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The Dynamic Strength Response of Alumina-Epoxy Formulations to Shock Loading

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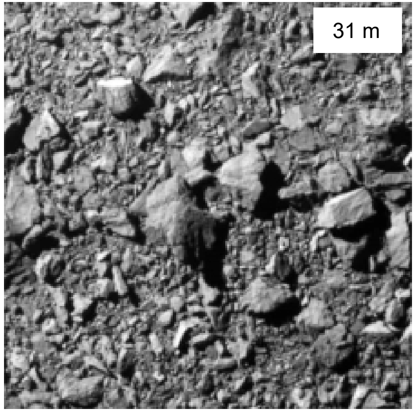
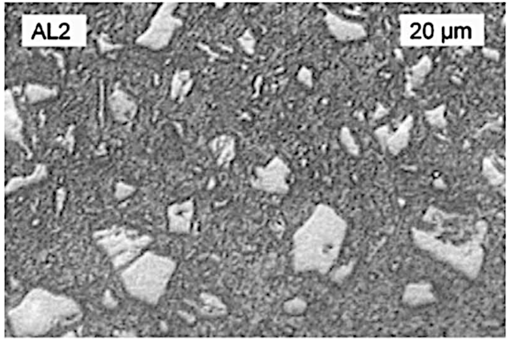
Motivation

Goal: Characterize the mesoscale interaction dynamics of the binder and the particles for composite matrix microstructure materials

- These materials have different applications including
  - Geologic materials
    - Sedimentary rocks
  - Engineered materials
    - Carbon Fiber
- Little work done regarding material response in the shock regime
- A range of behavior occurs for different particle loading densities



Final Image from NASA Dart Mission [NASA/Johns Hopkins APL]



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

Richtmyer-Meshkov Instability (RMI)

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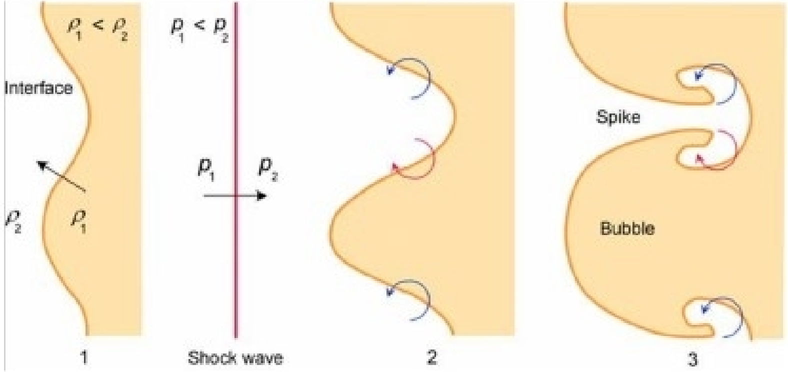
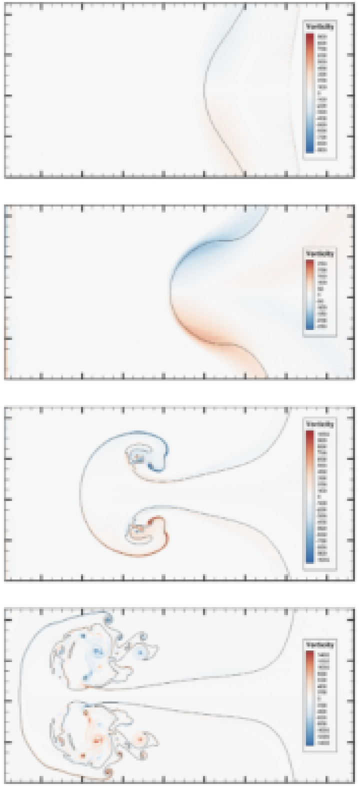
- RMI occurs when two materials of different densities are subjected to shock loading
- Commonly seen in fluids but can also be observed in solid materials
- Perturbation growth can be stalled or arrested through dissipative or restoring forces
  - Material Strength
  - Viscosity
  - Surface Tension
  - Magnetic Fields



[Springer (Shock Waves)]



RM instability between air and SF_6
[Zhou et al (2021)]

Previous Tamped RMI Work

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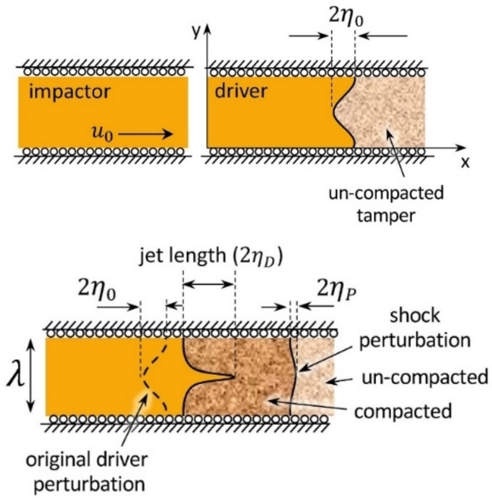
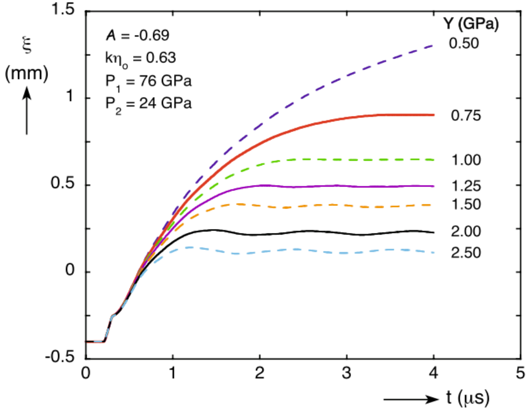
- Investigated the RM instability in porous media such as powders as well as solid materials tamped with liquids
- Used for constitutive model calibration
- Jet length is dependent on material strength
- Experimental behavior is compared to simulations to calibrate the material strength
- RMI inversion 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 $k\eta_0$
    - $k\eta_0 = \frac{2\pi}{\lambda}\eta_0$
  - Pressure



Hudspeth et al (2020)



