GREAT DESIGNS IN STEEL

Advanced Industrial Simulation Method for Spot Weld Separation Validated with Components

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A/S P

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Outline

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Test Material and Test Matrix

Single Spot Weld Characterization and Modeling Results

Component Tests and Simulation Results

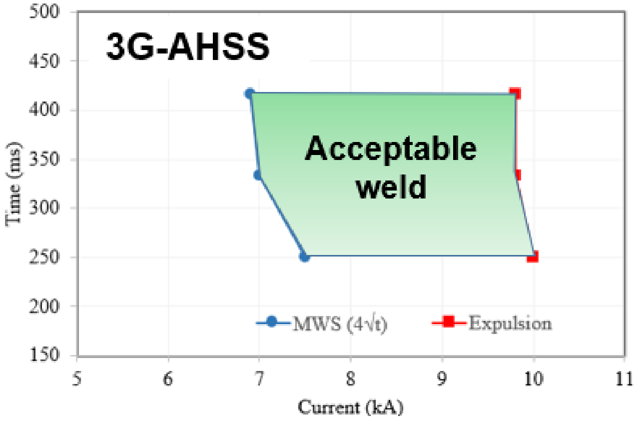
Summary and Future Work

Introduction

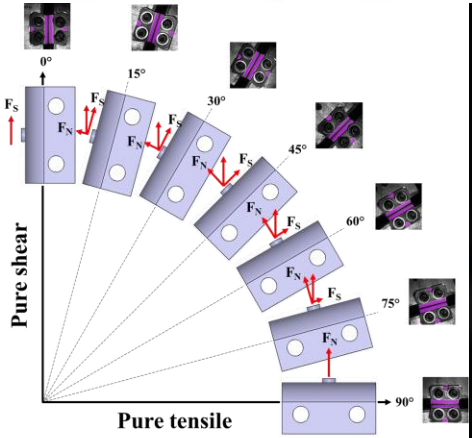
GDIS

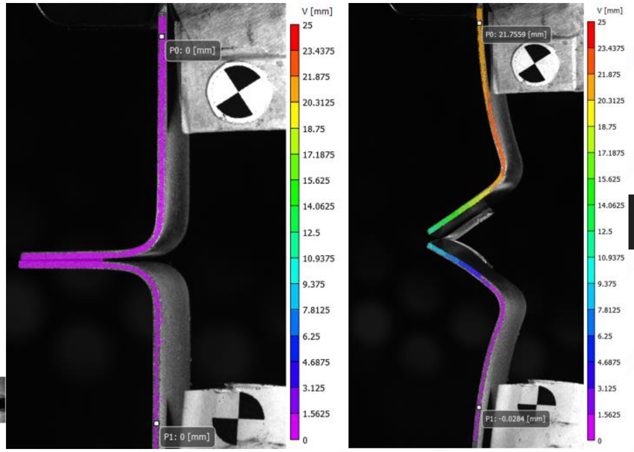
Coupon Test and Simulation

RSW process optimization

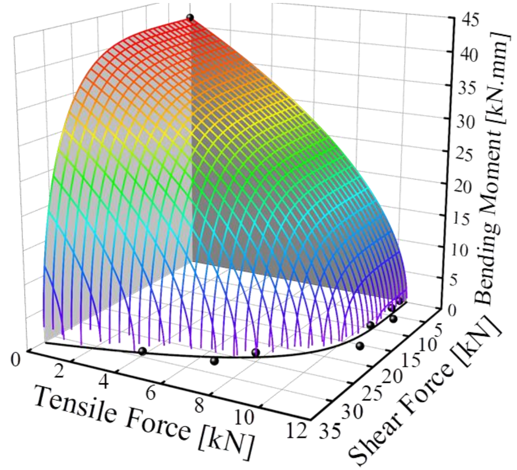


Characterize single spot weld



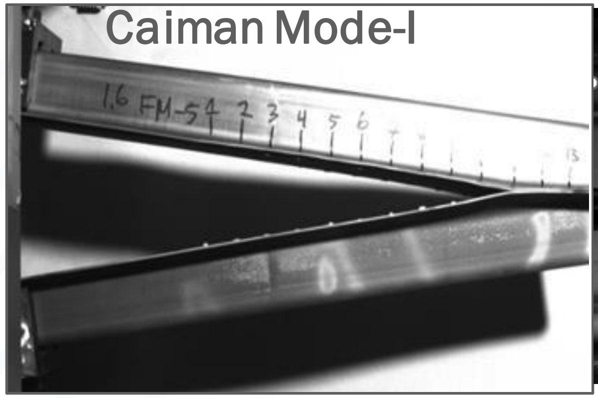


Develop 3D fracture surface

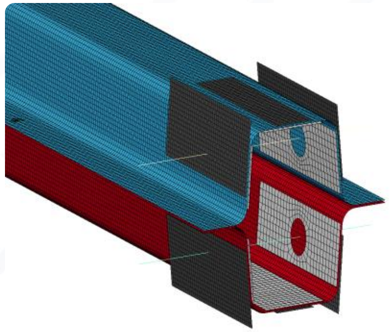


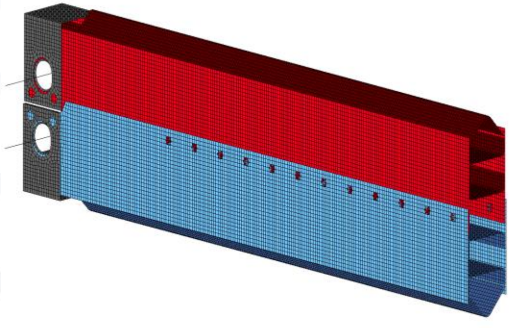
Component Validation

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





Objectives

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- Develop testing methods for spot weld strength characterization
- Characterize the mechanical properties of RSW single spot weld through mechanical coupon tests
- Create fracture surface using single spot weld mechanical coupon data
- Weld component test under different loading modes
- Validate spot weld strength cards using component tests

Material and Test Matrix

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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 (0, 15, 30, 45, 60, 75, 90)
- Tensile shear
- Coach peel
- Cross tension

Component Test Matrix:

- Caiman Mode I (Quasi static & Dynamic)
- Caiman Mode III (Quasi static & Dynamic)

Single Spot Weld Characterization and Modelling Results:

Standard and Advanced Characterization

Coupon Mechanical Tests: Standard Characterization

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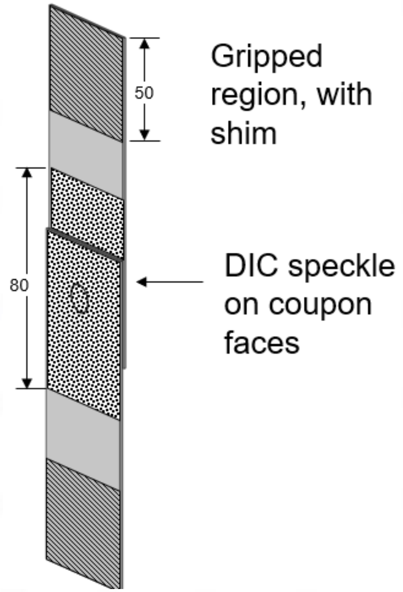
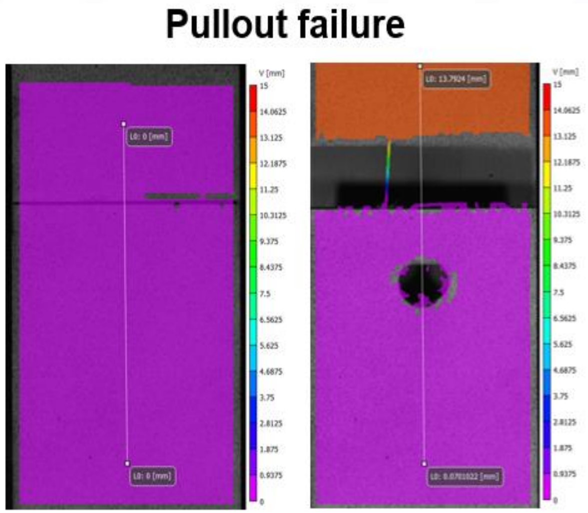
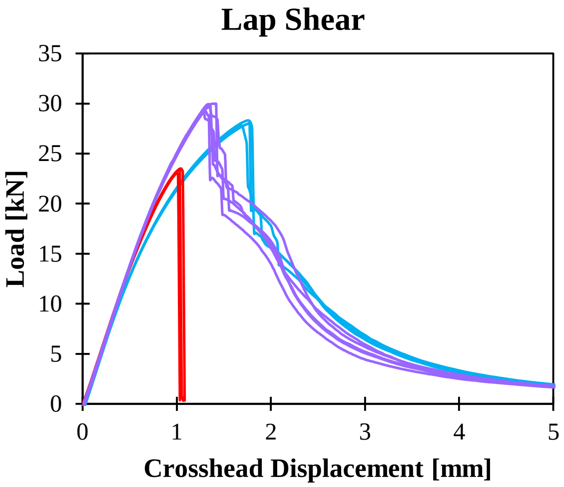
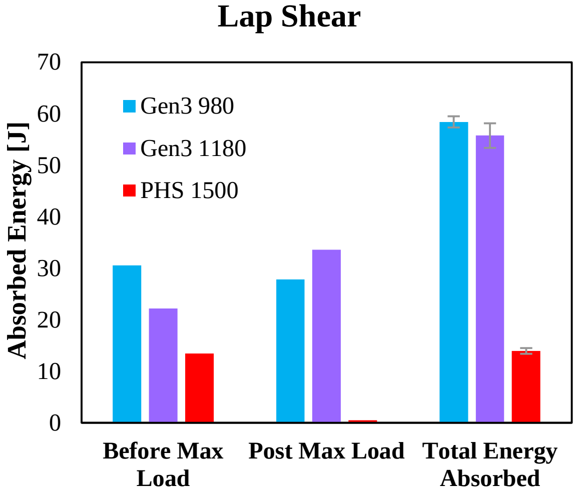
Lap shear

