

Extending Ultrasonic Welding Techniques to New Material Pairs

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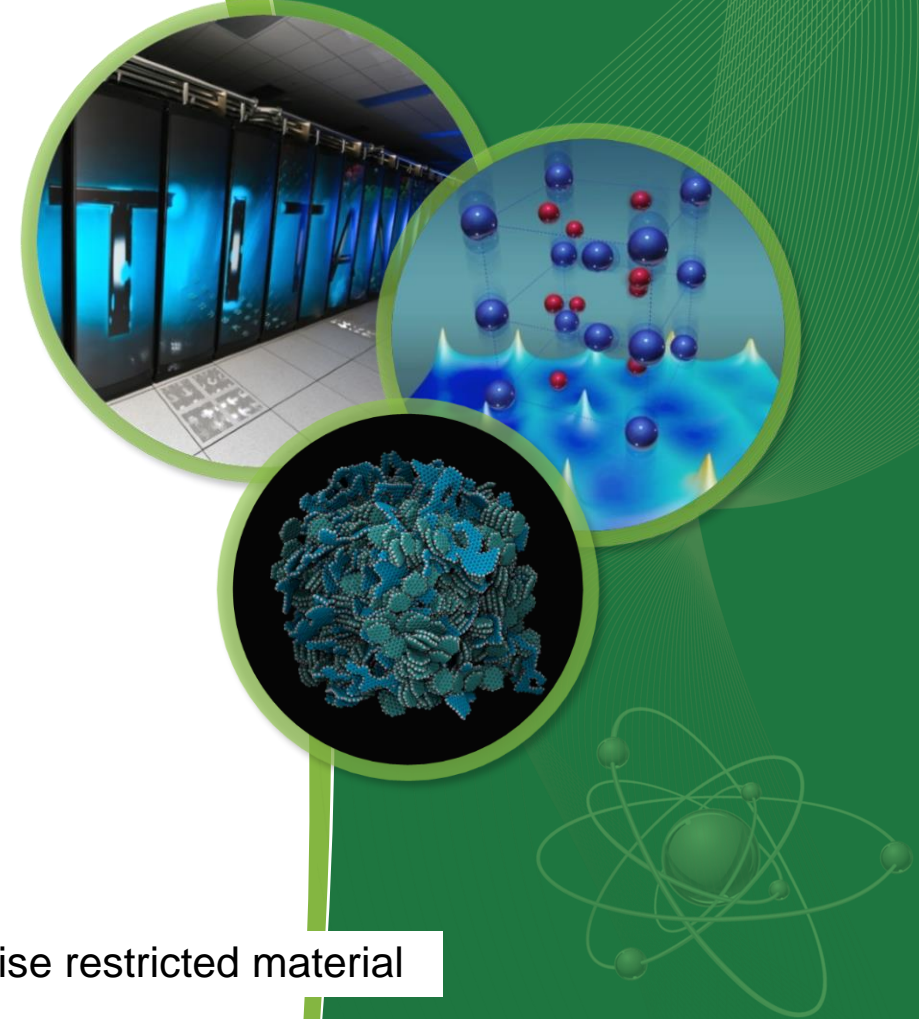
Argonne National Laboratory

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Project ID: MAT222

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Overview

Timeline

- Start: December 2020
- End: September 2023

Budget

- Total project funding- \$2,500,000
 - Oak Ridge National Laboratory (ORNL) - \$1,750,000
 - Pacific Northwest National Laboratory (PNNL) - \$450,000
 - Argonne National Laboratory (Argonne) - \$300,000

Barriers

- Dissimilar materials joining is a complex process with several variables that affect joint quality*
- Identifying and controlling process conditions resulting in high quality joints across several material and stack up combinations is very complicated*