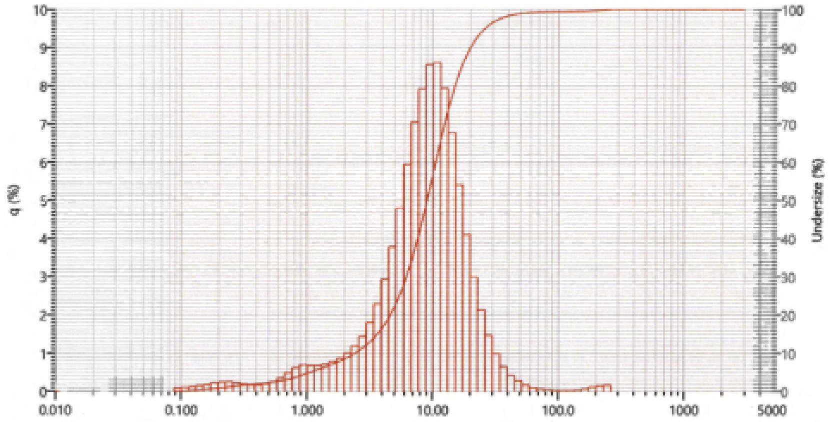
Vogler et al (2021)

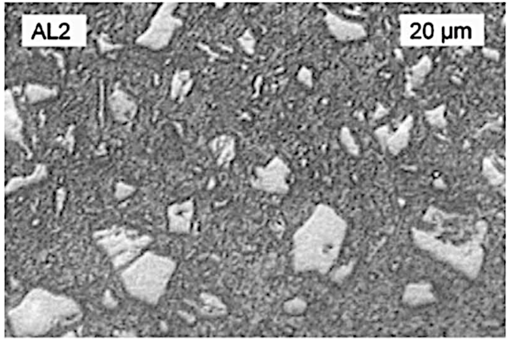
Study Objectives

- Alumina-Epoxy matrix (ALOX)
    - Al_2O_3 Loaded Epoxy
    - Epon828 Resin with DEA as the curing agent was used for the 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 cured with DEA)

- In these experiments, the corrugation aspect ratio $k\eta_0$ and pressure were varied in addition to the volumetric loading to promote jet formation





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

Experimental Details

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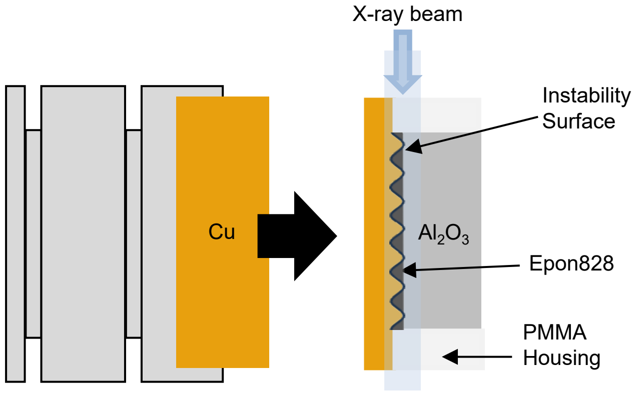

