GREAT DESIGNS IN STEEL

DEVELOPMENT OF ADVANCED TESTING AND MODELING METHOD FOR SPOT-WELD SEPARATION CONSIDERING HEAT AFFECTED ZONES UNDER DYNAMIC LOADING MODE

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OUTLINE

- **Project Summary**
- Common industrial method for testing and simulation of resistance spot welds
- Advanced detailed microstructure characterization method of resistance spot welds
- Component level validation of resistance spot weld fracture models
- Summary and Future work

PROJECT GOALS AND OBJECTIVES

Goals:

To develop advanced characterization methodology and FEA modeling practice for the fracture prediction of a resistance spot weld (fusion zone and heat affected zone (HAZ).

Objectives:

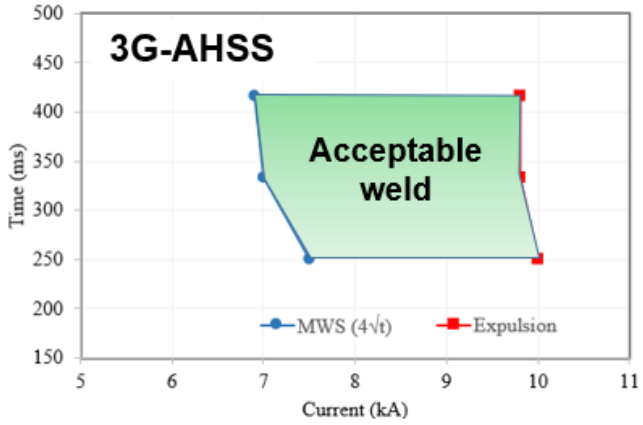
Develop and evaluate an advanced characterization methodology for crash modeling of weld/HAZ.

- Identify and define gaps for Weld / HAZ experimental characterization methodology and develop new methodology
- Identify and define gaps for a material card in LS-DYNA for FEA modeling of weld nugget and HAZ failure and propose new modeling methods

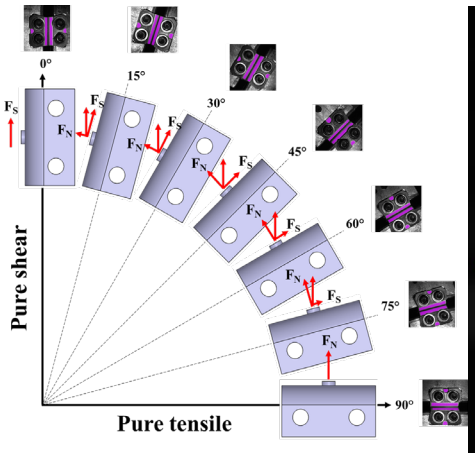
INTRODUCTION

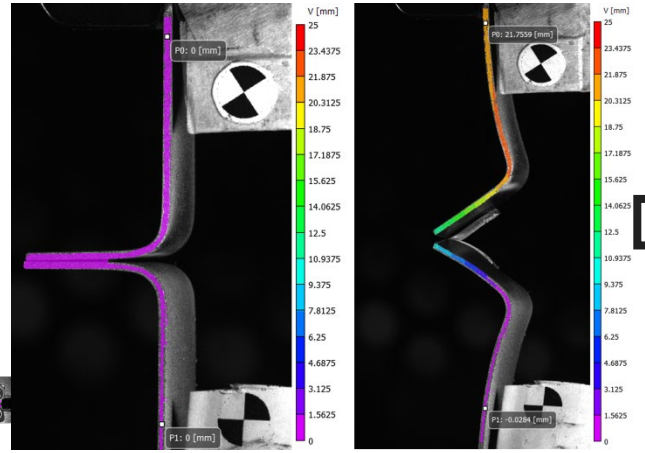
Phase-1

Develop welding schedule

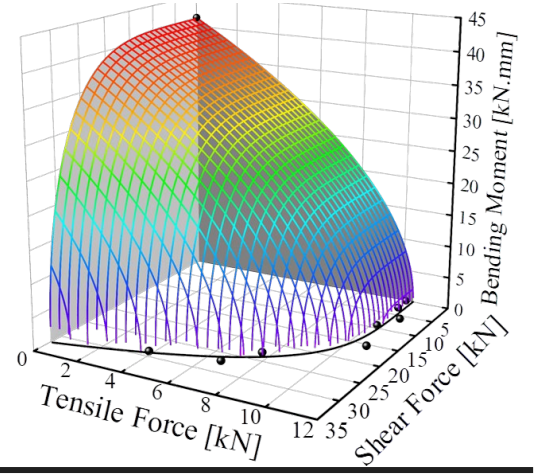


Characterize single spot weld



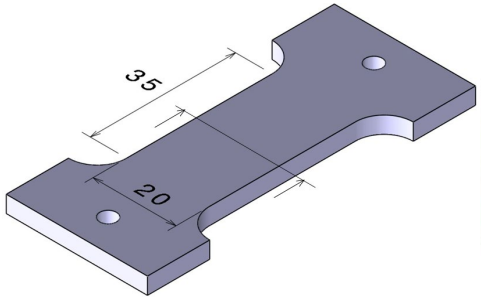


Develop 3D fracture surface

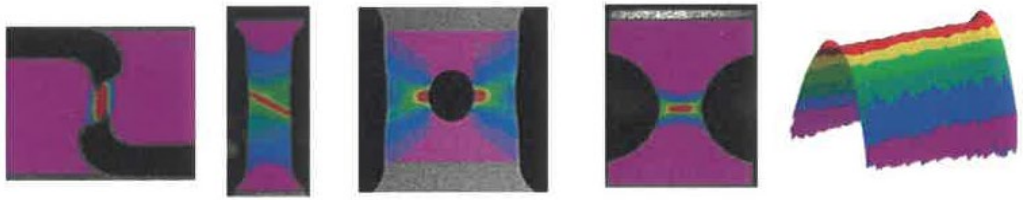


Phase-2

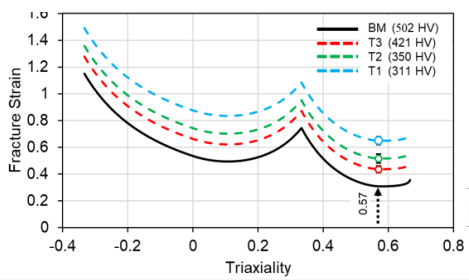
Produce large coupons represent different HAZ's across the RSW using Gleeble

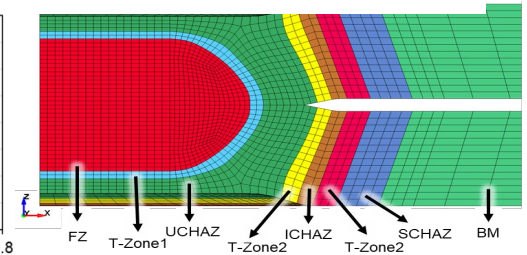


Mini Shear | Mini tension | Hole tension | Notch tension | V-Bend



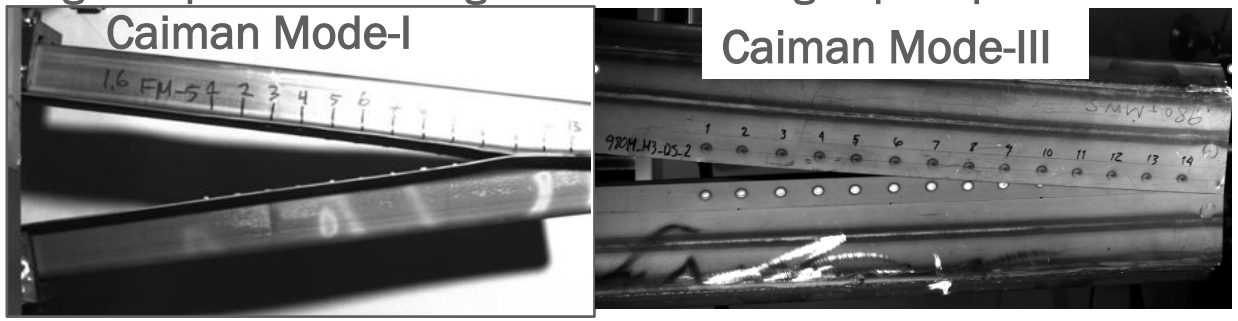
Develop maso-scale model that include HAZ to compare it with CAE model



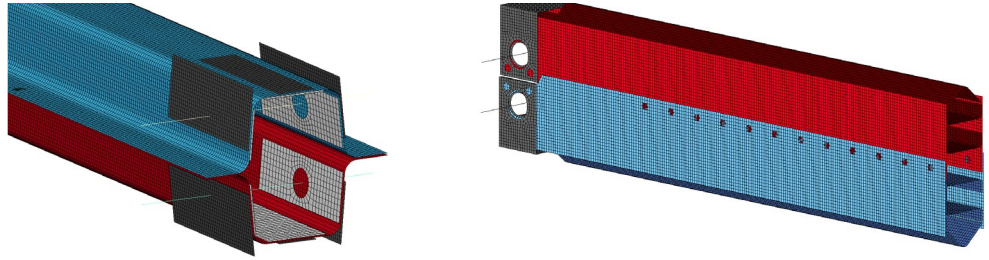


Phase-3

Using the optimized welding schedule to test group of spot weld failure



Using the single spot weld failure properties to calibrate CAE model for group of spot welds



MATERIALS AND TEST MATRIX

Material selection:

- 1.4 mm 3rd Gen 980 (CR600Y980T-RA-HE-UNCOATED)
- 1.4 mm 3rd Gen 1180 (CR850Y1180T-RA-SE-UNCOATED)
- 1.4 mm PHS 1500 (CR1500-PHS-AS)

Coupon Test Matrix:

- KSII at several angles
- Tensile shear
- Coach peel
- Cross tension

Gleeble Coupon Test Matrix:

