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Characterizing the dynamic strength of a polymer epoxy using the Richtmyer-Meshkov Instability

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The Dynamic Strength of Polymers is not well characterized

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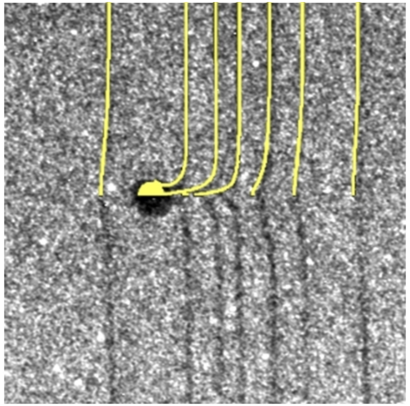
- Little work done regarding strength in the shock regime
- Recent particle tracking experiments performed by Bober et al indicated that silicone has a flow strength of 500 to 750 MPa, stronger than some metals
- Epon 828 Epoxy
  - Has been previously investigated in planar impact experiments
  - Can be polymerized with a variety of curing agents
  - Many shock Hugoniot datasets in the literature fail to list curing agent
  - Often assumed that the Equation-of-State (EOS) is the same regardless of curing agent



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

EPOXY. Epon 828

Average ρ_0 = 1.185 g/cm³.

Sound velocities longitudinal 2.63 km/s.
shear 1.16 km/s.

Reference 51

ρ_0 (g/cm³)	U_s (km/s)	U_p (km/s)	P (GPa)	V (cm³/g)	ρ (g/cm³)	V/Vo	Exp
1.192	2.263	0.000	0.000	.8389	1.192	1.000	ssp ×
1.184	3.285	.370	1.430	.7489	1.335	.887	iml ○
1.184	3.355	.411	1.633	.7411	1.349	.877	iml ○
1.184	3.421	.494	2.001	.7228	1.384	.856	iml ○
1.184	3.805	.639	2.879	.7028	1.423	.832	iml ○

[LASL Marsh Compendium]

Pressure and Strain Rate Hardening

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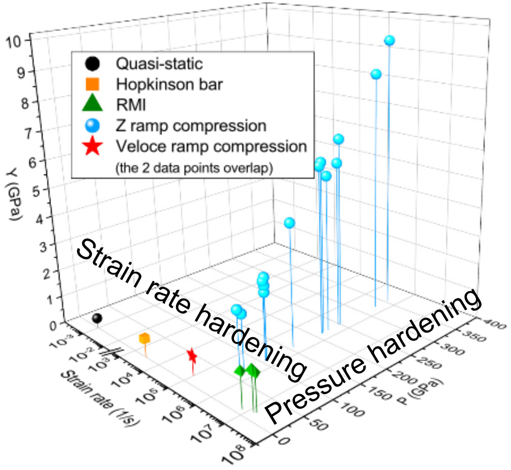
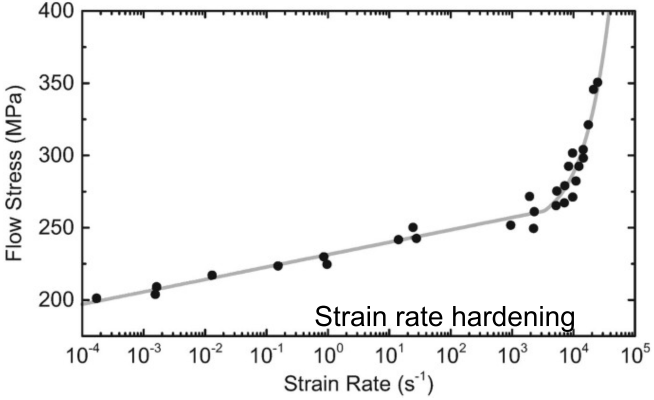
Tantalum



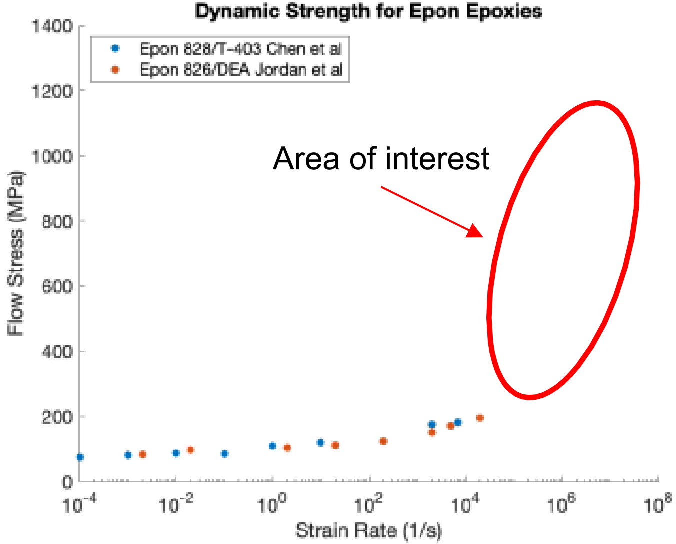
Prime et al (2019)

Copper



Lea and Walley [High Strain Rate Metal Plasticity]