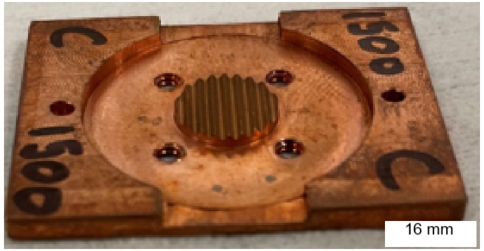

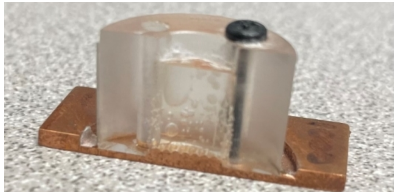

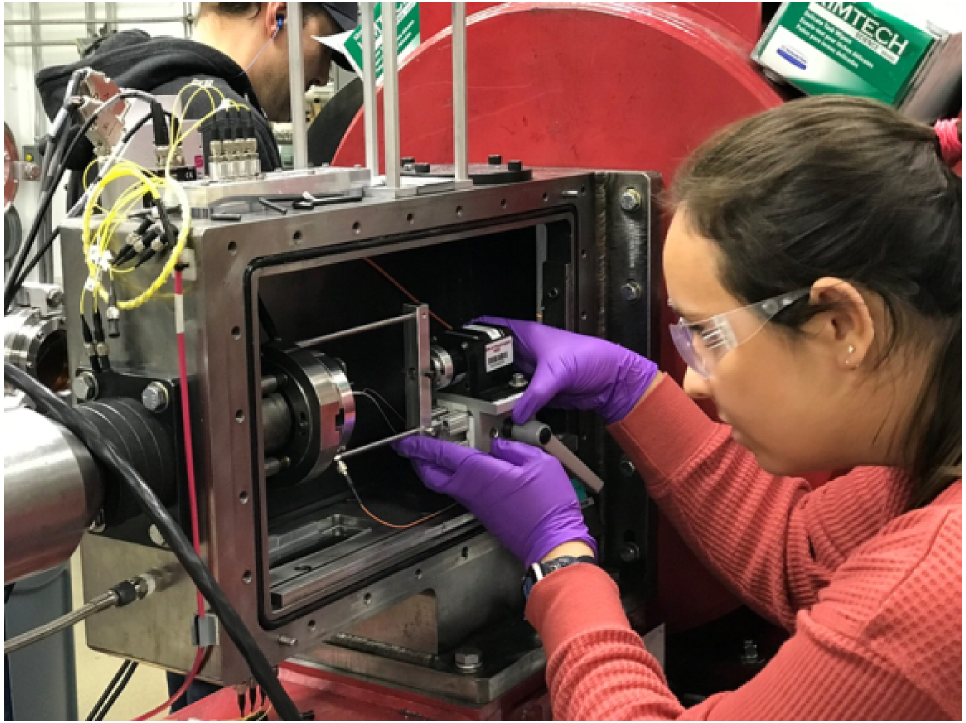

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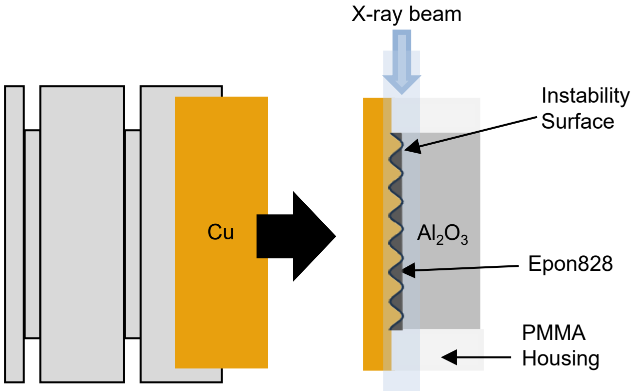
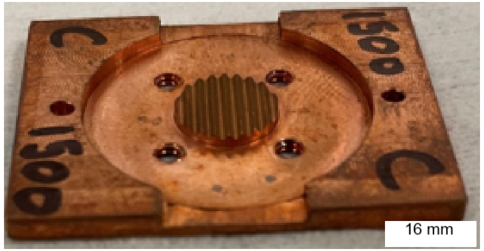
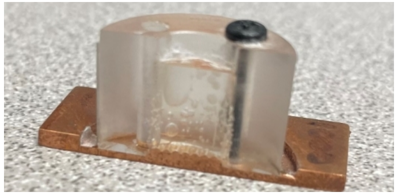
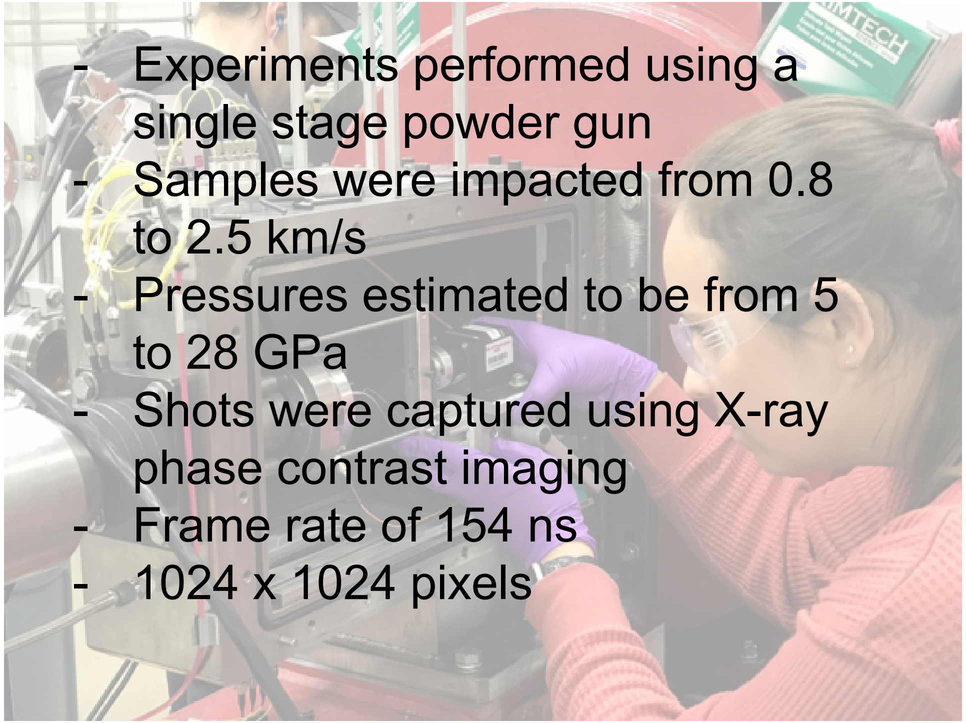


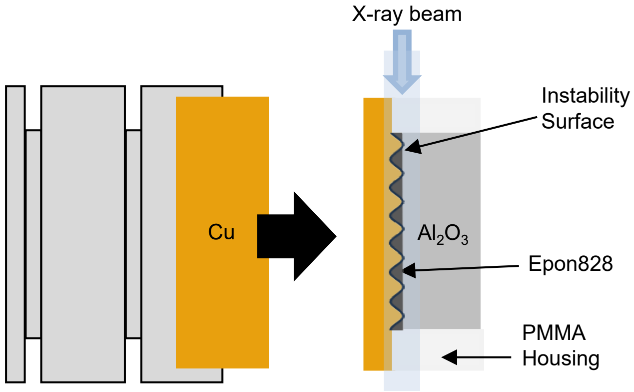


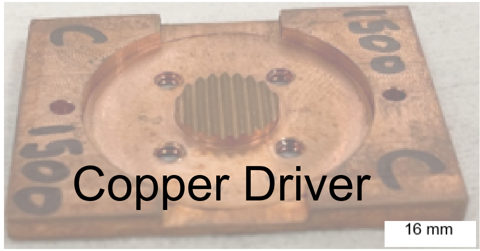


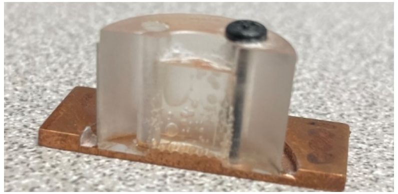


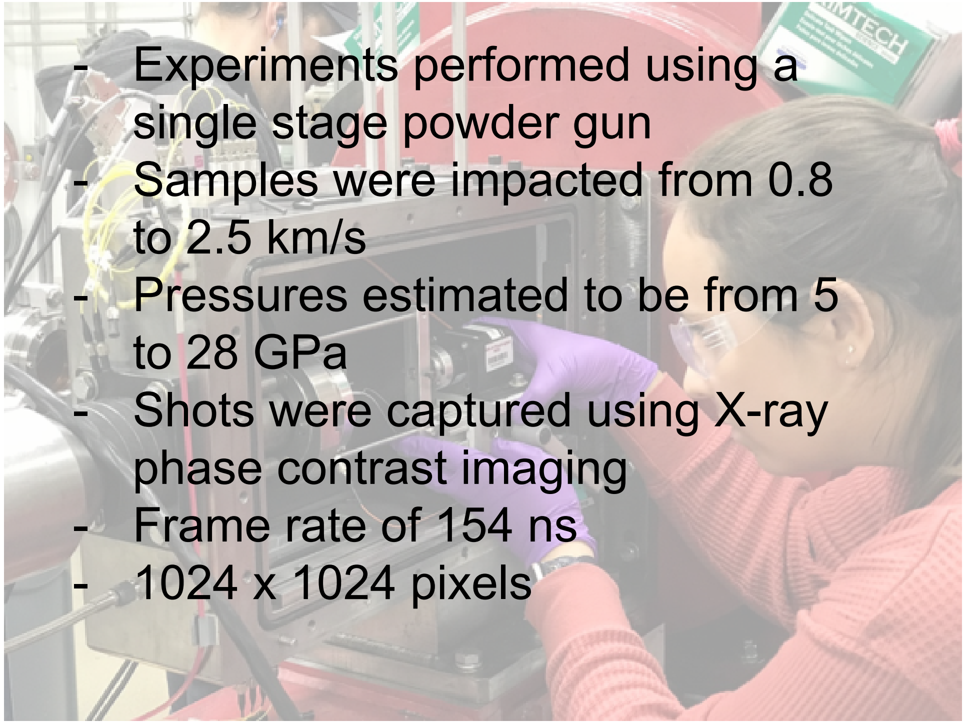
- Experiments performed using a single stage powder gun
- Samples were impacted from 0.8 to 2.5 km/s
- Pressures estimated to be from 5 to 28 GPa
- Shots were captured using X-ray phase contrast imaging
- Frame rate of 154 ns
- 1024 x 1024 pixels