Partners

- ORNL – project lead
- PNNL
- Argonne

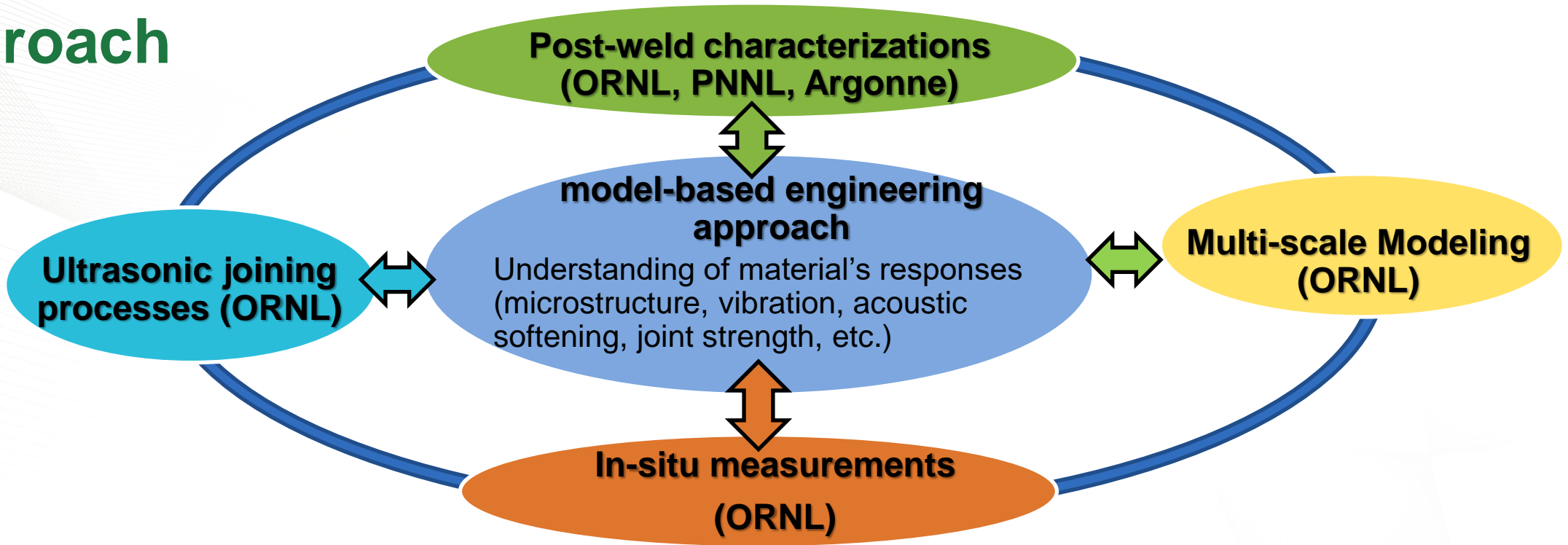
*DE-LC-000L084, 2020 VTO Lab Call 2.

<https://eere-exchange.energy.gov/FileContent.aspx?FileID=b10fa8e4-637c-4aa1-b74a-3d28755ee925>

Relevance

- Build upon the success in Phase I of the Joining Core Program
 - Major achievements in Phase I
 - Ultrasonic spot welding (USW) of immiscible Mg/Fe Mg/steel pairs
 - Ultrasonic assisted self-piercing riveting (UASPR) to join Al/Mg pairs
 - Unique characteristics of ultrasonic based joining
 - Ability to metallurgically bond immiscible material pairs
 - Acoustic softening phenomenon
- Objective
 - Extend ultrasonic based joining techniques to join various material combinations in **multi-joint components**
- Key challenge
 - Complex interactions with ultrasonic vibration when making welds at different locations (how to make welds with consistently good quality)

Approach



- A model-based engineering strategy will be applied to accelerate the development process
 - Ultrasonic Spot Welding (USW) of Mg-steel component level coupons that consists of multiple joints (FY21)
 - Extend USW to join Al-Mg and Al-steel component level coupons (FY22)
 - Use the variant of other ultrasonic based joining method to join polymer-metal pairs (FY23)

