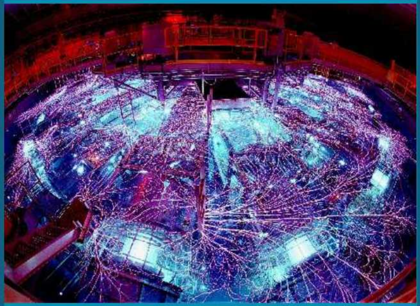
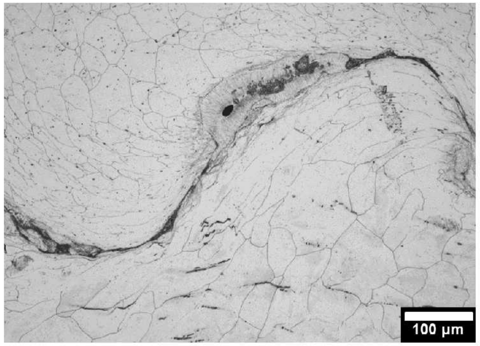
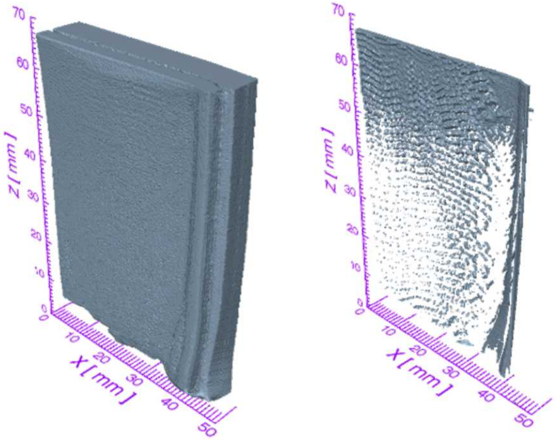
SAND2019-2634C

Characterization of Interfacial Bond Surfaces in Explosively Bonded 304L Stainless Steel







TMS Annual Meeting & Exhibition

March 14th, 2019

PRESENTED BY

Thomas A. Ivanoff, Jonathan Madison, Olivia Underwood, Lisa Deibler, Jeffrey Rodelas and Chris Finfrock

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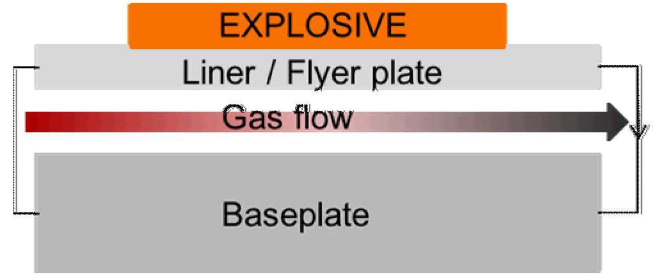
Benefits and Challenges to Explosive Bonding

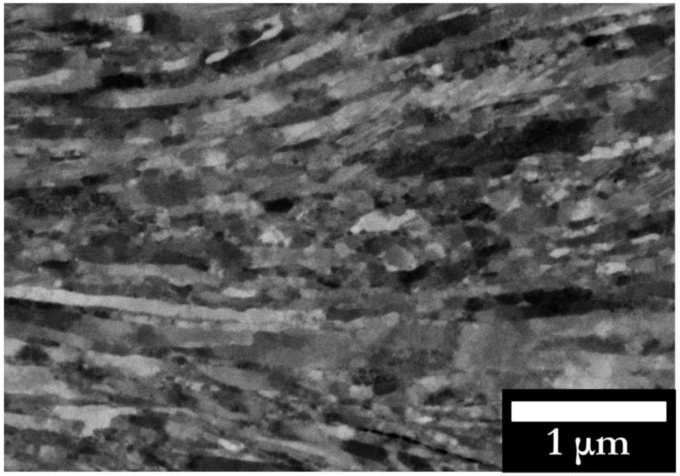


Why explosive bonding?

1. Rapid bond formation
2. Metallurgical bond (hermiticity)
3. Bond large surface areas (1,000 cm^2)

Challenges

1. Delamination at the bond interface
2. Porosity along the bond interface and an inconsistent (wavy) bond
3. Melting along the bond interface



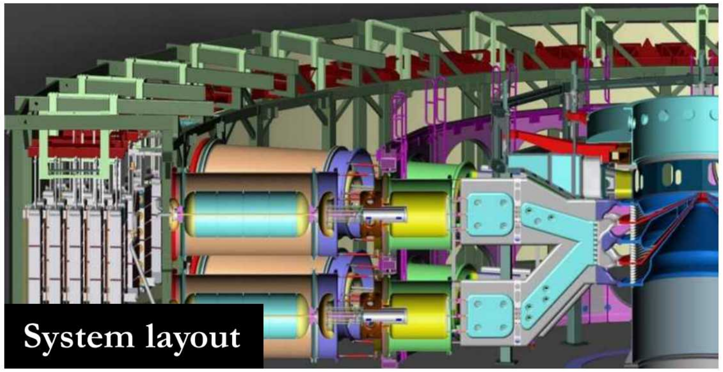
Metallurgical bonding across the bond interface. High resolution scanning electron microscopy.

Bonding between two plates. Note the incomplete bonding and porosity. Micro-computed tomography.

