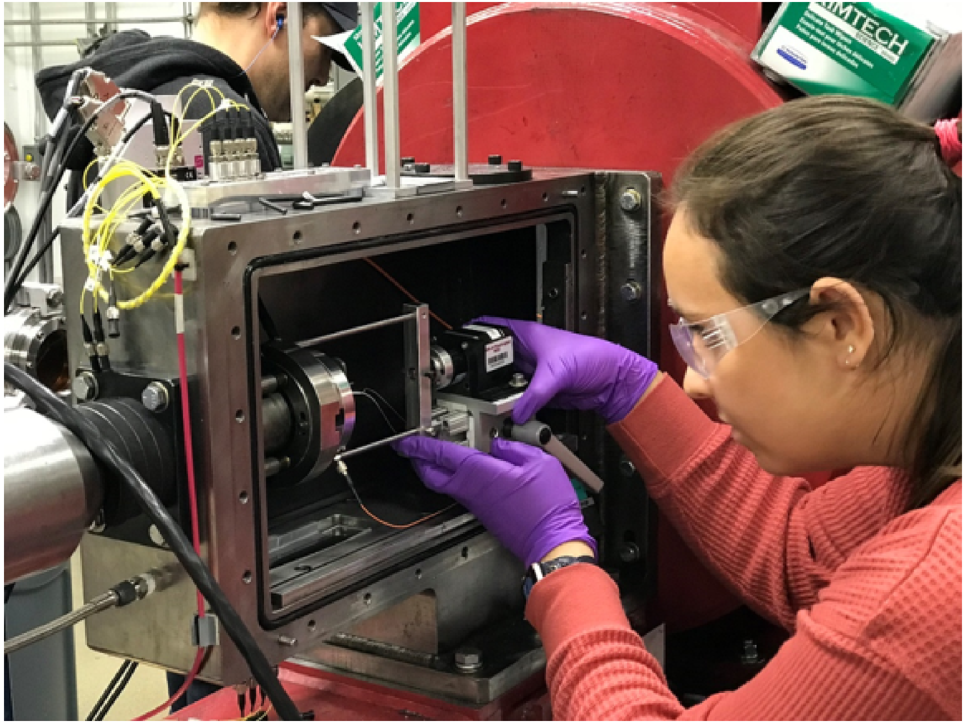
- Experimental Facility at the Advanced Photon Source (APS) Facility at Argonne National Laboratory
- Energy range from 7-36 keV – with energies to 100 keV for imaging

Experimental Details









Experimental Details

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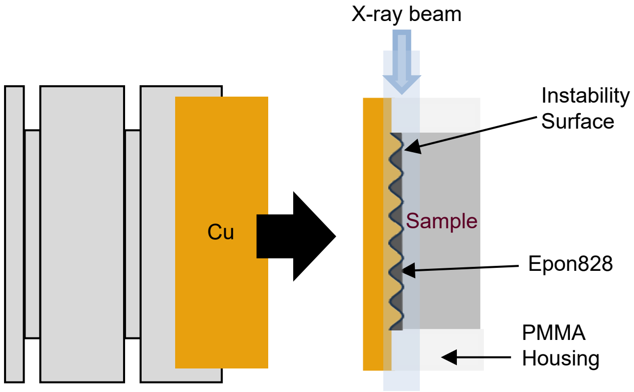

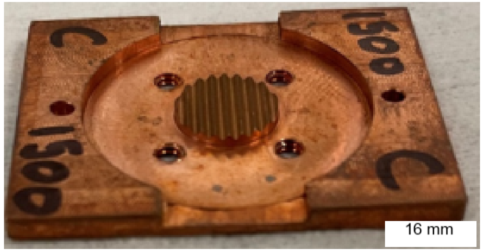

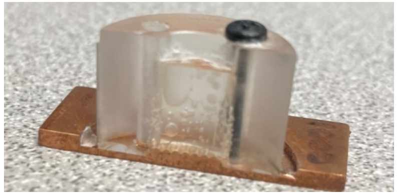

- Experiments performed using a single stage powder gun
- Samples were impacted from 0.8 to 2.5 km/s
- Pressures estimated to be from 5 to 28 GPa
- Shots were captured using X-ray phase contrast imaging
- Frame rate of 154 ns
- 1024 x 1024 pixels

Experimental Overview

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Neat Epon828 Epoxy

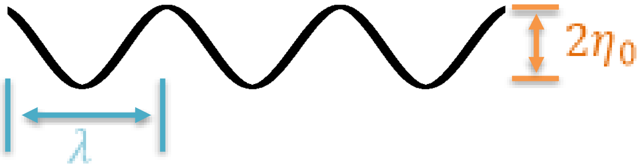
$k\eta_0$	Stress (GPa)
1.000	5.2
1.500	8.2
0.750	12.8

21.5% Al_2O_3

$k\eta_0$	Stress (GPa)
1.500	7.3
1.000	10.9
1.750	12.1

44% Al_2O_3

$k\eta_0$	Stress (GPa)
1.750	6.4
1.750	9.8
1.750	11.1
1.750	17.2
0.750	24.7
1.500	28.1