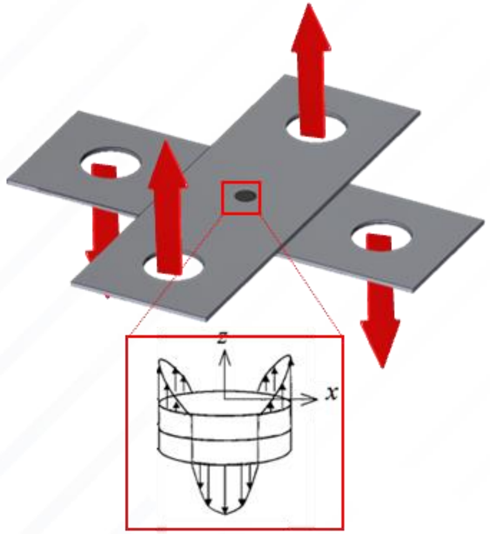


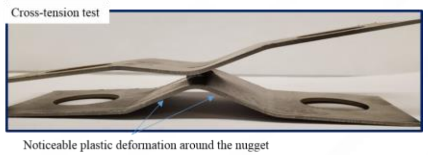


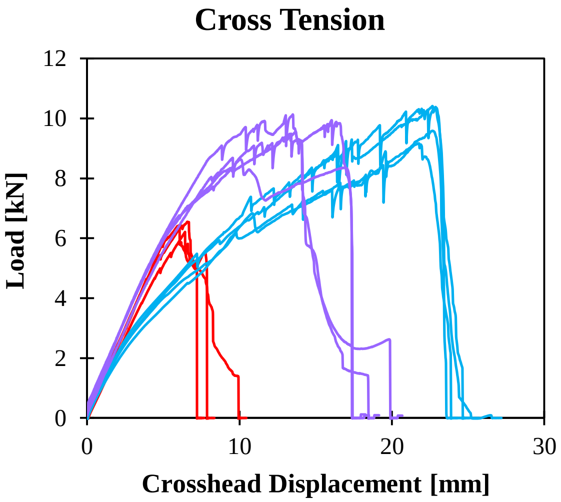


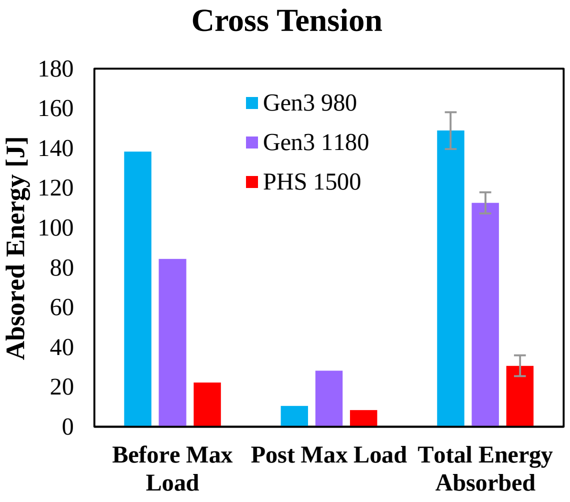


Cross tension









Coupon Mechanical Tests: Advanced Characterization

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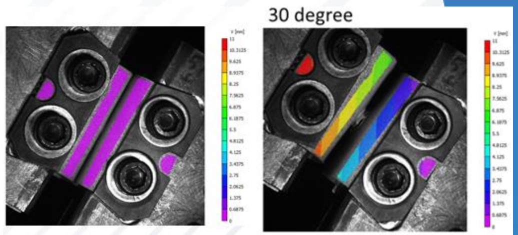
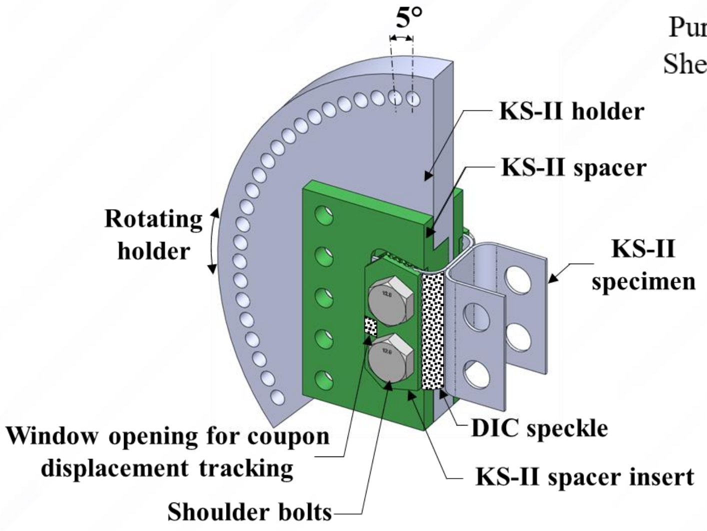
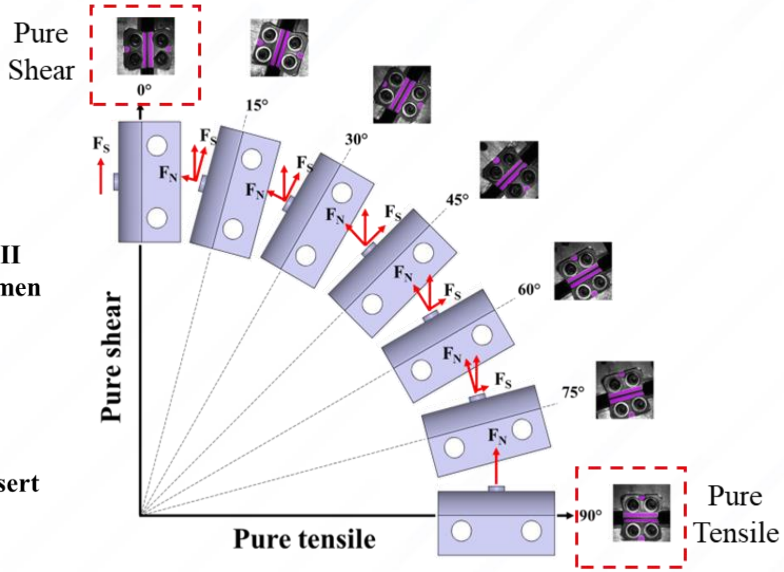
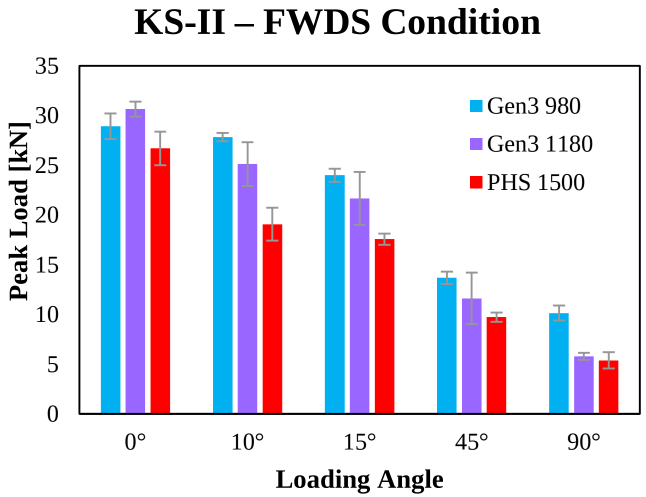


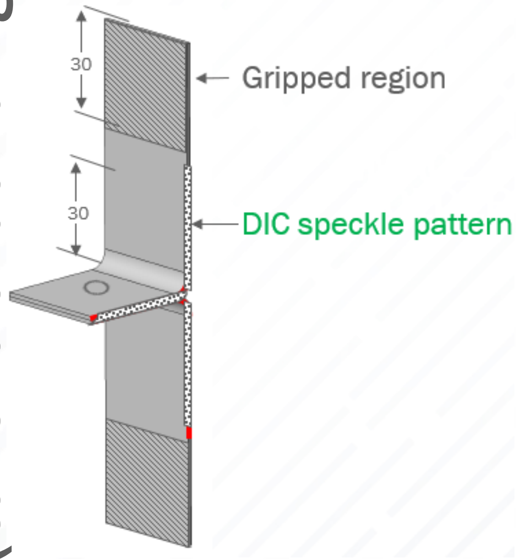
KS-II (shear & tensile)

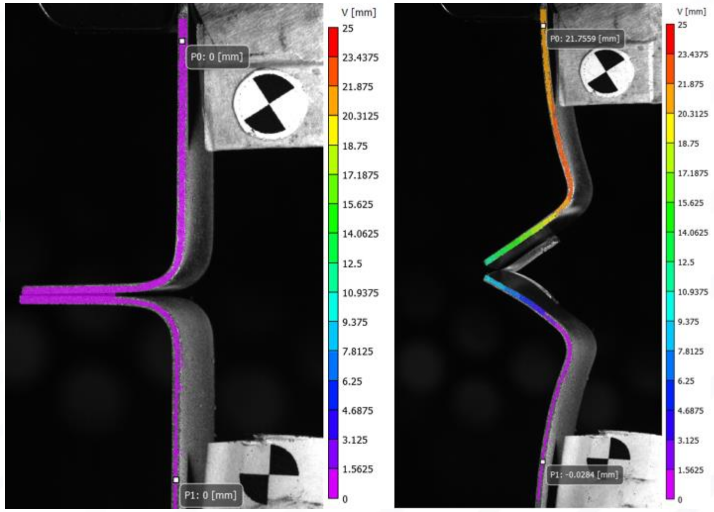


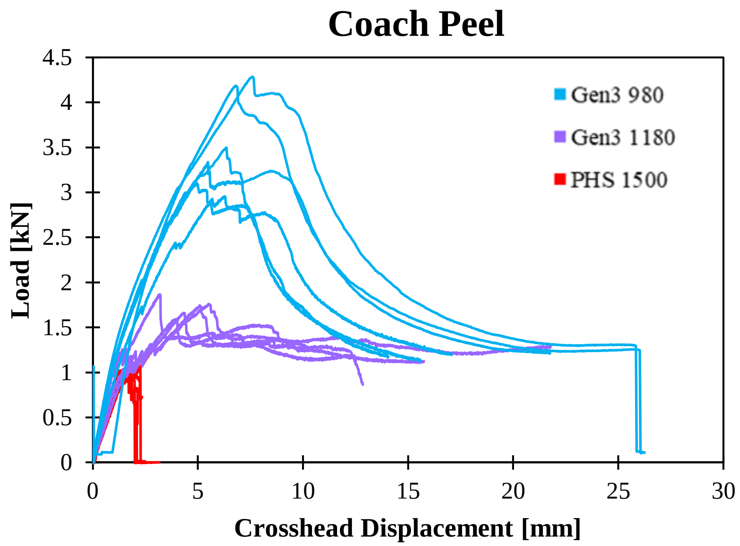




Coach peel (tensile & bending)







Fracture Surface for Single Spot Weld

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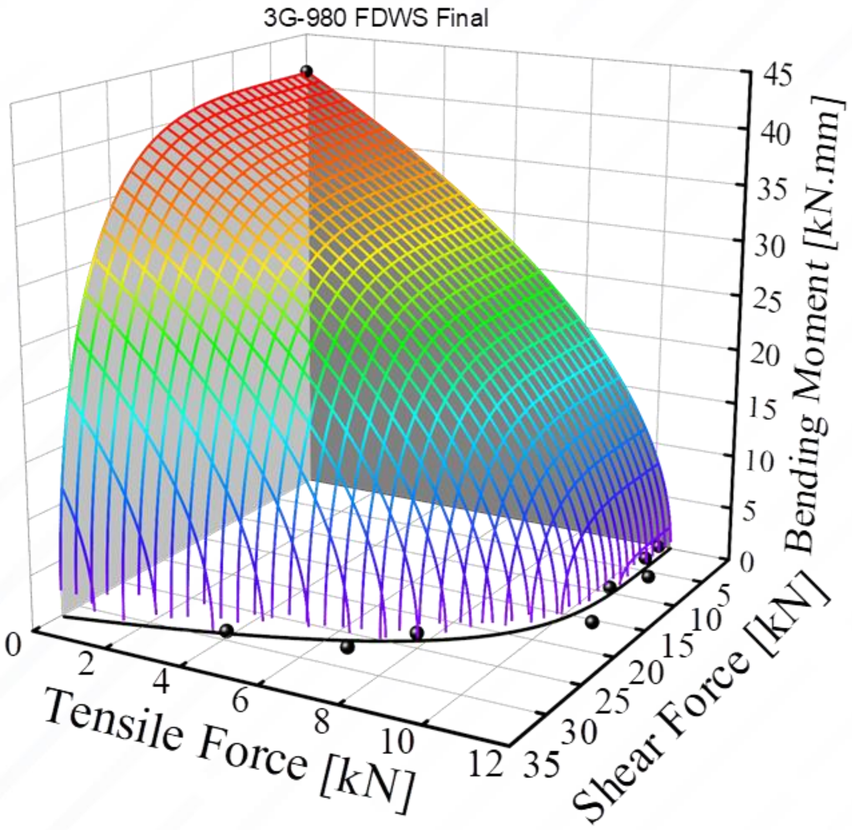