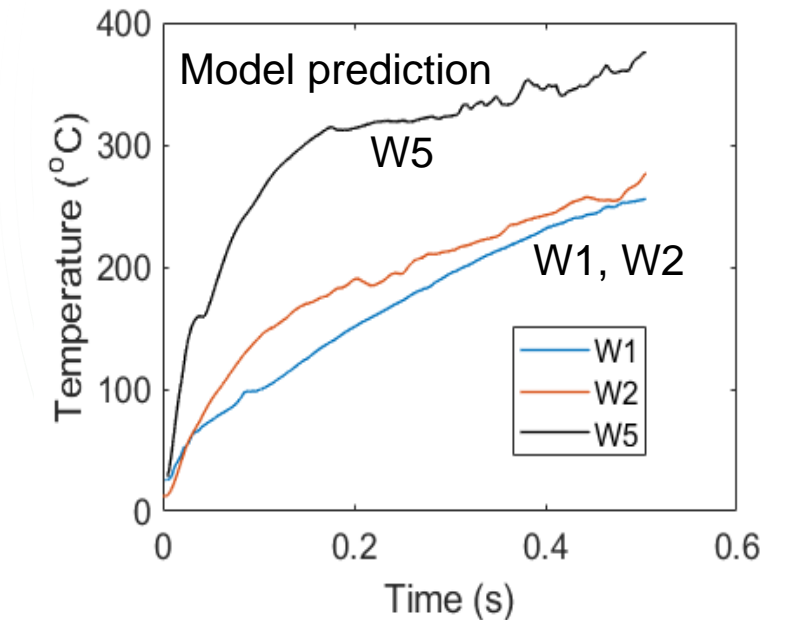
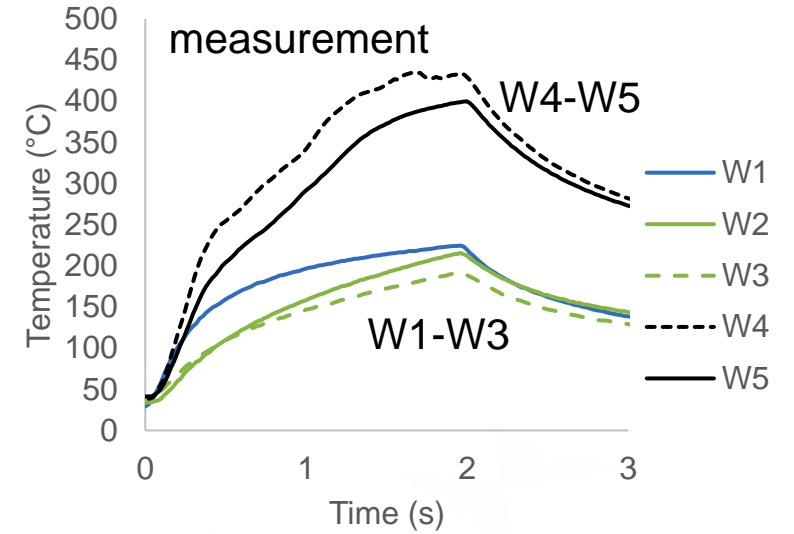
Technical Accomplishments: heat generation (1st milestone)