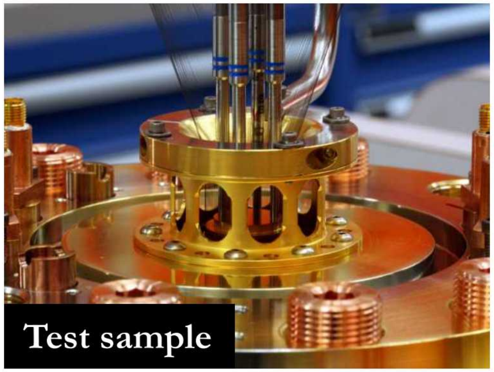
Testing in Extreme Environments with the Z machine

Z machine at Sandia National Laboratories

- World's most powerful and efficient laboratory radiation source
- Pulsed power system creates extreme environments for materials testing


System layout


Test chamber

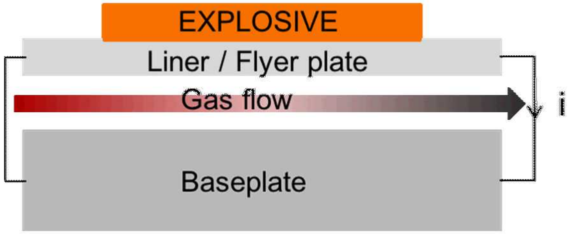

Test sample

Challenges

- Tests are sensitive to contaminates and require a clean environment
- Undesirable/dangerous compounds are often produced
- Tests are completed rapidly and require precise timing and control

This study explores the use of plastic explosives to close a 6 inch gas flow valve in the Z machine

- Precise timing required
- Valve hermetically sealed within ~100 μs
- Cannot contaminate the test environment

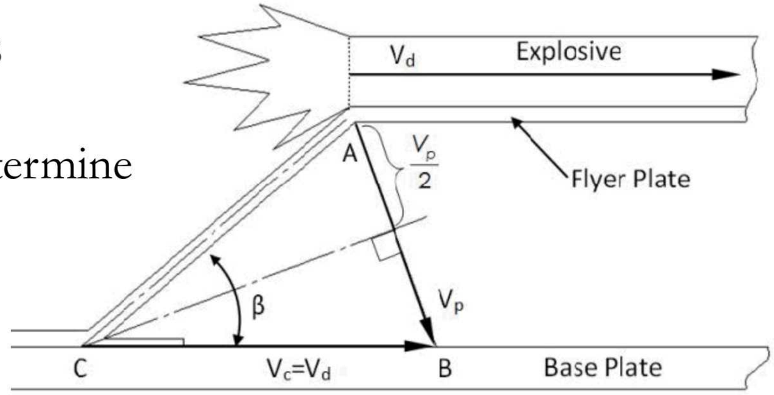


Schematic of explosive closure valve

Explosive Bonding Parameters

Three primary process parameters determine the quality of a bond

- Collision velocity (V_c)
- Collision angle (β)
- Flyer plate thickness



J. Ribeiro et al. ***J. Phys, Conf. Series,*** vol. 500 (2014), pp. 052038.1-6

It is favorable to keep the collision velocity below the speed of sound in the materials being bonded (5-6 km/s in stainless steel)

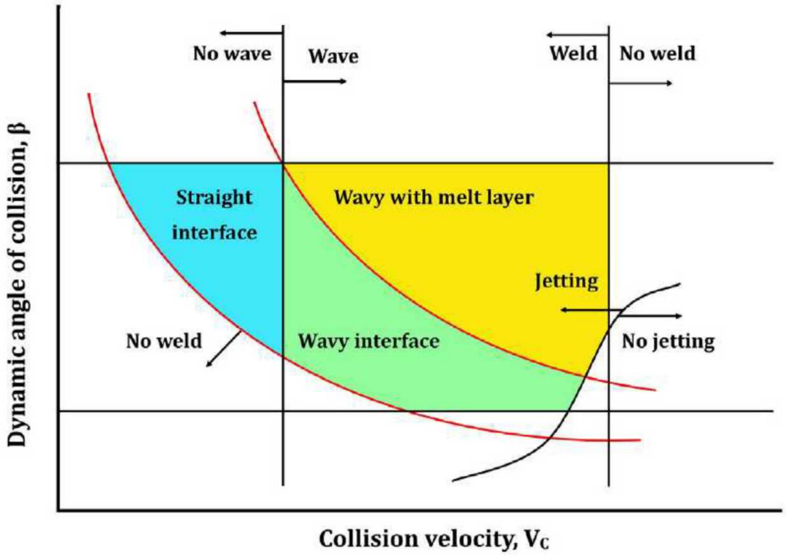
Traditionally, ammonium nitrate and fuel oil (ANFO) is used because its detonation velocity is between 2-3 km/s

Z machine requires plastic explosives

- Detonation velocities between 6-7 km/s

Provides over ANFO:

- Cleanliness
- Faster closure speed
- Improved timing



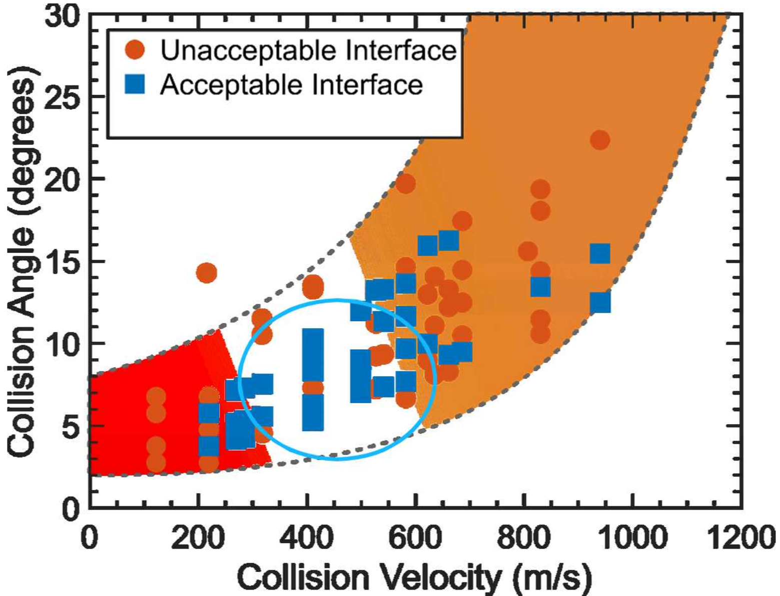
M. Athar & B. Tolaminejad, ***Mat. & Design,*** vol. 86 (2015), pp. 516-525