Experimental Details









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Experimental Overview

44% Al_2O_3

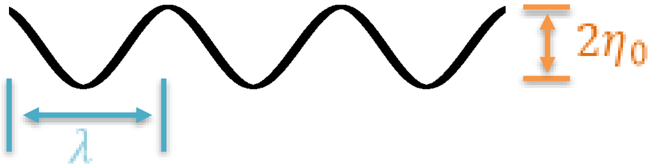
$k\eta_0$	Pressure (GPa)
1.750	6.4
1.750	9.8
1.750	11.1
1.750	17.2
0.750	24.7
1.500	28.1

21.5% Al_2O_3

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

Neat Epon828 Epoxy

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

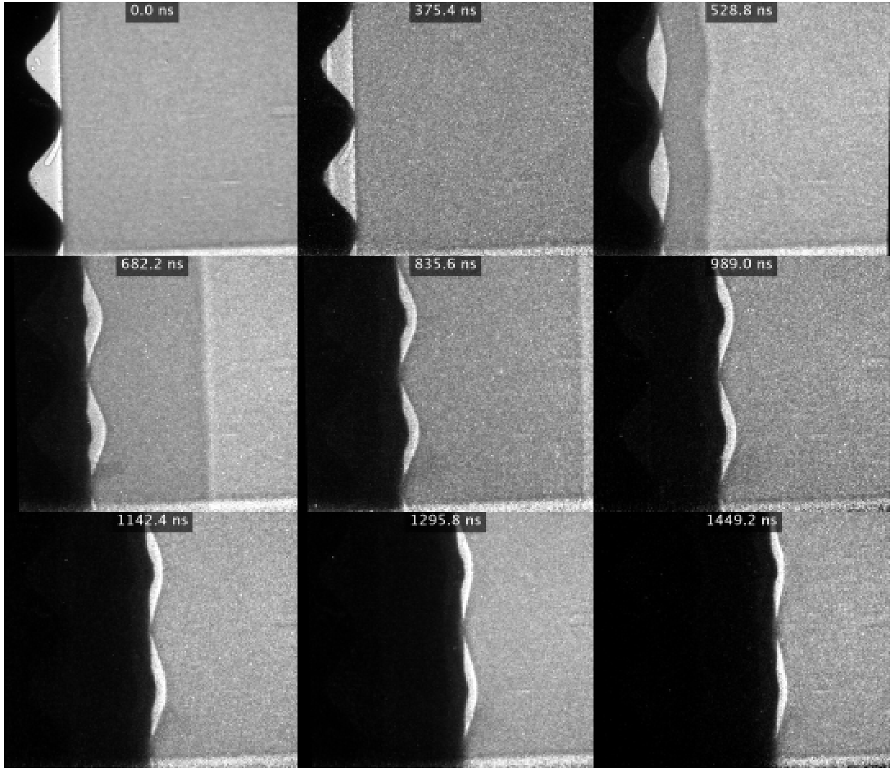


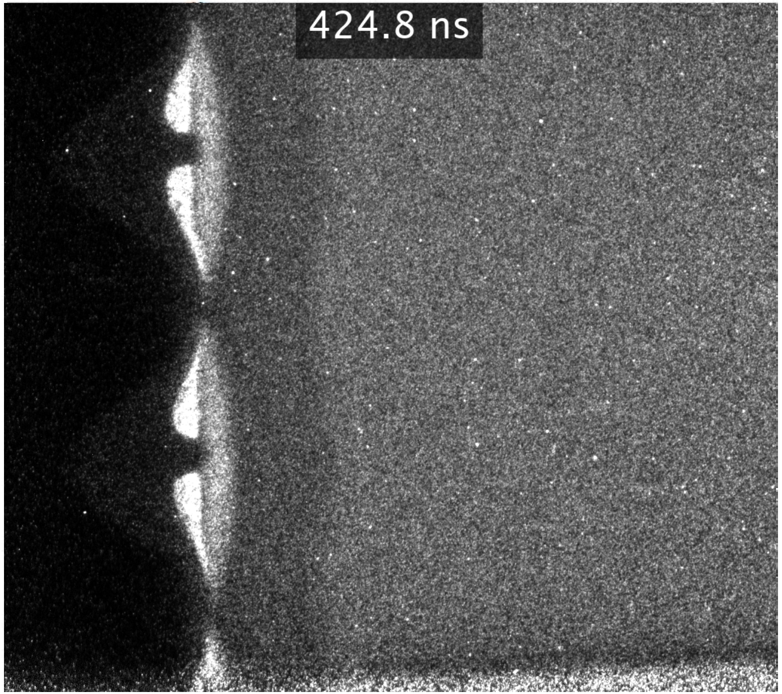
$$k\eta_0 = 2\pi\frac{\eta_0}{\lambda}$$

* Pressure calculated with impedance matching

Experimental Data

21.5% Al_2O_3 encased in Epon828, 11 GPa





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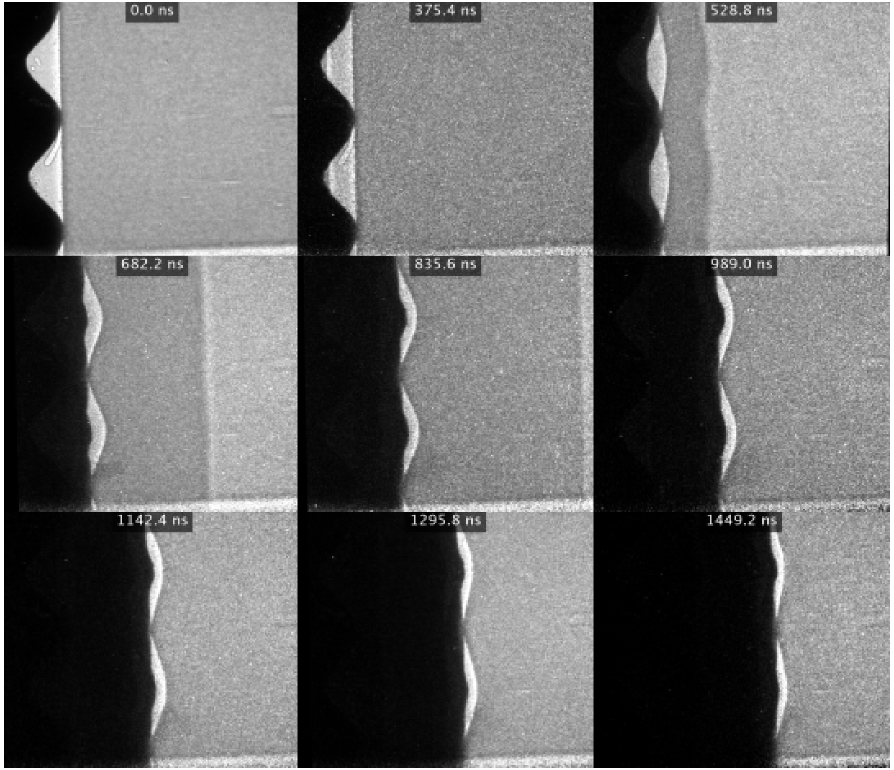