Black paint for infrared thermography



Thermography measurement

Model prediction



$T_{max} = 226^{\circ}C$ W1

$T_{max} = 224^{\circ}C$ W2

$T_{max} = 195^{\circ}C$ W3

W4 $T_{max} = 443^{\circ}C$

$T_{max} = 437^{\circ}C$ W5

$T_{max} = 253^{\circ}C$ W1

$T_{max} = 253^{\circ}C$ W2

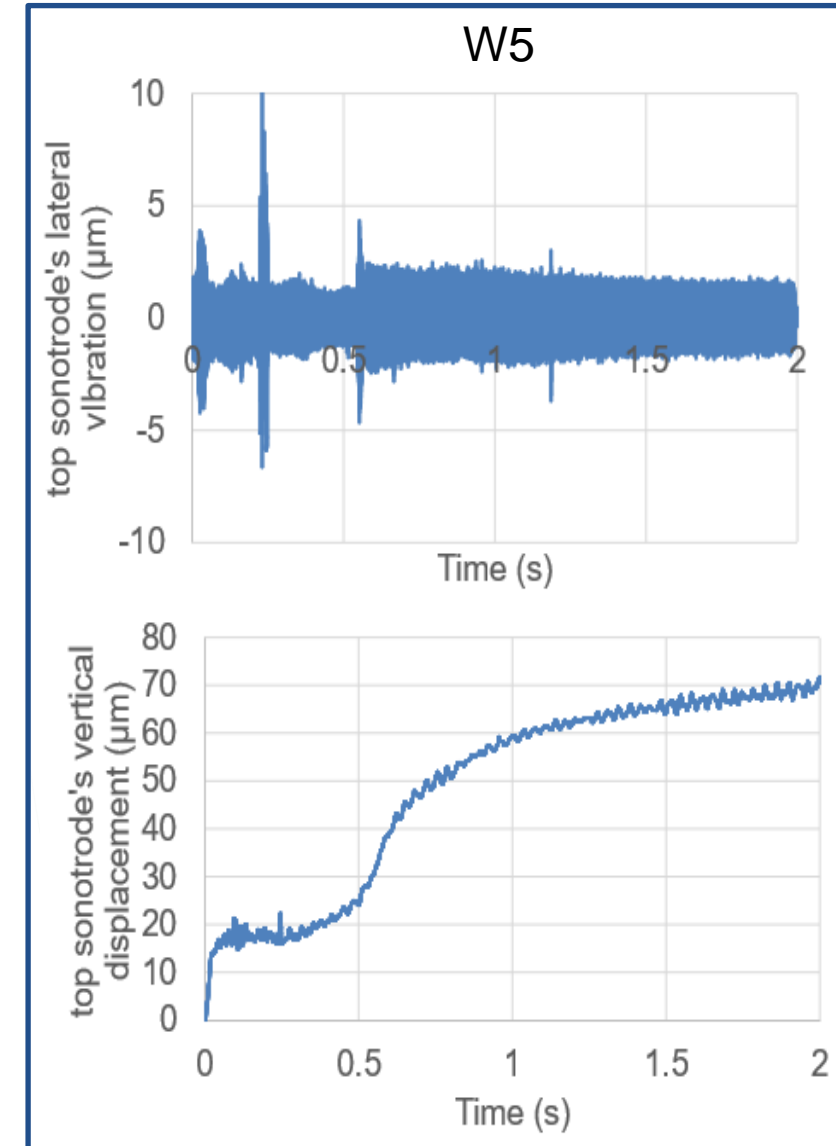
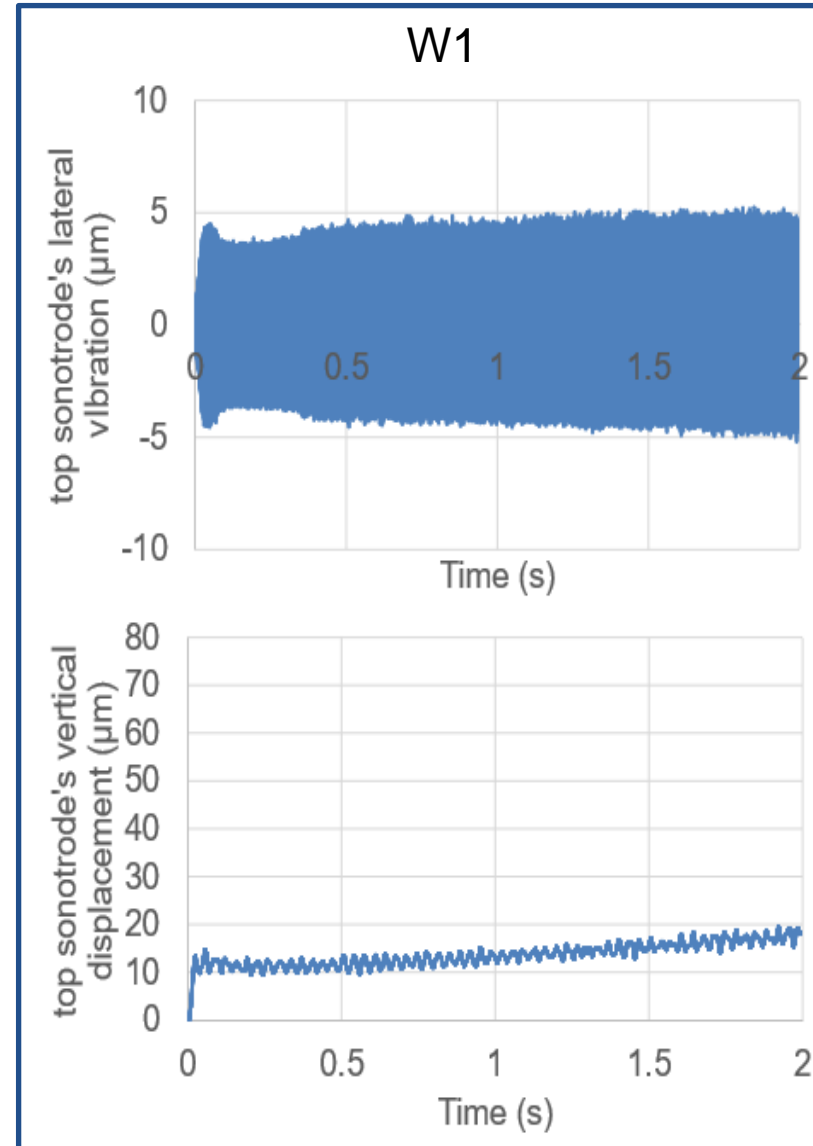
Low peak temperature