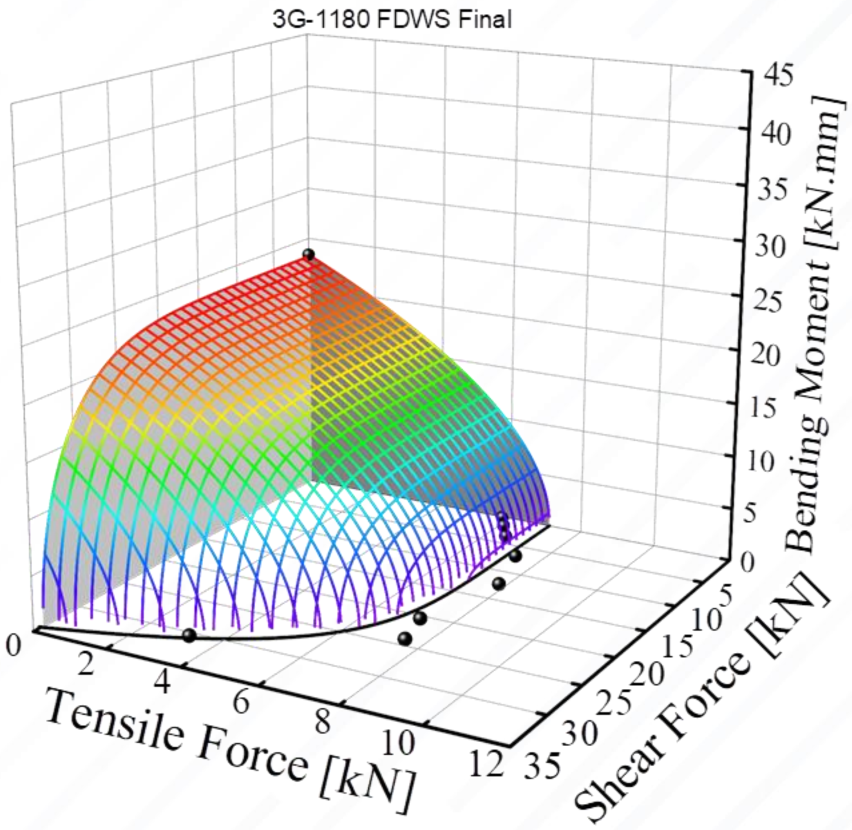

$$f = \left\{ \left(\frac{f_s}{32.071}\right)^{4.666} + \left(\frac{f_n}{10.458}\right)^{1} + \left(\frac{b_m}{41.407}\right)^{2} \right\} = 1$$

$$f = \left\{ \left(\frac{f_s}{34.160}\right)^{6} + \left(\frac{f_n}{7.116}\right)^{1} + \left(\frac{b_m}{23.359}\right)^{2} \right\} = 1$$

Note: Approximate MAT100 failure surface is characterized for CAE simulation.
Advanced Seeger Model is also characterized using test data, which provides better correlation.
Please refer to Mohammad Shojaee's presentation for more details

Coupon Simulation Results

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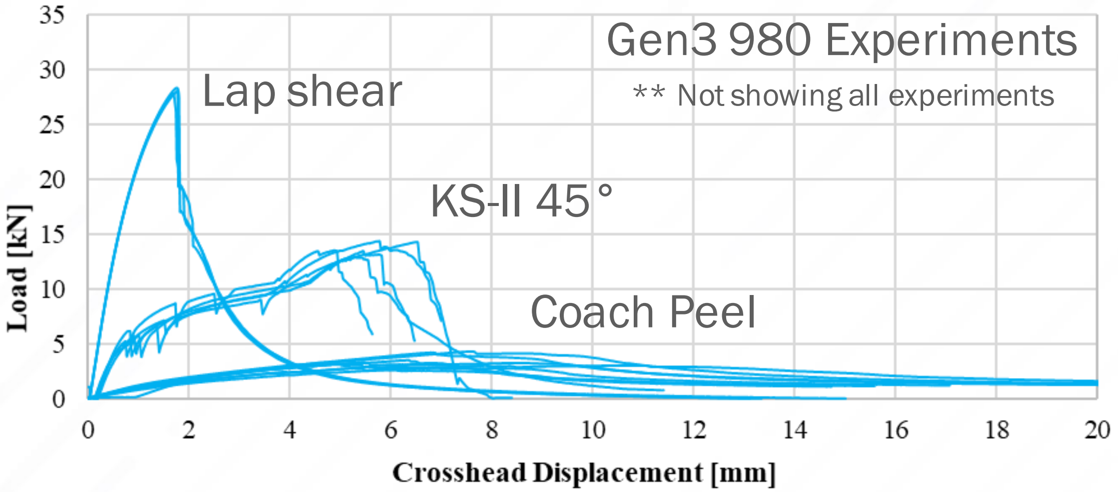
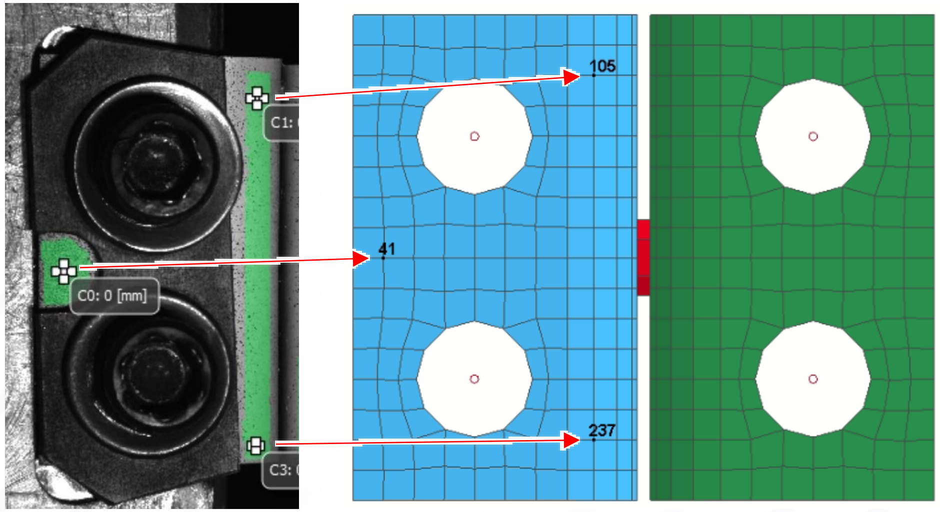
Steps completed:

1. Process experimental data force vs displacement – target for simulations

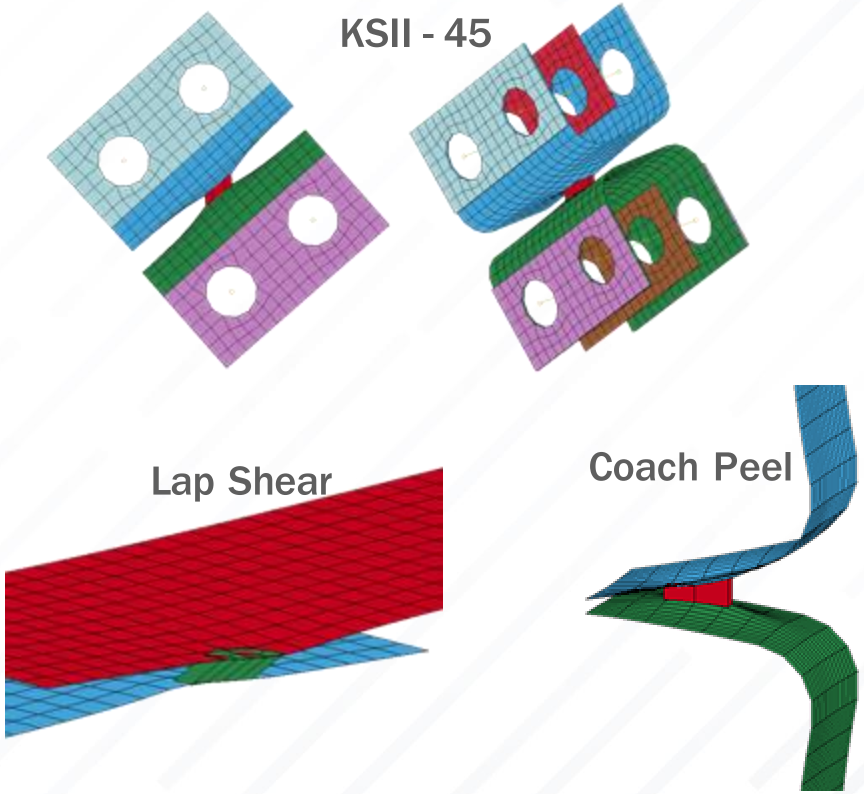


2. Extract simulation boundary conditions from experiments
   - Novel method of KS-II 3D DIC analysis



3. Develop LS-DYNA simulation models of each single spot weld experiment

** Not all simulation models shown



Initial calculation for model bending parameter:

$$Bending\ moment\ (M)[kN.m] = \frac{F_{Max\,CP}[kN] \times L_{CP}[m]}{\sqrt{1 - \left(\frac{F_{Max\,CP}\,[kN]}{F_{Max\,KS-II\,90°}\,[kN]}\right)^2}}$$