$$k\eta_0 = 2\pi\frac{\eta_0}{\lambda}$$

* Stress calculated with impedance matching

Experimental Data

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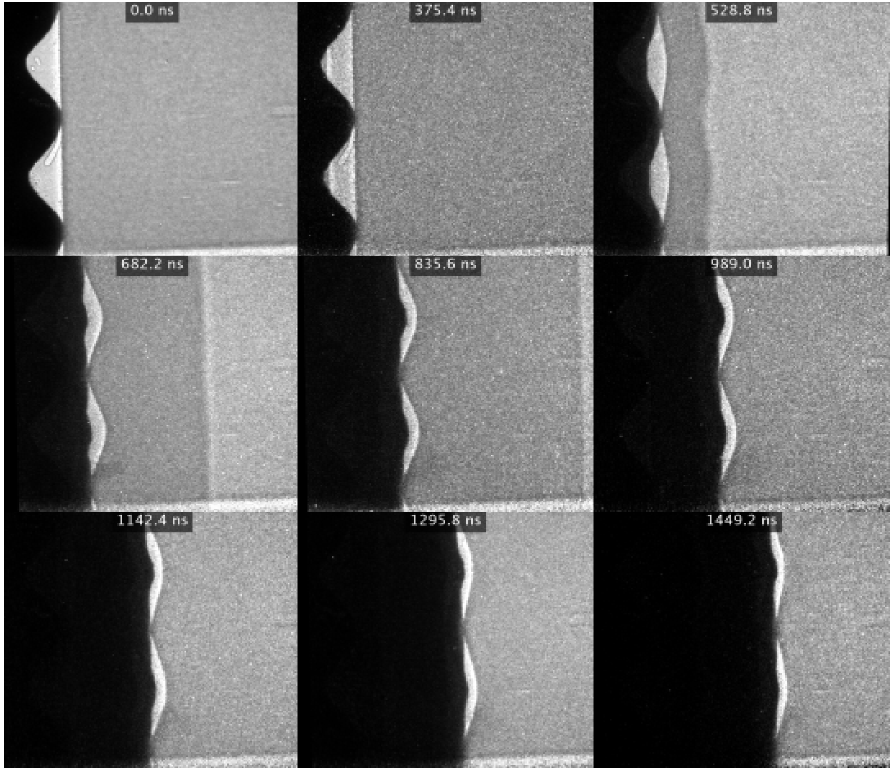
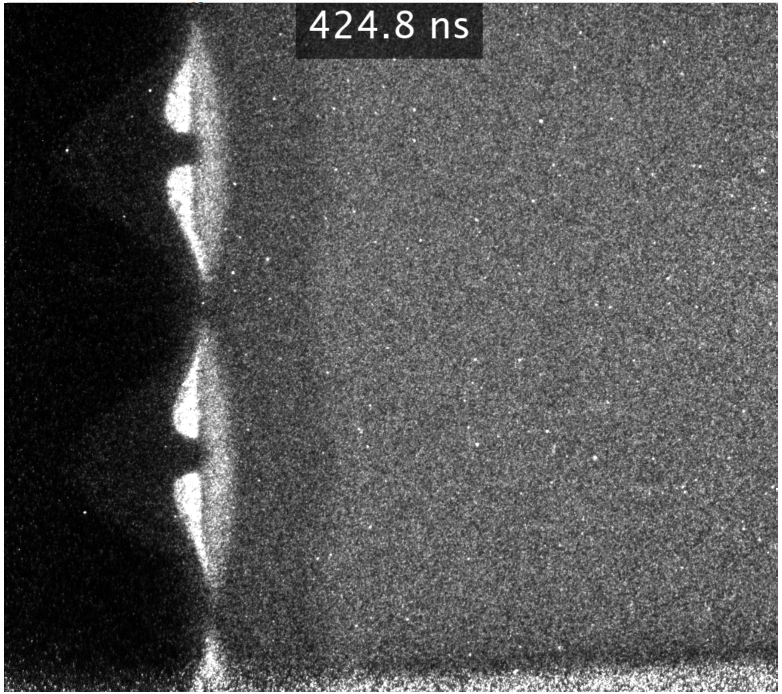
21.5% Al_2O_3 encased in Epon828, 11 GPa





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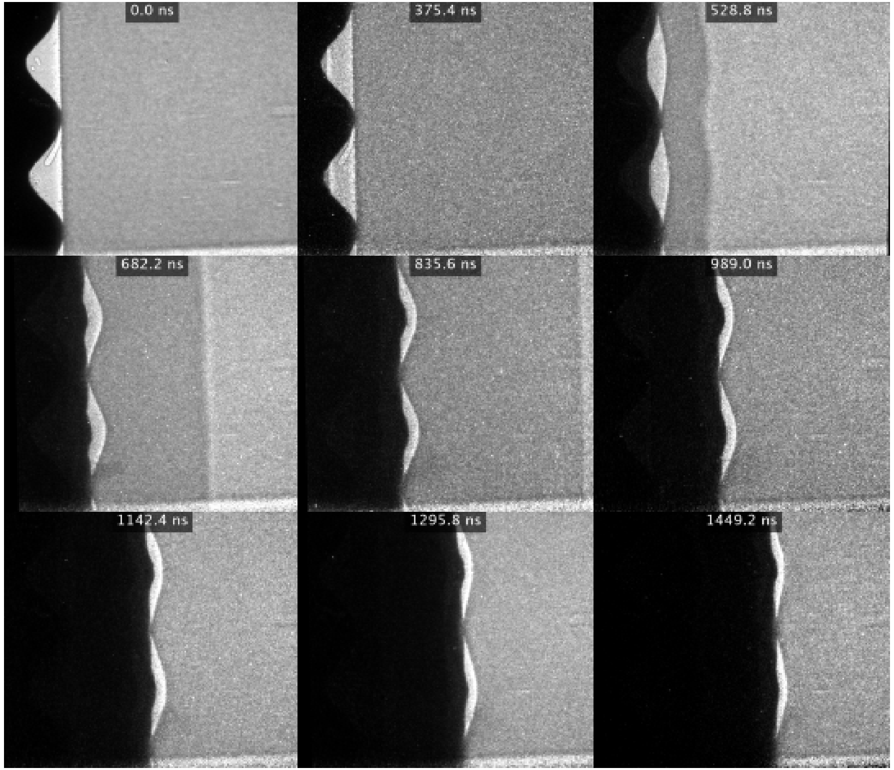

