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Sandia National Laboratories

Investigating Process-Structure-Property Relations of Shock Loaded Wrought and Additively Manufactured 304L Stainless Steel

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STAR
Shock Thermodynamics Applied Research

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Org. 1647 – Solid Dynamic Experiments

Shock Thermodynamics Applied Research Facility - (STAR)

U.S. DEPARTMENT OF ENERGY NNSA

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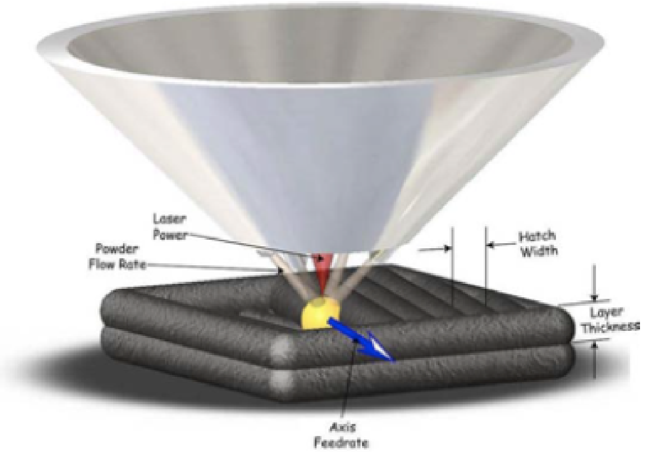
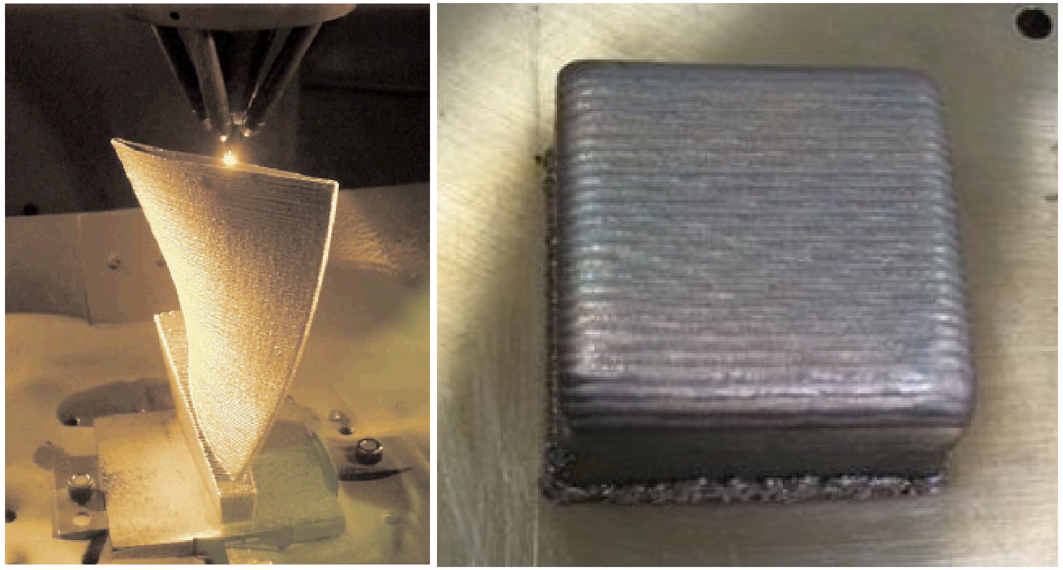
Overview

- 304L stainless steel (SS304L) is a prevalent material in engineering designs.
- LENS™ technique can be used to additively manufacture SS304L.
- SNL has interest in studying AM SS304L for high strain rate applications.
- Thrust to compare AM with a wrought baseline.