Goals

The aim of this study is to determine the processing window for explosive bonding using plastic explosives, similar to the work completed for explosive bonds fueled by ammonium nitrate and fuel oil (ANFO)

To this end, the interfacial bond quality in **304L stainless steel** plates explosively bonded using **plastic explosives** is characterized and evaluated using:

- Metallography
- Ultrasonic testing
- **Three-dimensional reconstructions from micro-computed tomography**
- **Mechanical testing (lap-shear, microhardness)**

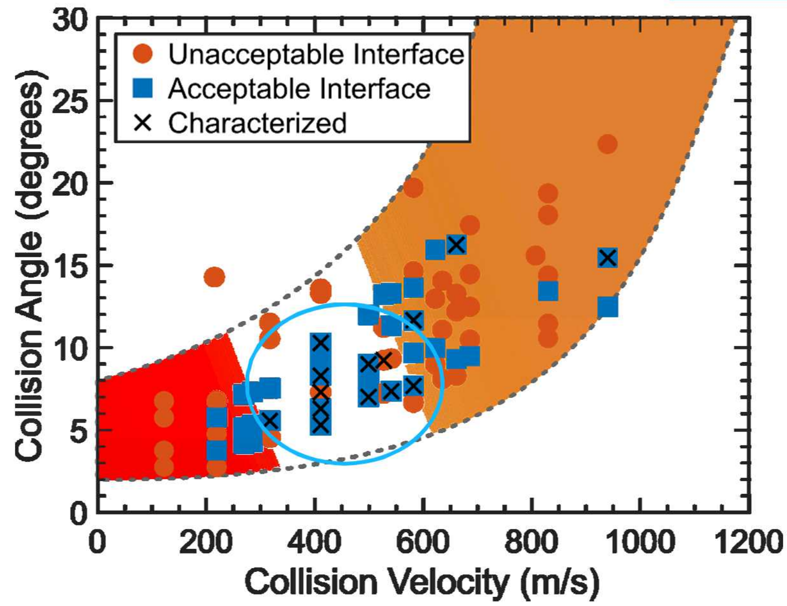


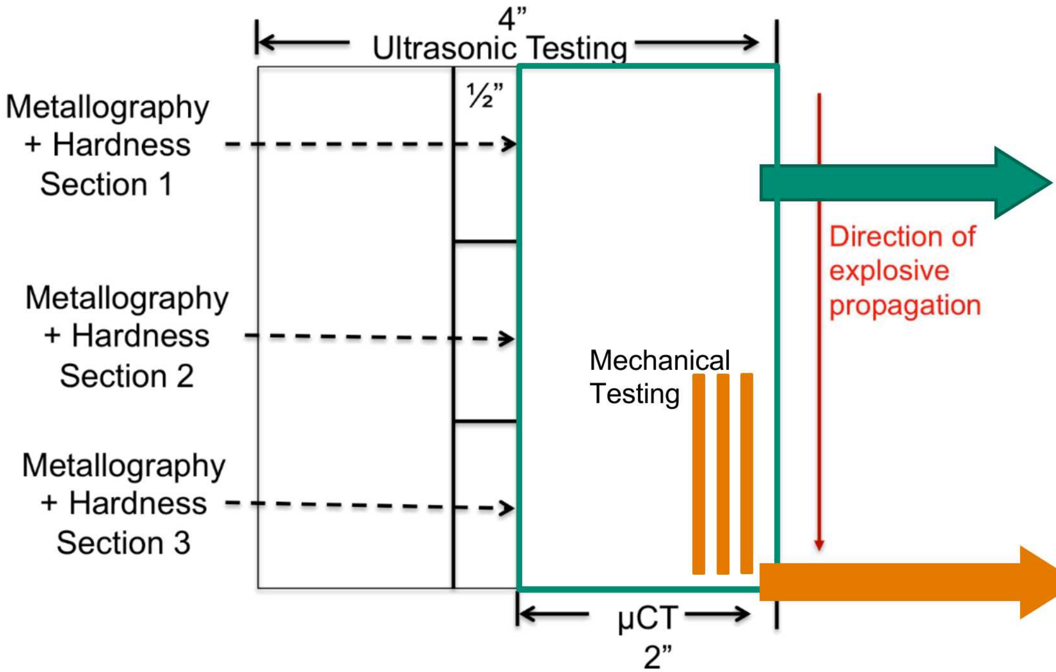
Experimental Setup

15 process settings explored

- Flyer plate thickness: 0.125 in. to 0.25 in.
- Base plate thickness: 0.25 in.

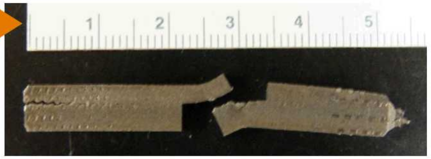
Each plate sectioned after bonding for micro-computed tomography (μCT) and mechanical testing





Schematic of the bonded plates demonstrating how material was sectioned for different characterizations.