Mechanical test matrix for HAZ Gleeble simulation									
Region	**SCHAZ**			**ICHAZ**			**UCHAZ**		
Material	**980**	**1180**	**PHS**	**980**	**1180**	**PHS**	**980**	**1180**	**PHS**
Mini-tensile	**550 °C (0.5 sec)**	**550 °C (0.5 sec)**	**550 °C (5 sec)**	**750 °C (1.2 sec)**			**1100 °C (1.2 sec)**		
Mini-shear									
V-bend (multiple sizes)									
Notch-tensile									

SCHAZ = Sub-critical Heat Affected Zone
ICHAZ = Inter-critical Heat Affected Zone
UCHAZ = Upper Critical Heat Affected Zone

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- **Common industrial method for testing and simulation of resistance spot welds**
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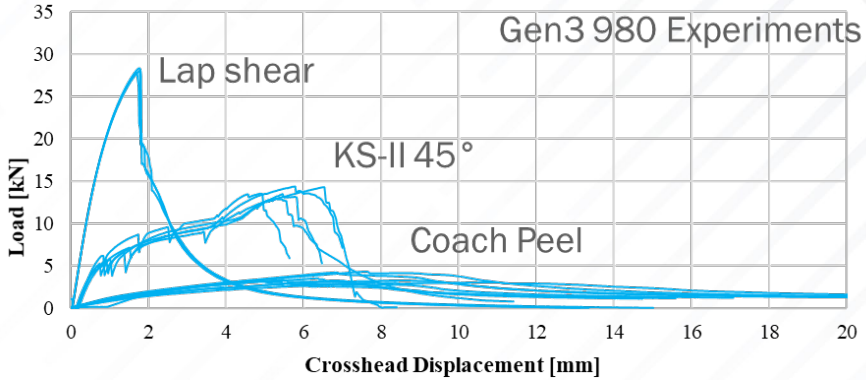
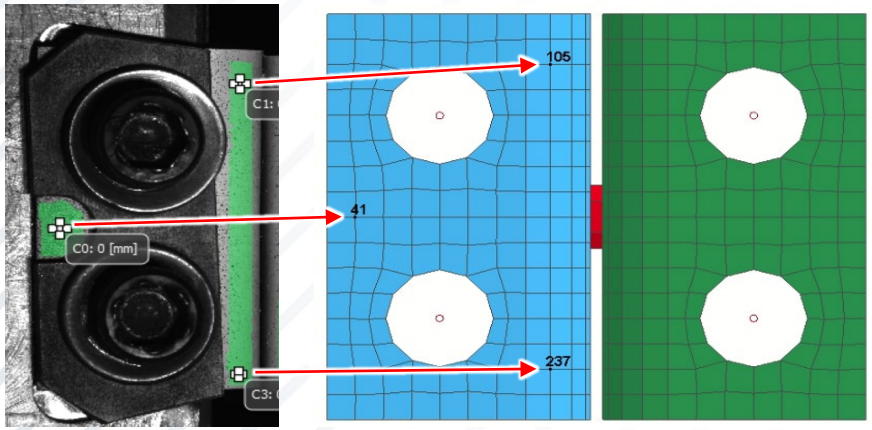
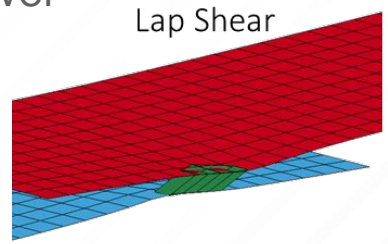
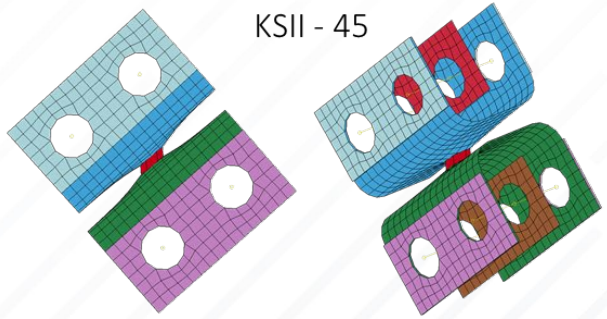
SPOT WELD MODELING USING COUPON TESTS

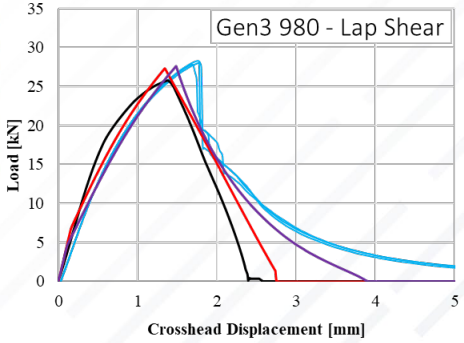
1. Process experimental data force vs displacement – target for simulations
2. Extract simulation boundary conditions from experiments - Novel method of KS-II 3D DIC analysis
3. Develop LS-DYNA simulation models of each single spot weld experiment
4. Calibrate three different LS-DYNA material models to compare performance
5. Validate spot weld failure on component level

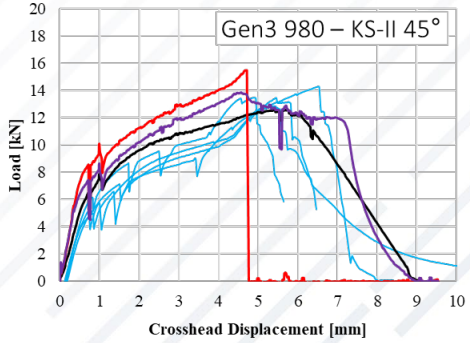


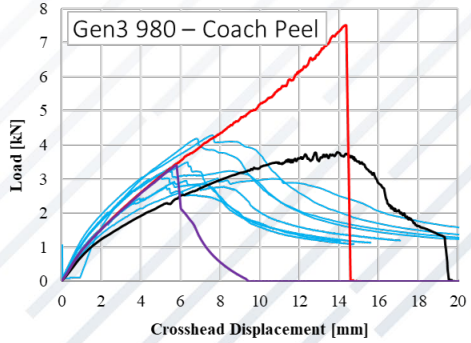








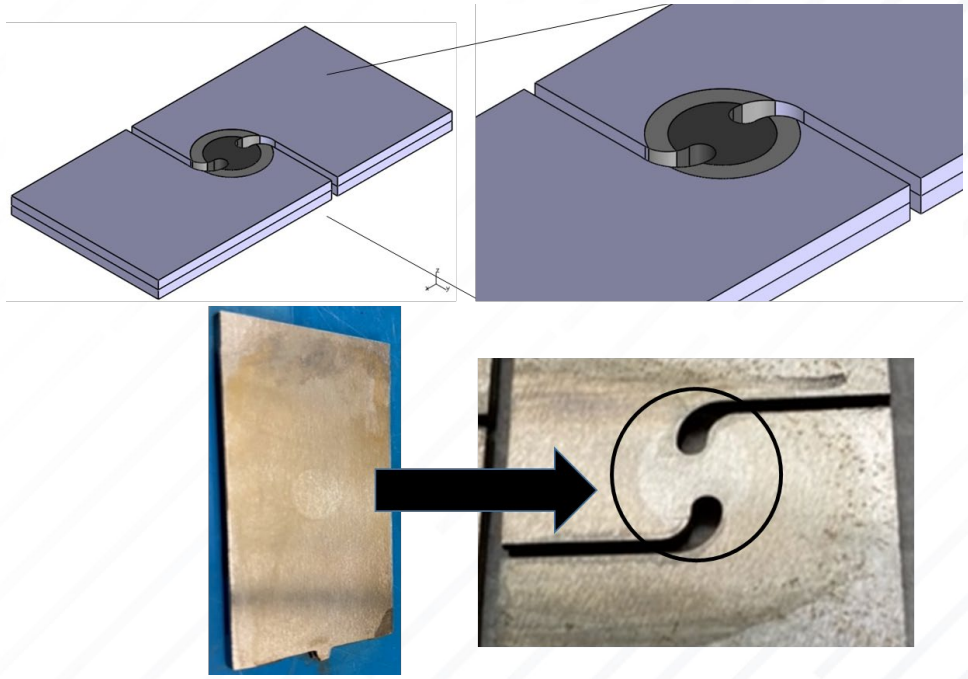




TWO NEW COUPON TEST CONFIGURATIONS: MINI SHEAR TEST

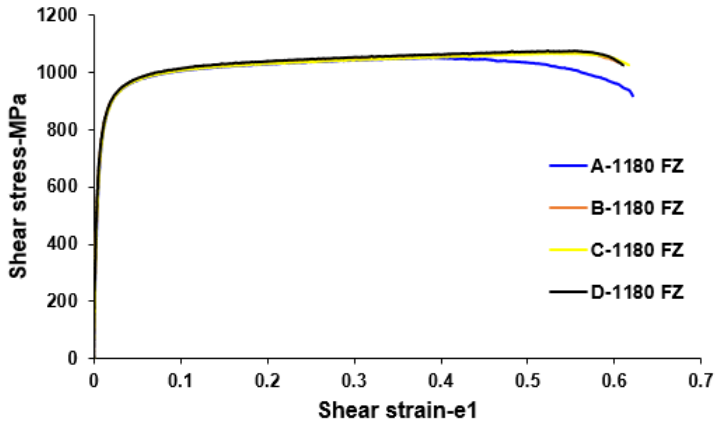
Mini-shear test to extract the FZ mechanical properties (can be used to estimate UCHAZ properties)

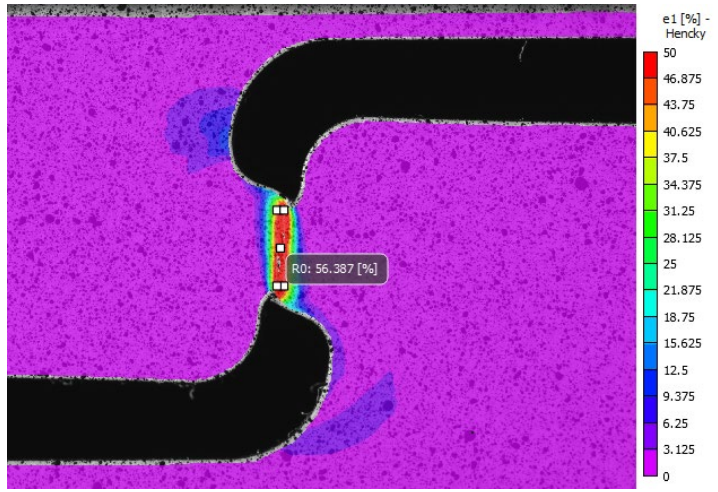
- Two mini-shear coupons (25 mm by 50 mm) with orientation 56° respect to the rolling direction were welded together.
- The coupons grinded to remove the top layer of the HAZ that surrounding the nugget (0.4mm removed from each side).
- The samples were etched using Nital etching solution to reveal the fusion zone area to make sure the weld in the center of the sample.
- Finally, EDM were used to machine the final mini-shear geometry.