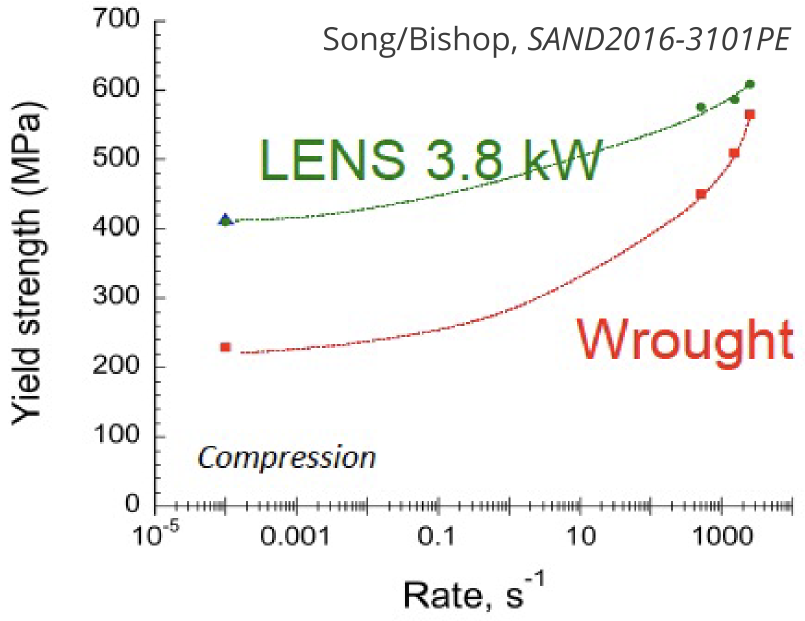


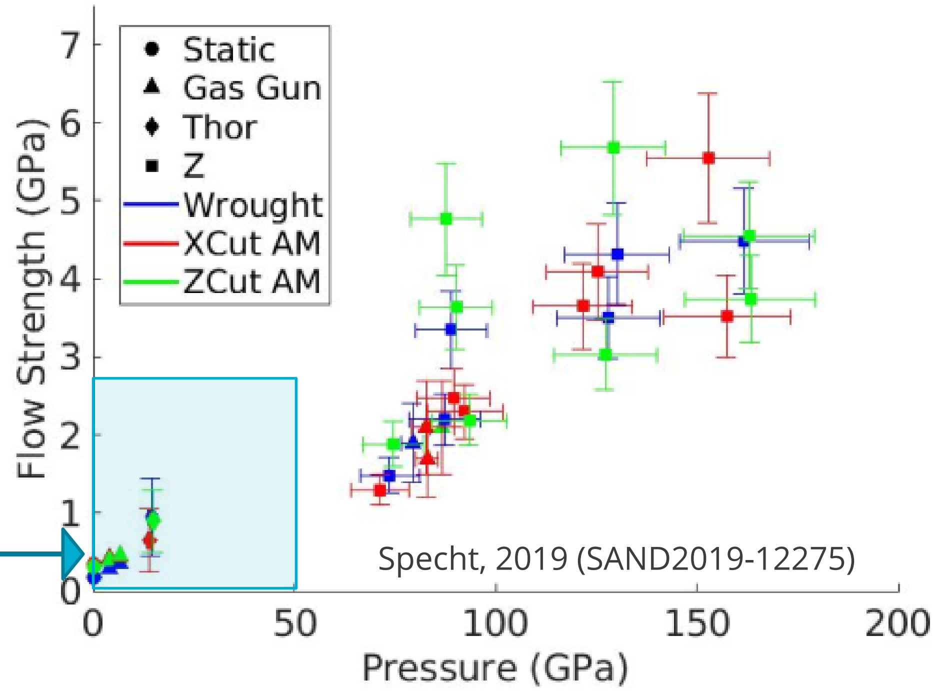
B. Reedlunn, D. Adams, J. Carroll, *SAND 2015-5097C*

- <u>Objective of this work:</u>
  - Perform comparative high-strain rate studies to identify similarities and differences in the compressive dynamic properties.

Motivation: Previous Works

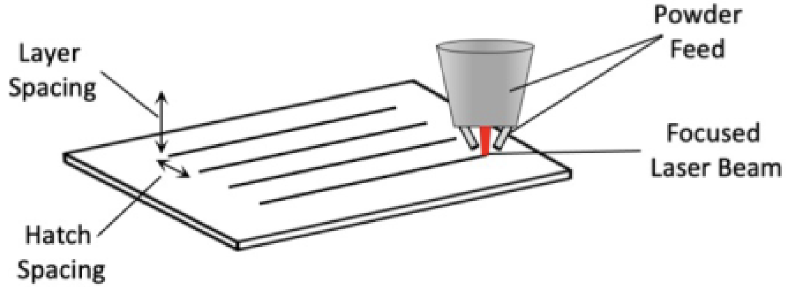
- AM SS304L vs. wrought baseline.
  - Decades of strain-rates
  - Tensile & compressive strength
- Differences in yield strength of sample variants at low to moderate strain-rates.
- Agreement in flow strength between sample variants at pressures >50 GPa .
- Further characterization is needed between pressures of 0-50 GPa.