Coupon Simulation Results

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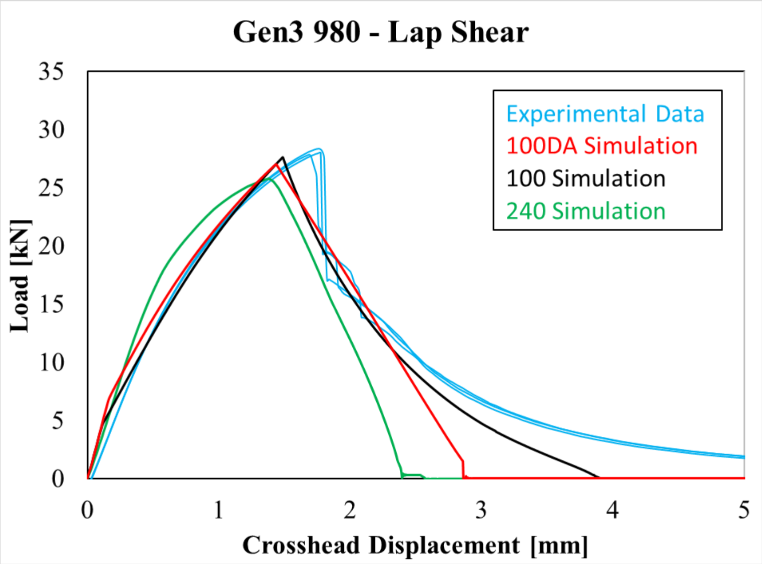
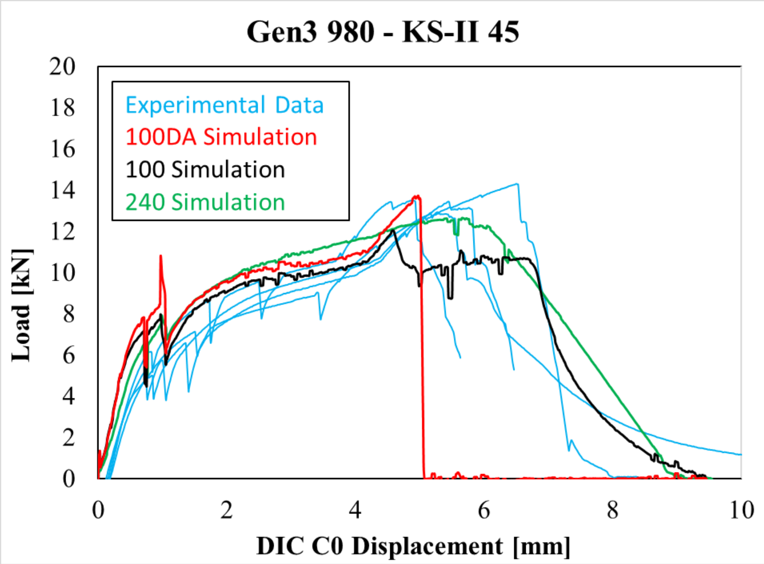
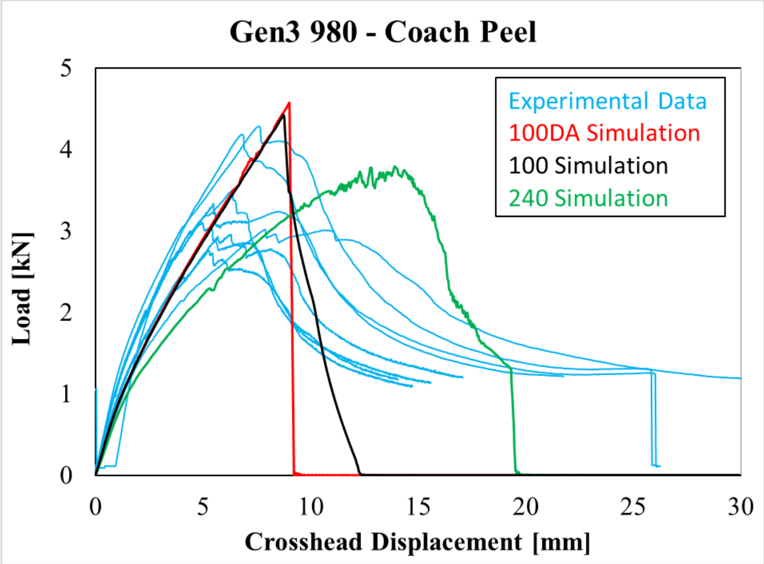
4. Calibrate three different LS-DYNA material models to compare performance







Good agreement between models and experiments for tensile-shear loading conditions

Current model failure criterions have difficulty accurately predicting coach peel (predominantly bending load)

- MAT_100: Has tensile, shear, and bending term in failure model, but limited fracture definitions
- MAT_100DA: Similar to MAT_100, but had to manually over predict bending load to predict component test
- MAT_240: Good fracture behavior but no specific bending term in failure model

Caiman Mode I Experiments and Modelling Results:

Quasi-Static & Dynamic Loading Rates

Component Tests: Caiman Mode I (Quasi-static)

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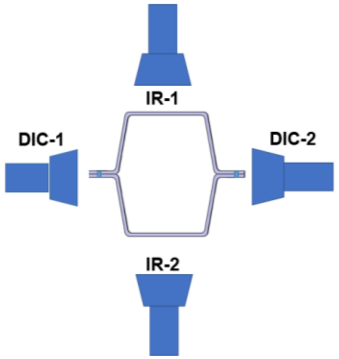
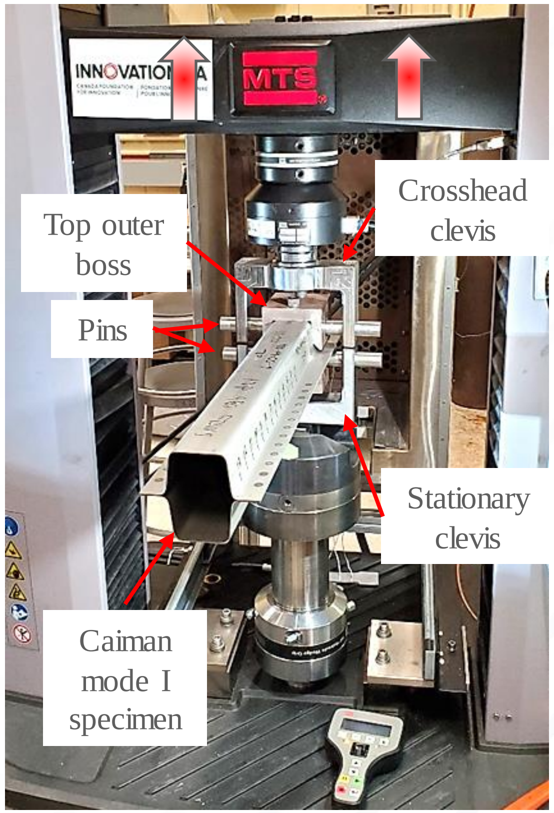
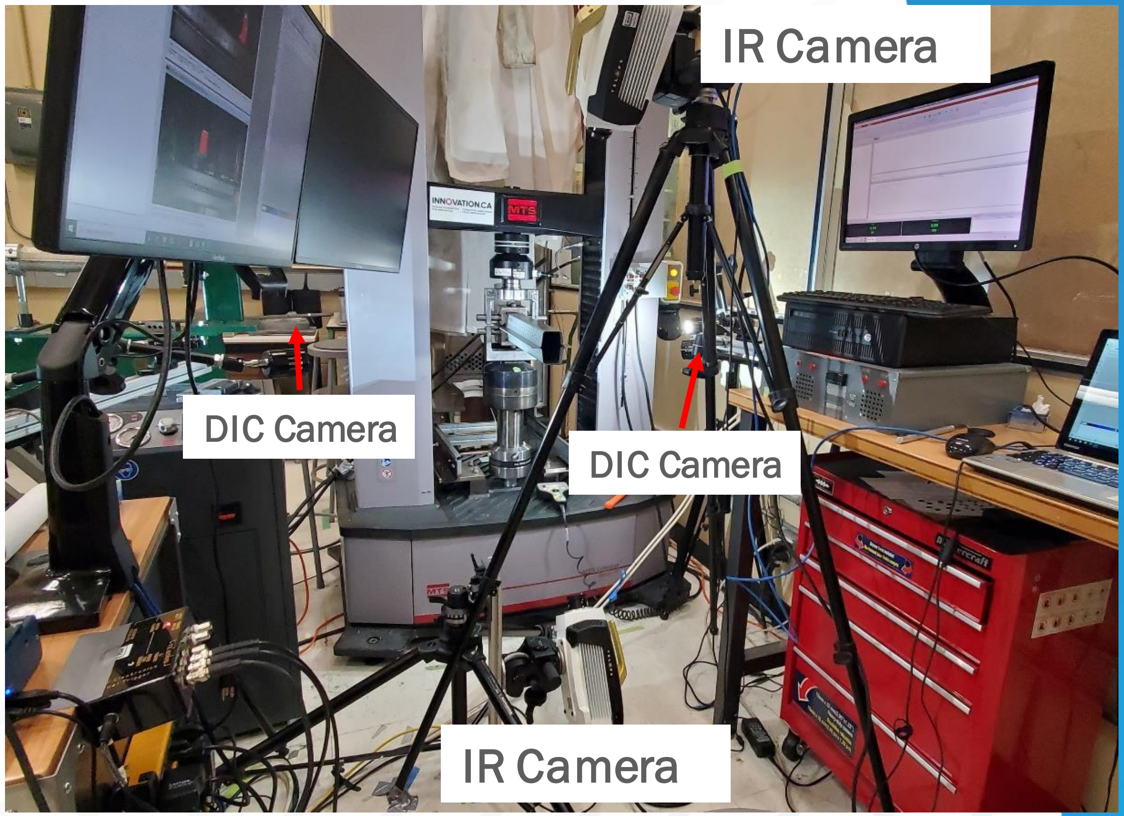
- 14 spot welds per flange (~2/3 length of the rail)
- Pins and bosses pull channels apart
- Welds sequentially loaded with a normal tensile & bending stress
- Similar to Mode-1 type fracture mechanics







Caiman Mode I Quasi-static: Test Results

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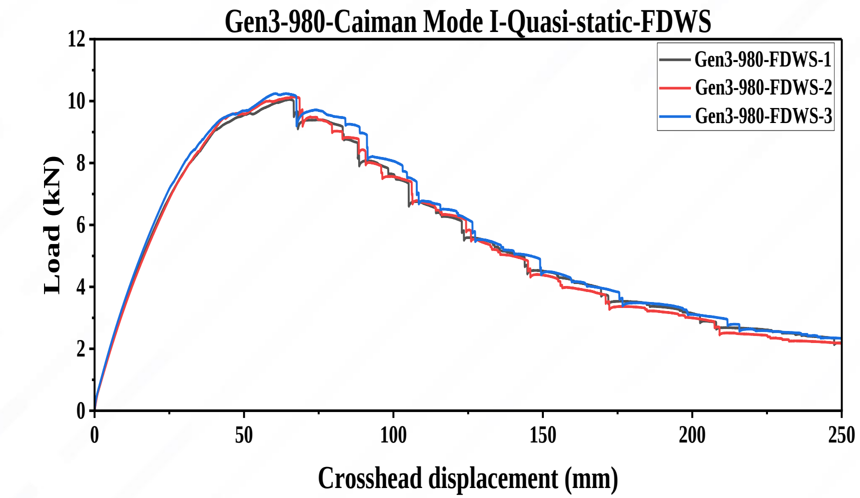