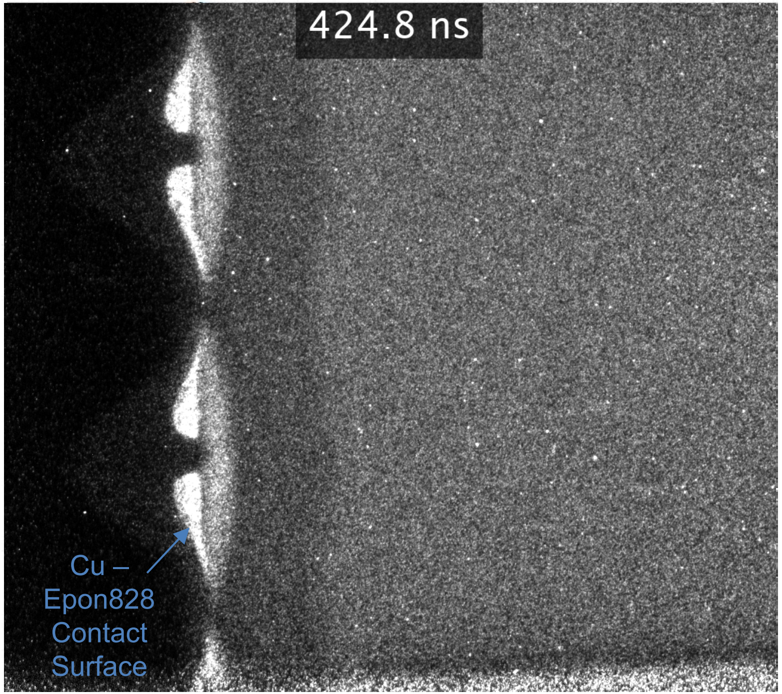

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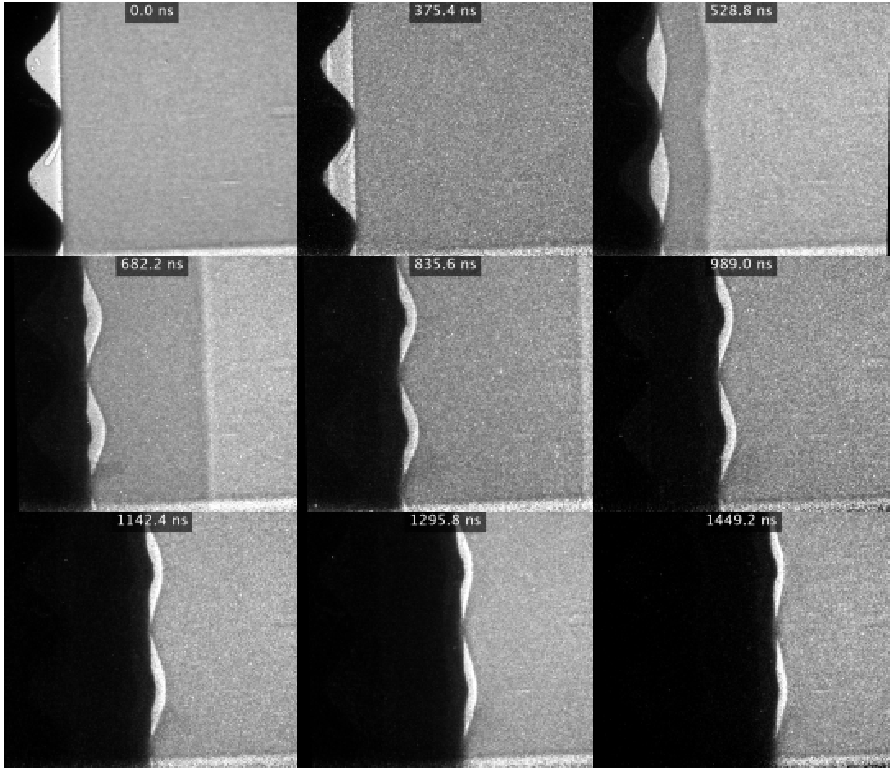

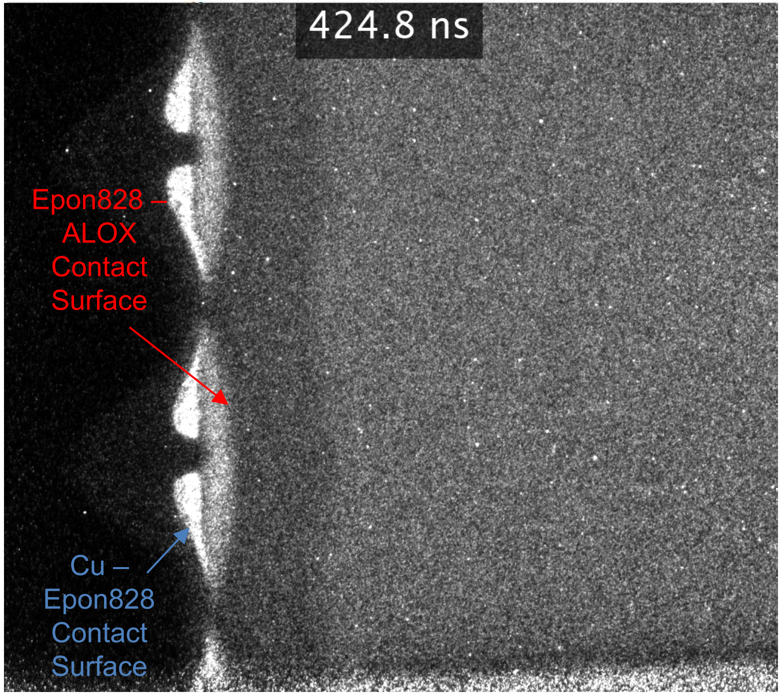

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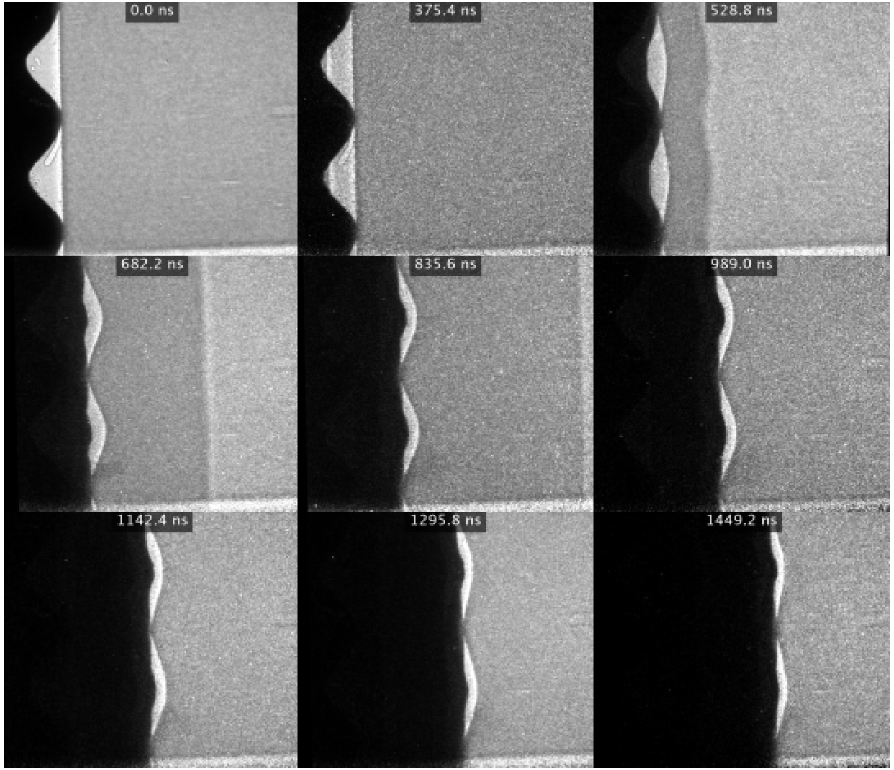