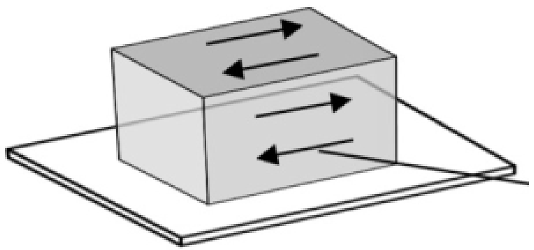


Material: SS304L

Process

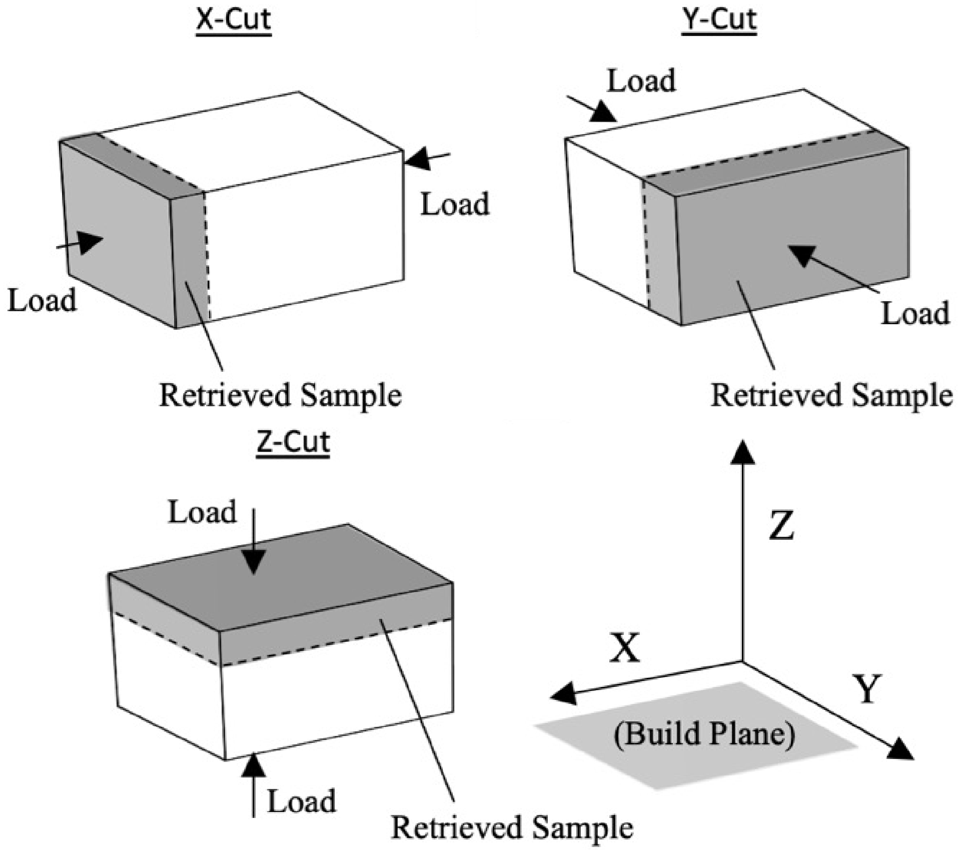


Printed Billet



- Variations studied:
  - Wrought
  - As-built AM Z-Cut
  - Heat treated & recrystallized wrought
  - Heat treated & recrystallized AM Z-Cut
    - 1250ºC
- Microstructural differences
  - Grain size & structure

Nomenclature



Research Question

Do process-structure-properties (PSP) influence the high-strain rate dynamic behavior?