Bonded plates characterized using μCT

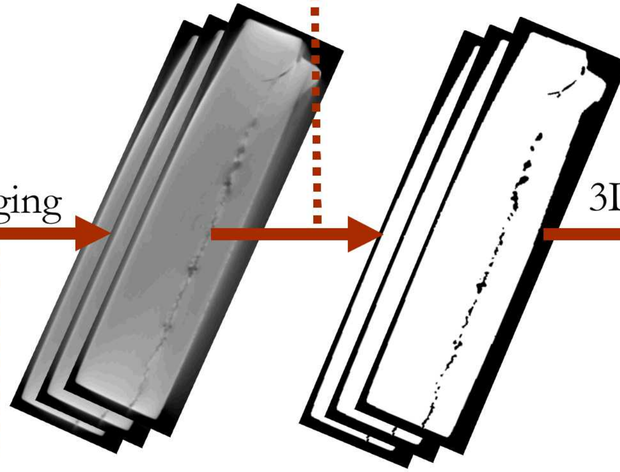


Lap-shear test specimen

3D Reconstruction Method

Part to be reconstructed

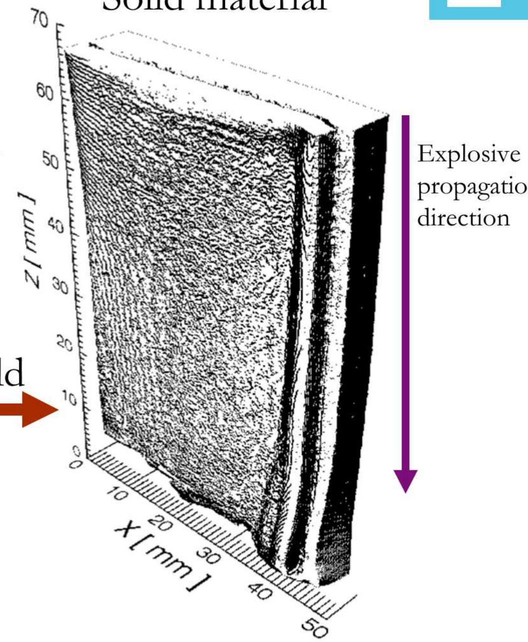
Imaging



Prepare 2D images for 3D reconstruction

3D Rebuild

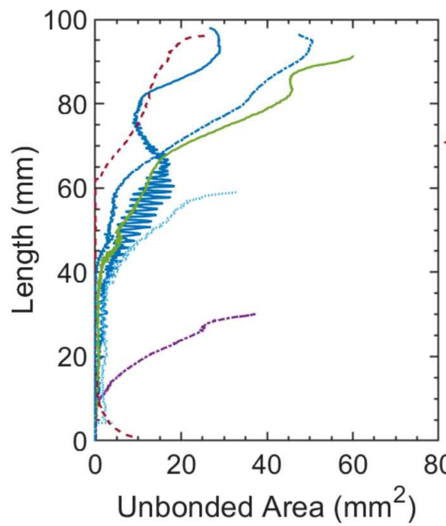