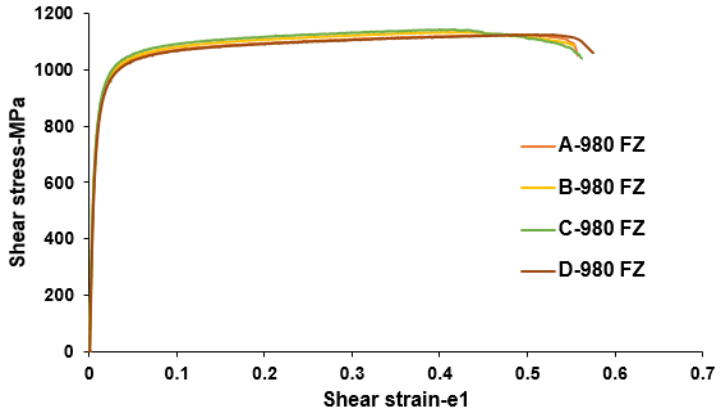
MINI-SHEAR RESULTS

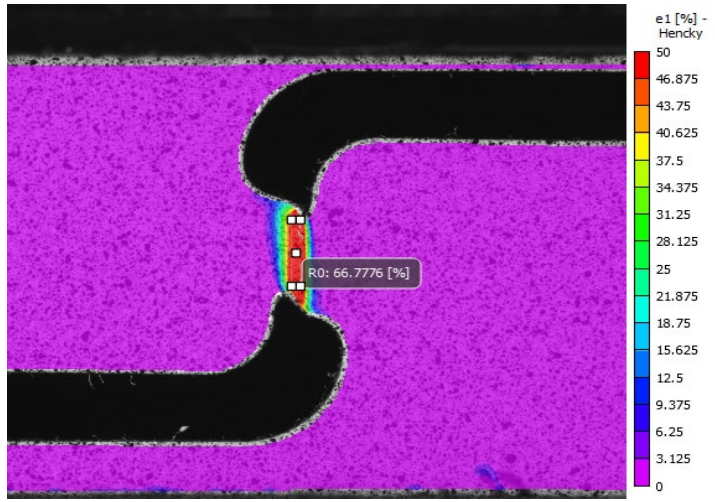
3rd Gen 980 - FZ minishear



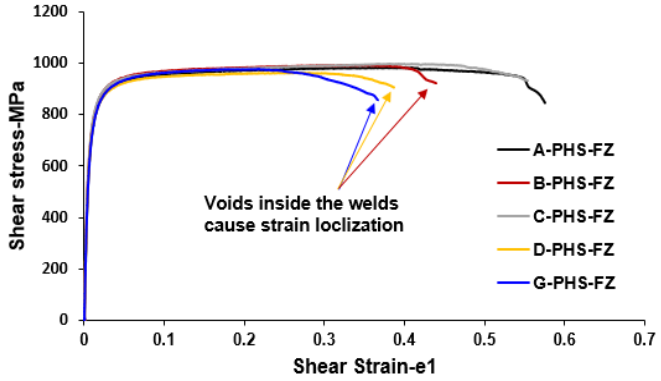


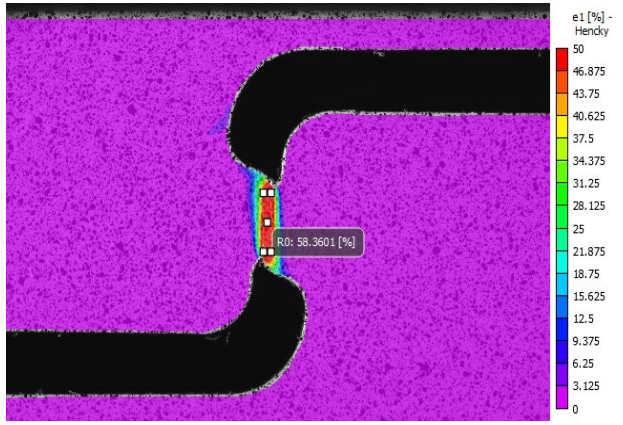
3rd Gen 1180 - FZ minishear



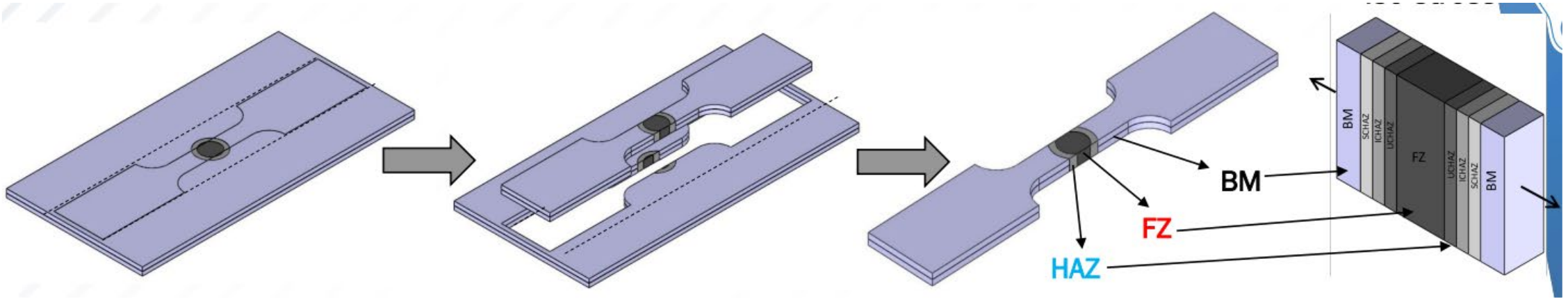


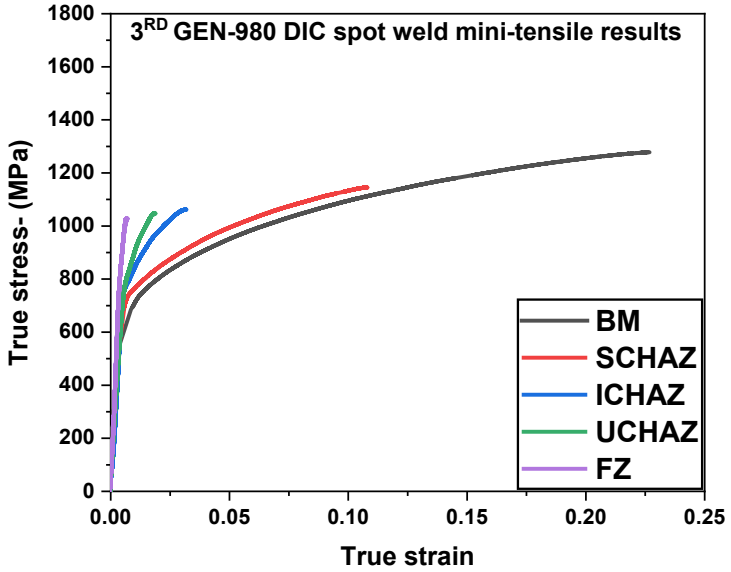
PHS1500 - FZ minishear

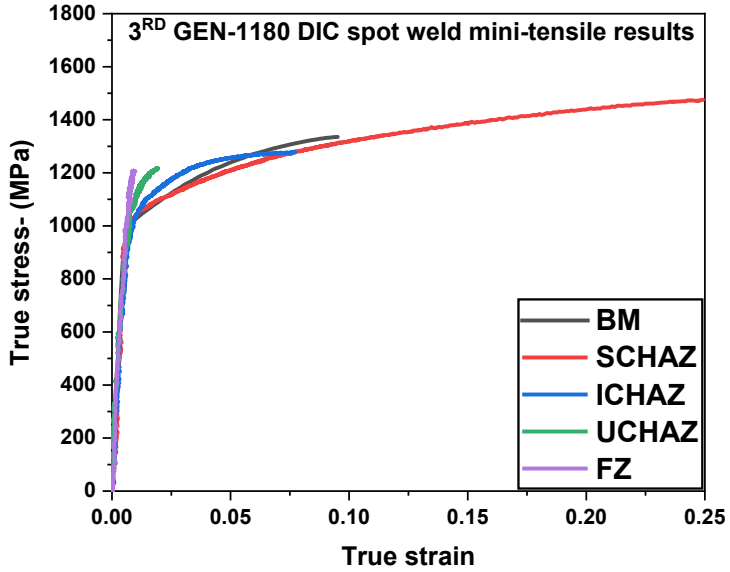


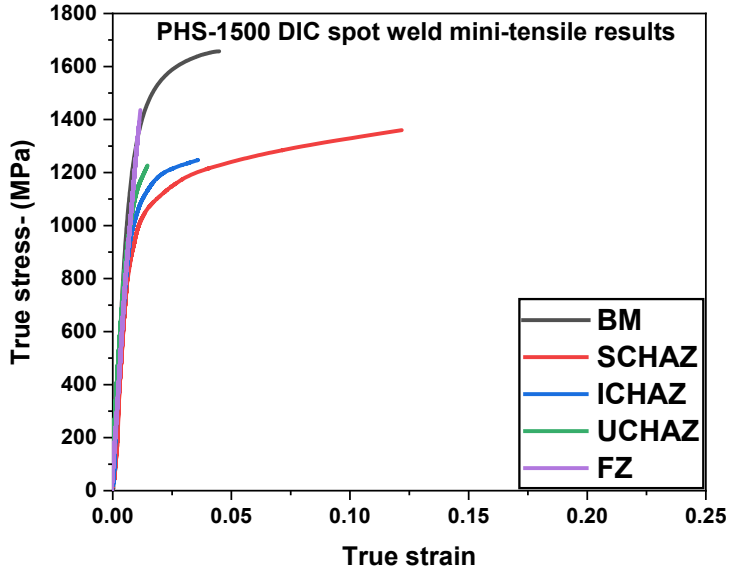


TWO NEW COUPON TEST CONFIGURATIONS: : MINI TENSILE TEST









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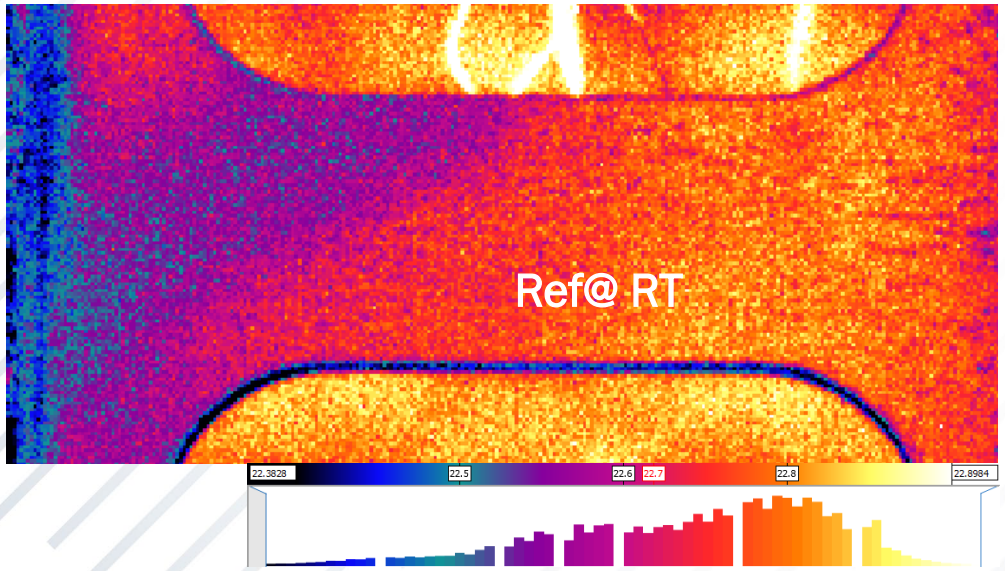
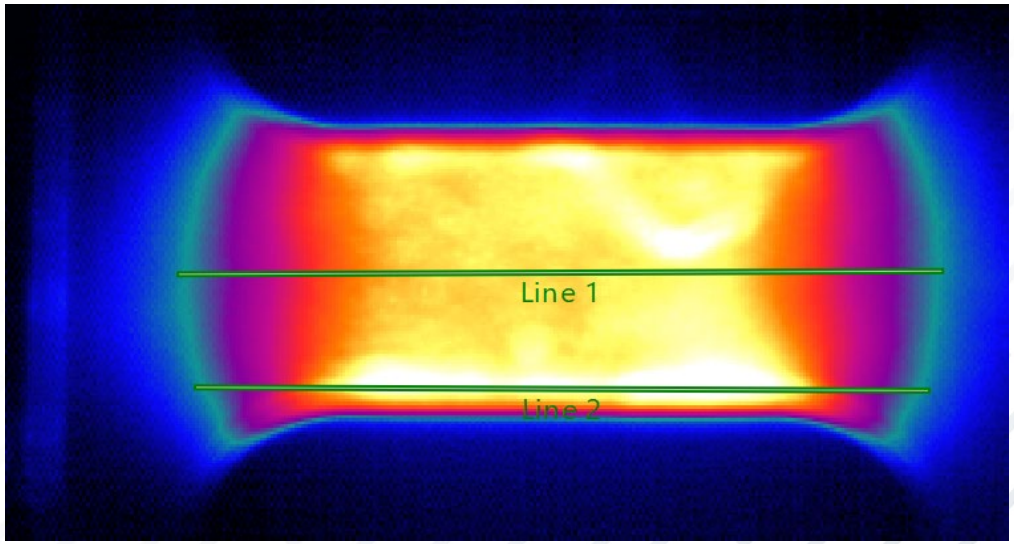
SPOT-WELD HAZ CHARACTERIZATION USING GLEEBLE SIMULATOR