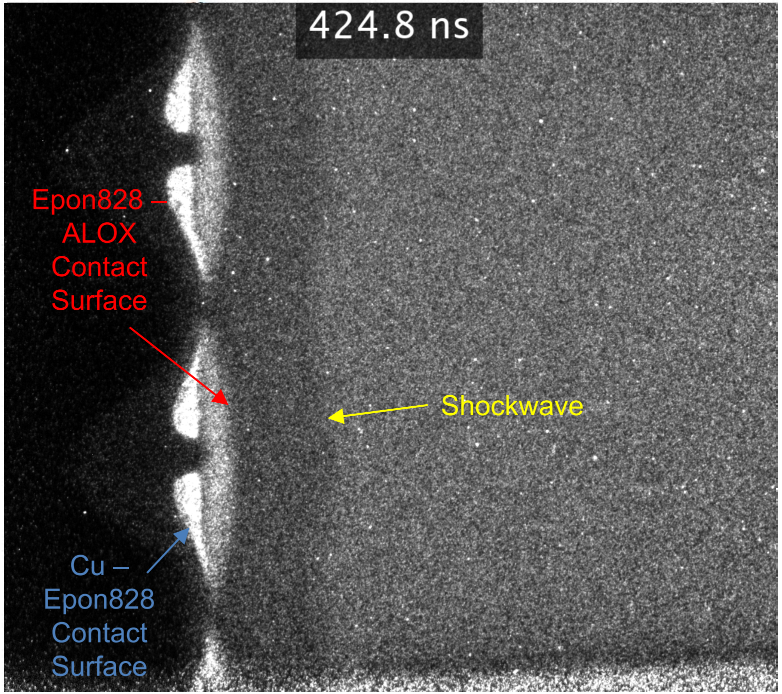

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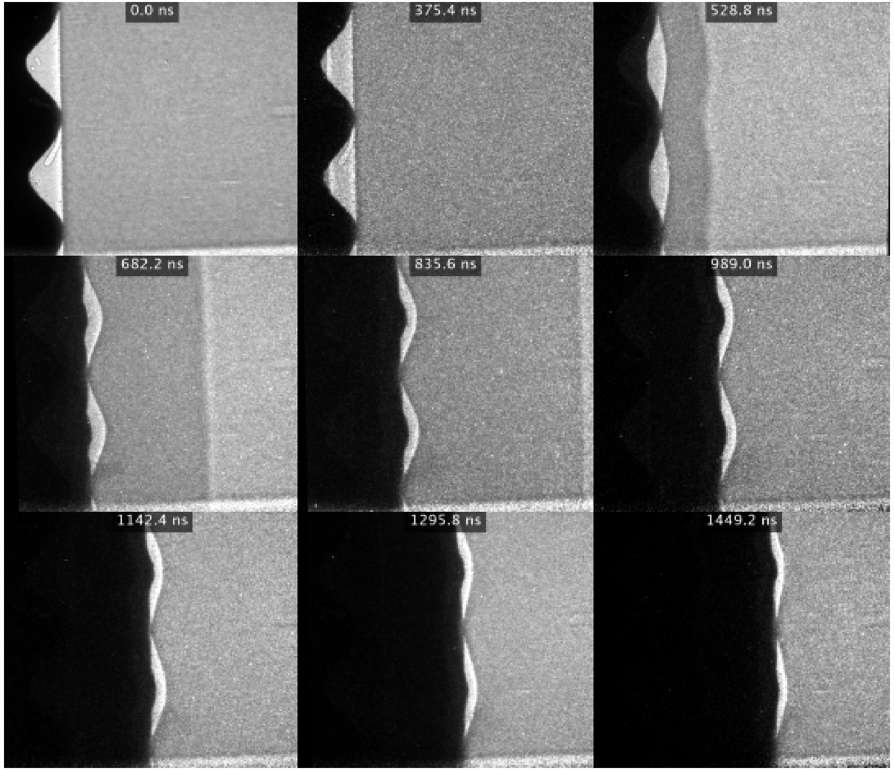