Solid material



Non-destructive

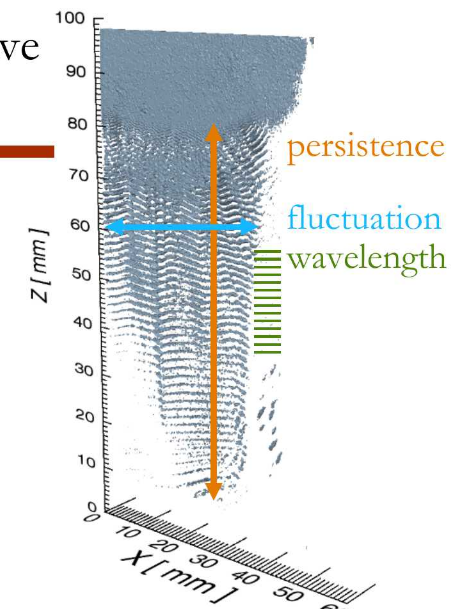
- Micro-computed tomography

Nikon Avonix M2 225/450 kV Helical Scanner



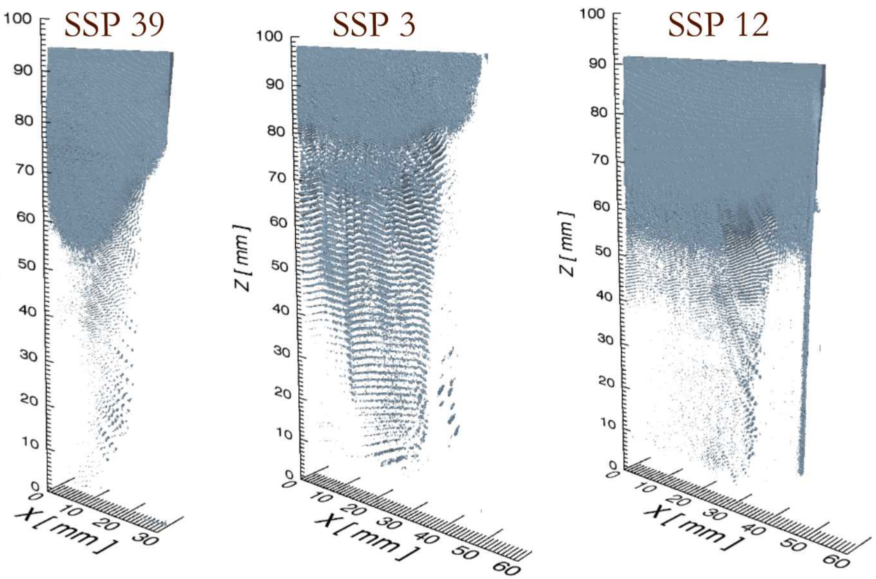
Quantitative Analysis

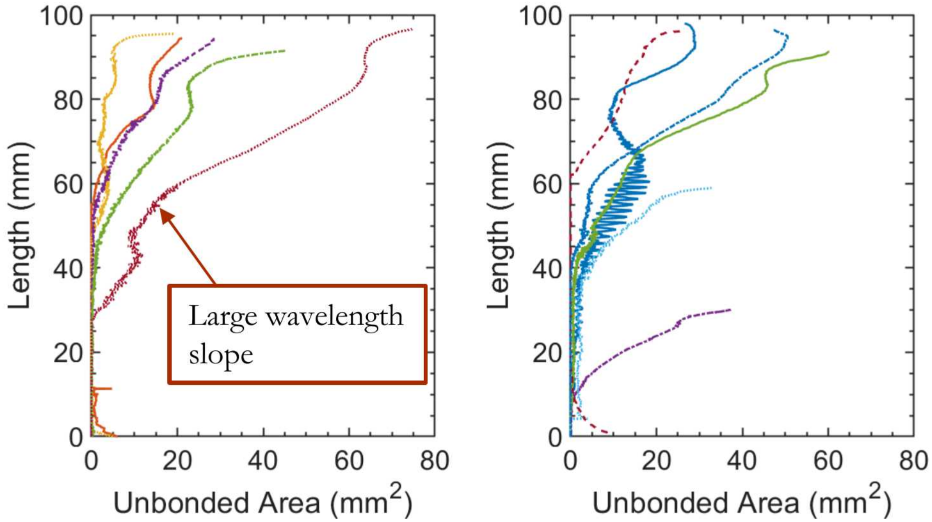
Unbonded volume



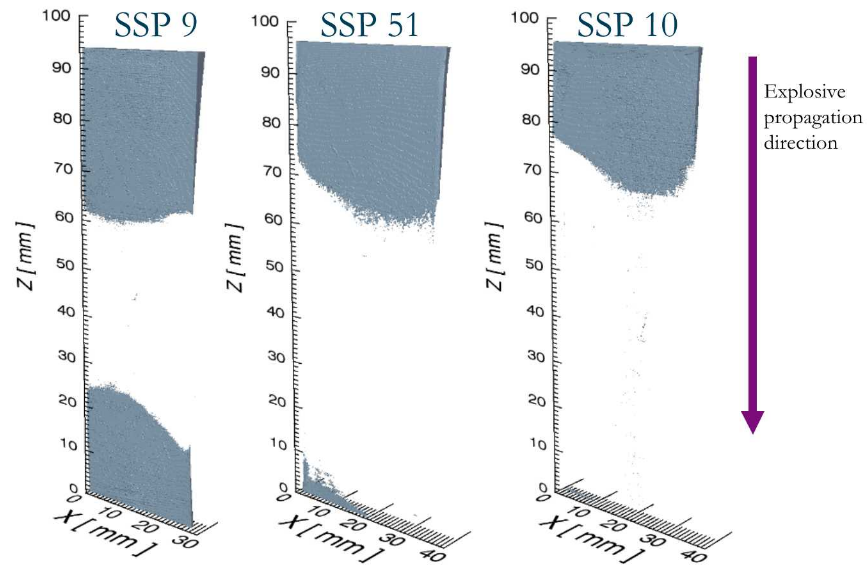