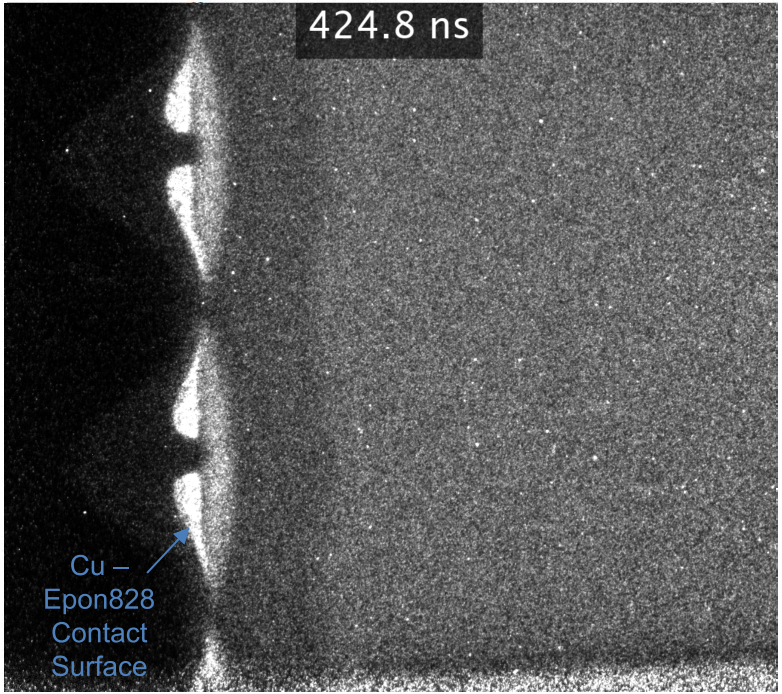

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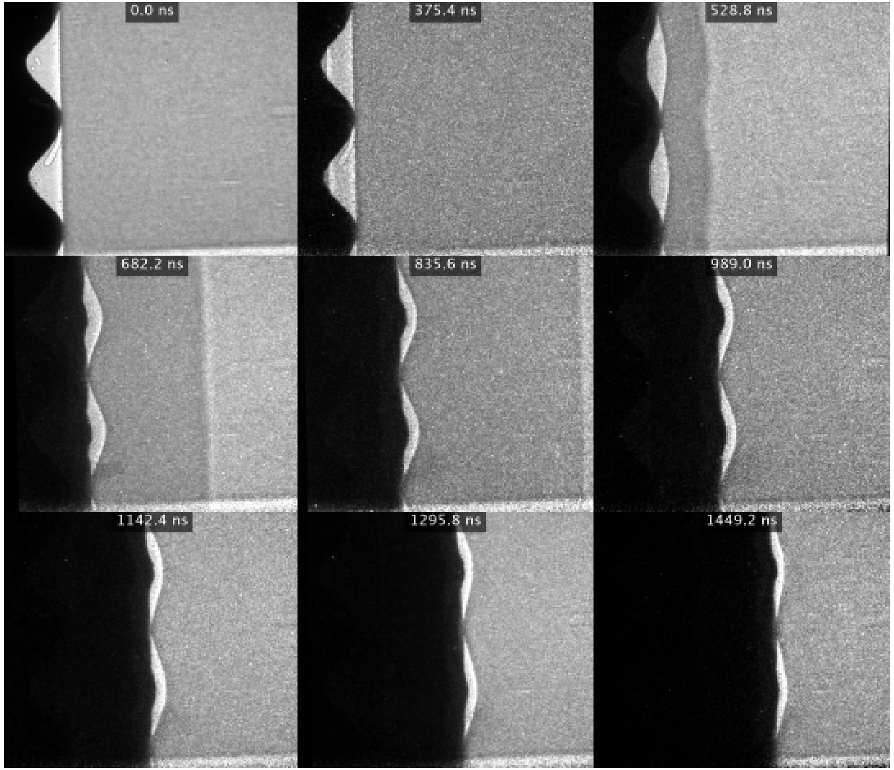