- Thermo-mechanical simulator (Gleeble) is commonly used to simulate different HAZs and extract full coupon mechanical testing and microstructural analysis.

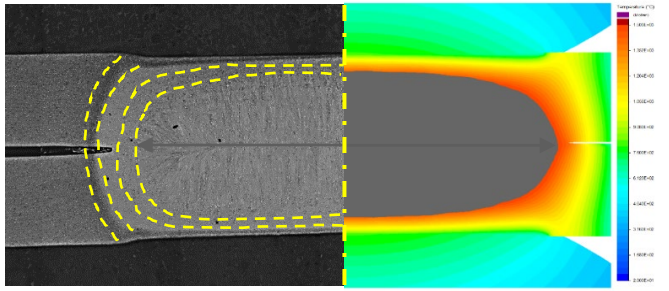
- To simulate different HAZs the heating and cooling rate should be precisely controlled. Actual welded coupons are usually used as a baseline to compare the microstructure and hardness of the simulated specimens.

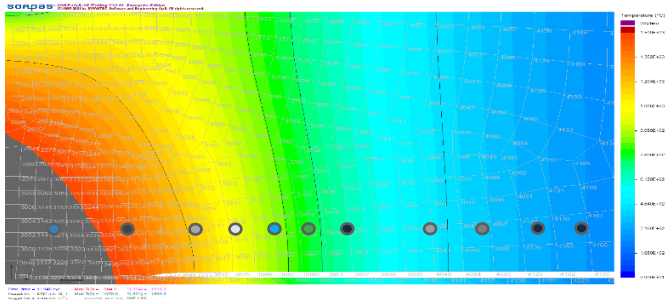


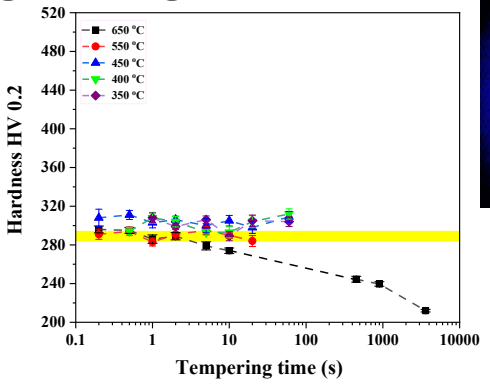


THERMO-MECHANICAL SIMULATION OF THE HAZ FOR 3RD GEN AHSS

Using Sorpas simulation to determine the heating and cooling rates

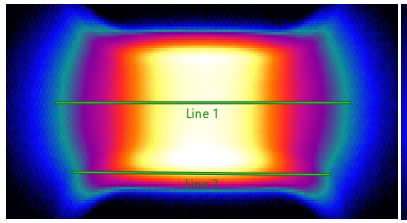




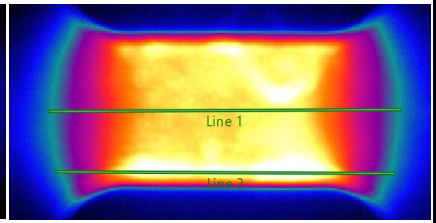


Using thermal cameras to confirm the temperature distribution along the gauge length