Epoxy



Tamped Richtmyer-Meshkov Instability (RMI) Experiments

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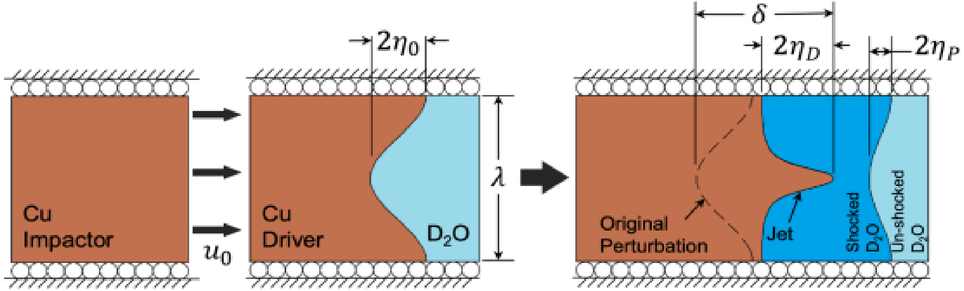
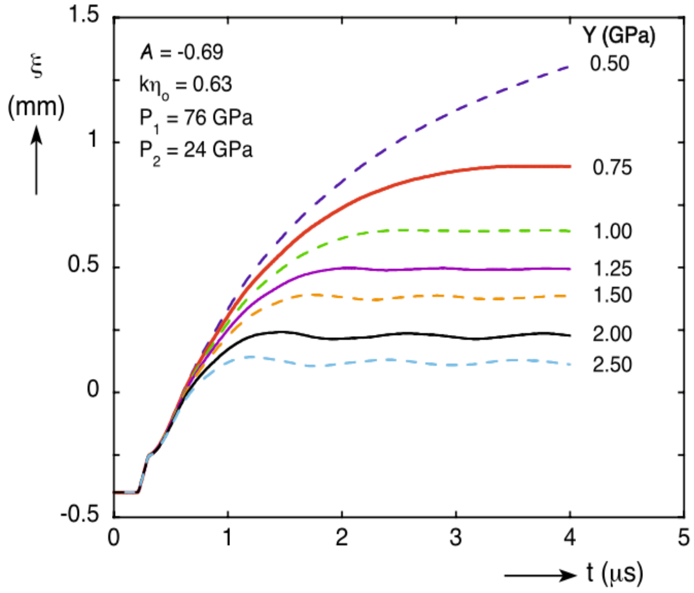
- Used for constitutive model calibration
- Experimental behavior is compared to simulations to calibrate the material strength
- RMI inversion behavior is affected by
  - Driver strength, Y_p
  - Tamper strength, Y_T
  - Shock stress, σ
  - Atwood Number, $A = \frac{\rho_T - \rho_D}{\rho_T + \rho_D}$
  - Corrugation aspect ratio $k\eta_0$

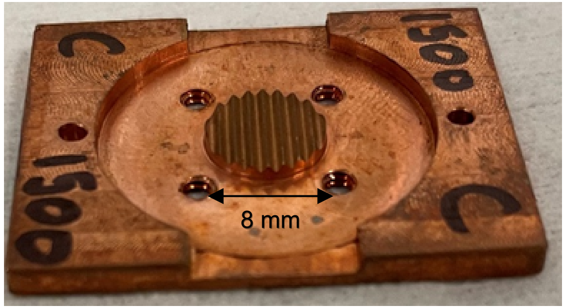


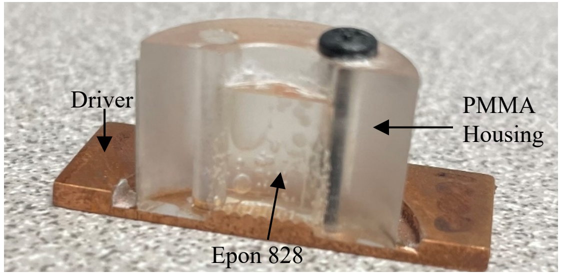
Olles et al (2021)

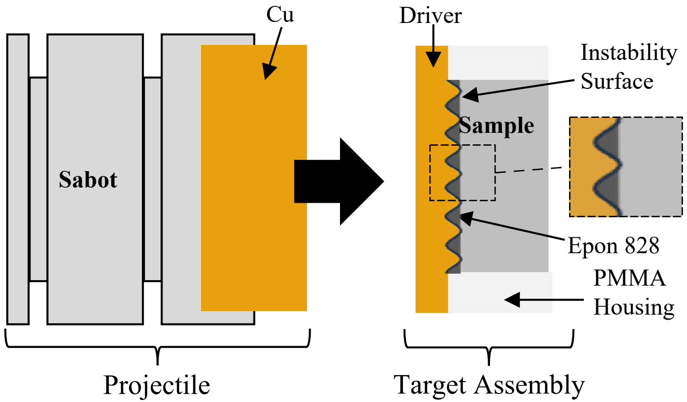


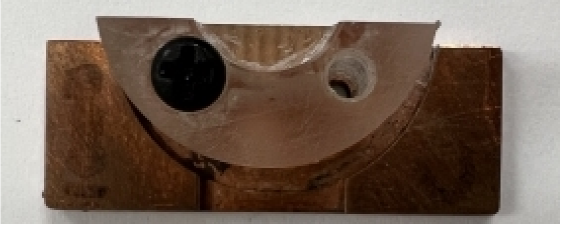
Vogler et al (2021)