Material: SS304L

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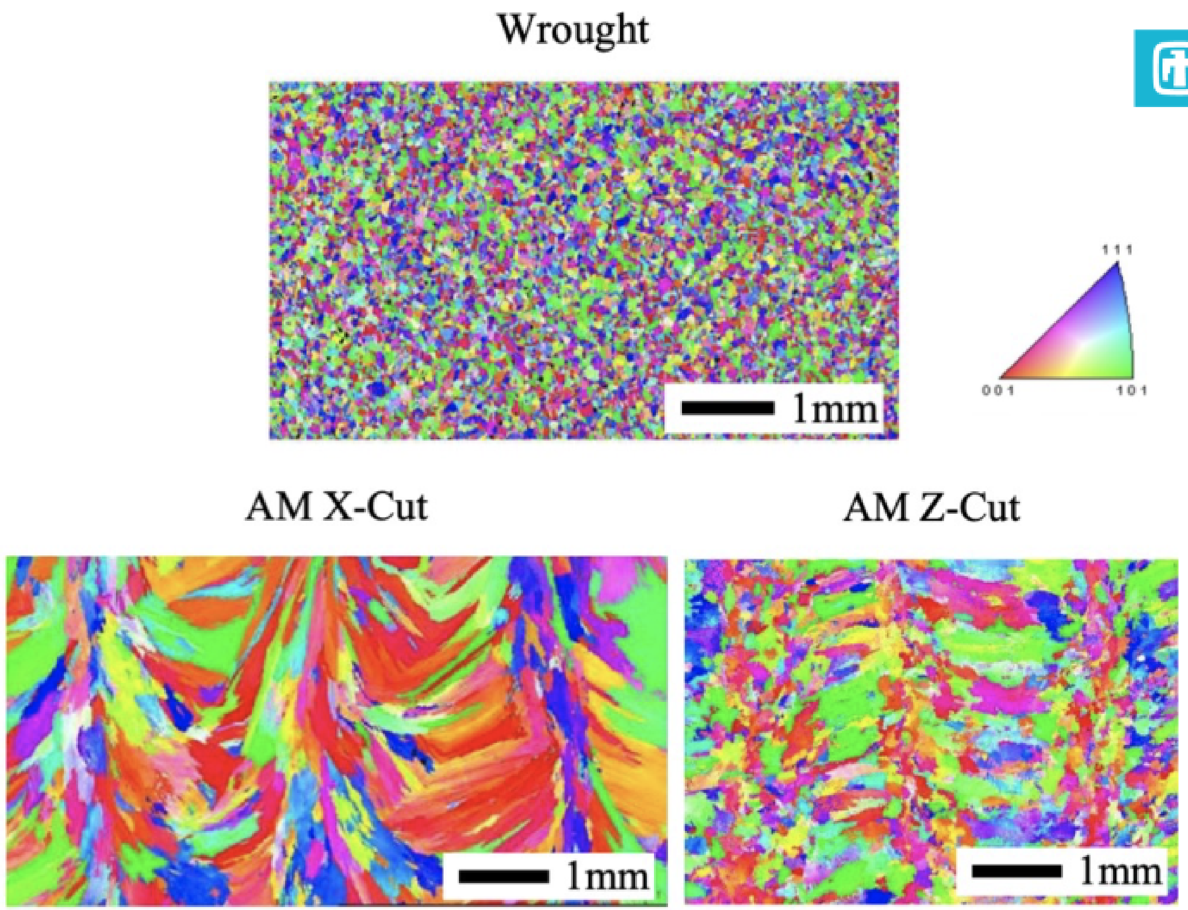
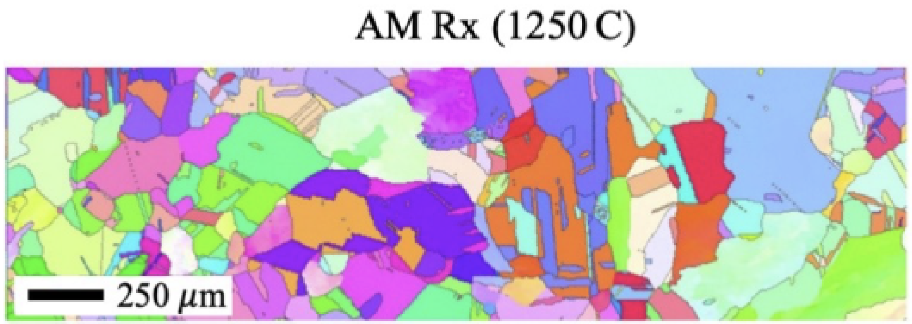


Specht, 2018 (*SAND2018-11649 C*)