3D Reconstruction of Unbonded Volumes

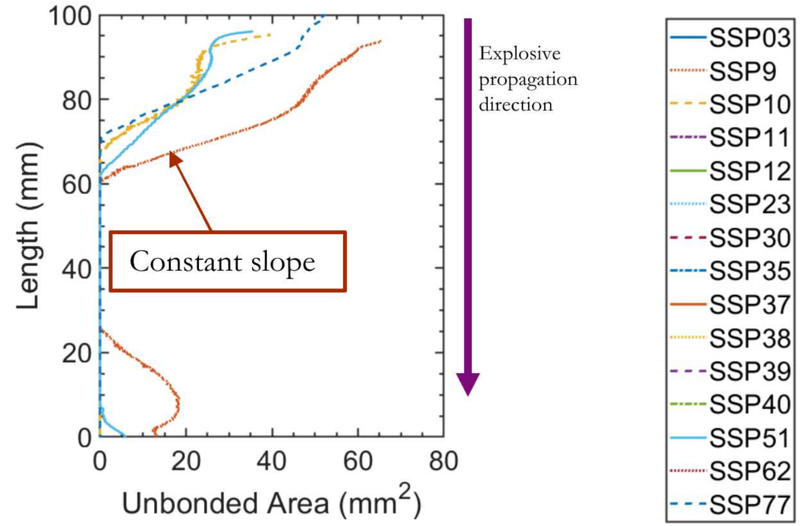
Porous bond interfaces





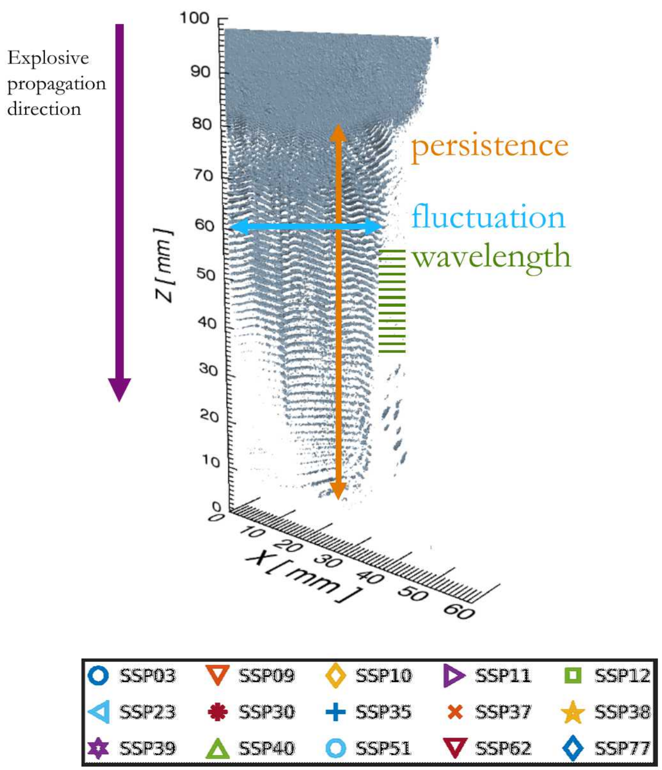
Solid bond interfaces

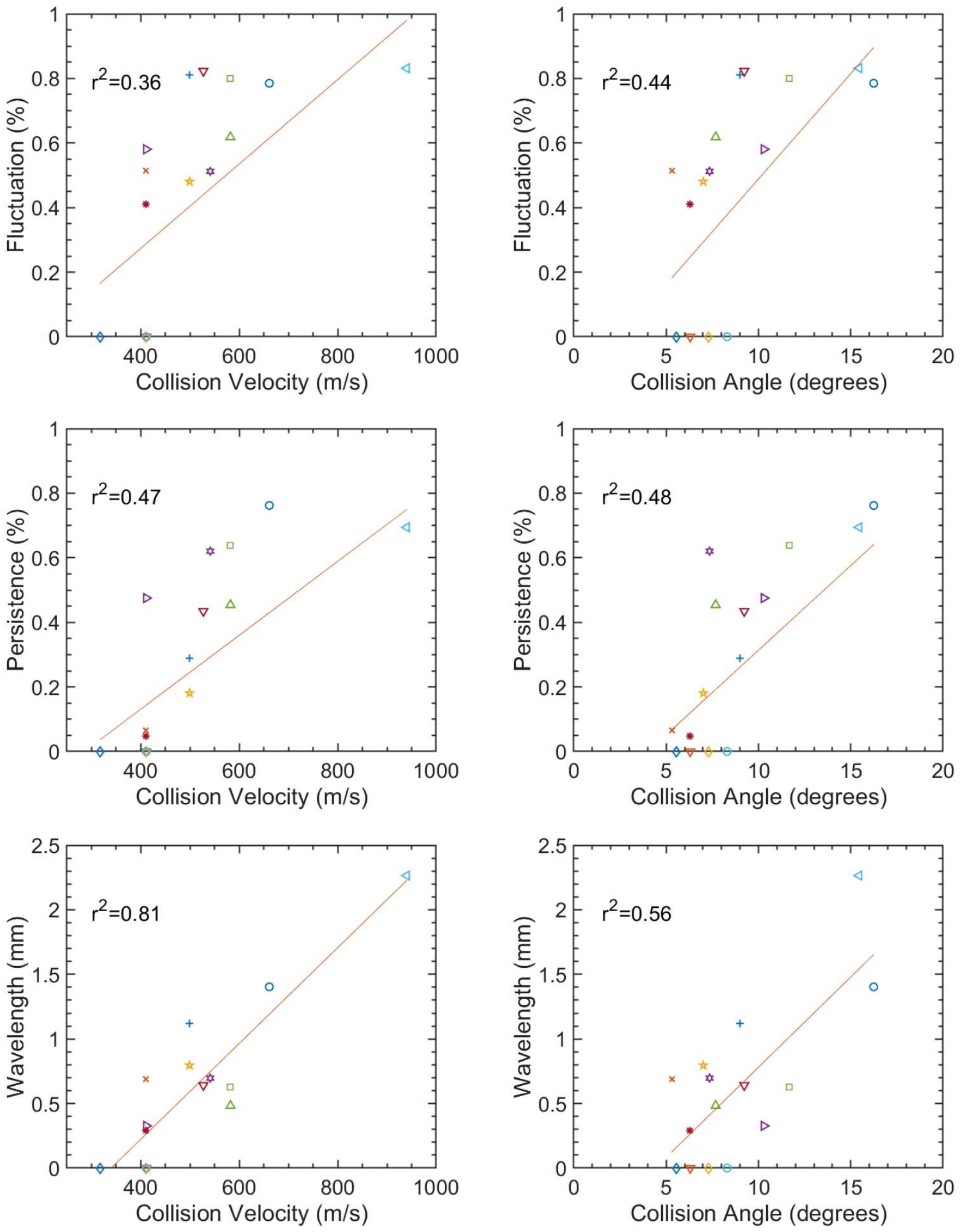




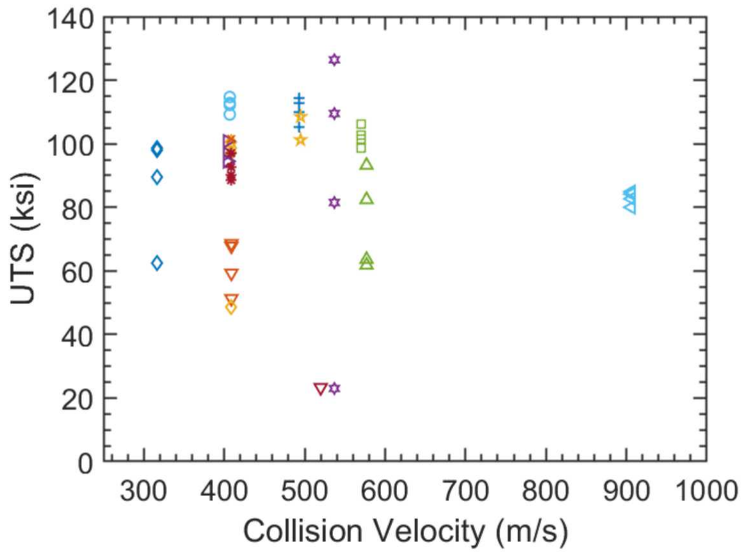
Process Parameter Relationship with Bond Character