Experimental Details and Setup









Evaluating Radiography Data

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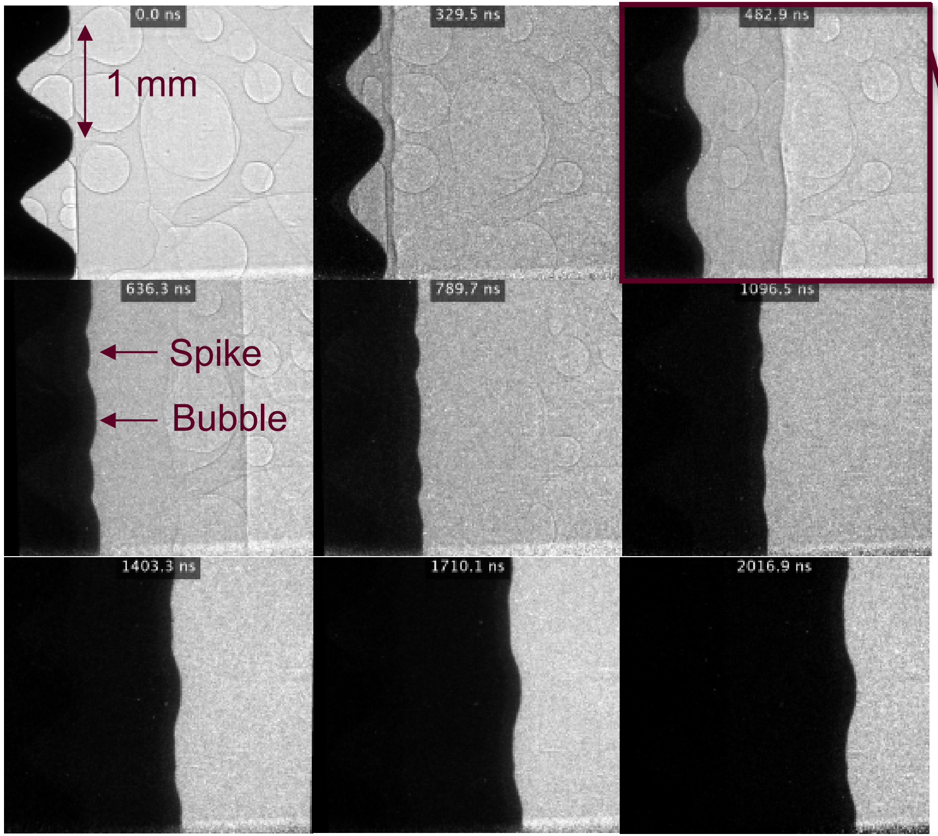

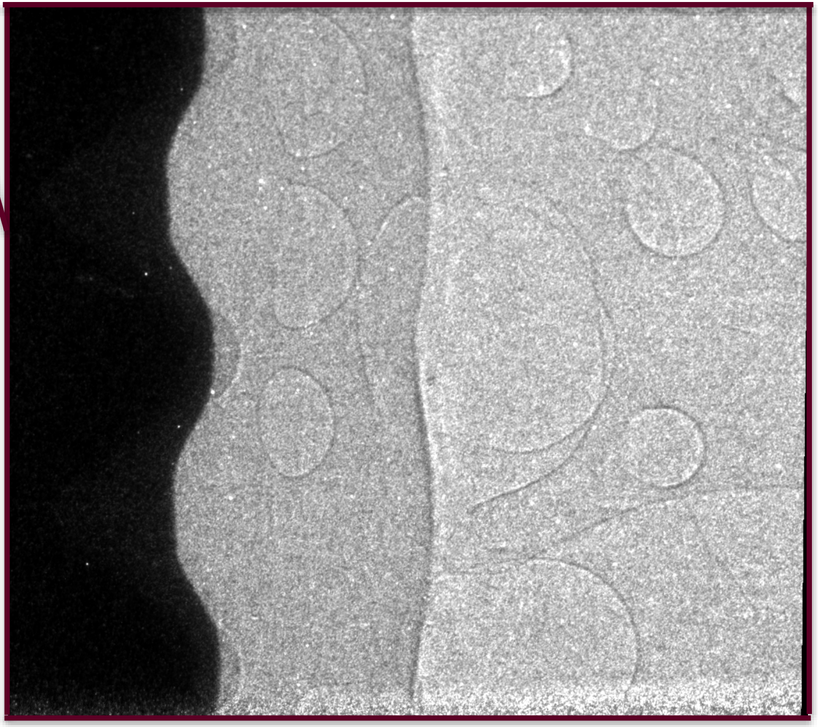

Impacted at 1.2 km/s and 5 GPa

Evaluating Radiography Data

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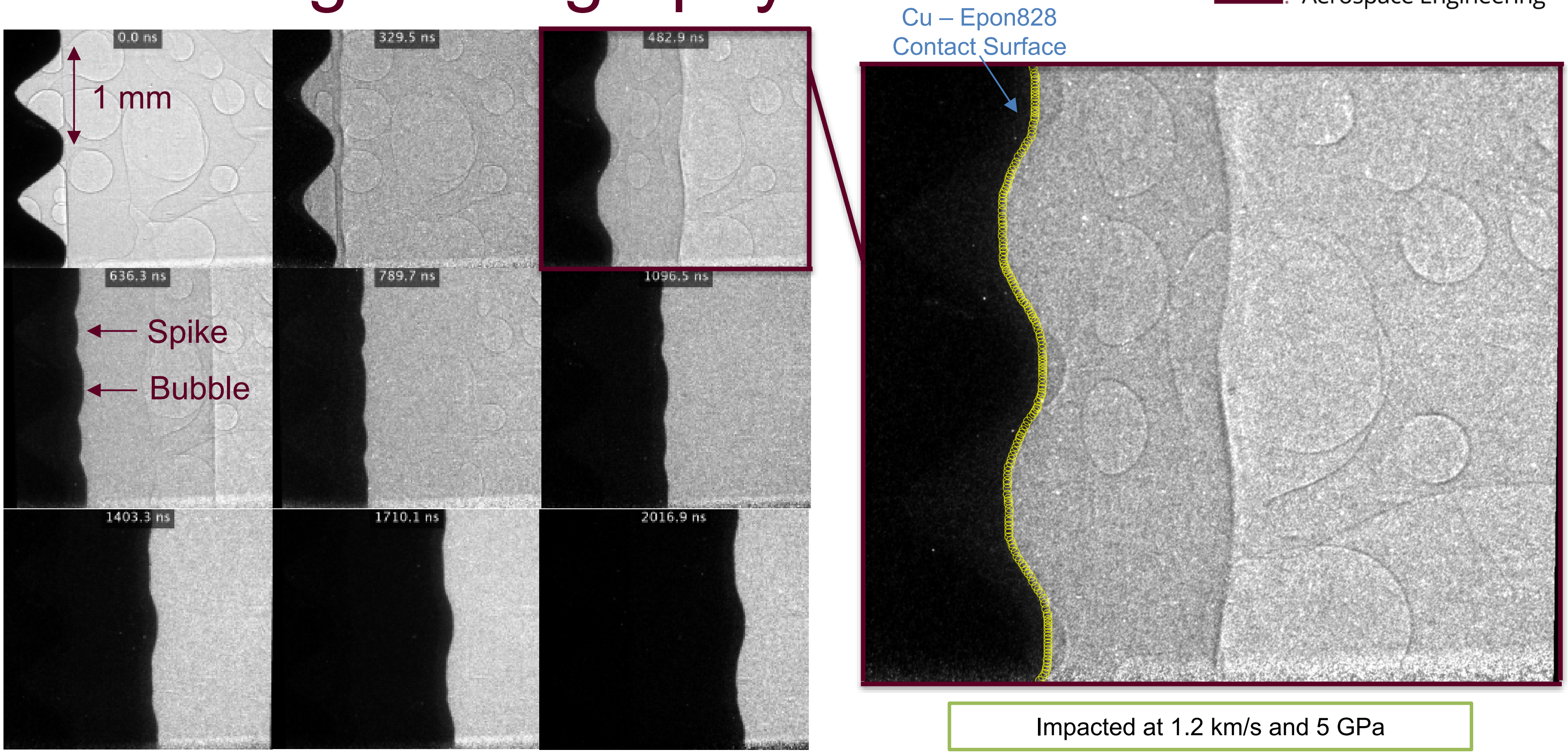