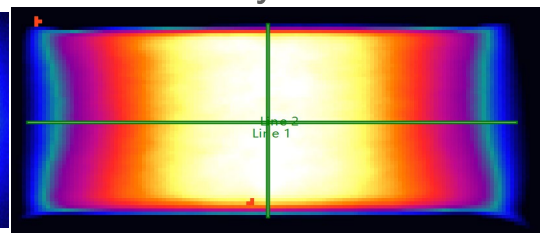
10 by 10 mm

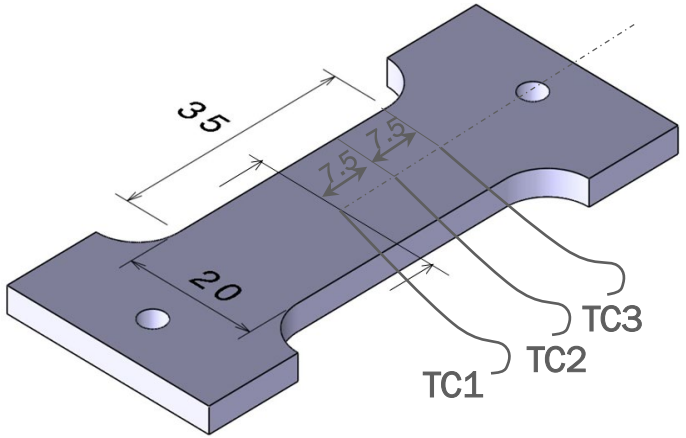


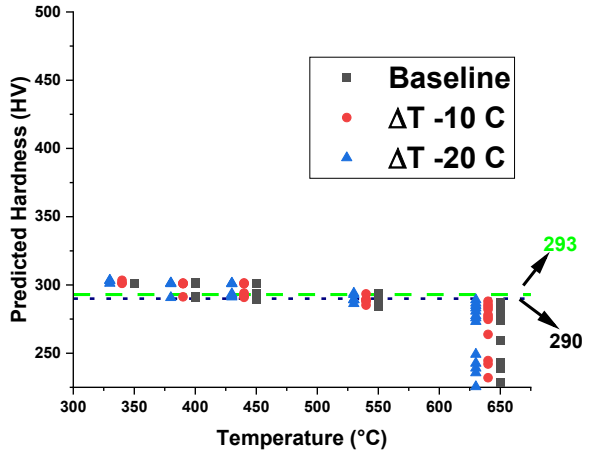
20 by 16 mm

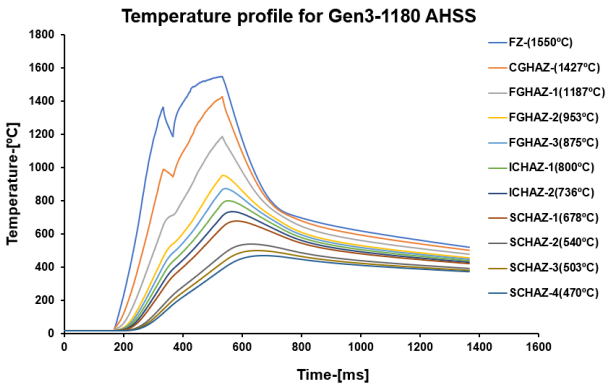


35 by 20 mm



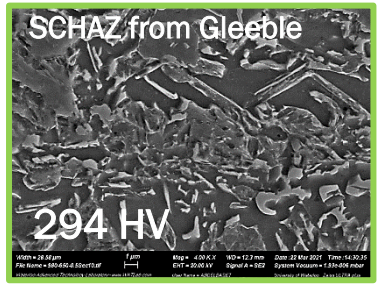


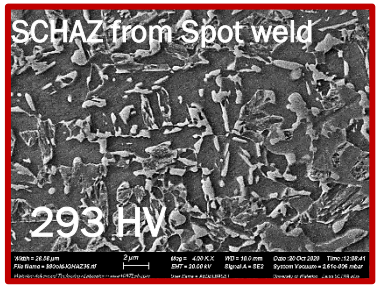


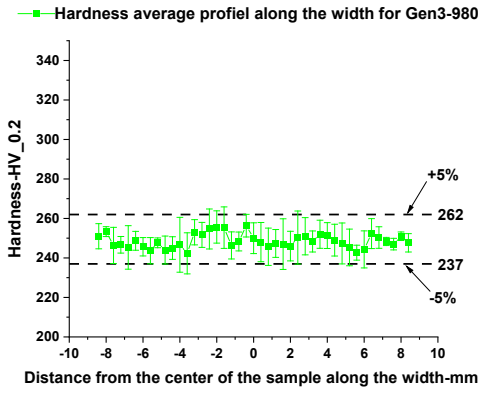


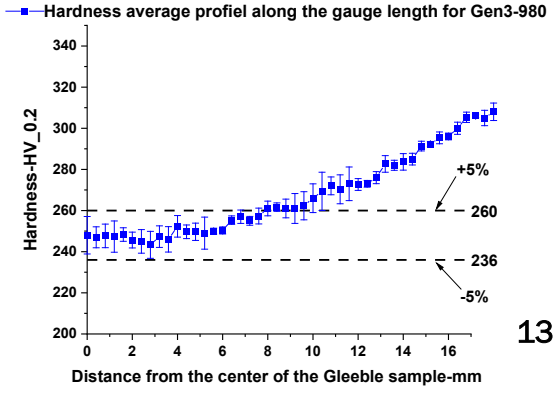
Fitting the hardness data into the HJ model

Matching the hardness and microstructure



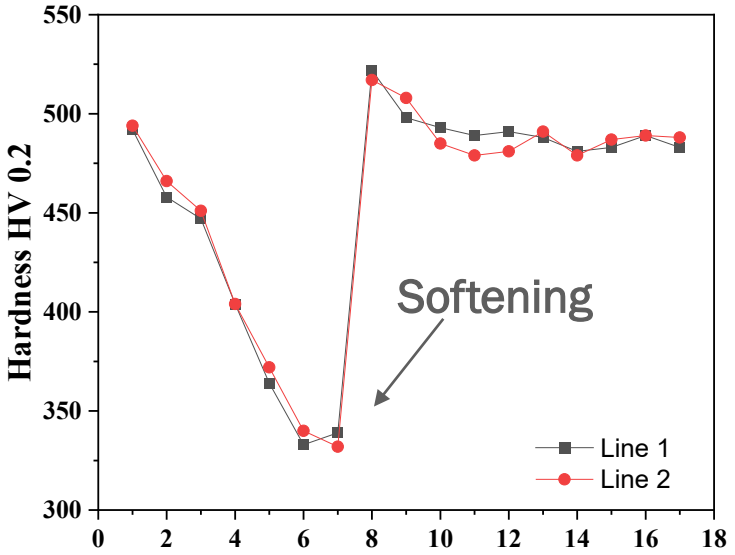






HARDNESS PROFILE FOR THE WELDED SAMPLES

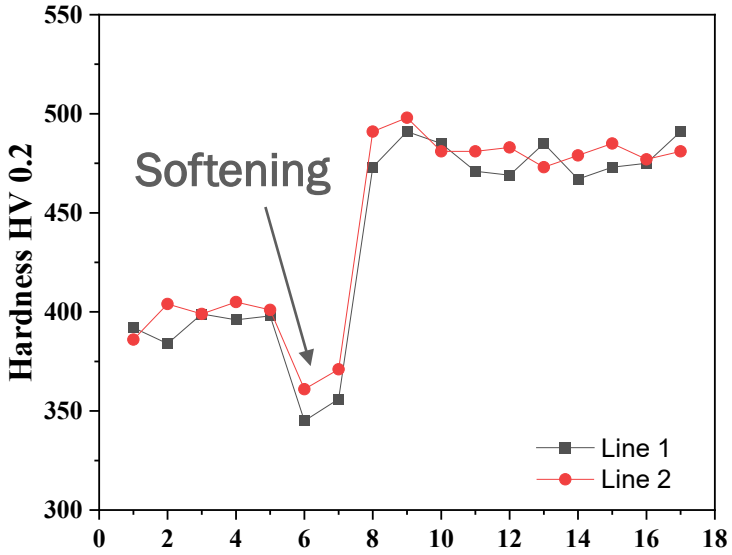
Material 1: PHS-1500



Average min hardness: **336 HV**
Corresponding sample:
550 ^{0}C - 5s

HJP 14100

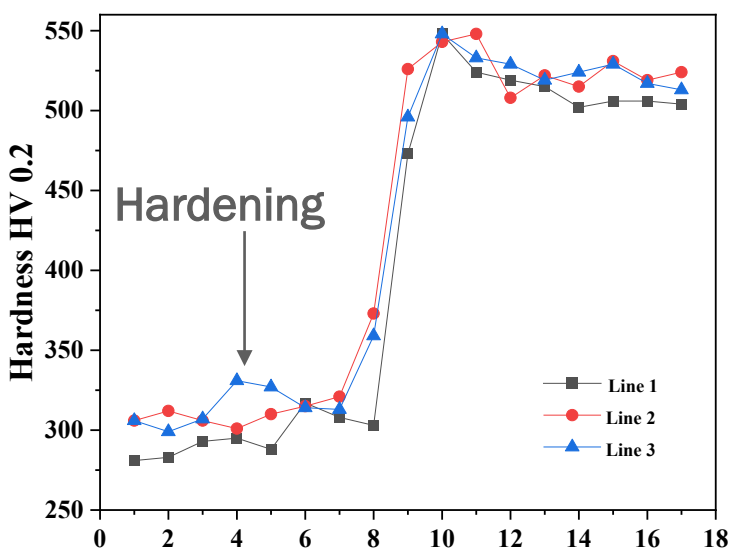
Material 2: 3rd Gen 1180



Average min hardness: **358 HV**
Corresponding sample:
550 ^{0}C - 5s

HJP 14095

Material 3: 3rd Gen 980



Average min hardness: **300 HV**
Corresponding sample:
650 ^{0}C – 0.2s

HJP 14527

$$H - J\ parameter\ = T(C + \log t)$$

Where C: is material constant [C = 17.7 – 5.8 x (% of C)];
t: tempering time in seconds; T is temperature in K.

HAZ THERMAL SIMULATION TEST MATRIX

Four mechanical tests will be performed on all three materials (3rd Gen 980, 3rd Gen 1180, and PHS1500). Five repeats will be tested and the average value with standard variation will be used to compare the experimental results with the FE model.

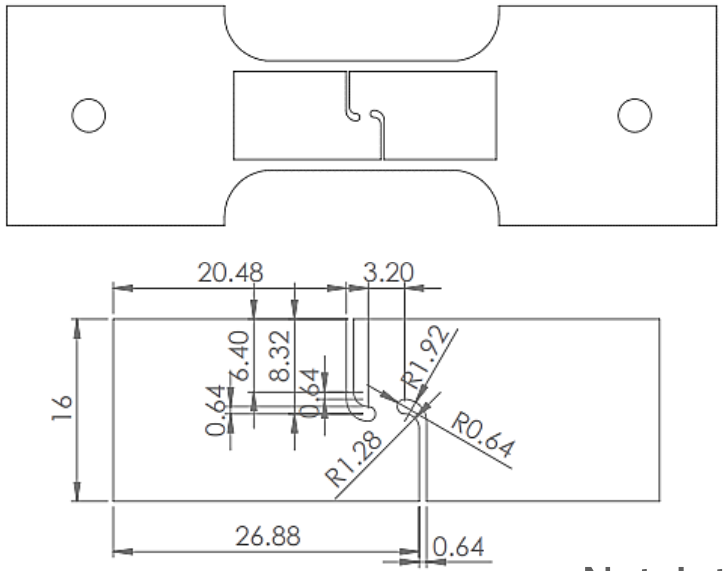
Mechanical test matrix for HAZ Gleeble simulation									
Region	SCHAZ			ICHAZ			UCHAZ		
Material	980	1180	PHS	980	1180	PHS	980	1180	PHS
Mini-tensile	550 °C (0.5 sec)	550 °C (0.5 sec)	550 °C (5 sec)	750 °C (1.2 sec)			1100 °C (1.2 sec)		
Mini-shear									
V-bend (multiple sizes)									
Notch-tensile									

- In total, 90 coupons will be simulated for each material to cover all HAZ's and 4 mechanical tests considering 5 repeats for each test.
- The simulated samples will be machined to the final geometry to perform the mechanical test.
- Extra samples will be simulated to confirm the microstructure and hardness results.