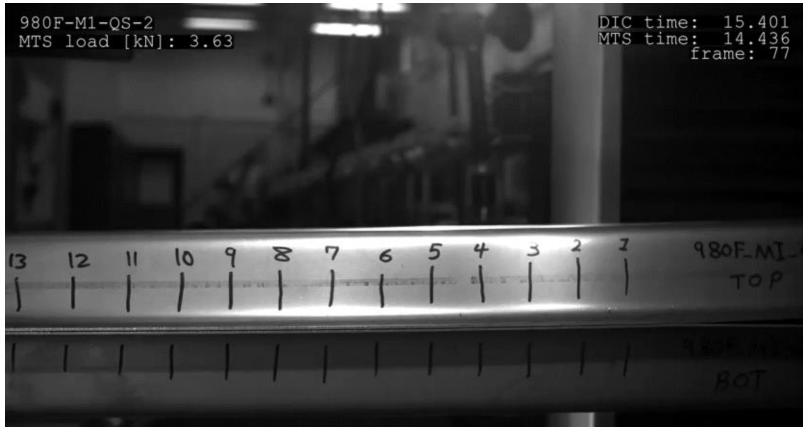

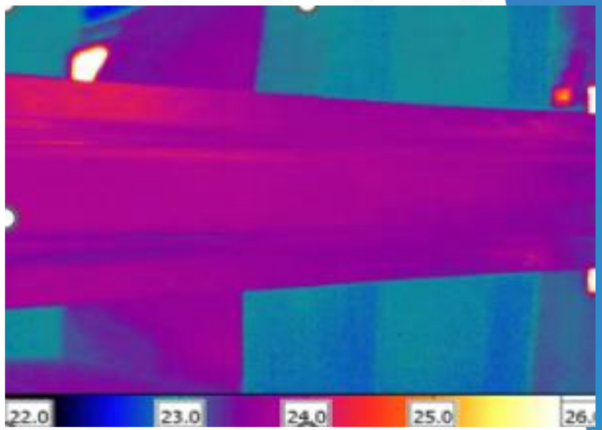

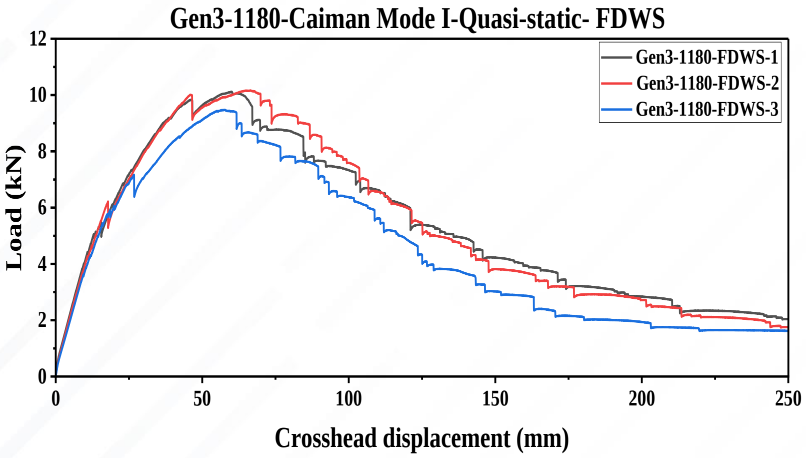

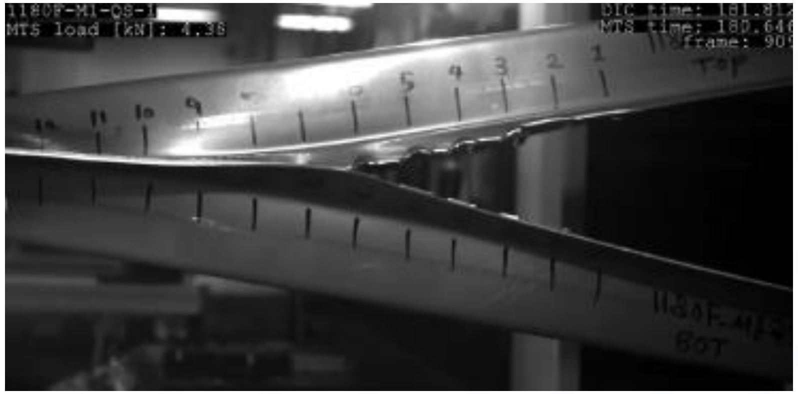

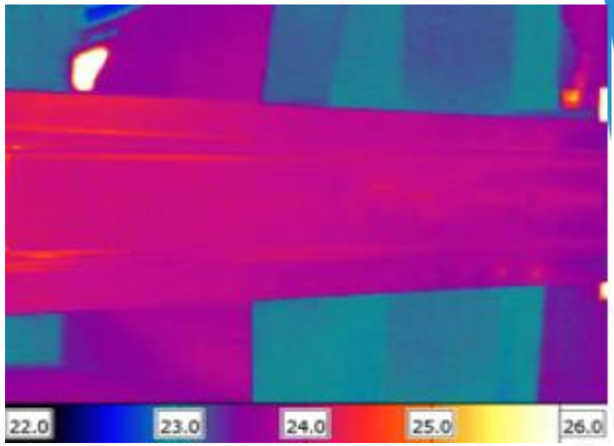

Videos show the failure behavior for Caiman Mode-I under Quasi-static condition

The thermal data is processed to assist in determining weld failure timing

Component Tests: Caiman Mode I (Dynamic)

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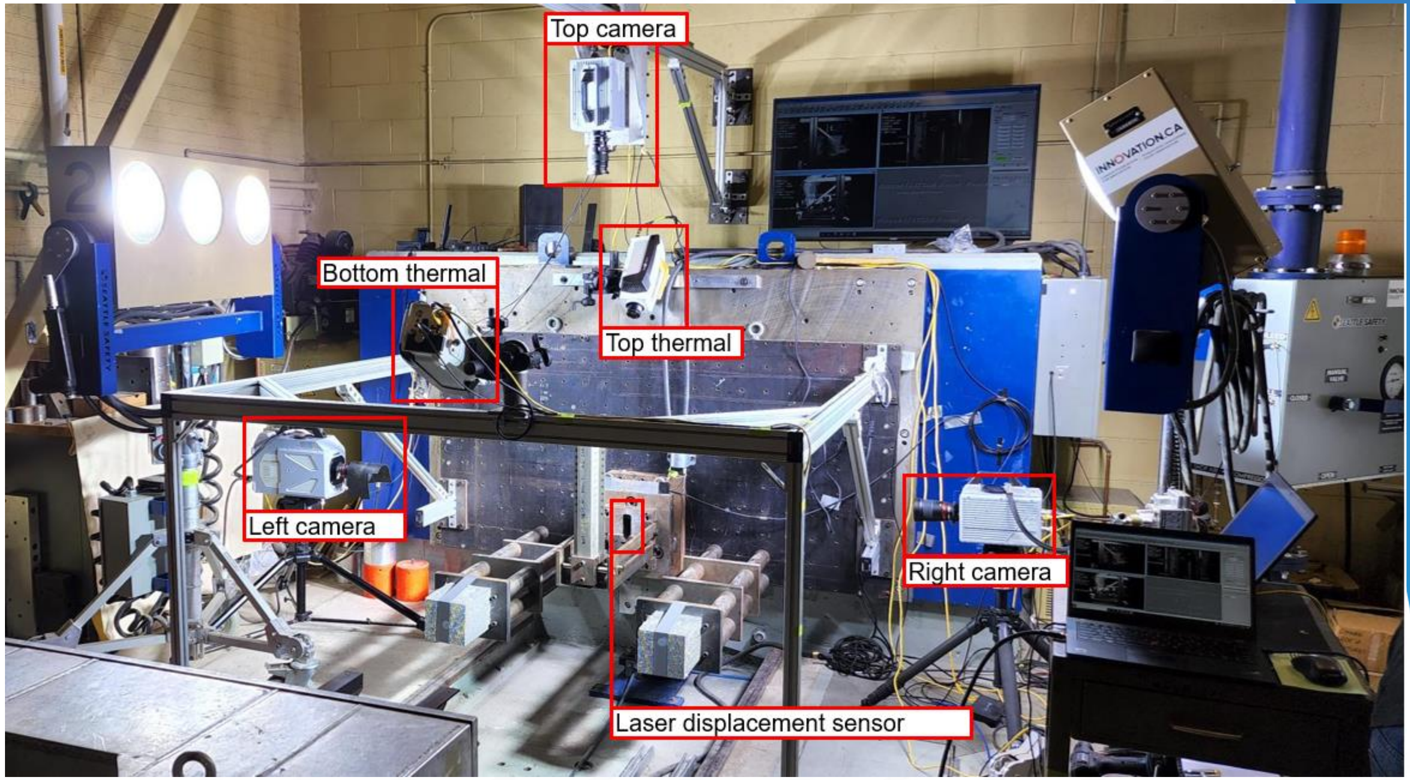
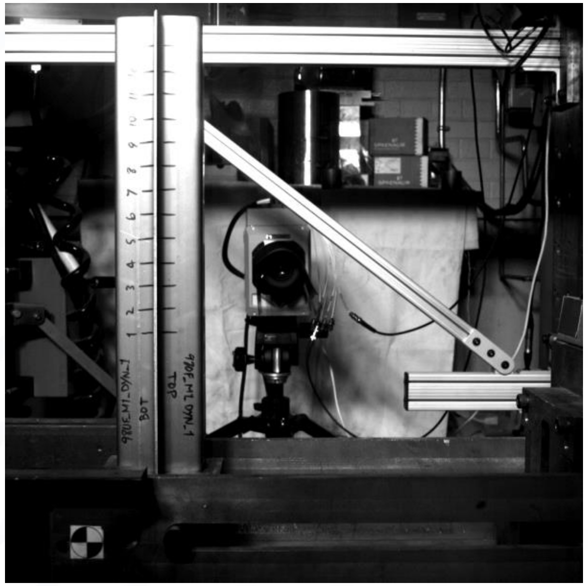
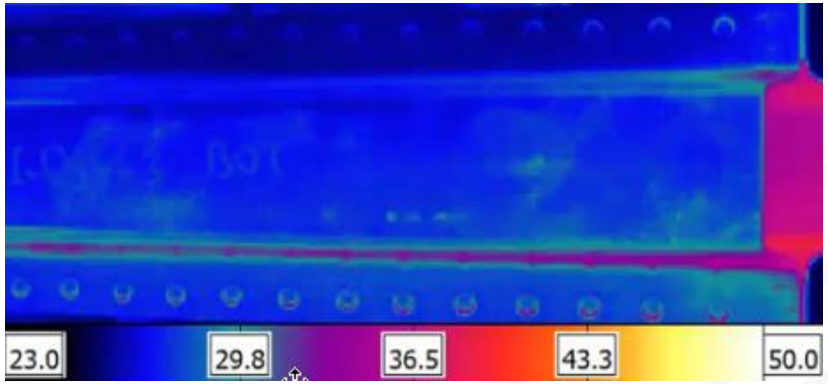
- Three High-speed Photron cameras (left, right, top) – 5000 fps
- Two thermal cameras (top and bottom of parts) – 5000 fps
- Initial sled velocity – 7 m/s (25 km/h)
- Laser-displacement sensor measures part boss displacement
- 215 mm sled travel before the honeycomb
- 250 mm total measurement range of laser sensor in this configuration