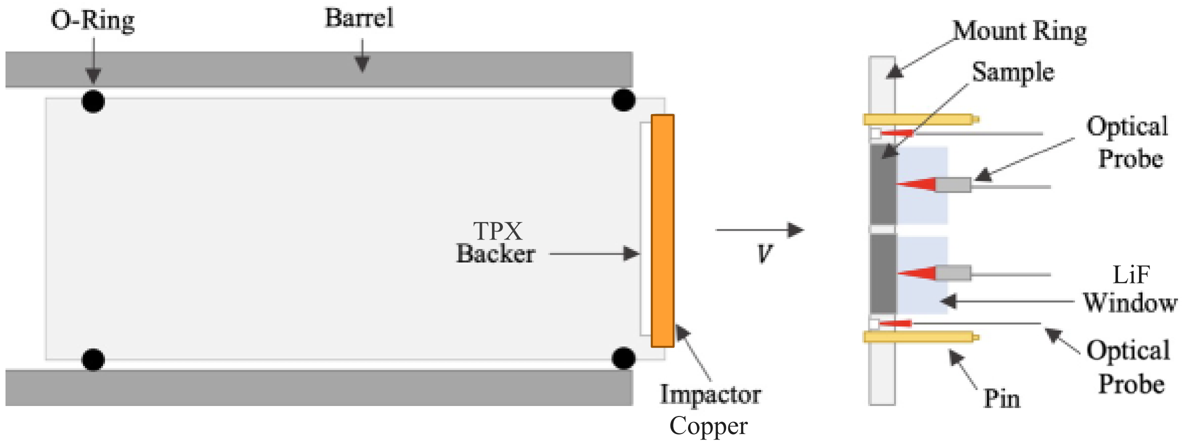


D. W. Brown, *Metallurgical and Material Transactions A*, 2019

Methods: Experimental Configuration

- Impact experiments at Sandia's Shock Thermodynamics Applied Research (STAR) facility.
- Forward ballistic configuration
- Four sample target:
  - Wrought
  - As-built AM Z-Cut
  - Heat treated & recrystallized wrought
  - Heat treated & recrystallized AM Z-Cut
- Waveform Measurements:
  - HEL, Hugoniot, Flow strength