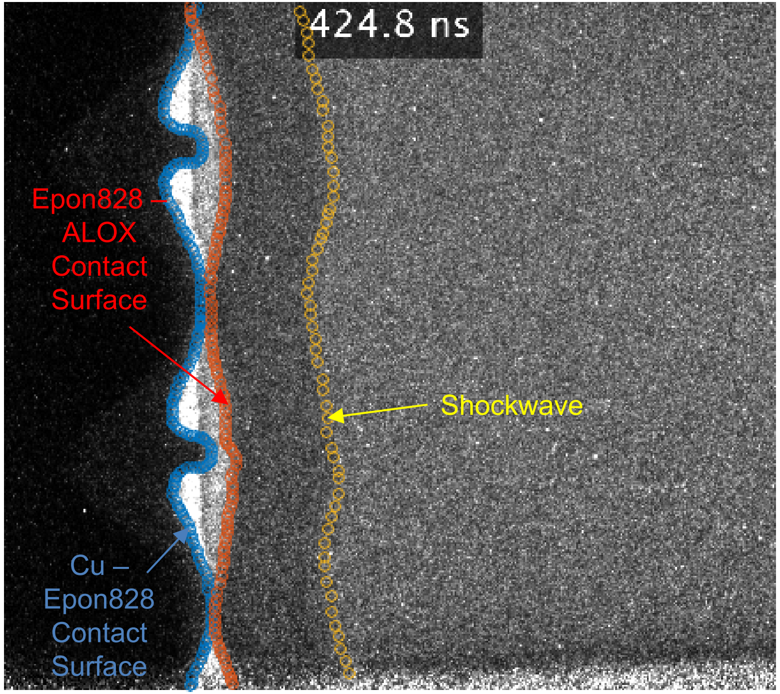

Simulations

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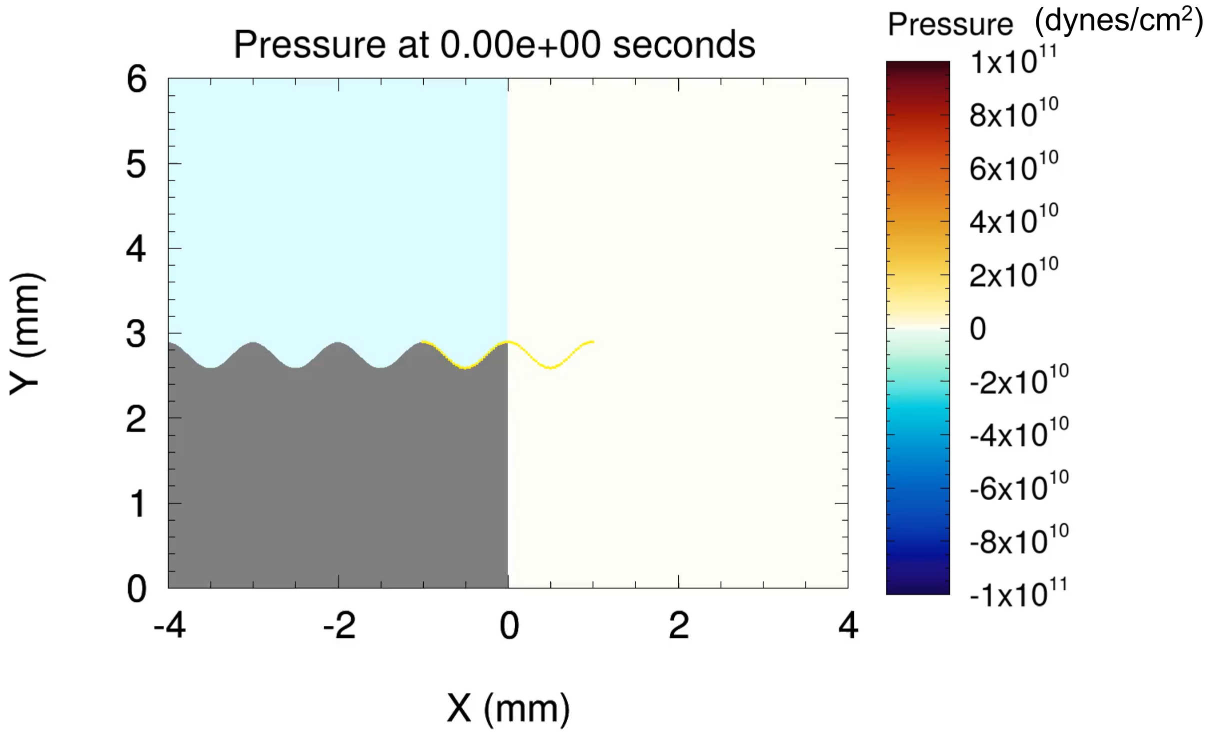
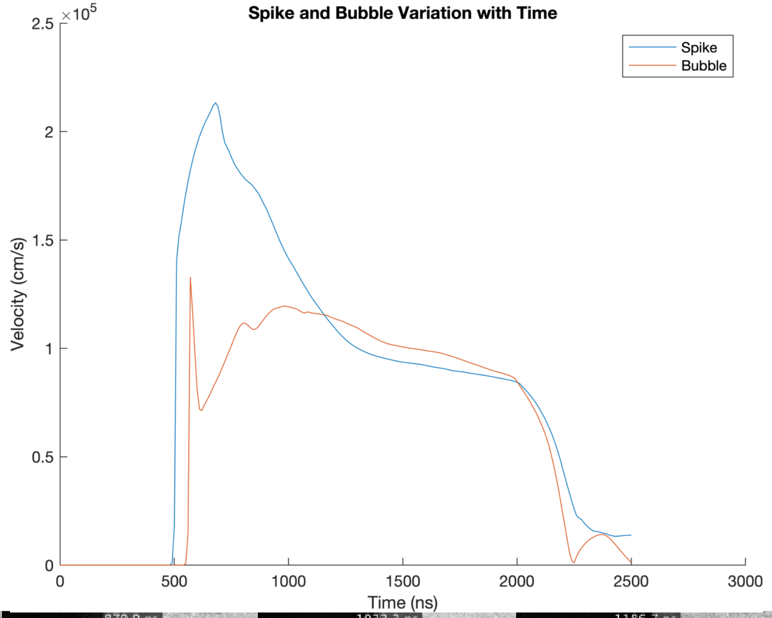
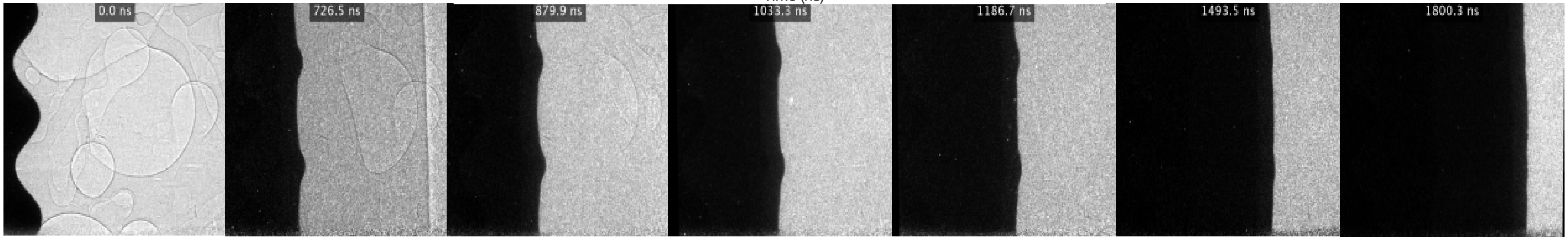


- Simulations were performed using the Sandia Eulerian hydrocode CTH
- CTH uses a fixed mesh that allows the material to move through it

Epon828 Resin Cured with DEA





Default Strength Models for Similar Polymers Cannot Capture RMI Deformation

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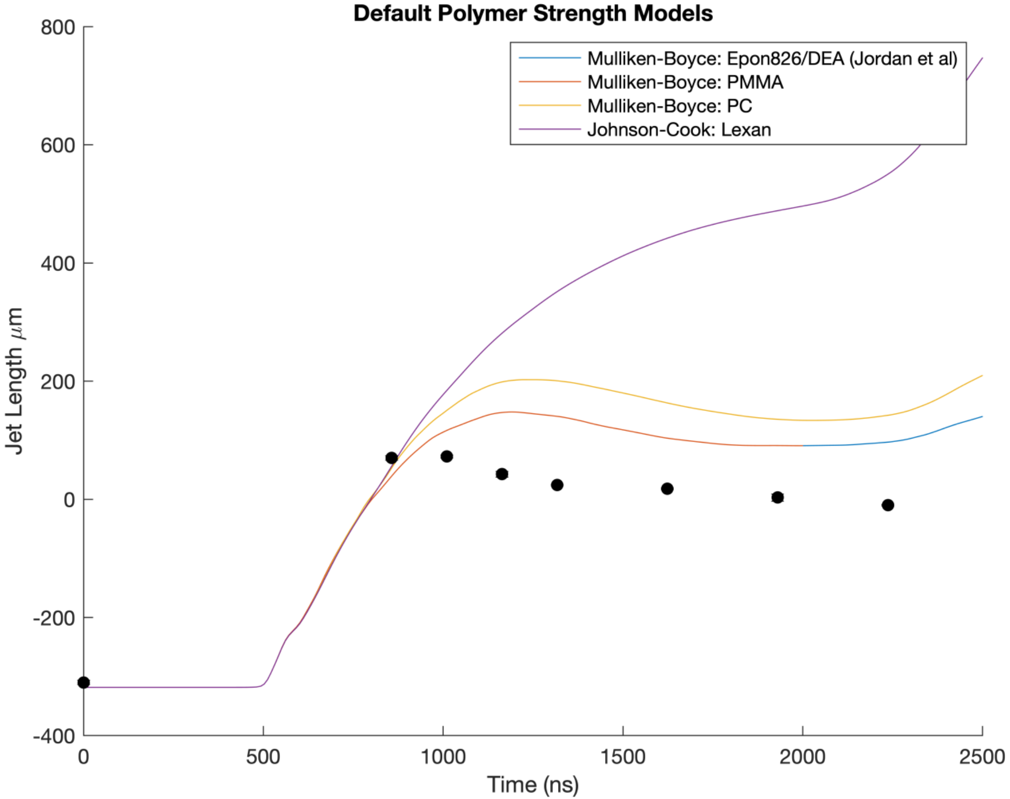