High peak temperature

$T_{max} = 375^{\circ}C$ W5

Technical Accomplishments: vibration and indentation (1st milestone)

- Measured on the top sonotrode
 - Lateral vibration amplitude: $W1 > W5$
 - Vertical displacement (indentation): $W1 < W5$
- Resultant weld appearance
 - Surface mark: $W4$ to $W5 > W1$ to $W3$
 - Suggests that $W4$ and $W5$ had larger weld nugget



Collaboration and Coordination with Other Institutions

- Oak Ridge National Laboratory
 - Project lead: Joining process, in-situ measurements, post-weld characterization, modeling
- Pacific Northwest National Laboratory
 - Advanced electron microscopes
- Argonne National Laboratory
 - Advanced X-ray synchrotron source

Proposed Future Research

- FY21: Optimize USW process to make multiple steel-Mg joints on a single component and complete the evaluation of joint quality
- FY22: Extend USW to other lightweight material pairs including Mg-Al and Al-Steel
- FY23: Select one variant of ultrasonic based joining technique to join other material pairs that are not feasible with USW

Any proposed future work is subject to change based on funding levels

Summary

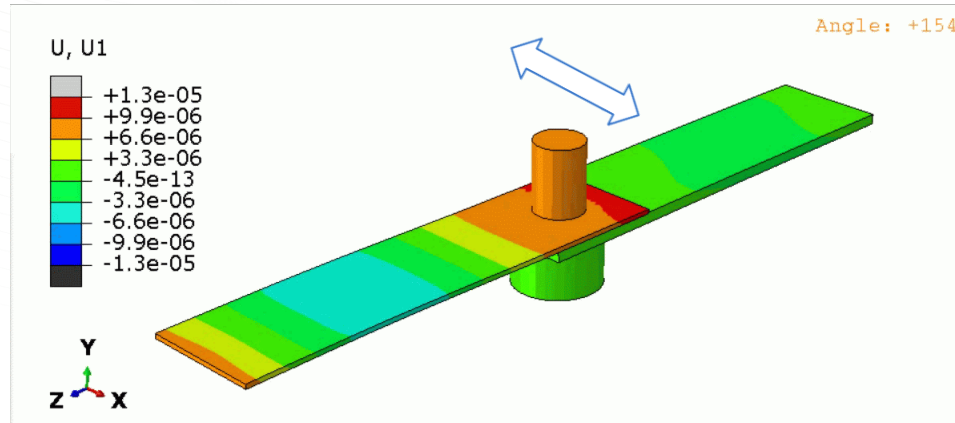
- Established material set, welding schedule and instrumentation for initial welding trials.
- Completed the in-situ temperature and vibration measurements of the initial welding trials.
- Numerical models are being developed and refined to optimize welding conditions.