Cross-Sectional View



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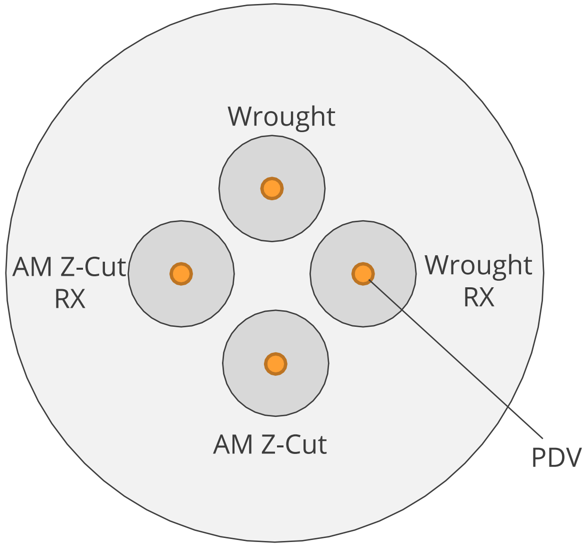
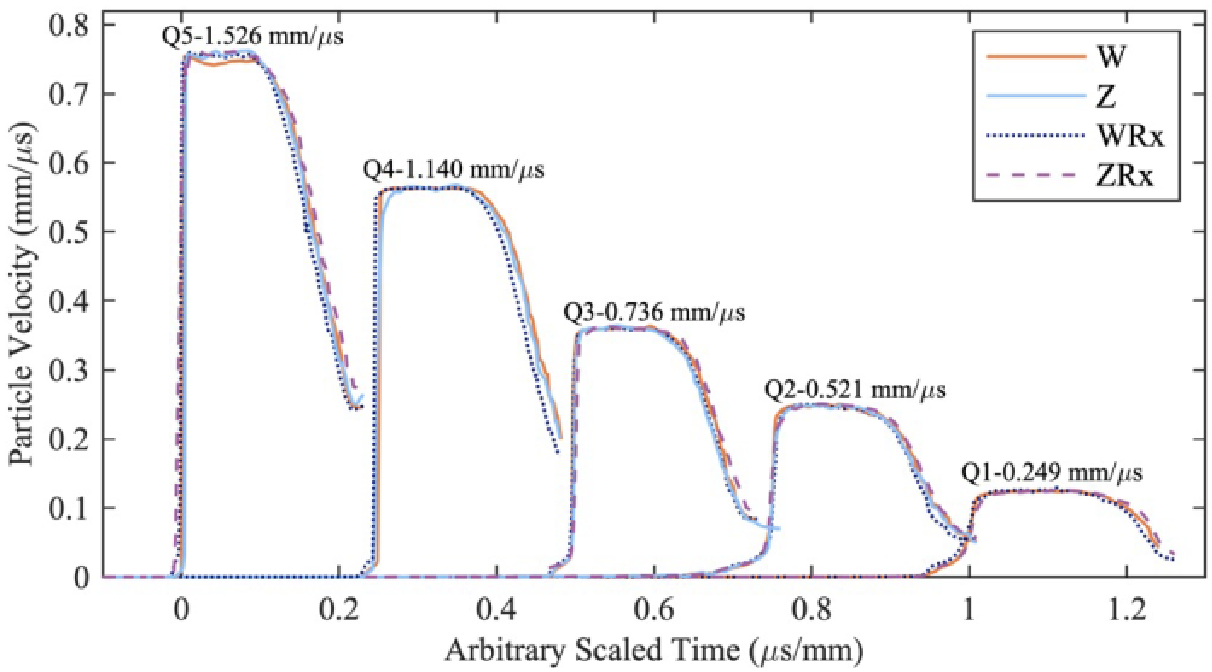
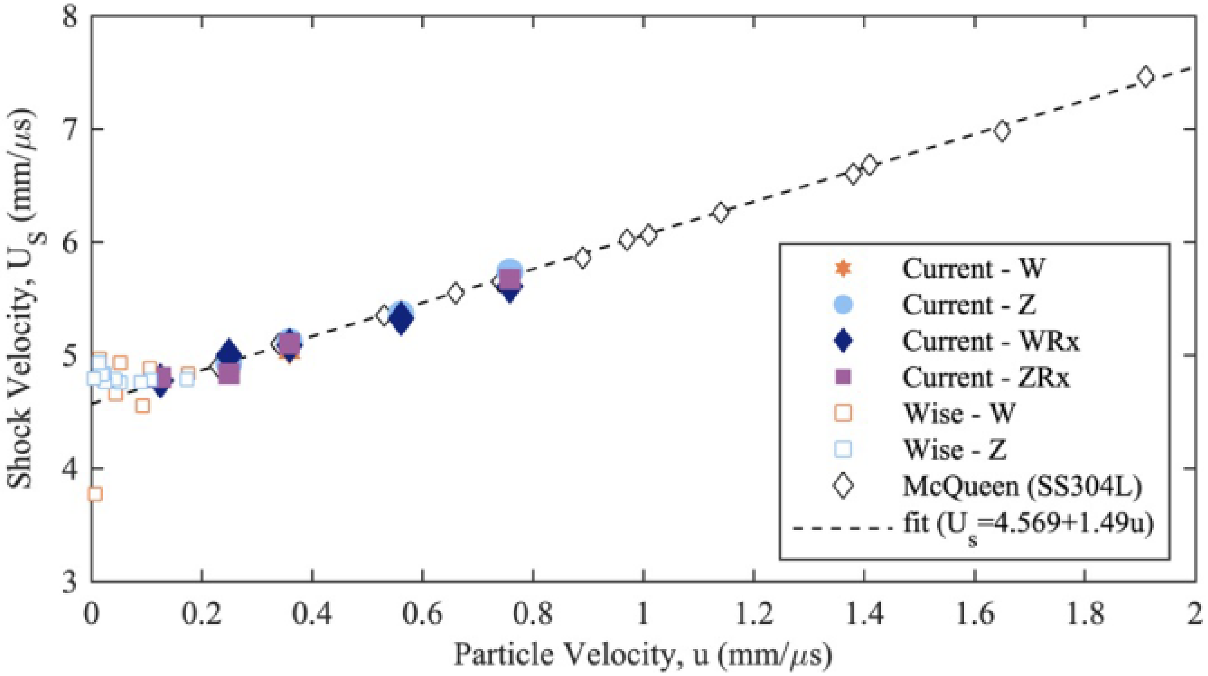
Target Plate