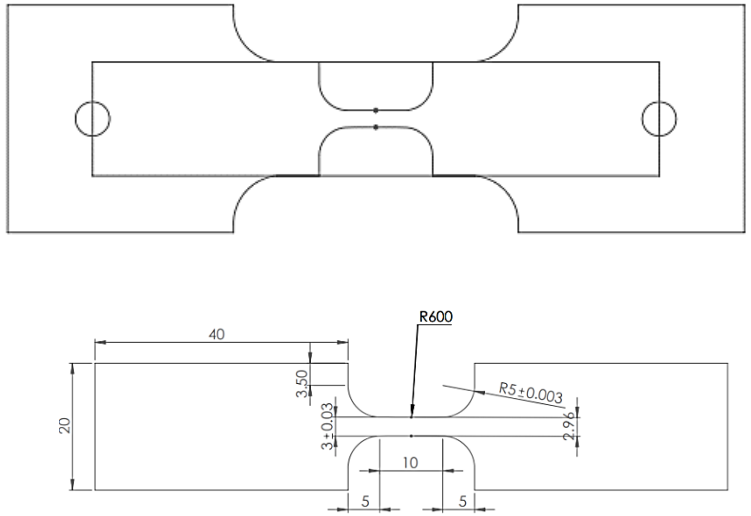
SUGGESTED MINIATURE HAZ COUPON GEOMETRIES

For constitutive calibration and fracture characterization of HAZ, miniature geometries were fabricated using a Gleeble thermo-mechanical simulator. Design constraints were presented in the coupon shape and the gauge area homogeneously heated by the Gleeble

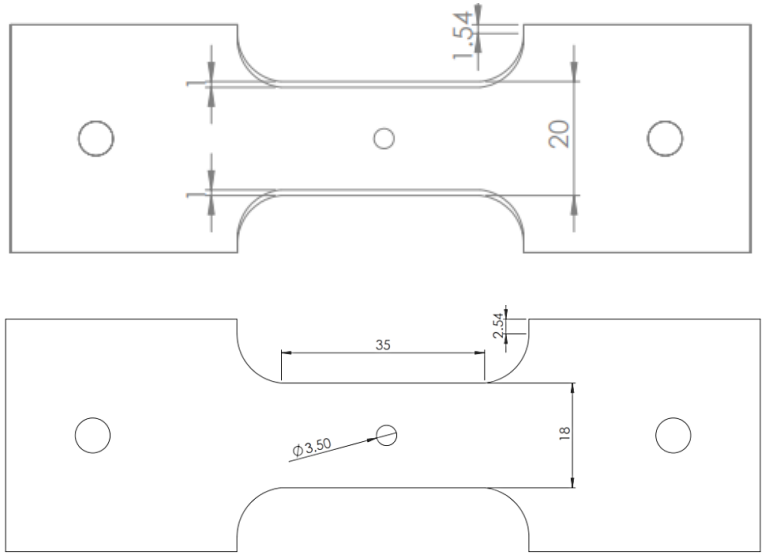
Micro-shear



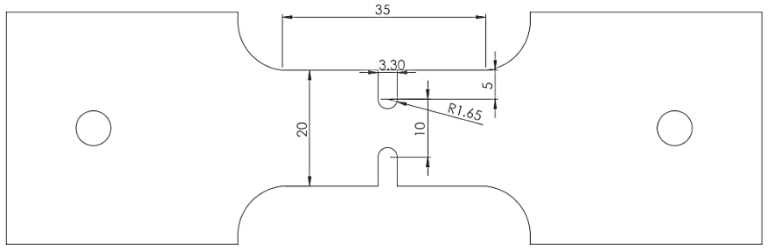
Mini-tensile



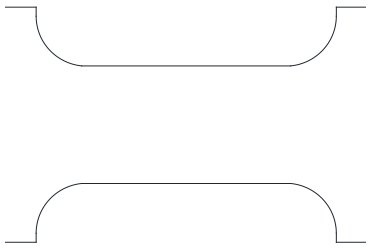
Hole-tensile



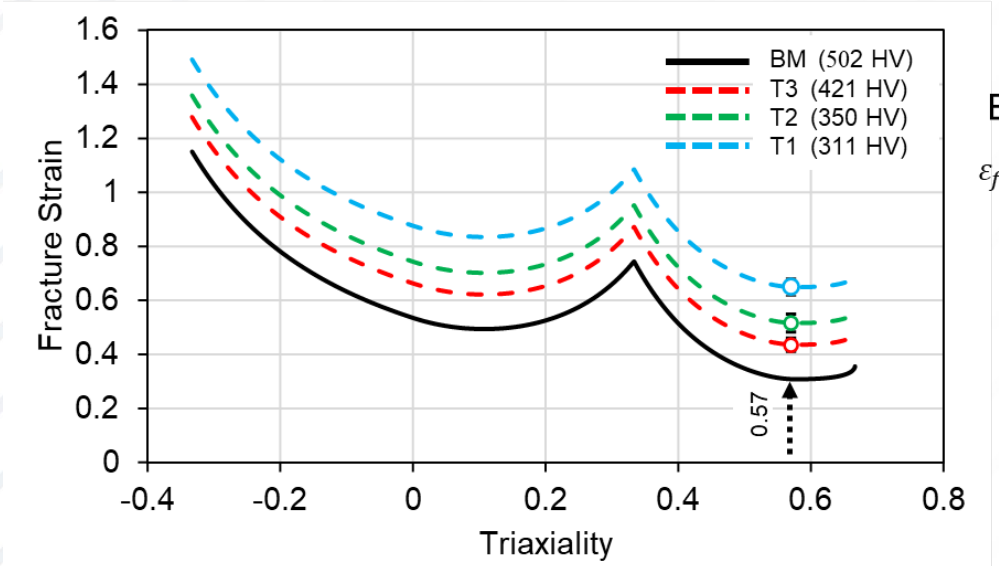
Notch-tensile



Sub-size V-bend



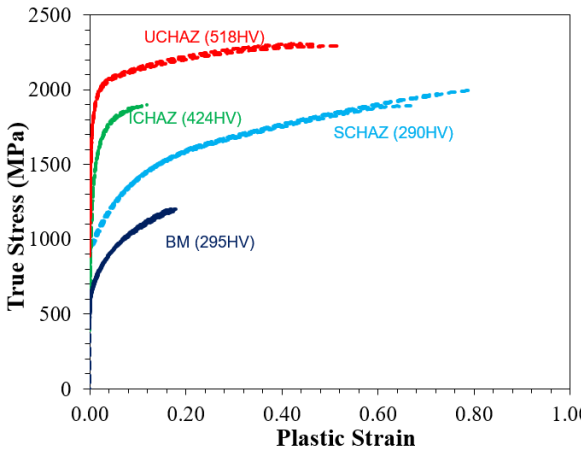
HAZS PLASTICITY AND FAILURE CHARACTERIZATION (FUTURE WORK)

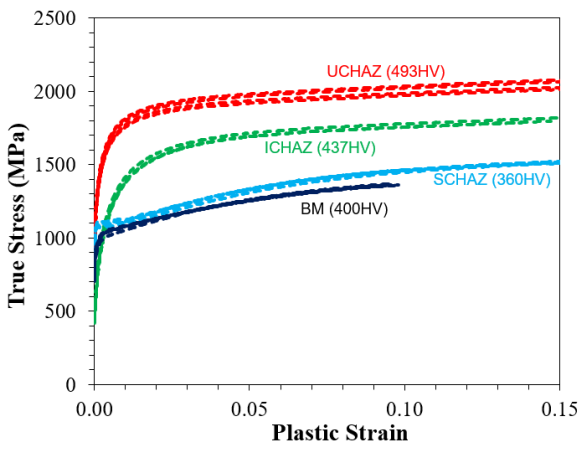


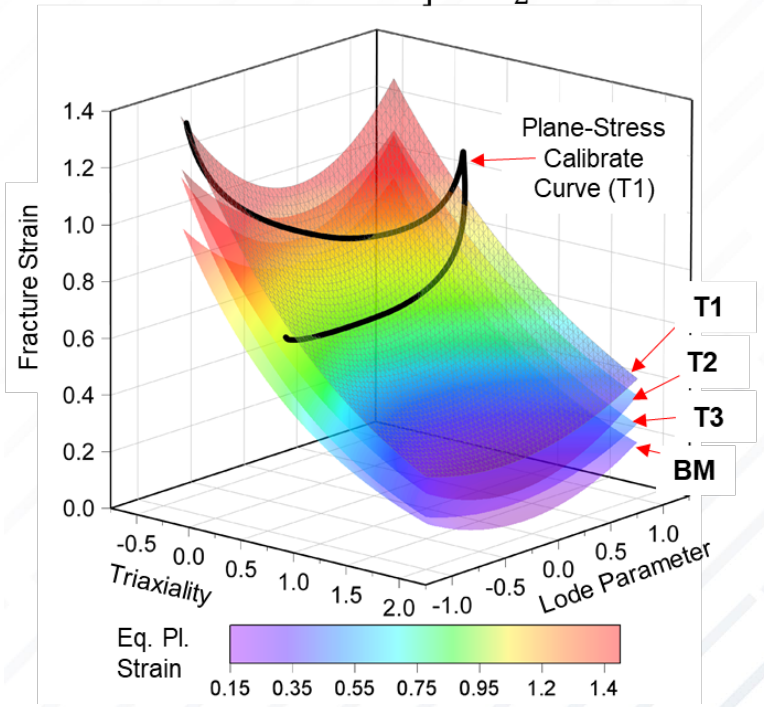
In plane stress $\dot{\theta} = -\frac{27}{2}\eta\left(\eta^2 - \frac{1}{3}\right)$