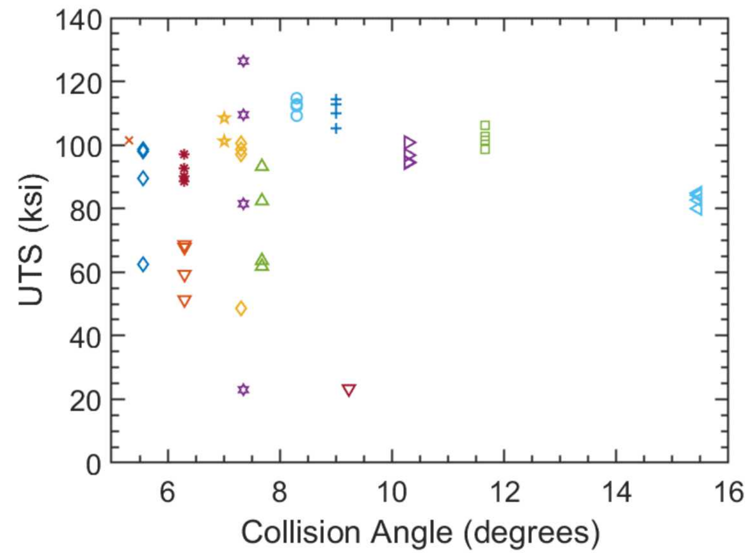
Wavelength demonstrates a linear dependence on collision velocity





UTS from Lap-shear Tensile Tests

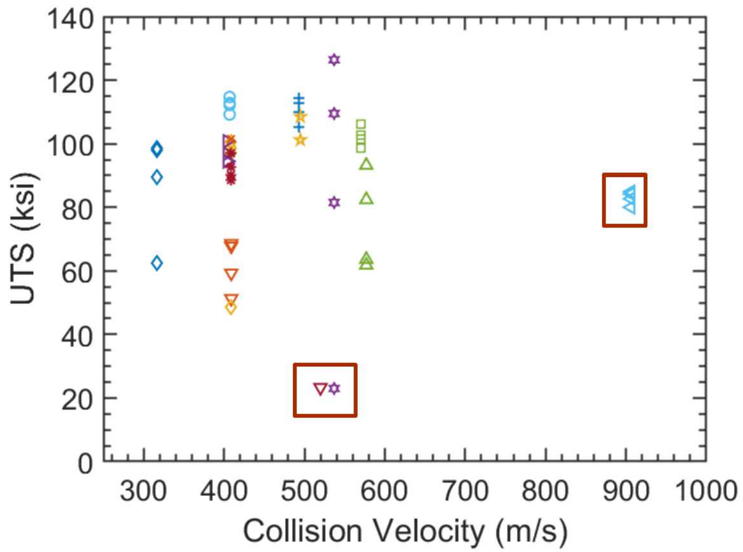


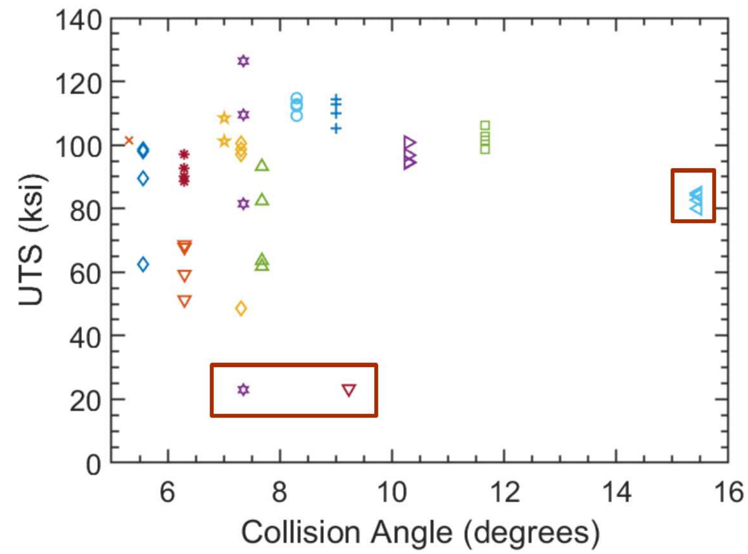


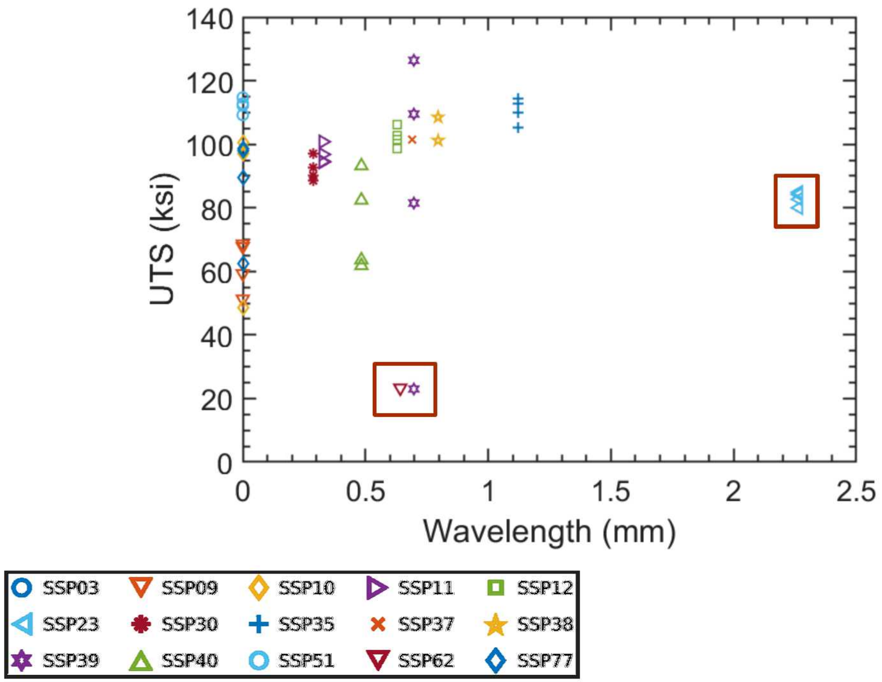
No relationship between UTS and collision velocity or angle