Results: Waveforms & Hugoniot

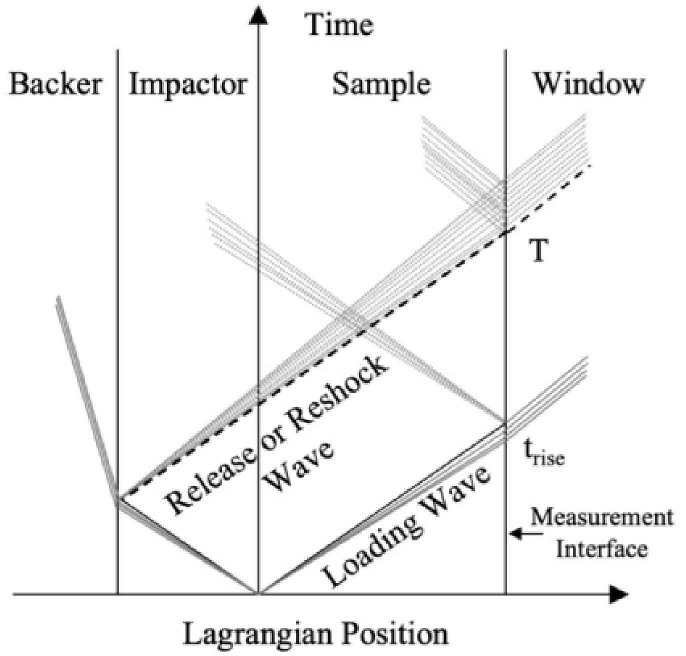




- Experiments:
  - Impact: 0.25 - 1.5 km/s
  - Stress: 5-35 GPa
  - Waveform structure
    - Rise, Amplitude, Release
- Hugoniot Elastic Limit:
  - W = 0.5-0.6 GPa
  - WRx = 0.7-1.1 GPa
  - Z = 0.4-1.0 GPa
  - ZRx = 0.6-0.8 GPa
- Shock/Particle Velocity
  - Compares well with previous data
  - Similar response for variants

Results: Flow Strength

- Flow strength measurements via release or reshock waves.
  - I.e. Asay Method or self consistent Lagrangian Analysis
- Wave characteristics indicate material strength.
  - (Quasi-elastic response)
- Integrate wavespeeds to determine strength.
  - This work only uses release.



Unloading

$$\tau_c + \tau_H = -\frac{3}{4}\rho_0 \int_{u_1}^{u_H} (C^2 - C_B^2)\frac{du}{C}$$

Reloading

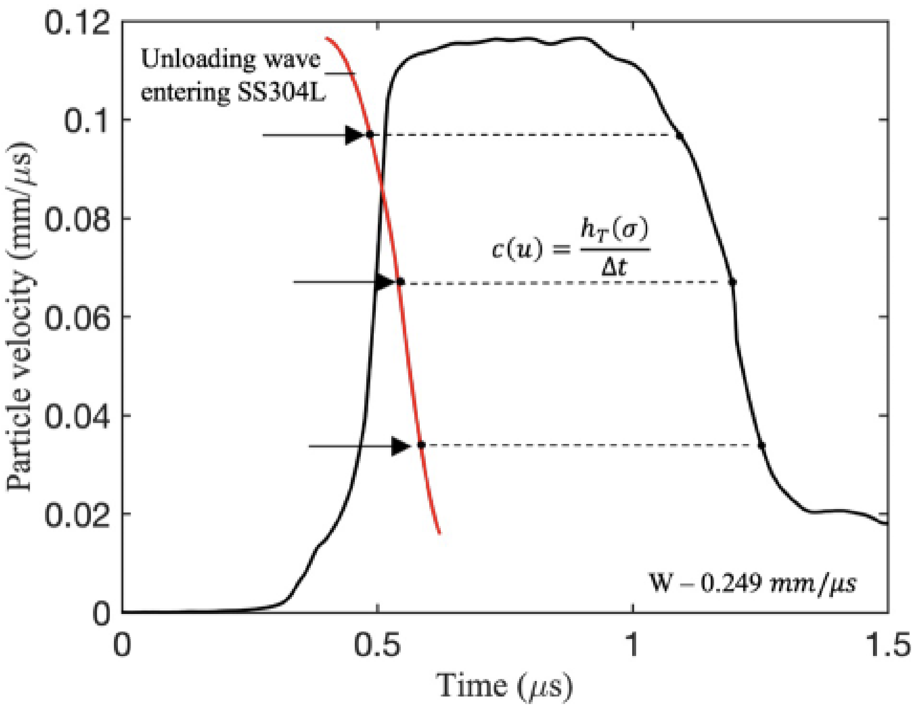
$$\tau_c - \tau_H = \frac{3}{4}\int_{u_H}^{u_2} (C^2 - C_B^2)\frac{du}{C}$$

$$Y = \underbrace{(\tau_c + \tau_H)}_{\text{Release}} + \underbrace{(\tau_c - \tau_H)}_{\text{Reloading}}$$