Caiman Mode I Dynamic: Test Results

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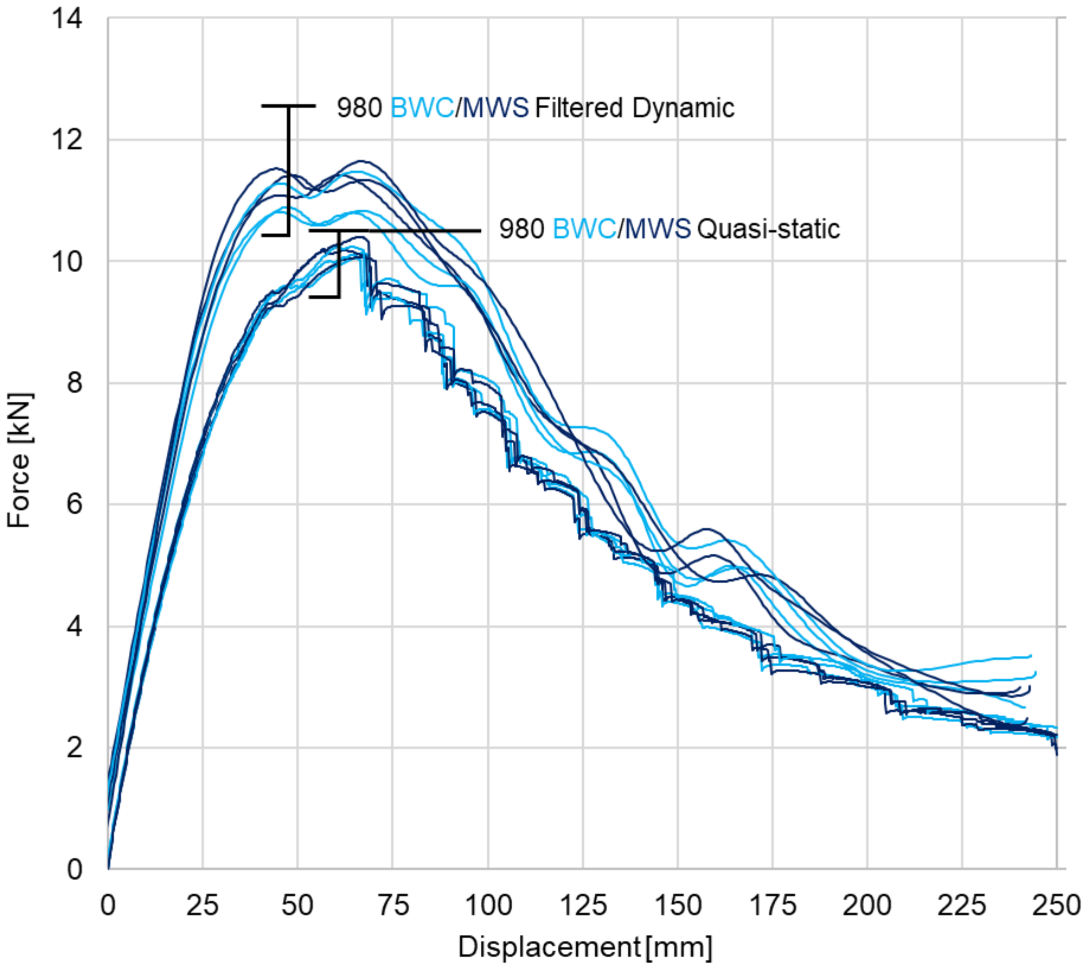
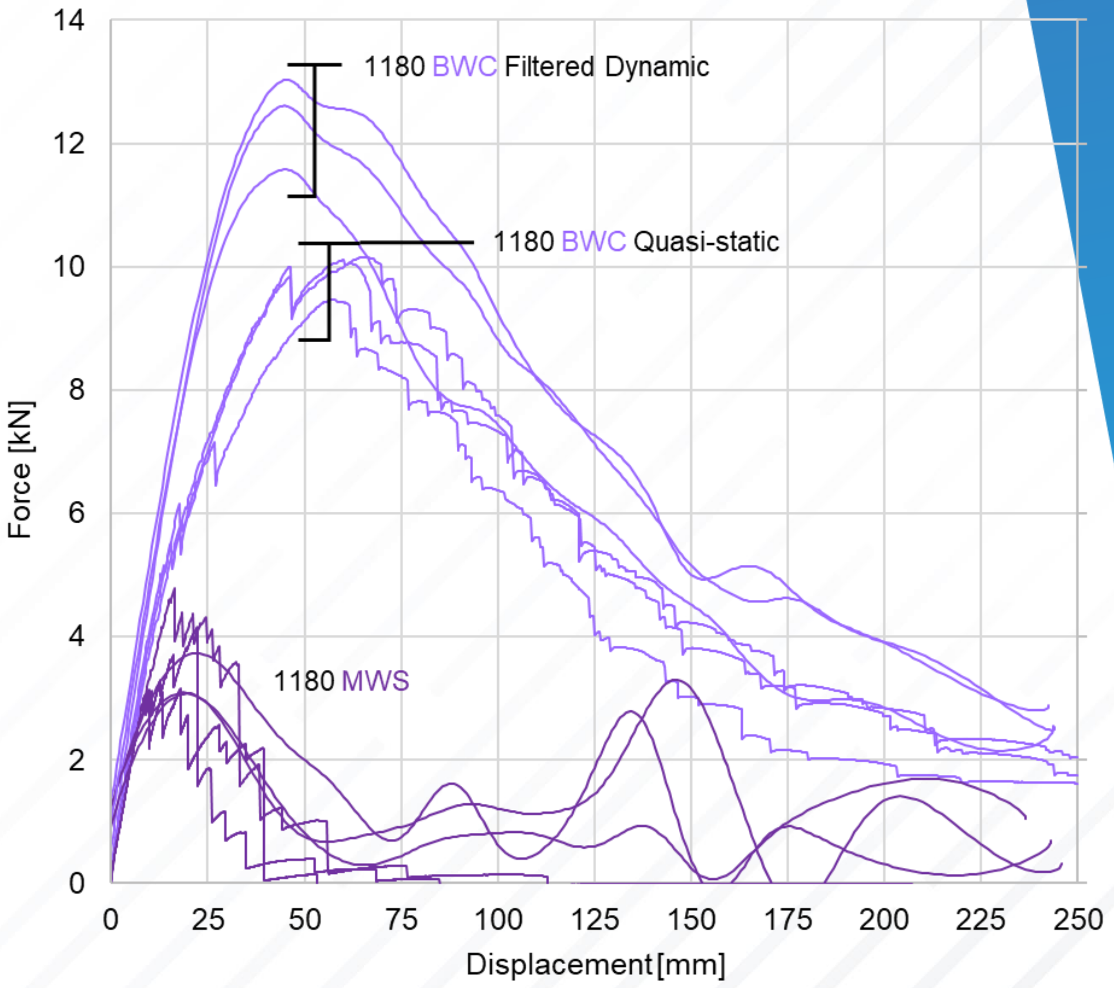
Comparing the filtered dynamic test load cell data to the quasi-static load cell data





Caiman Mode I: LS-Dyna Simulations

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Component base metal: Same for both modes

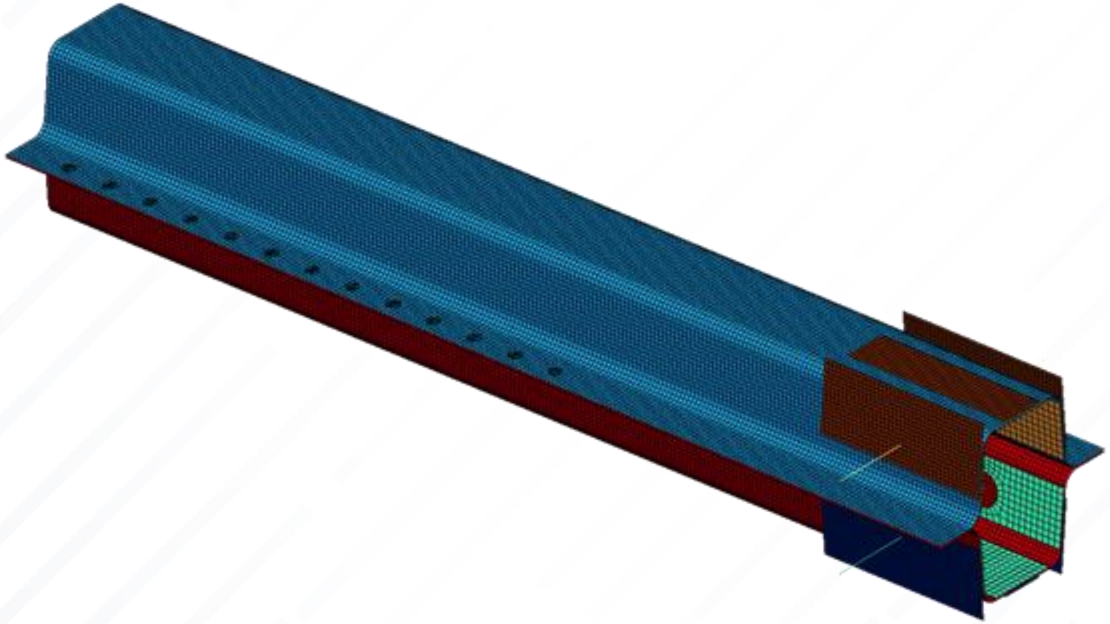
- Shell element formulation 16 (fully integrated)
- 2.5mm length
- 5 through-thickness integration points
- MAT_133 (Barlat Yld2000) with isotropic yielding
- Hardening curve fit from tensile and mini-shear tests
- Currently NO fracture

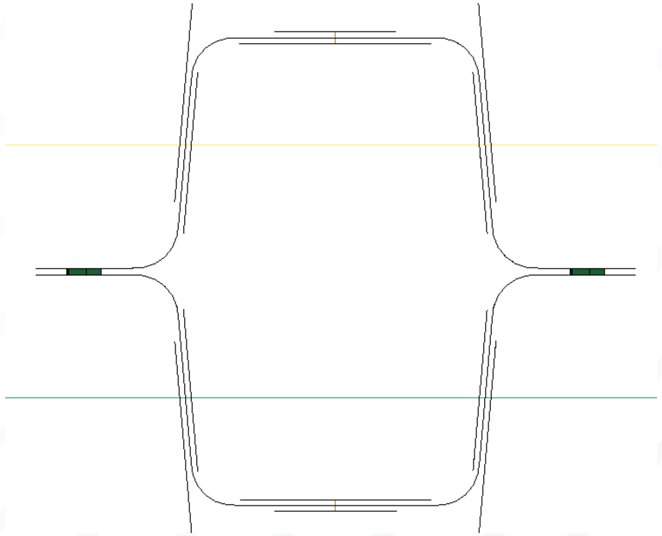
Spot welds: Same spot weld model applied to both modes

- Brick elements – 8 element assembly
- Cross section area equiv. to experimental spot welds
- Tied to parent metal shell midplanes
- MAT_100, MAT_100DA, and MAT_240
- Weld models fit from single-spot weld lap shear experiments

Caiman Mode 1:

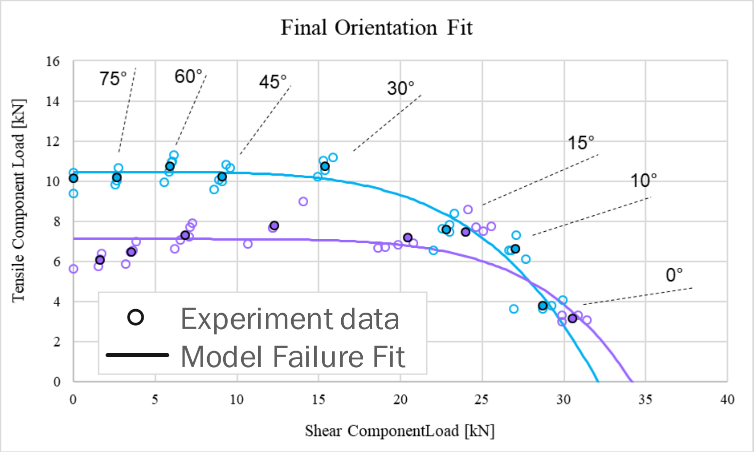
- Fixtures/bosses are rigid shells
- Lower pin (beam) fixed in x, y, and z space
- Upper pin (beam) prescribed to displace up (+Y)
- Bosses constrained to rotate about pins
- Tensile failure through the spot welds (FE data)



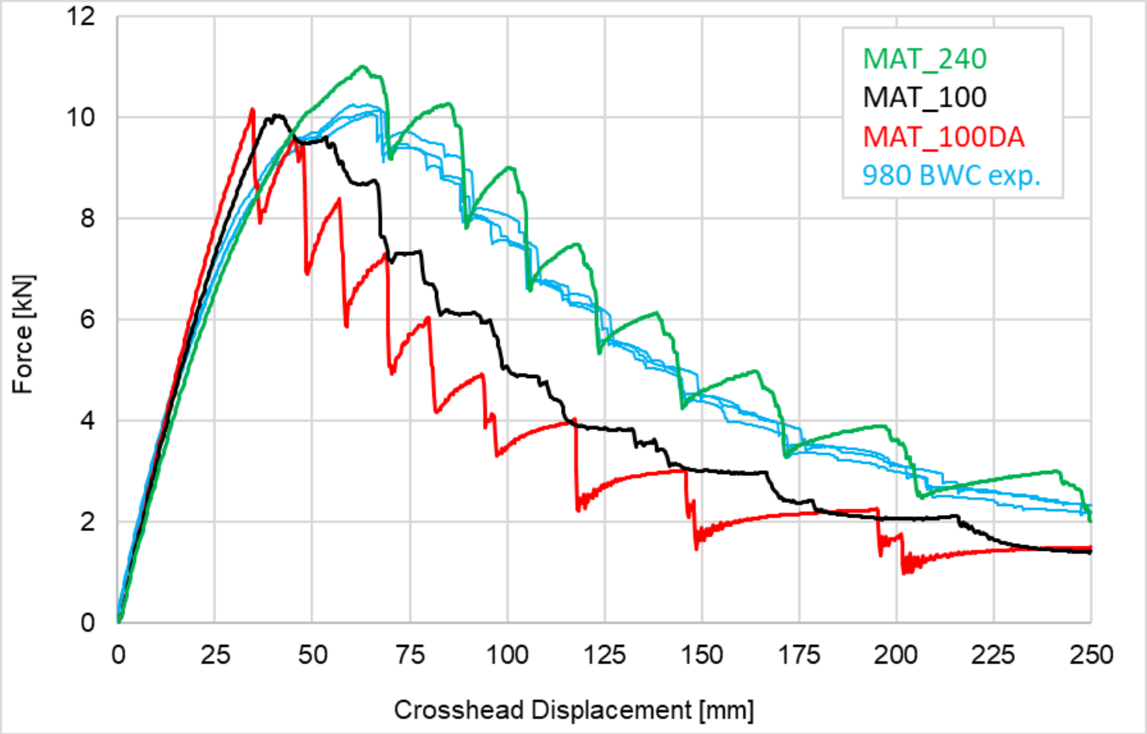


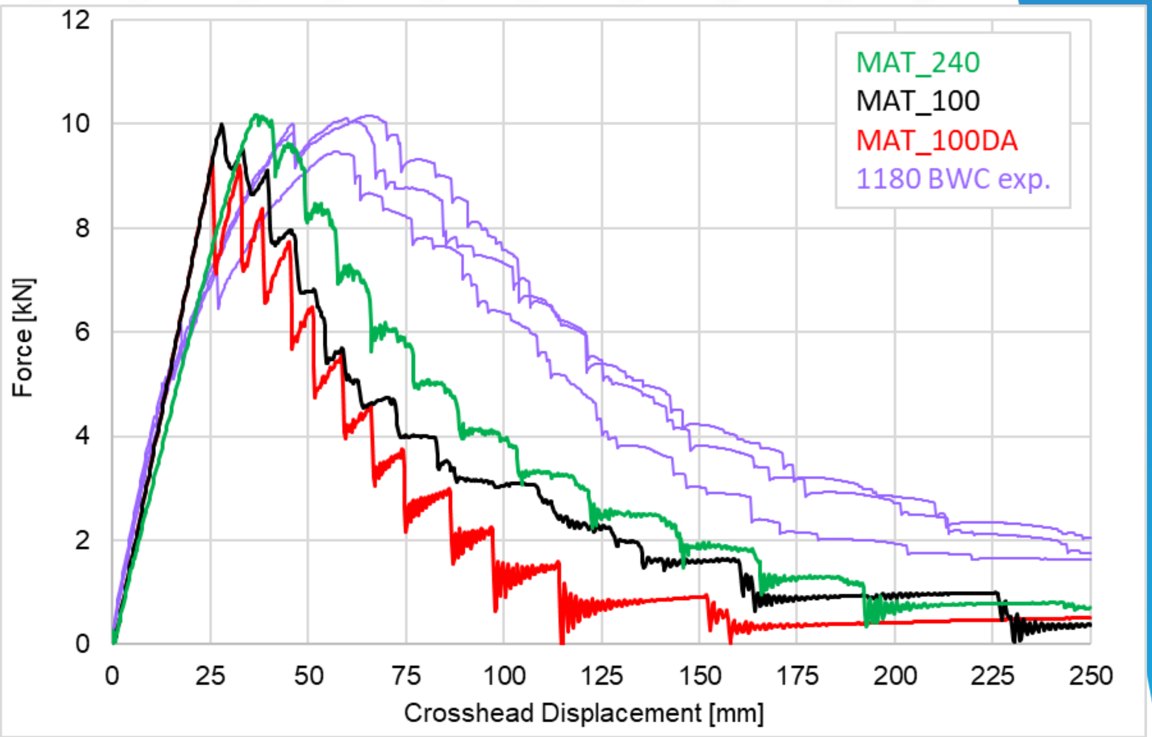
Caiman Mode I Quasi-static: Simulation Results

- Spot weld models calibrated from single spot weld experiments
- MAT_240 does best, but models have difficulty predicting component experiments
- Suspected due to limitations in model failure criterion



- Calibrated weld failure surface from KS-II single spot weld tests
- Test data has been corrected from 'ideal' fixture orientation to final coupon rotation at failure





Caiman Mode III Experiments and Modelling Results:

Quasi-Static & Dynamic Loading Rates

Caiman Mode III: Test and Simulation Results

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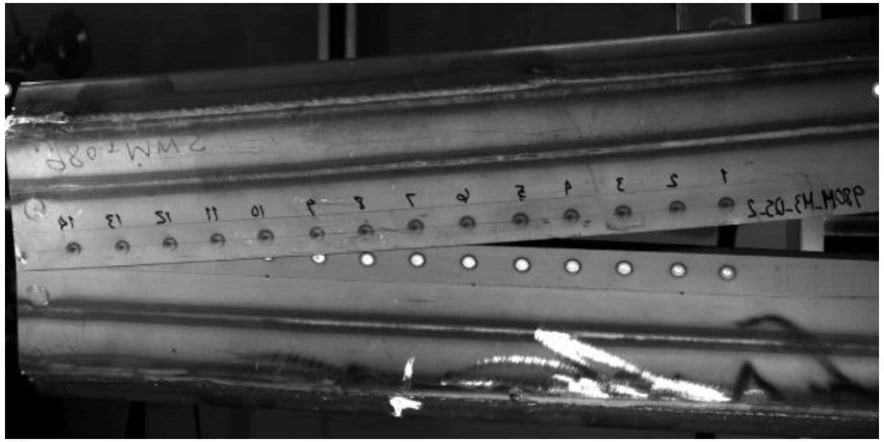
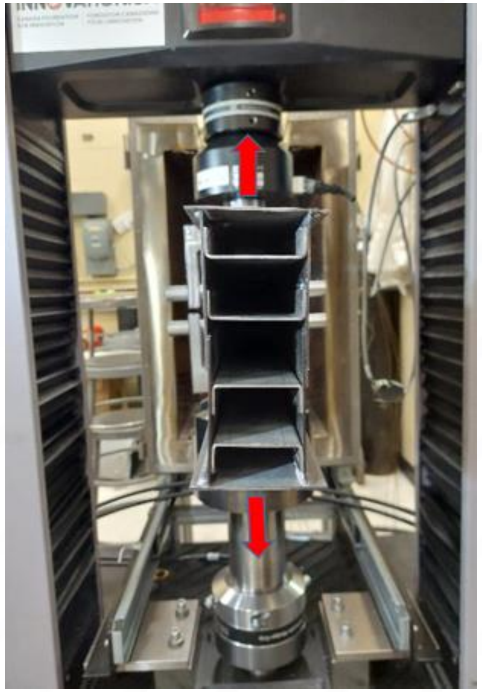
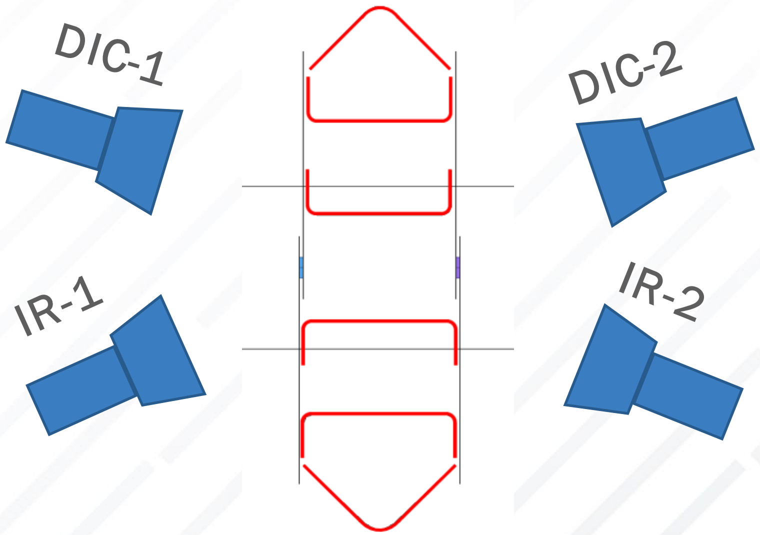
- 4 C-channels used to join walls and act as internal stiffeners
- V-shape closing plate to prevent sidewalls from buckling
- C-channels and closing plate made out of 3rd Gen 980 steel
- Clamping boss design same as Mode I design
- Quasi-static and dynamic test conditions