Jet Length Comparison

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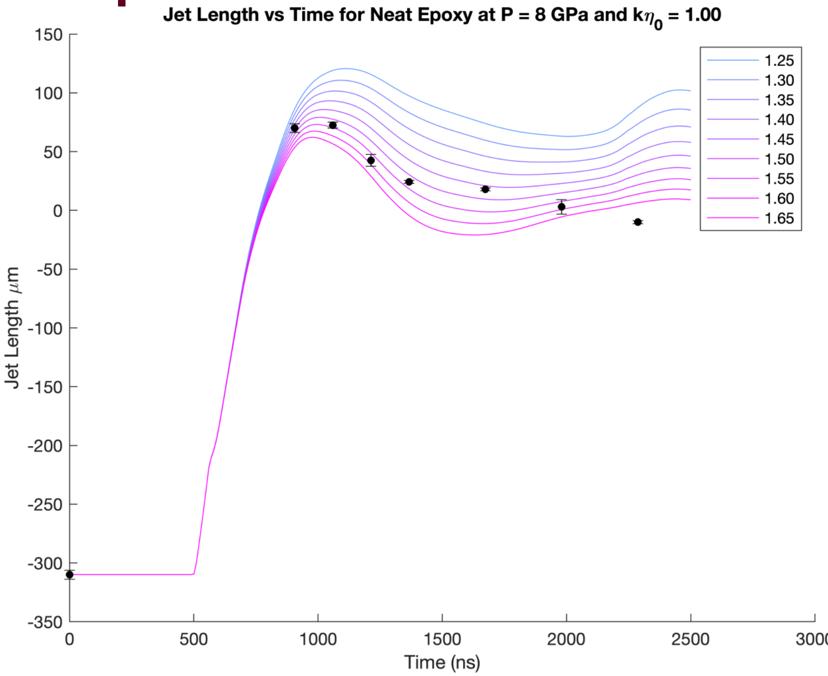

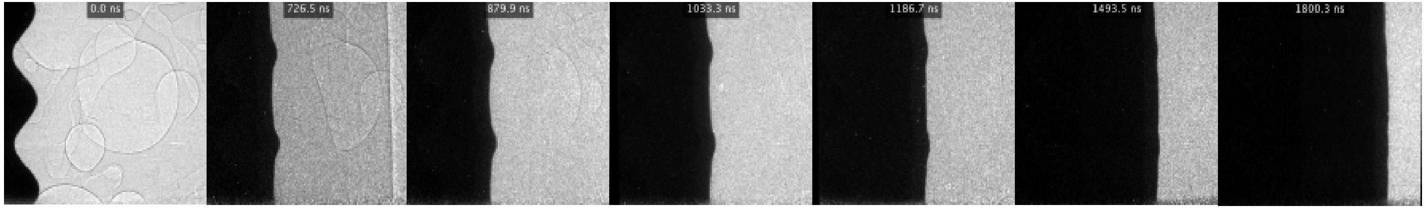

Contour Comparison

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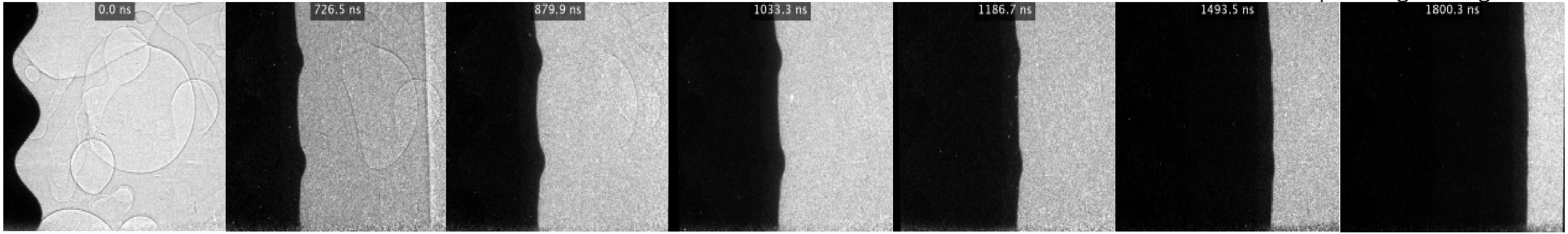