- Parent material influences results

UTS from Lap-shear Tensile Tests







No relationship between UTS and collision velocity or angle

- Parent material influences results

Possible weak dependence of UTS on bond character

- Similar results for fluctuation and persistence

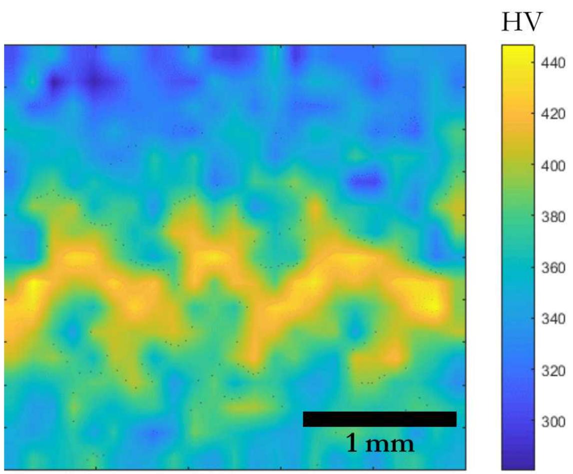
Outliers mask potential relationships

- Unidentified porosity contribute to spread in data

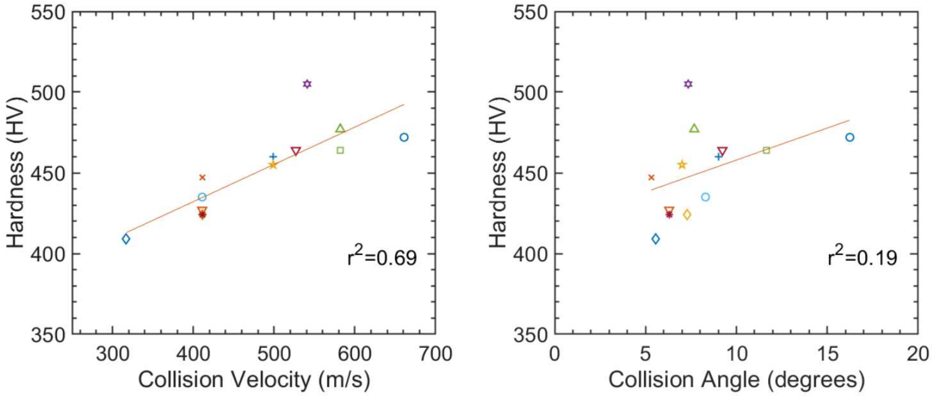
Vickers Microhardness

Microhardness provides greater spatial fidelity compared to lap-shear test

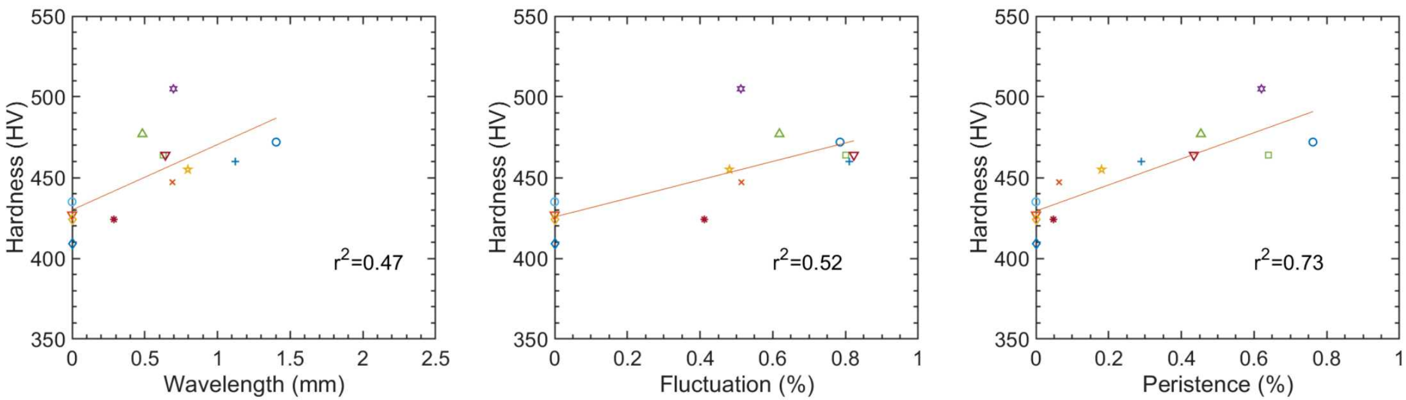
- Study local hardness variation across the bond interface and into the parent material



Relate peak hardness to interface parameters:



Hardness shows a relationship with collision velocity and persistence



Conclusions

304L stainless steel plate was successfully bonded using plastic explosives

- Hermetically sealed interfaces were produced
- Processing window is narrower than that for ANFO

The characteristics of the bond interface (wavelength, persistence and fluctuation) are correlated with collision velocity and angle

- More tests are needed to improve these relationships and expand the mapped process space

UTS as measured from lap-shear test is not correlated with processing parameters or bond characteristics

- Parent material likely influences testing; obscures differences in bond strength and increases spread
- Testing smaller, more homogenous areas along the interface by in-situ mechanical testing using an SEM may improve understanding of mechanical strength across a bond

Spatial variation of mechanical strength across an interface can be identified using microhardness.

- Peak hardness across a bond is related to processing parameters