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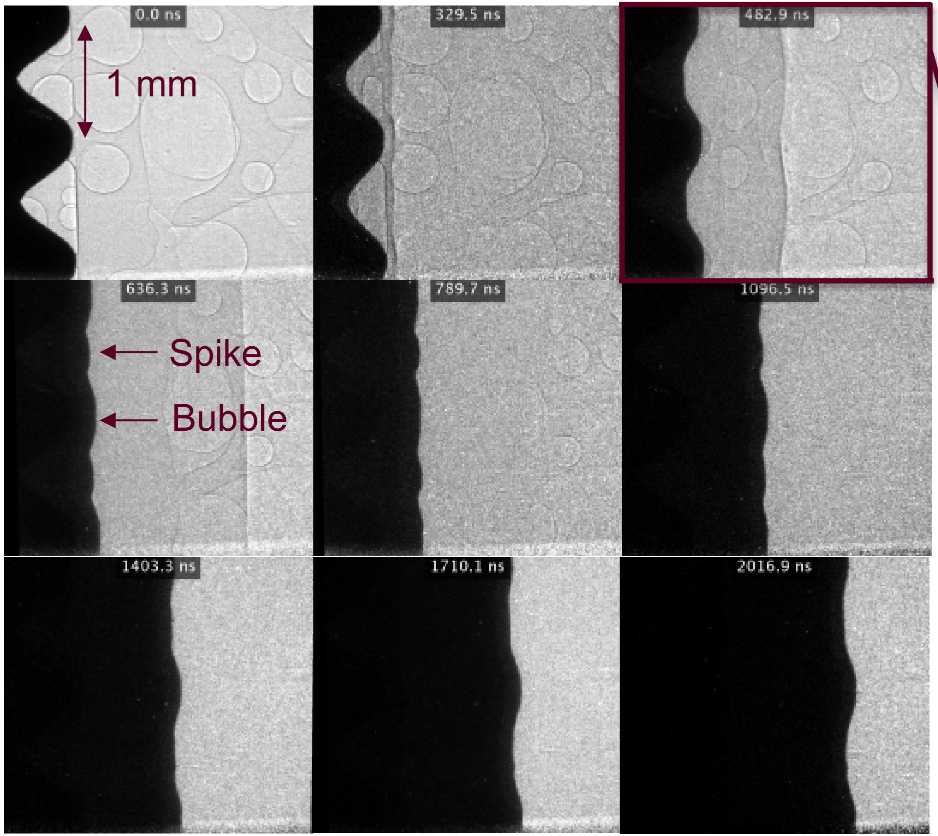
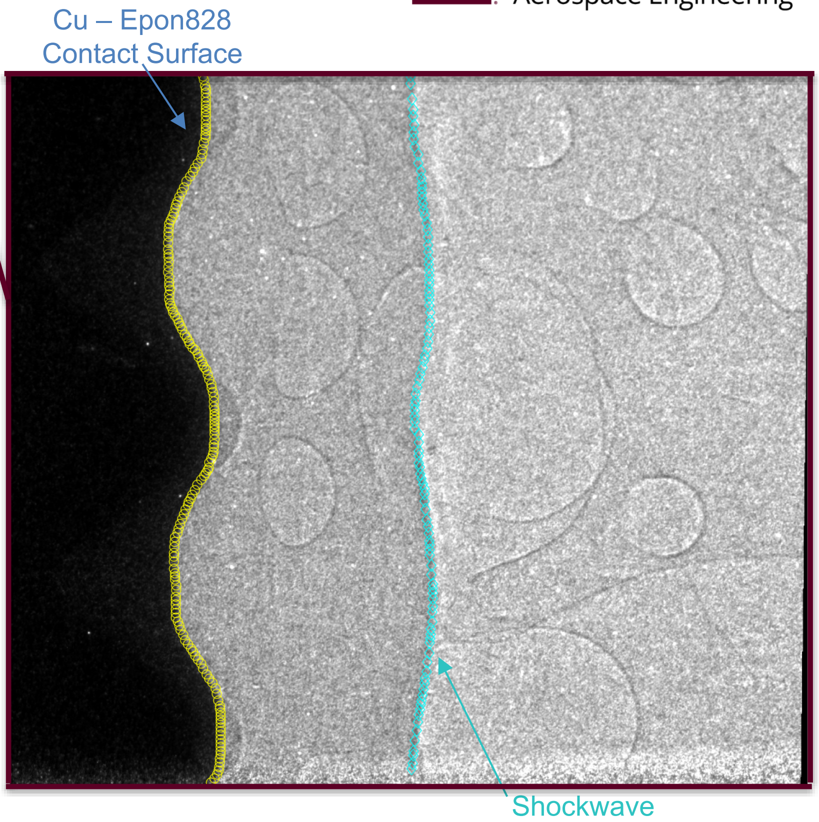
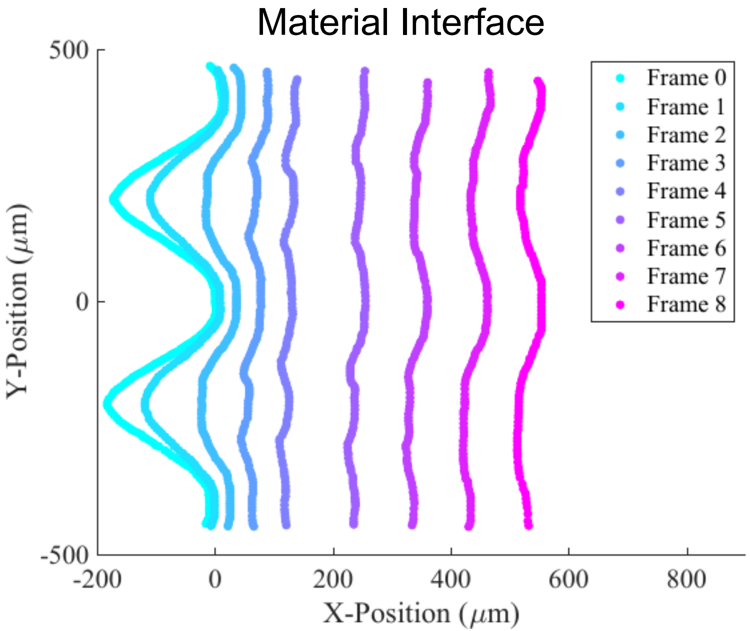