Technical Back-Up Divider Slide

Technical Back-Up Slides

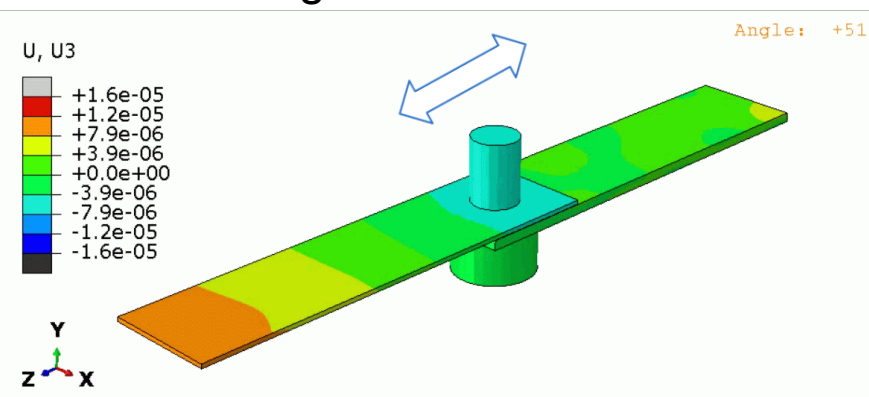
Assuming an identical vibration amplitude of 10 μm

Transverse vibration



Reaction force 1.5 kN

Longitudinal vibration

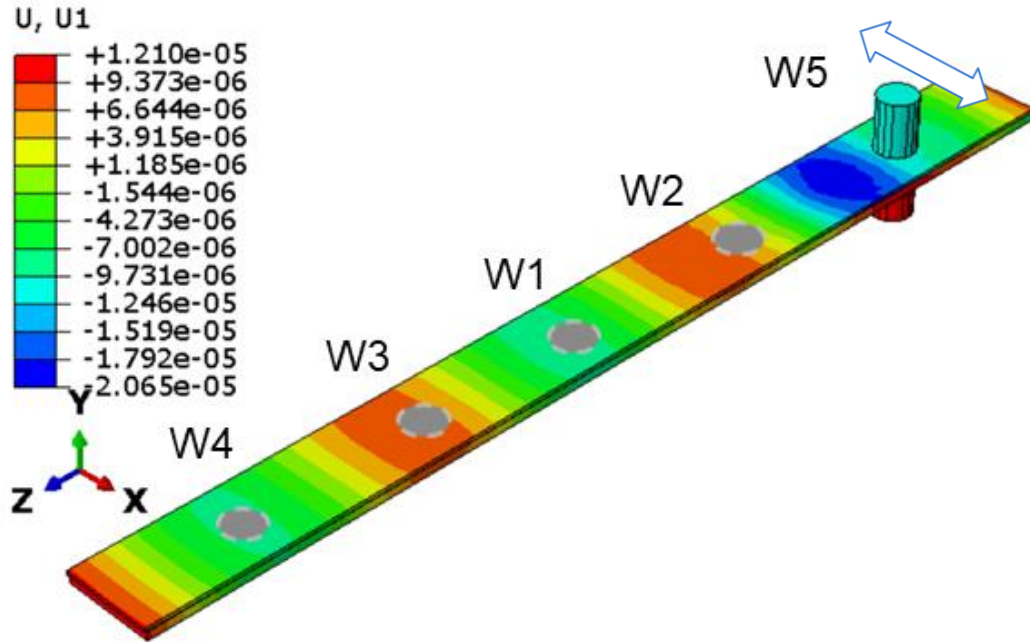


Reaction force 2.8 kN

- Small reaction force suggests it is easy to weld

Technical Back-Up Slides

Transverse vibration



Sonotrode reaction force (kN)