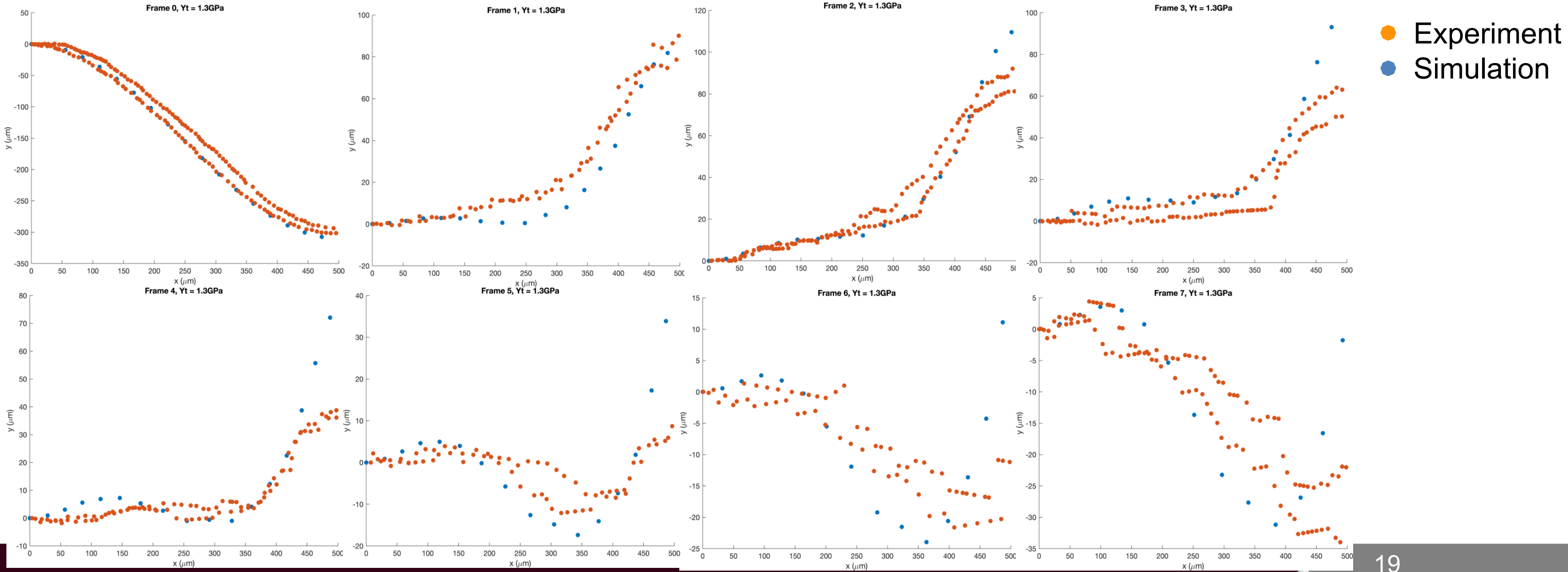

Elastic-Perfectly-Plastic Model

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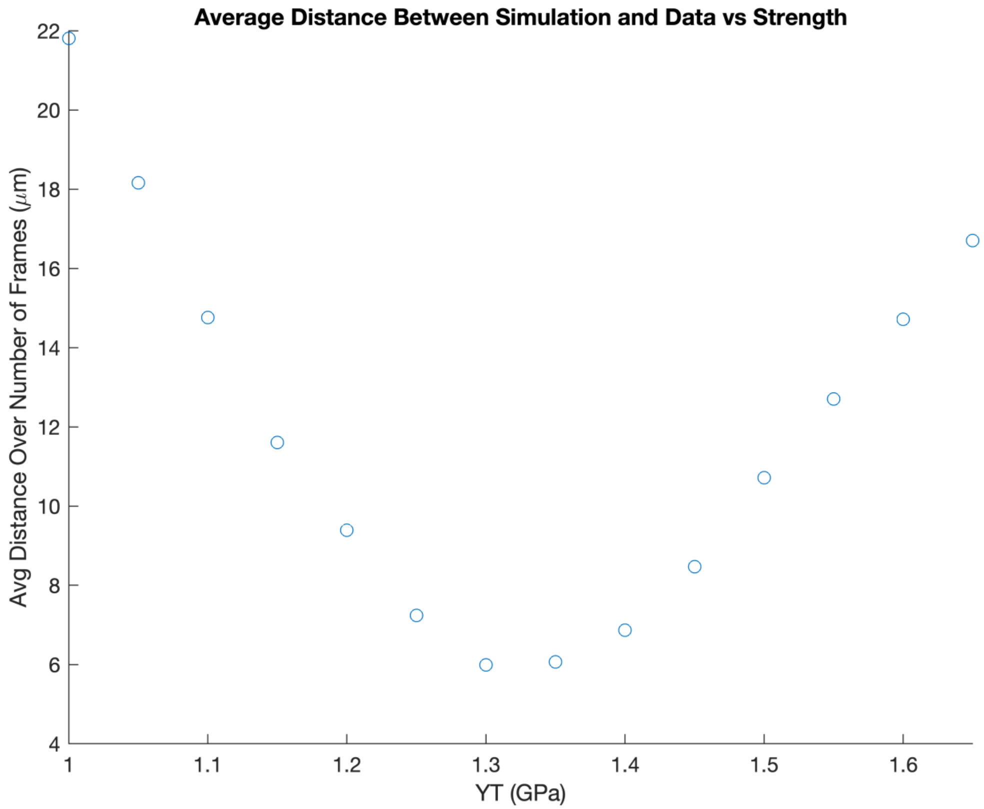
- Preliminary simulations were run using the elastic-perfectly-plastic model
- Used contour comparison to find a strength value where there was a minimum difference between the experimental data and the simulation
- Strength was estimated to be around 1.3 GPa for a stress of about 8 GPa



Johnson-Cook Model

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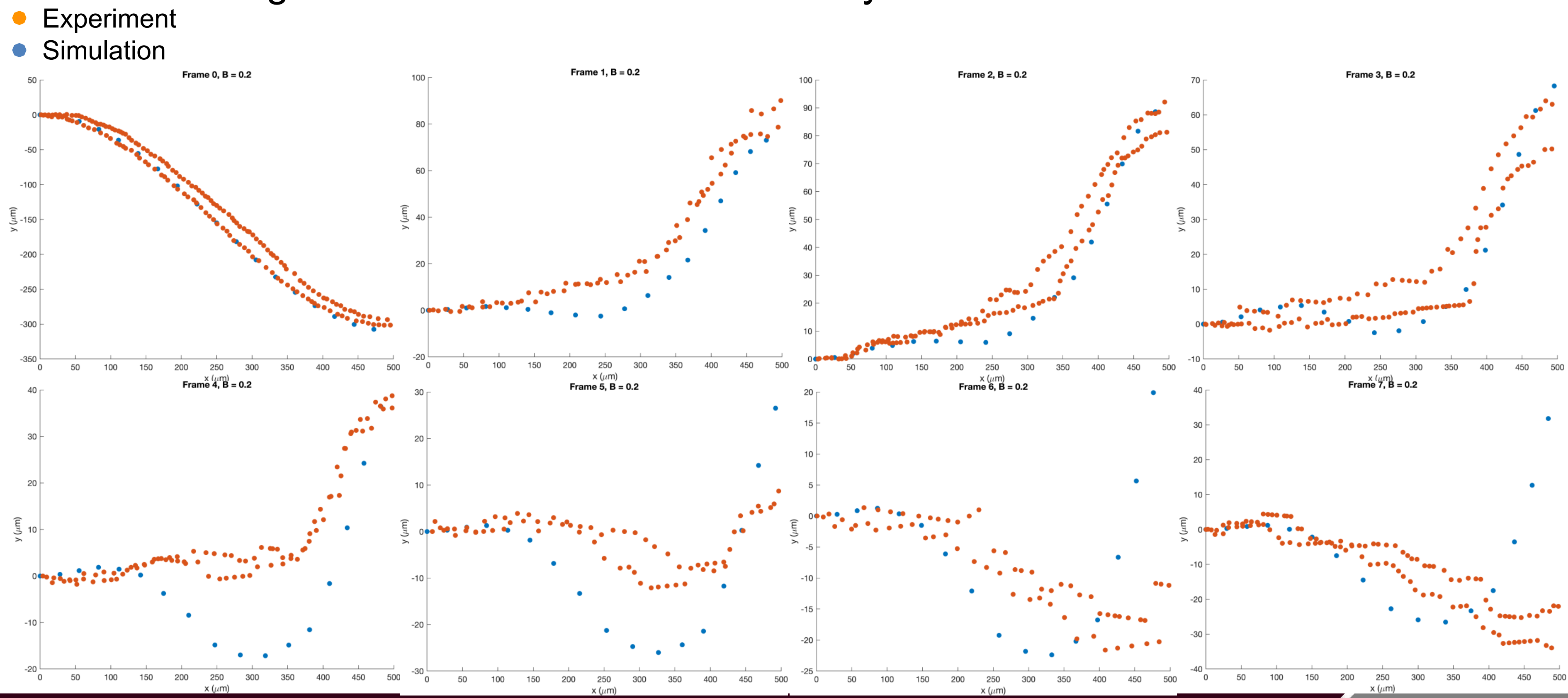
- Used strength value from the Elastic-Perfectly-Plastic model as a baseline case