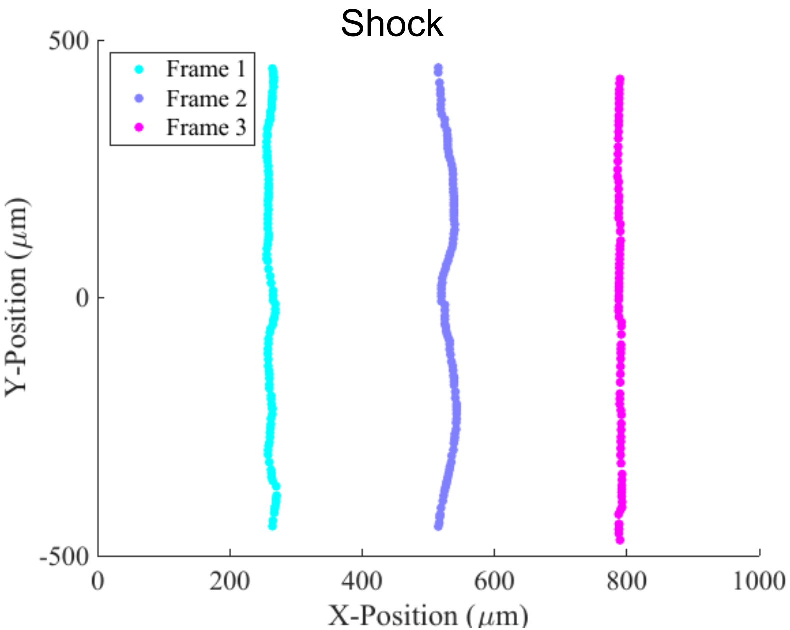


Impacted at 1.2 km/s and 5 GPa

Extracted Contours

- Contour locations can be used for three evaluations:
  1. Obtaining particle velocities (u_p)
  2. Obtaining shock velocities (U_s)
  3. Obtaining shock compressed density
  4. Comparing experiment to simulation in time to find the dynamic strength of a material





Relating Experiment to Simulation

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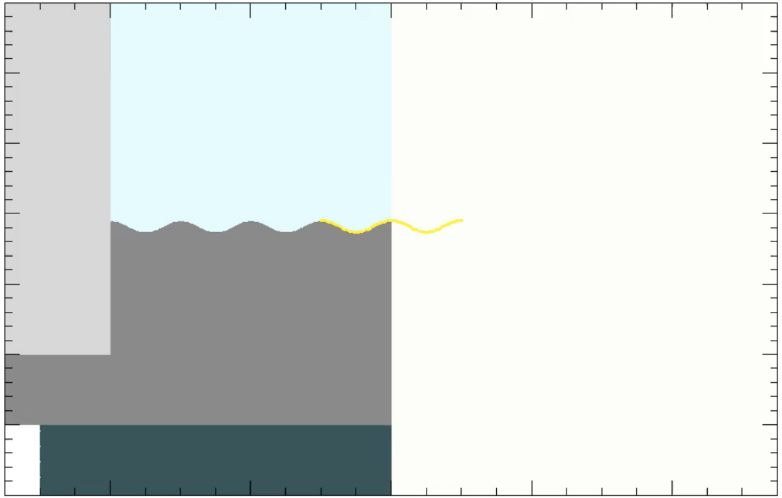
- Two material specific properties that need to be accurately represented
  - Equation-of-State (EOS)
    - Mie-Grüneisen
  - Strength Model
    - Elastic Perfectly-Plastic
- These are typically done using two separate types of experiments



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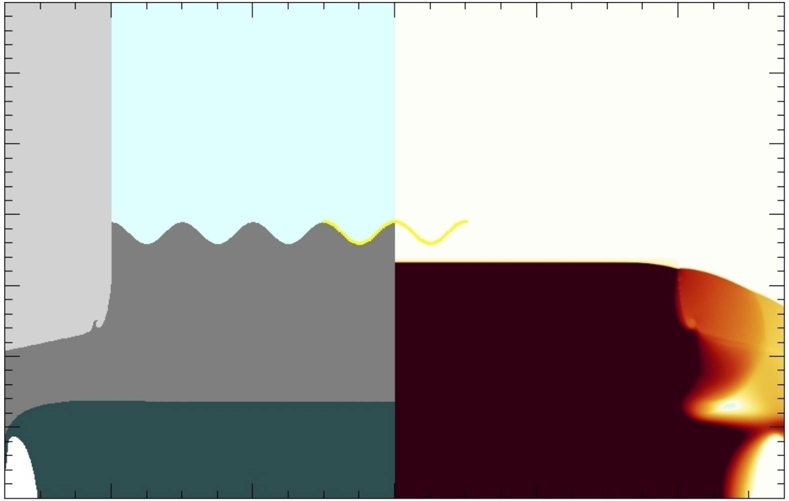