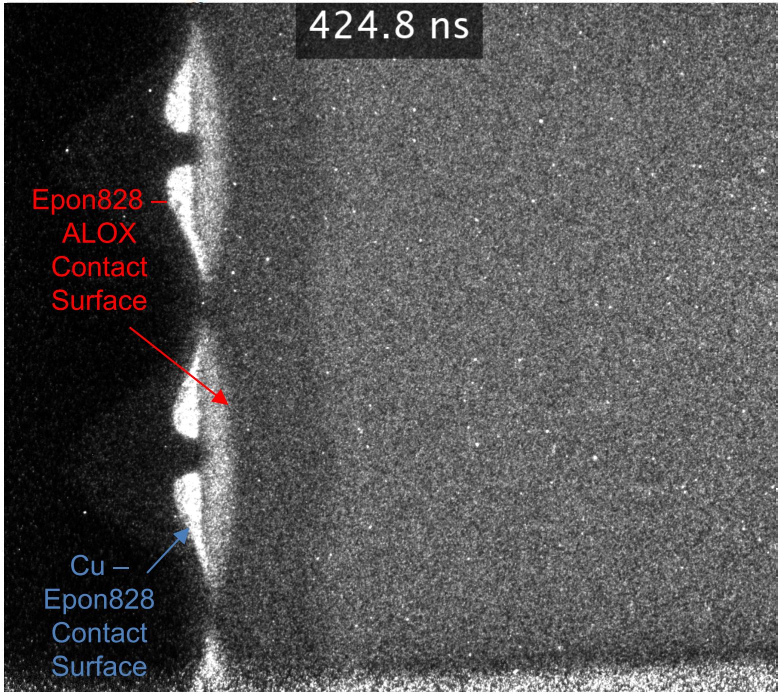

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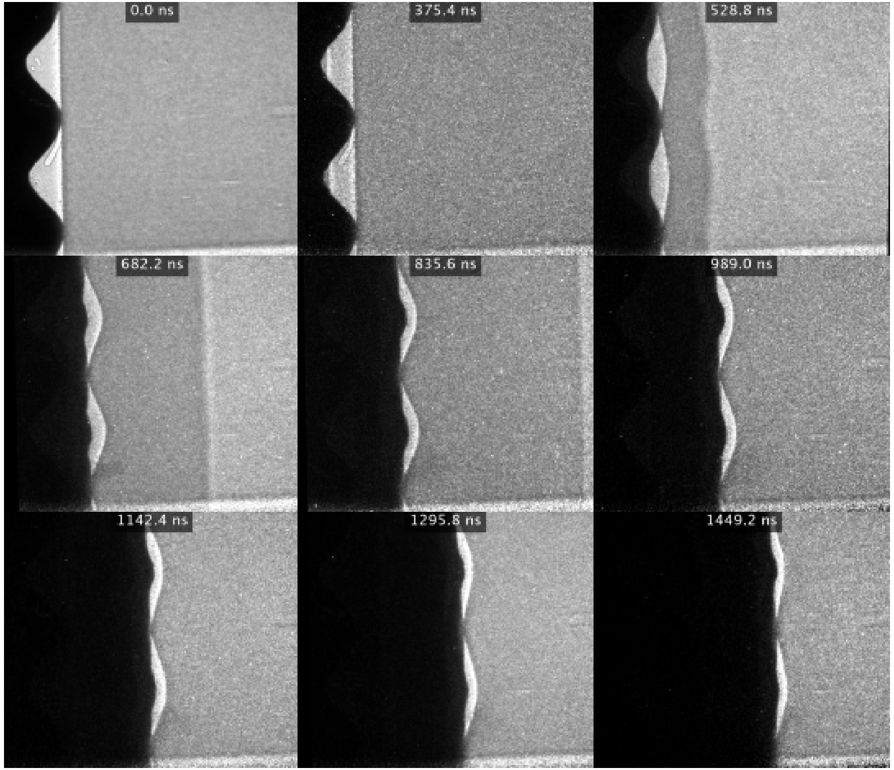

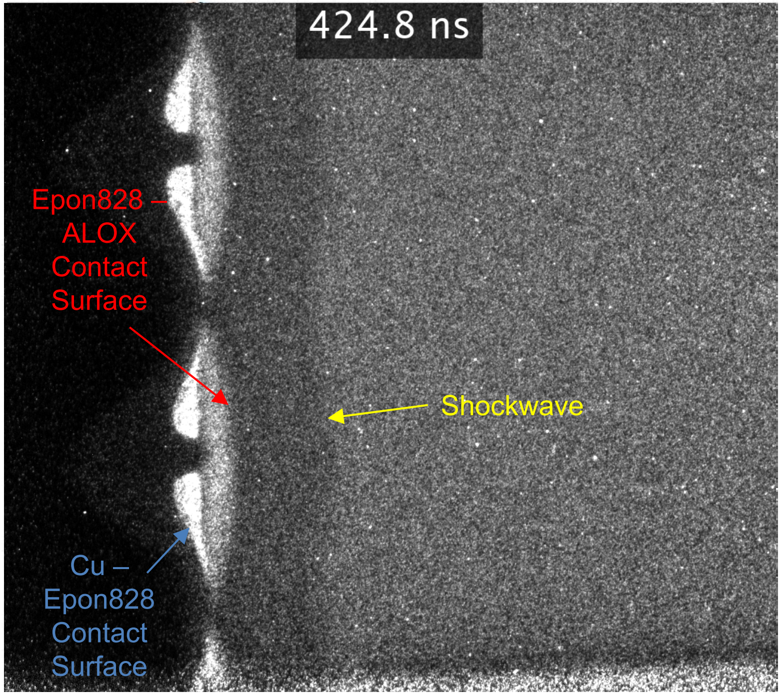

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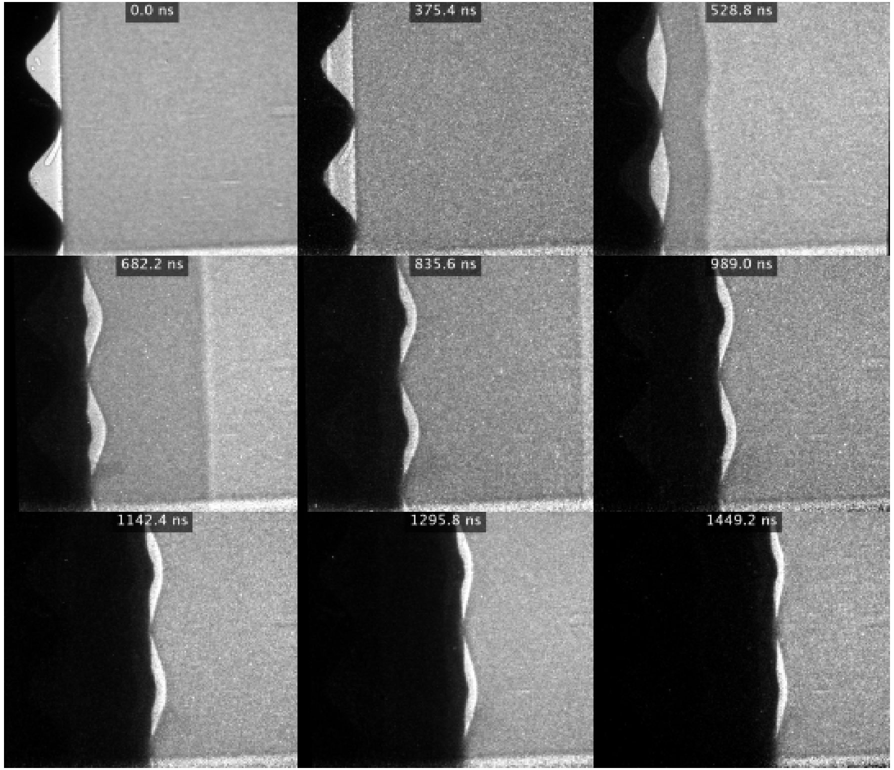