Bai-Wierzbicki Fracture Surface

$$\varepsilon_f(\eta,\dot{\theta}) = \left[\frac{1}{2}(D_1 e^{-D_2\eta} + D_5 e^{-D_6\eta}) - D_3 e^{-D_4\eta}\right]\dot{\theta}^2 + \frac{1}{2}(D_1 e^{-D_2\eta} + D_5 e^{-D_6\eta})\dot{\theta} + D_3 e^{-D_4\eta}$$





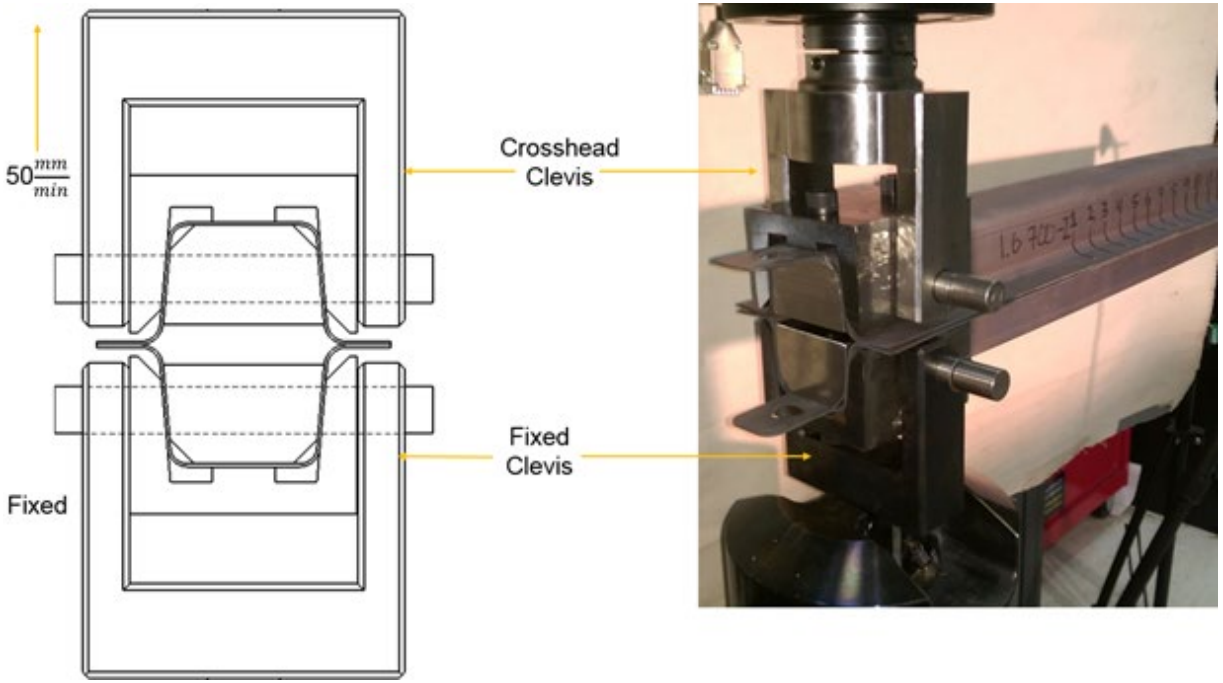


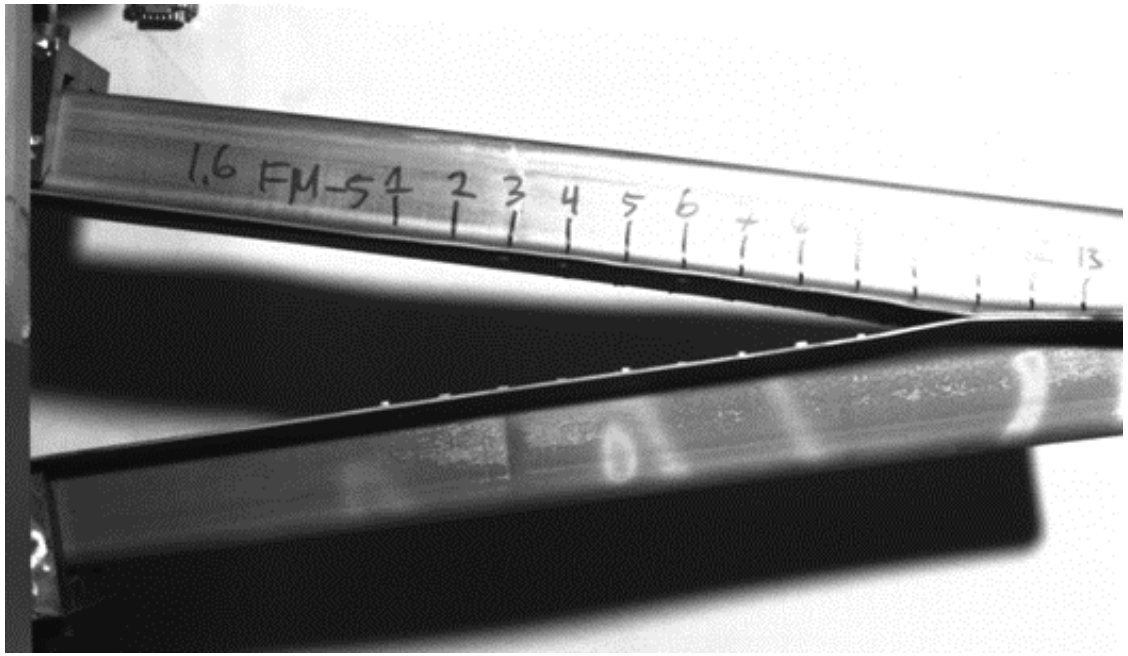
OUTLINE

- Project Summary
- Common industrial method for testing and simulation of resistance spot welds
- Advanced detailed microstructure characterization method of resistance spot welds
- **Component level validation of resistance spot weld fracture models**
- Summary and Future work

CAIMAN MODE I – DESIGN REVIEW

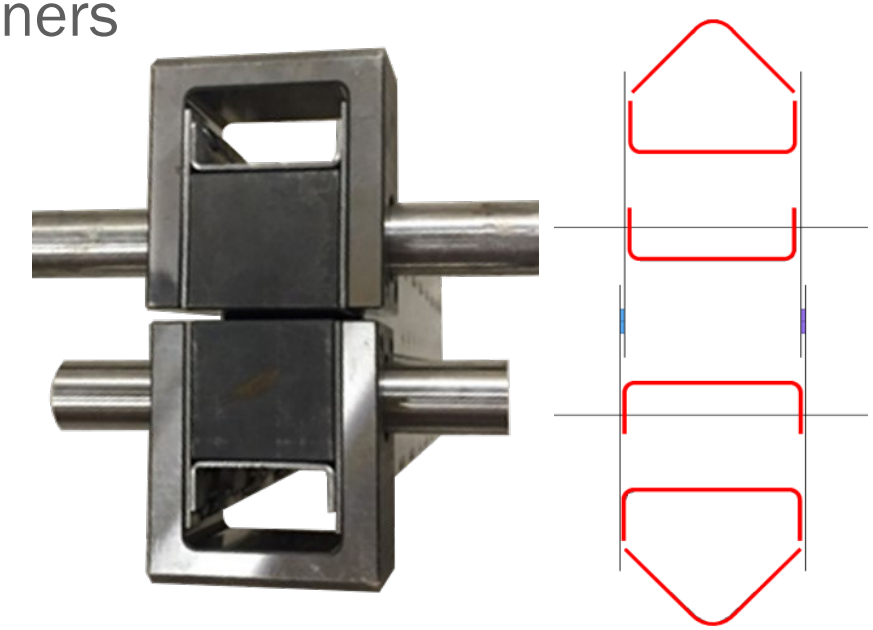
- RSW hat-channel rail assembly
  - 14 spot welds per flange (~2/3 length of the rail)
  - Pins and bosses pull channels apart
  - Welds sequentially loaded with a normal tensile stress
  - Mode I-type fracture