Alumina addition promotes jetting

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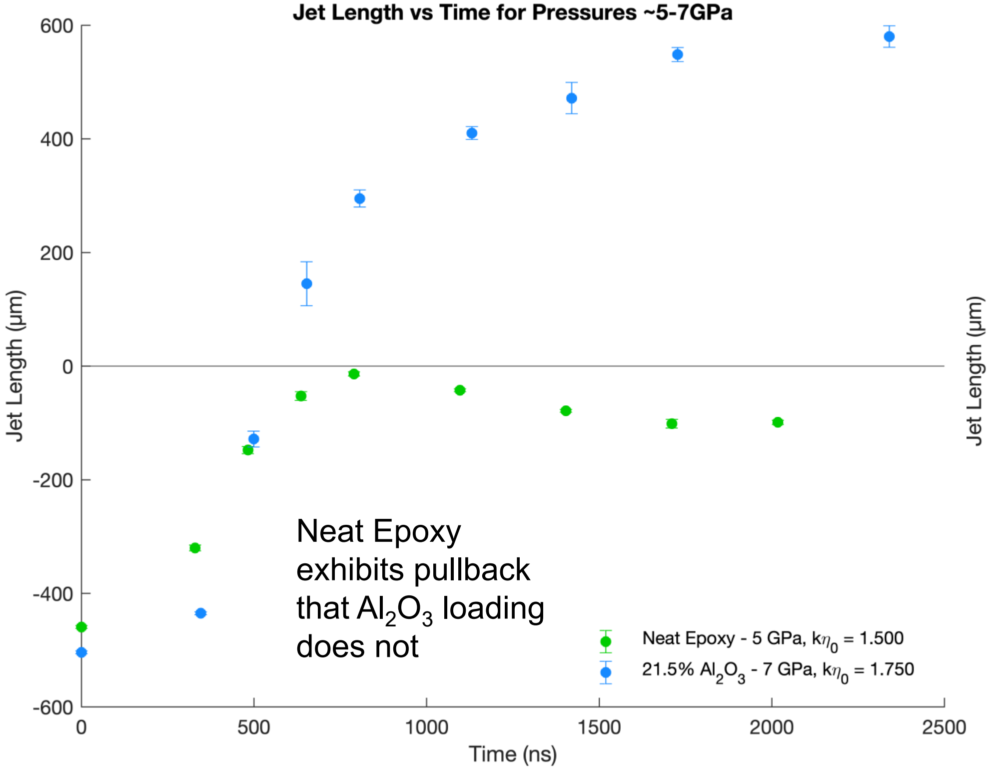
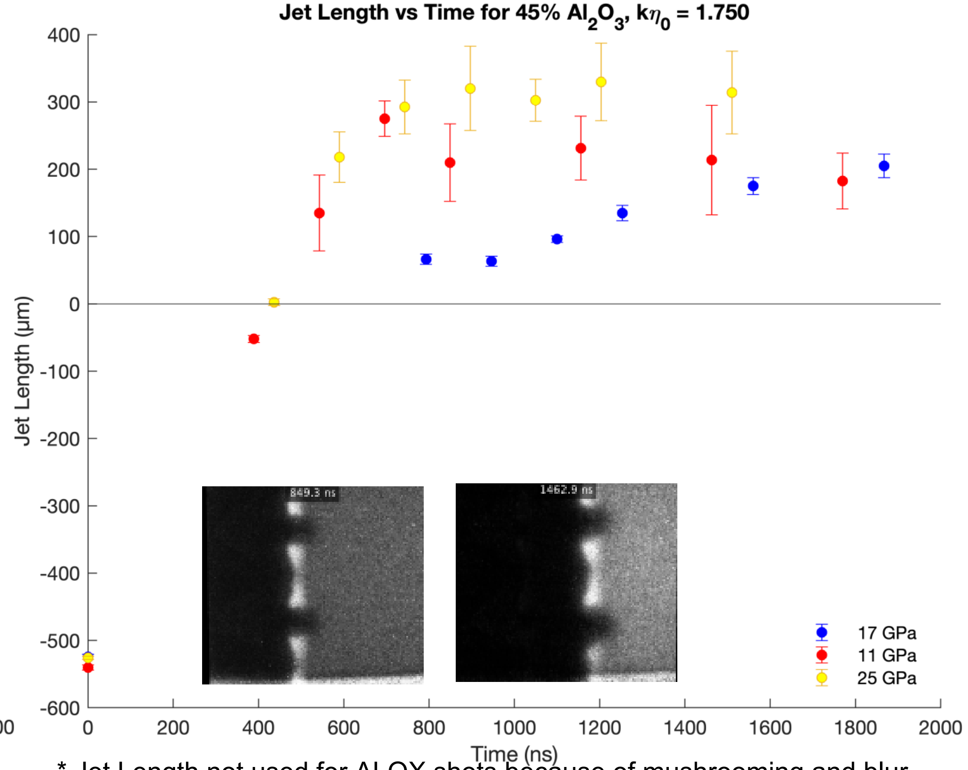


Neat Epoxy exhibits pullback that Al_2O_3 loading does not



* Jet Length not used for ALOX shots because of mushrooming and blur – contour calibration is necessary

*Bars indicate the width of the intensity gradient for the images

Conclusions

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- Conducted 12 RMI experiments with varying Al_2O_3 loading and drive conditions
- Epon828/DEA experiments proved to have unexpected strength causing a sort of “pullback” behavior
    - This pullback behavior has not been seen in previous studies
- Modeling analysis indicates that this behavior due to the strength
- Using a simple strength model does not fully reproduce the experimental data
- Further steps
    - Apply a more complex strength model
    - Calibrate a polymer specific strength model like Mulliken-Boyce
    - Framework to framework solution verification
    - Move on to ALOX strength modeling

DCS Acknowledgement

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Uncertainty Analysis