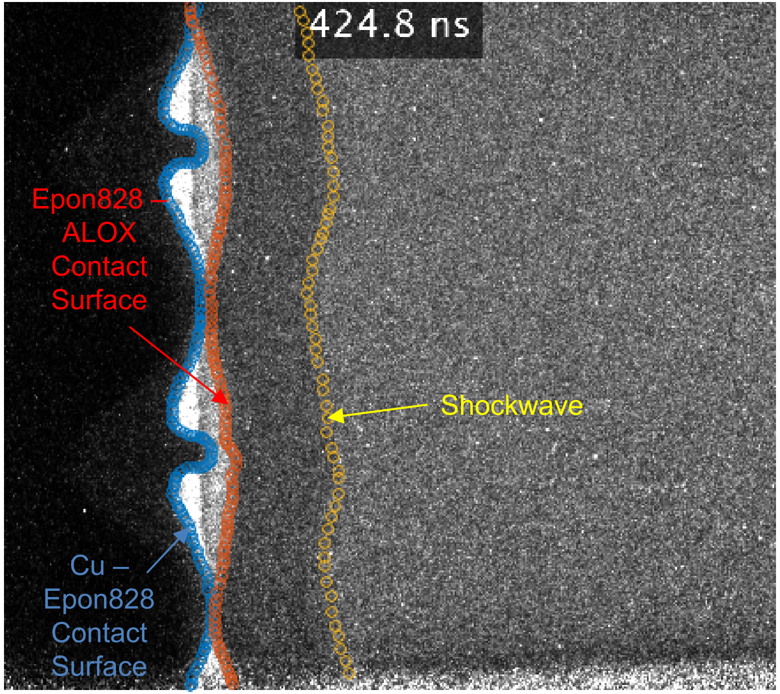

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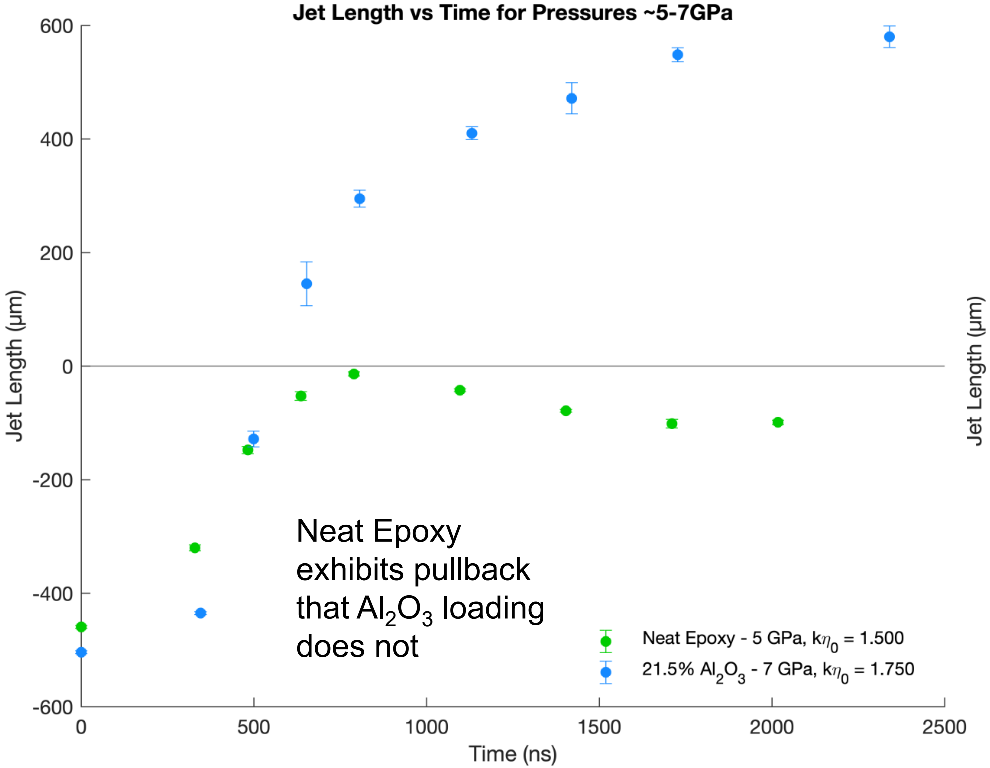
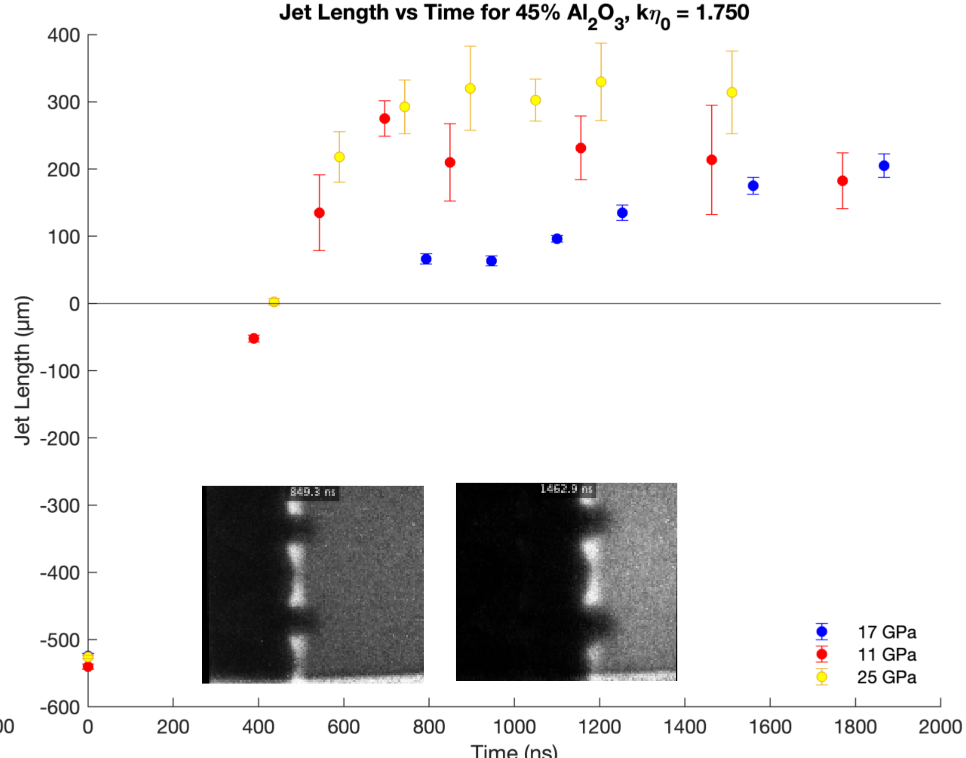
Alumina addition promotes jetting