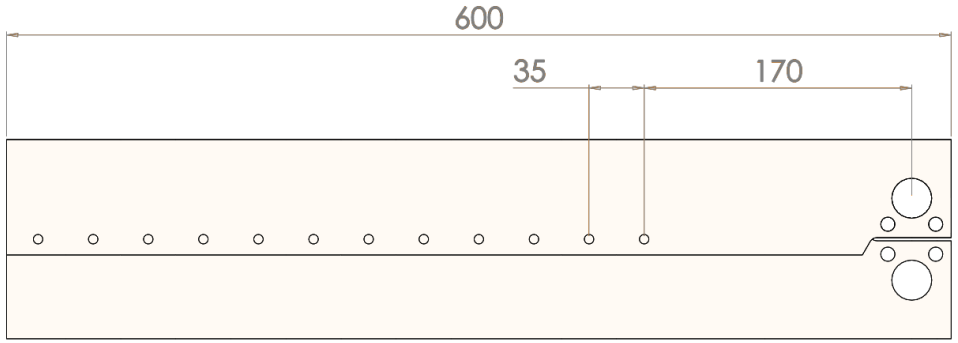




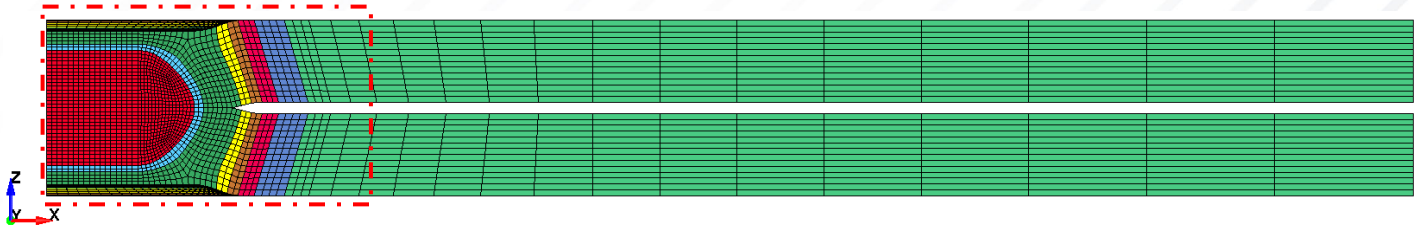
CAIMAN MODE III FINAL DESIGN

- 4 C-channels used to join walls and act as internal stiffeners
- V-shape closing plate to prevent sidewalls from buckling
  - C-channels and closing plate made out of 3rd Gen 980 steel
- Clamping boss design same as Mode I design
- Quasi-static and dynamic test conditions

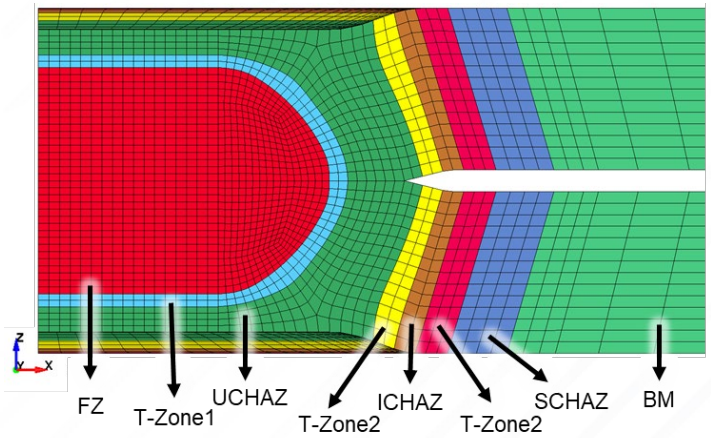




MESO-SCALE FAILURE MODELING (PROPOSED FUTURE WORK)



Meso-scale spot weld failure model



Source of data

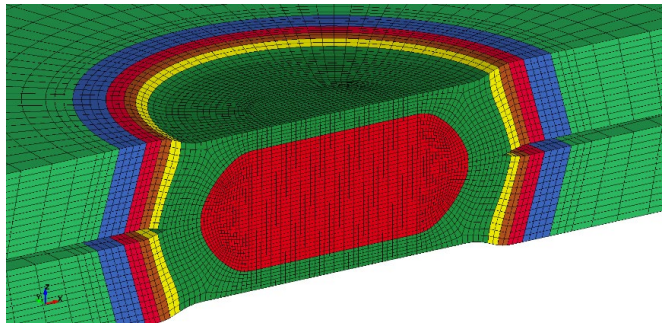
Required dataset

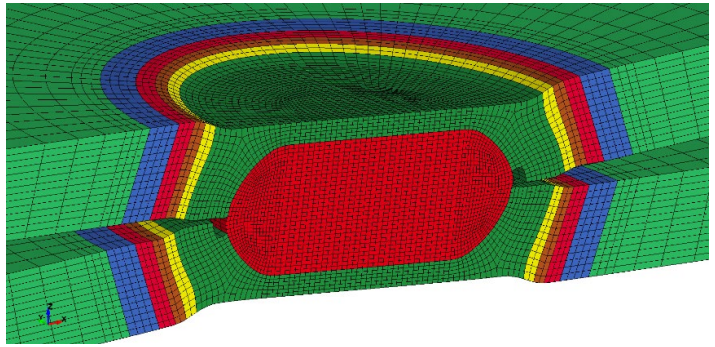
Weld geometry and corresponding microstructural observations → Detailed spot weld FEA model

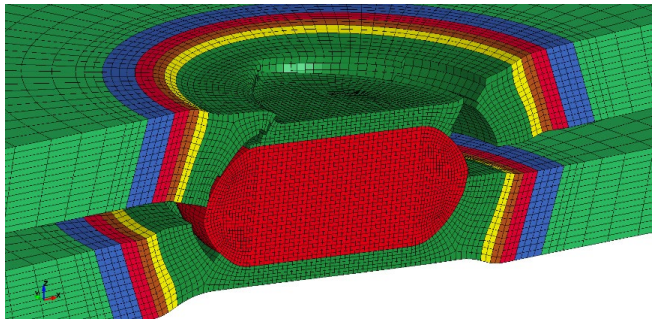
Miniature HAZ Gleeble coupon tests and simulation → Constitutive models with 3D Fracture loci

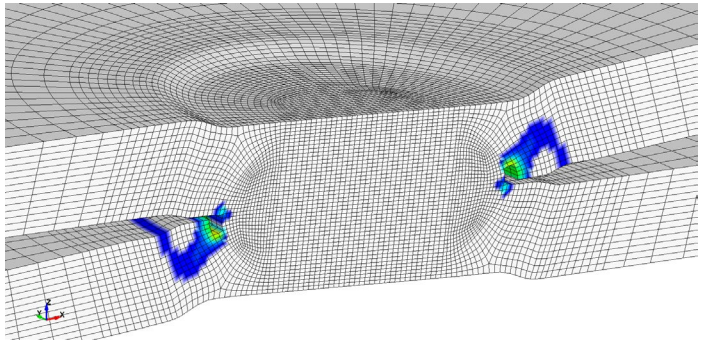
- Failure mode prediction
- Through-thickness damage progression
- Effect of microstructure on failure

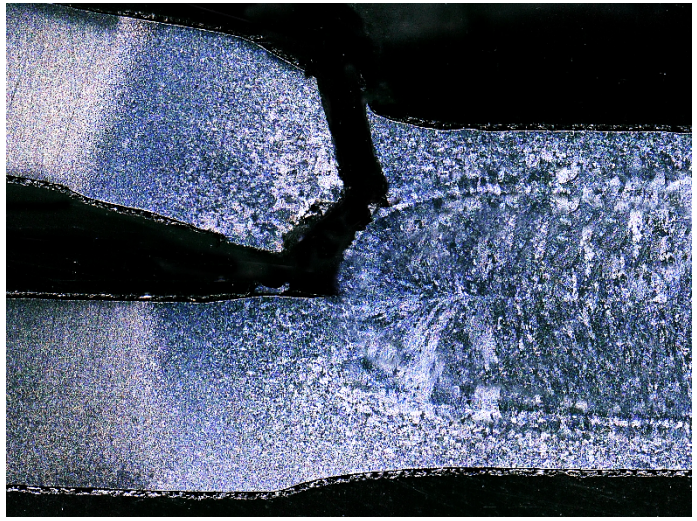
EXAMPLE: PHS – LAP-SHEAR TEST SIMULATION

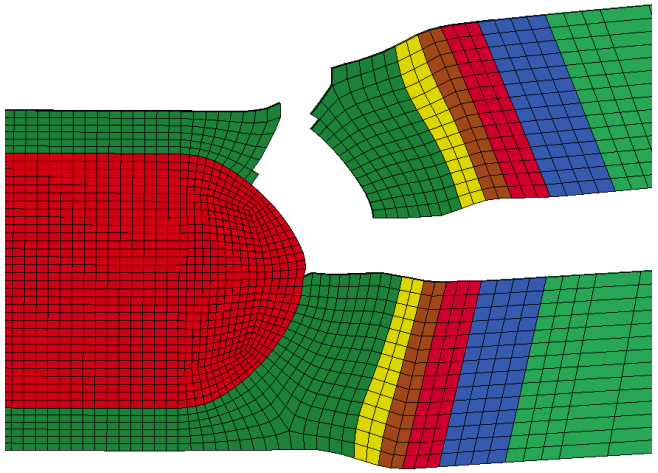


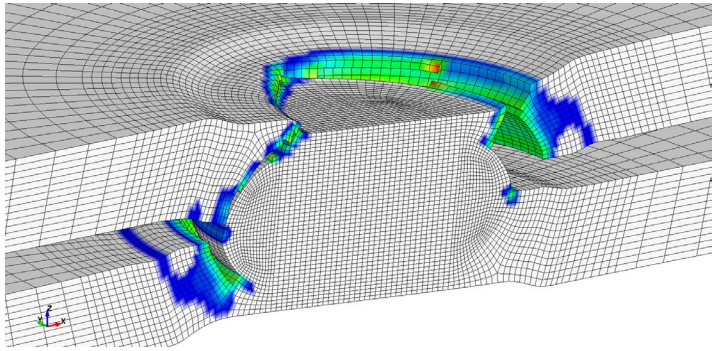












CONCLUSION

- Coupon tests including lap shear, cross tension, coach peel and KS-II (8 orientations) have been completed
- Two new testing configurations: Mini-shear and mini-tensile coupons have been developed
- CAE model and weld strength material cards have been developed using single spot weld coupon test data
- Gleeble thermal profiles for HAZs for three materials have been developed and optimized for coupon fabrication
- Miniature HAZ Gleeble coupon tests have been performed for plasticity and fracture loci characterization
- CAIMAN MODEL III component design has been finalized to produce shear failure mode in spot welds

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Auto/Steel Partnership

UNIVERSITY OF Waterloo

For More Questions, Please Meet the speaker at the Auto/Steel Partnership booth after this presentation.