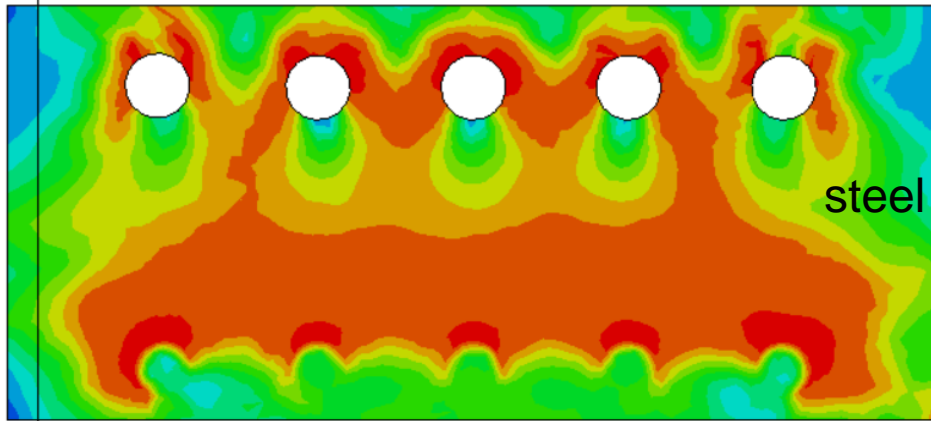
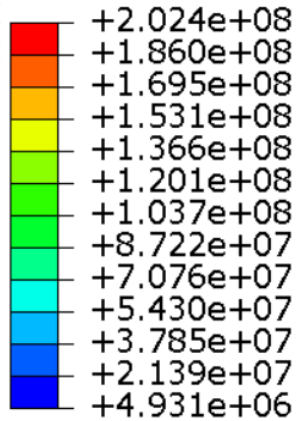
	W1	W2	W3	W4	W5
Weld spacing 1.5"	4.3	2.0	2.4	1.4	1.5
Weld spacing 2"	1.8	1.9	1.9	2.2	2.2

- Process optimization through model predictions
- Making multiple joints with 2" apart seems to result in a relatively consistent reaction force, hence consistent weld quality.

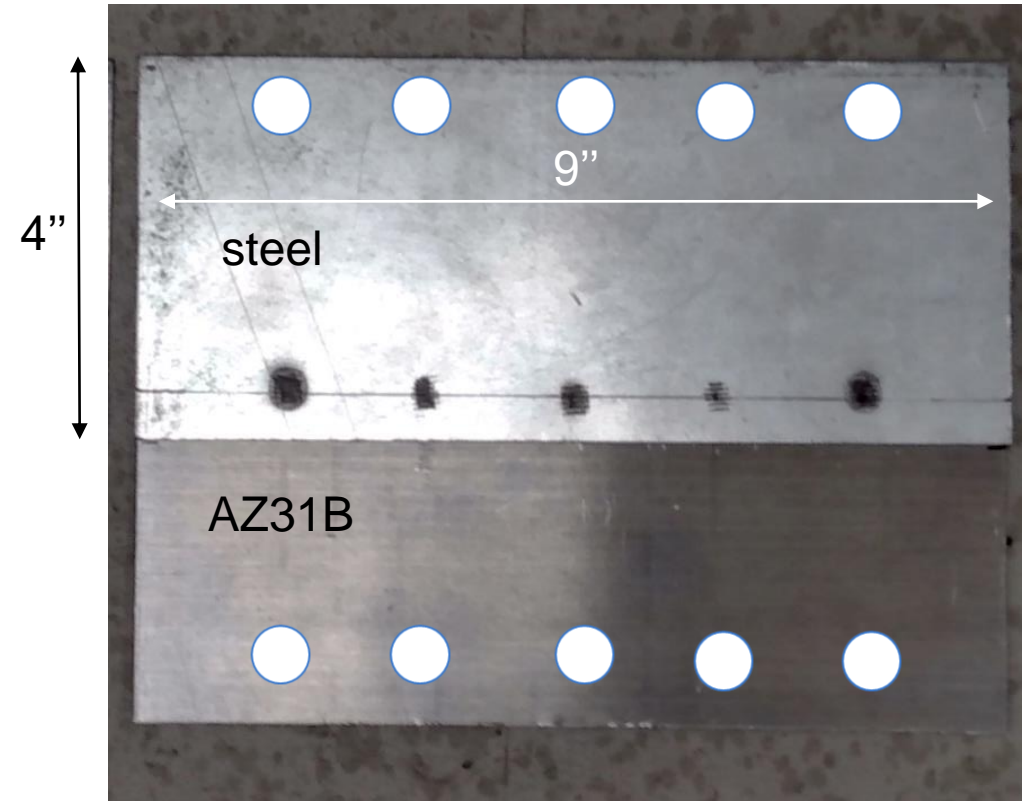
Technical Back-Up Slides

Design of multi-joint coupons and fixtures for mechanical testing

S_e Mises
(Avg: 75%)



Numerical model was applied to assist the design of coupons for lap shear testing



Coupons for lap shear testing