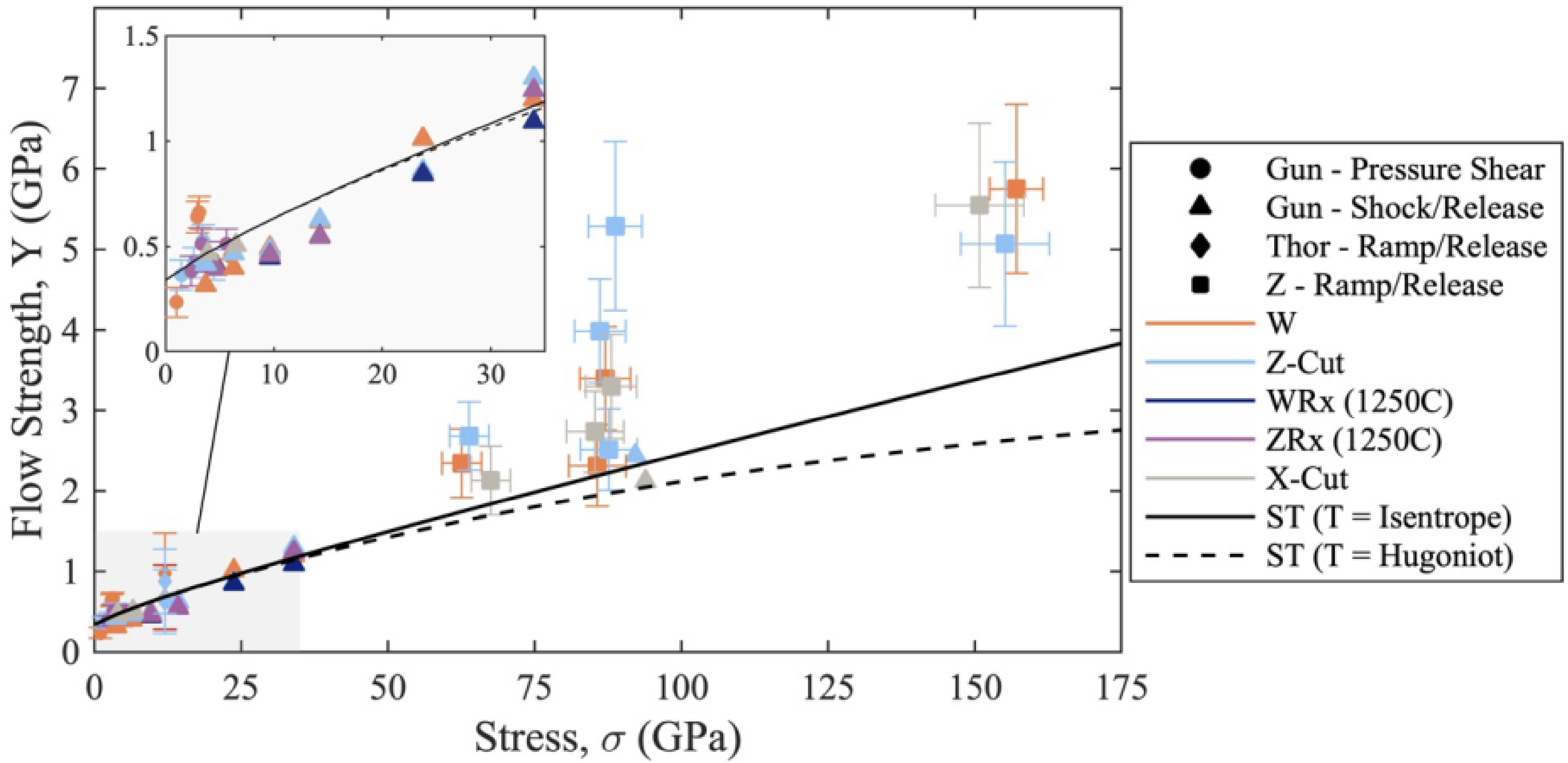
Assuming contribution from reshock = 0

↓

$$Y = \tau_c + \tau_H$$



Results: Flow Strength



Findings:

- Similar response between variants.
- Agreement with pressure-shear, shock/release, & ramp/release data.
- Agreement with previously calibrated strength model.
- Process-structure-properties do not significantly influence the high pressure flow strength of SS304L at the studied loading conditions.

Conclusions

- Five shock compression experiments were performed at Sandia's STAR Facility.
  - Impact Velocity: 0.25 - 1.5 km/s
  - Stress: 5-35 GPa
- Waveforms informed how process-structure-properties influence the high-strain rate dynamic response.
- HEL is influenced by process-structure-properties.
- Hugoniot & flow strength are not significantly influence by process-structure-properties.