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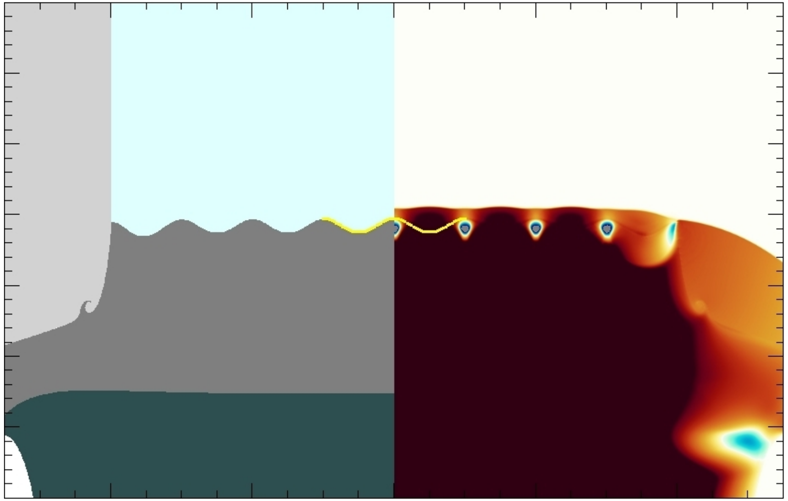

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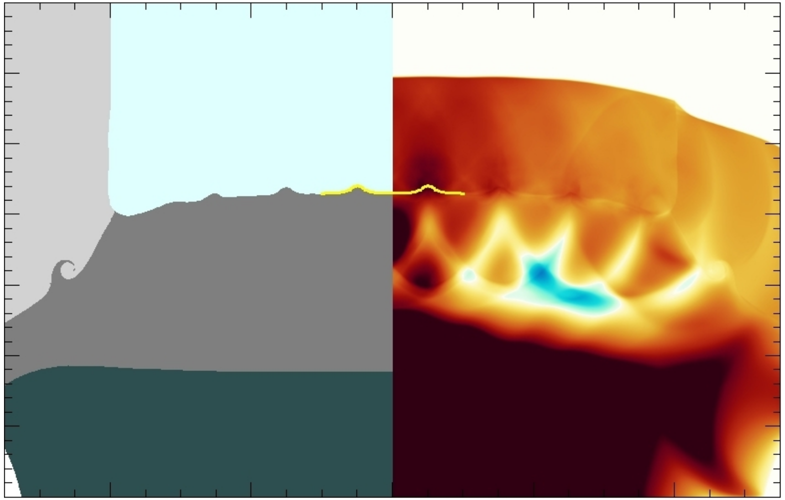

Calibrating an Equation-of-State (EOS) from U_s-u_p Data

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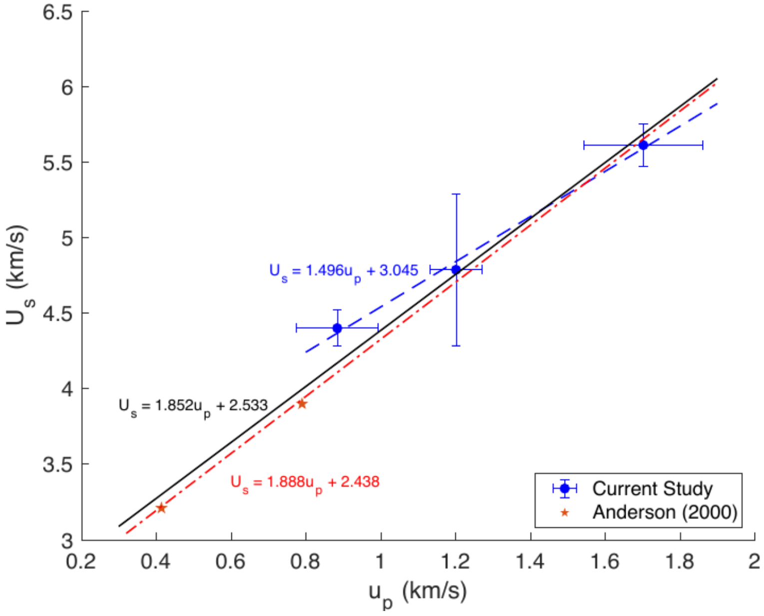
- U_s-u_p data tends to form a linear trend that can be approximated by the equation
  - $U_s = c_0 + s u_p$
  - c_0 is a sound speed-like quantity in the material
  - s is the slope
- Using prior literature data from Anderson (2000) in addition to the data gathered from this study, three possible U_s-u_p relationships were determined