* 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

Simulations

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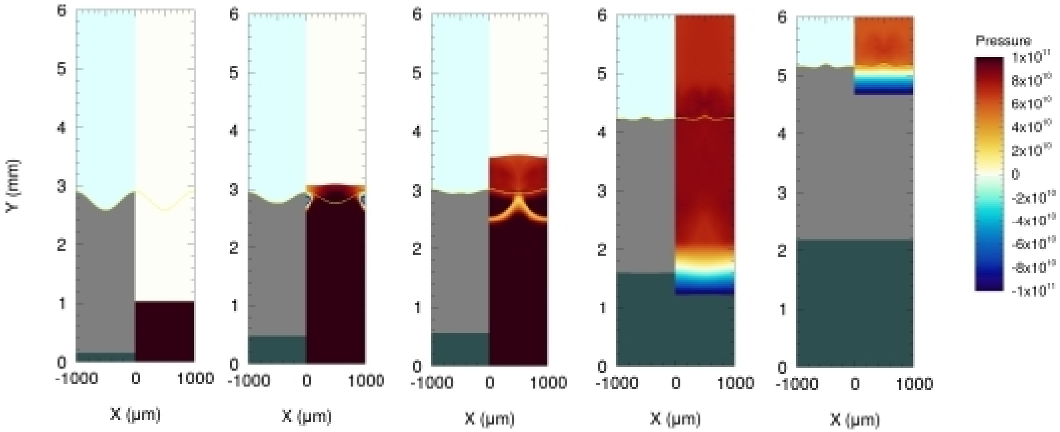
- Simulations were performed using the Eulerian hydrocode CTH
- CTH uses a fixed mesh that allows the material to move through it
- Each experiment is replicated in the simulations with varying the material strength
- Preliminary simulations were run using an elastic perfectly plastic model



Jet Length Reproduced by Simulation Strength is 1.8-2.2

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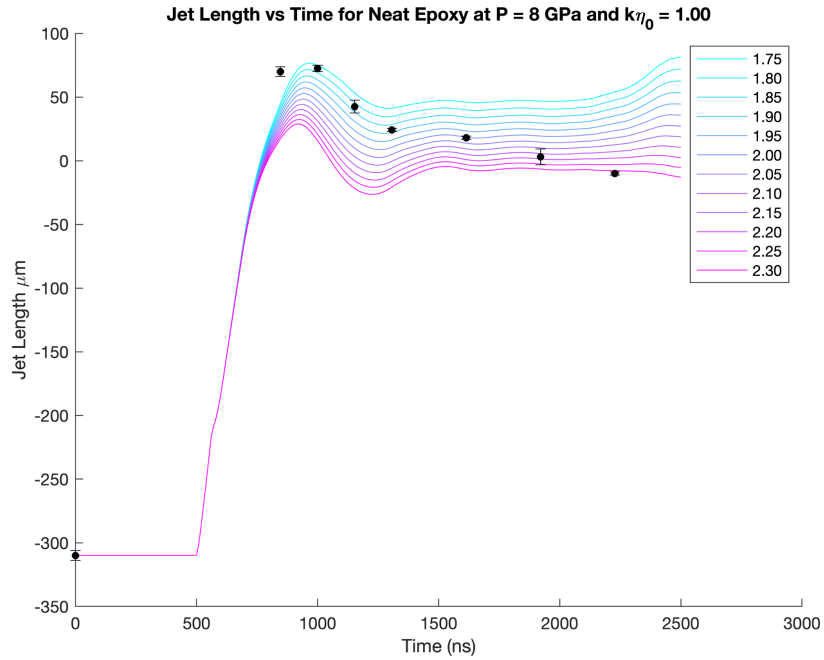
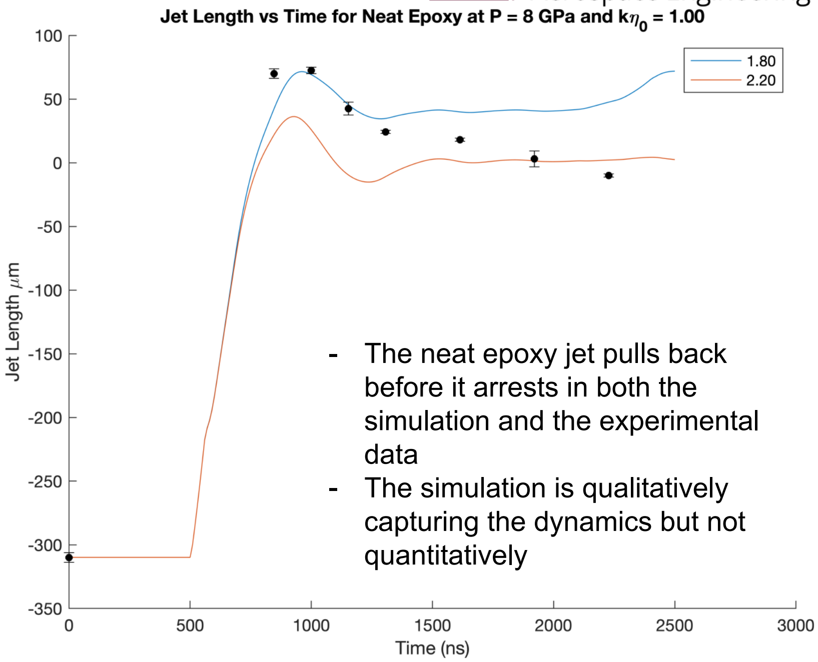
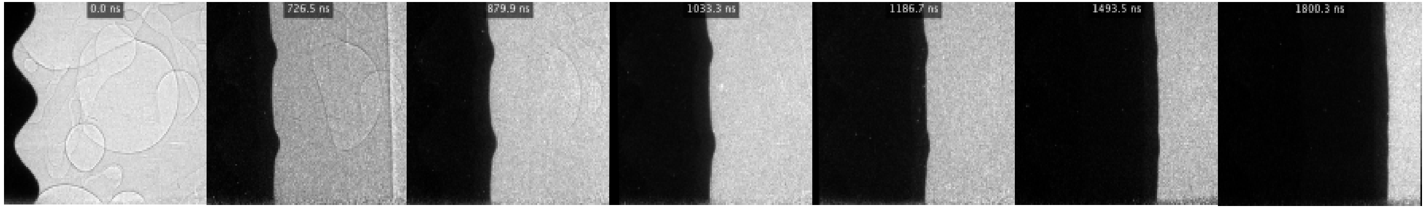




- The neat epoxy jet pulls back before it arrests in both the simulation and the experimental data
- The simulation is qualitatively capturing the dynamics but not quantitatively



Conclusions

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- Conducted 12 RMI experiments with varying Al_2O_3 loading and drive conditions
- Neat Epoxy jet pulls back after initial perturbation, while the ALOX shots do not
    - 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
    - Consider the potential of material decomposition

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