$U_s = 1.852u_p + 2.533$ Fit with all data

$U_s = 1.888u_p + 2.438$ Fit with one point filtered out

$U_s = 1.496u_p + 3.045$ Fit on RMI data alone

EOS calibrated to RMI datapoints best reproduces Anderson (2002) data

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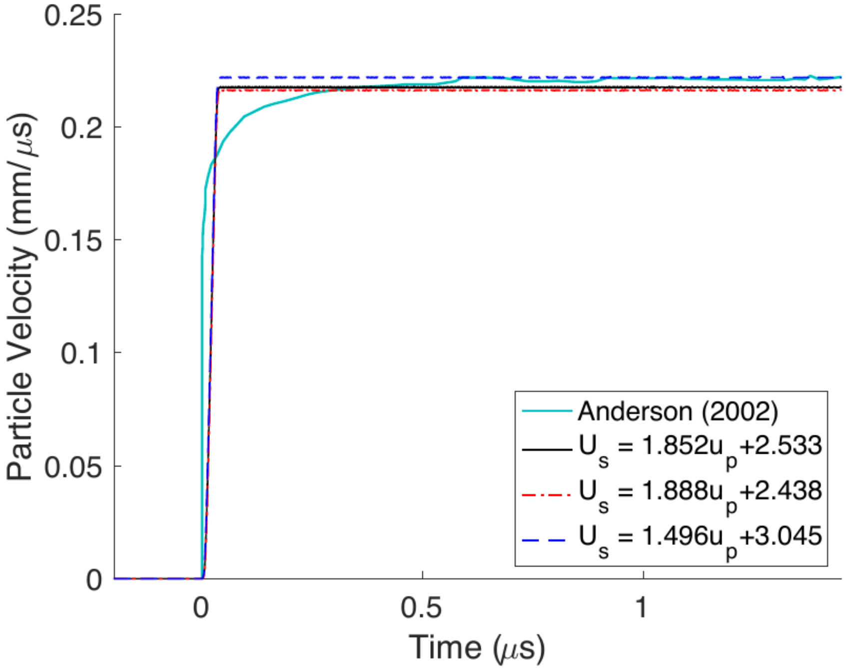

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- Simulation performed under hydrostatic conditions
- Matched the shock behavior with a 0.48% difference between simulation and experiment

Calibrating dynamic strength

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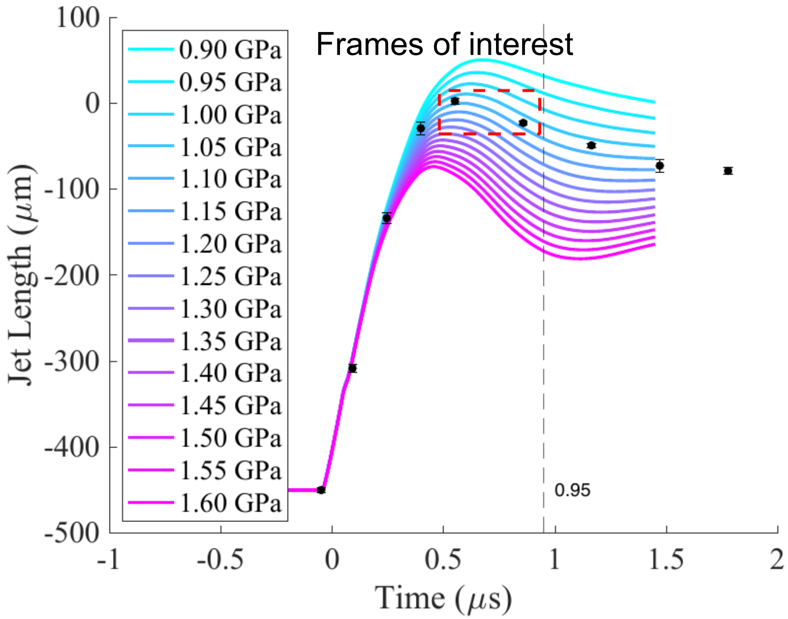

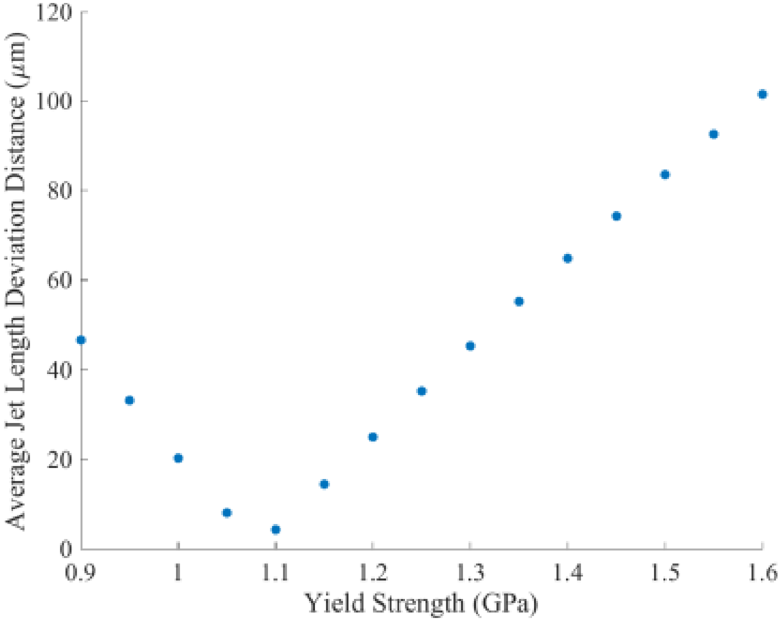

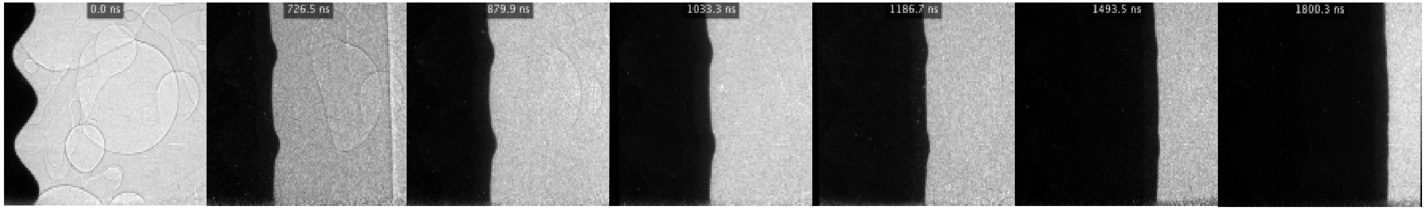

Loading Conditions

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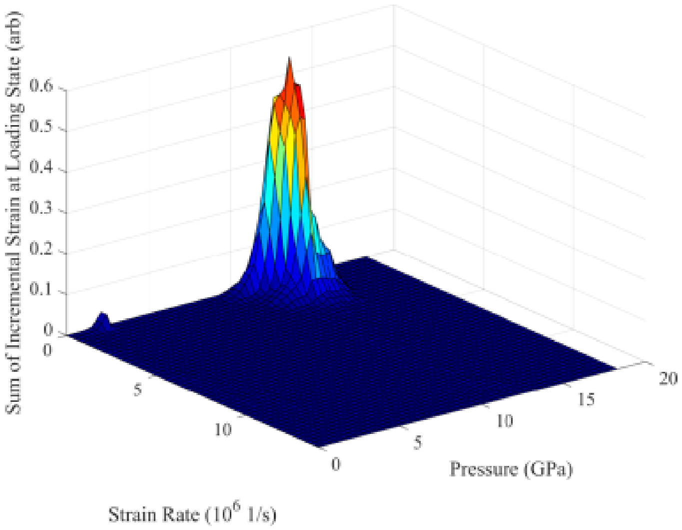

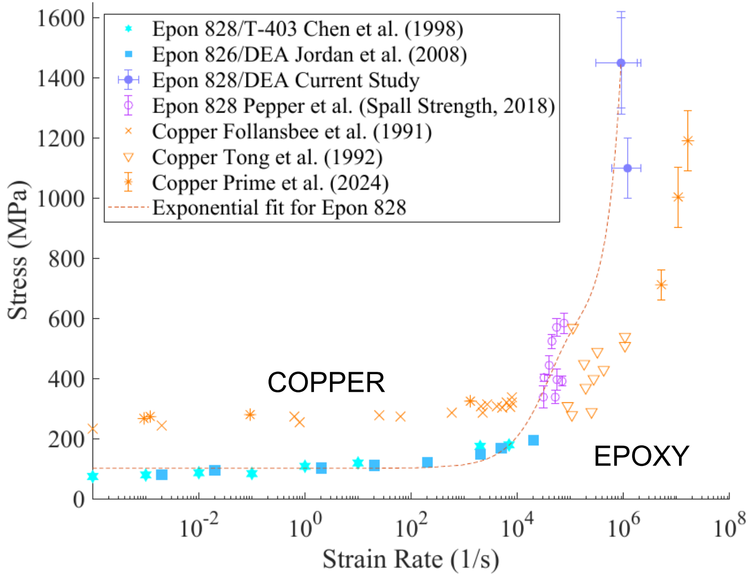

Test ID	Dynamic Strength (GPa)	Temperature (^{o}C)	Pressure (GPa)	Strain Rate (10^6 1/s)	Plastic Strain
23-4-013	1.10 ± 0.10	233.7 ± 55.7	5.40 ± 1.20	$1.20^{+0.90}_{-0.60}$	Peak: 0.005 Centroid: 0.269
23-4-007	1.45 ± 0.15	345 ± 55.7	8.40 ± 0.90	$0.90^{+1.20}_{-0.60}$	Peak: 0.00 Centroid: 0.285
23-4-015	1.45 ± 0.17	484.4 ± 13.9	12.6 ± 0.9	$0.90^{+0.9}_{-0.6}$	Peak: 0.00 Centroid: 0.421

Conclusions

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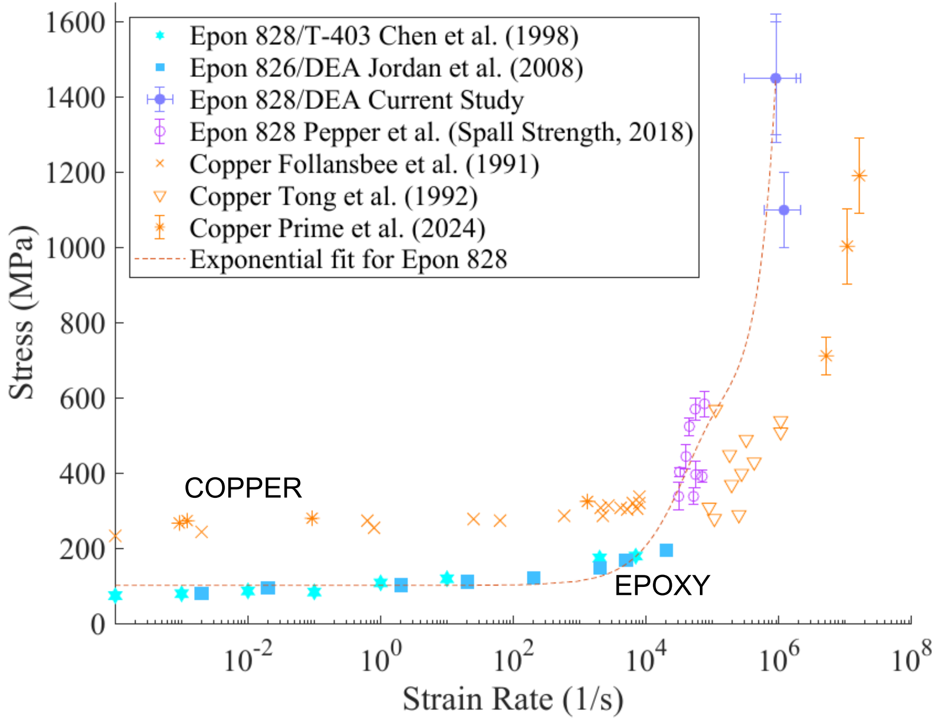
- Epon 828/DEA can exhibit dynamic strengths around 1.5 GPa at strain rates of 10^6 1/s which is higher than copper and comparable to high strength metals such as tool steel
- Showed a method for calibrating both the EOS and the dynamic strength off of a single type of experiment
    - This method eliminates the need for two separate types of experiments
- Contributed to the available Hugoniot data for Epon 828/DEA
- Presented a validated EOS in the 4-12 GPa Hugoniot stress range



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Thank you!

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