Caiman Mode III: Quasi-static Test and Simulation Results

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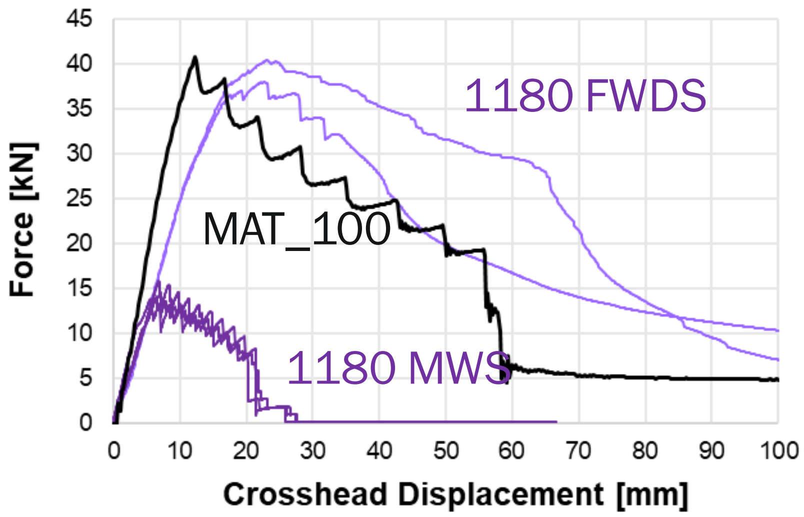
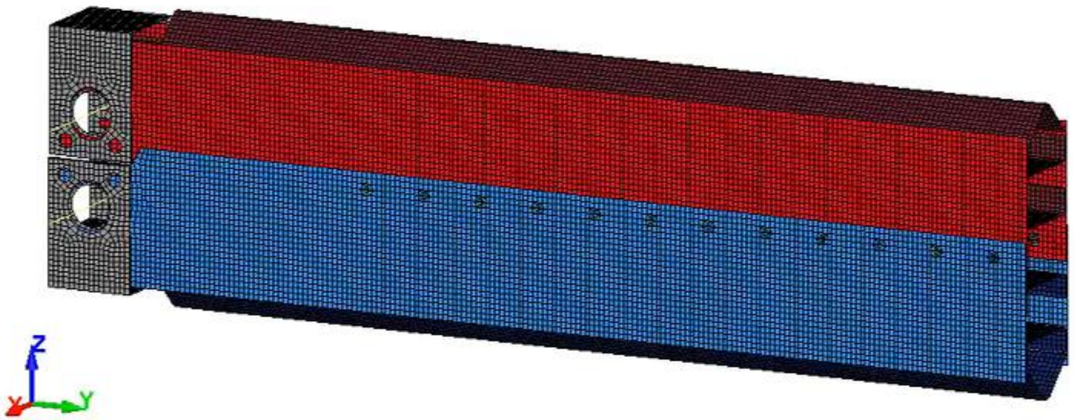
Caiman Mode 3:
- Same fixture strategy as Mode 1
- The reinforcement parts are made of (980)
- The top and bottom plates have V-shape
- Mig weld is a continuous weld modelled as tied-contact
- Shear failure through the spot welds (FE data)



Results shown only for 1180 material
980 material experiments failed in parent metal (<2 weld failures)

Gen3 1180 FWDS (7.5mm dia. nugget)



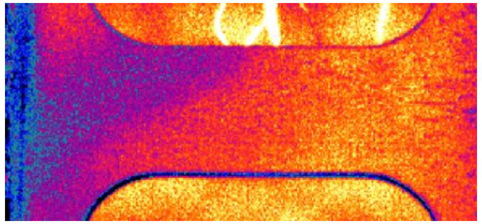
Advanced Modelling Methods:

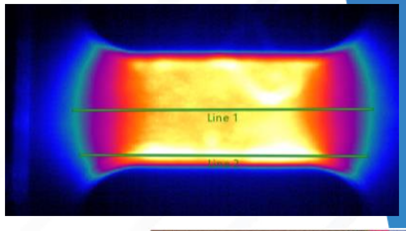
Gleeble HAZ Simulation Fracture Characterization Results

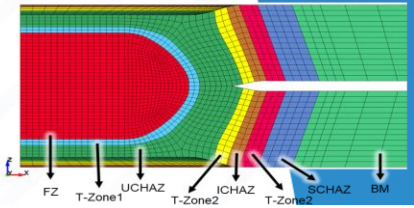
Advanced Modeling Methods (Gleeble)

GDIS

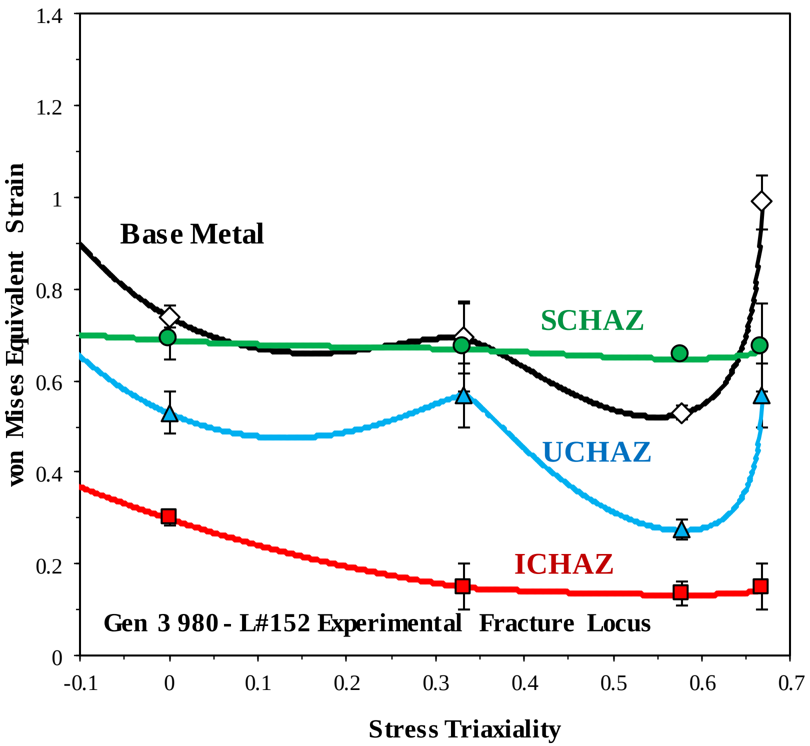
- Plane stress fracture loci calibrated for BM and HAZ:
  - Sub-critical (SCHAZ)
  - Inter-critical (ICHAZ)
  - Upper-critical (UCHAZ)
- ICHAZ lowest fracture strains across all materials examined
- Goal to model HAZ shell elements in Caiman component around spot weld nugget
  - Enhance the current spot weld models to predict weld failure more akin to experiments



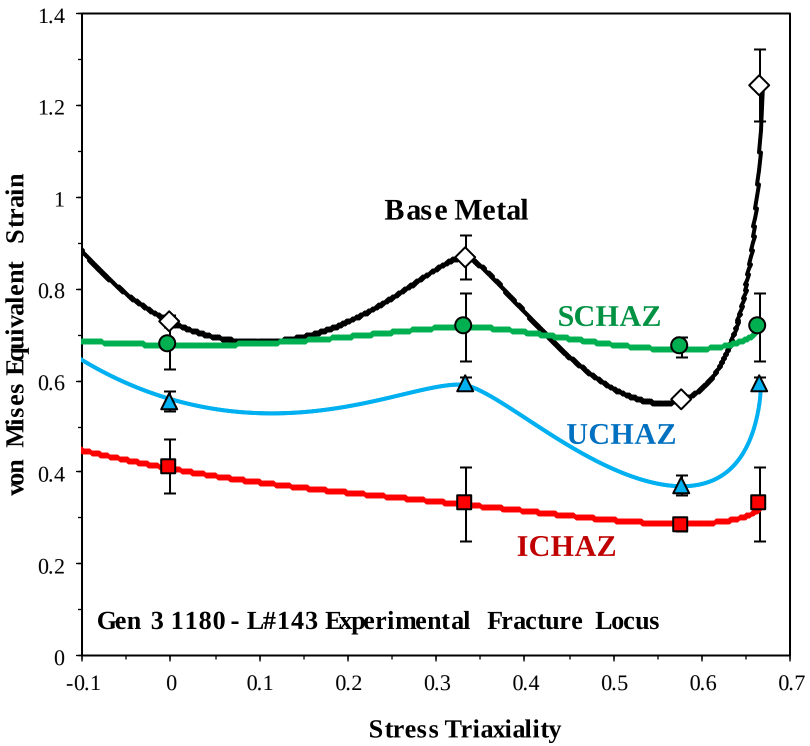




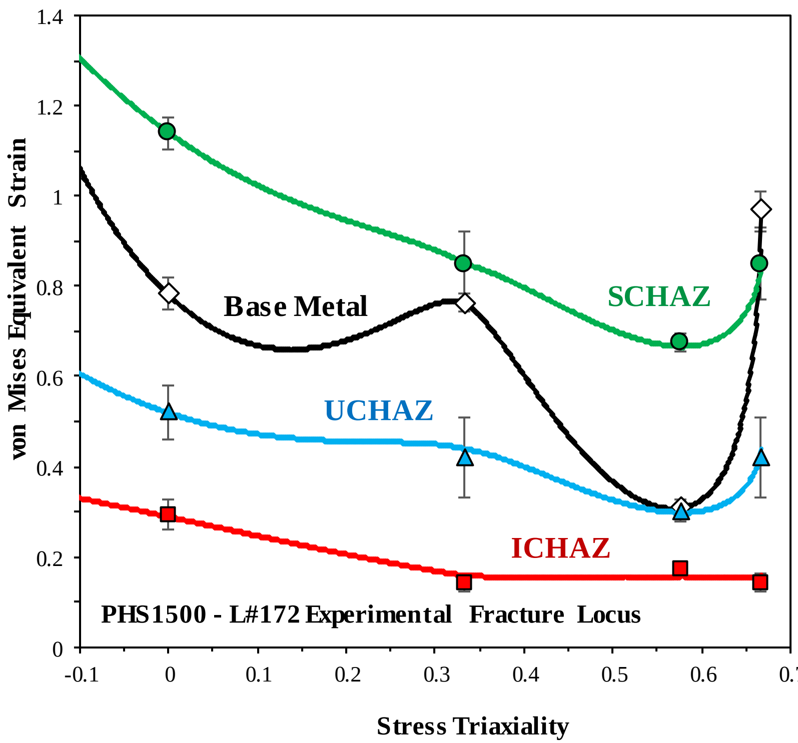
Gen 3 980 - L#152 Experimental Fracture Locus



Gen 3 1180 - L#143 Experimental Fracture Locus



PHS 1500 - L#172 Experimental Fracture Locus



[1] Shojaee, M., Tolton, C., Midawi, A. *et al.* *Int J Adv Manuf Technol* **132**, 943–965 (2024).

Summary and Future Work

GDIS

- Resistance spot weld schedule was optimized for 3G-980 and 3G-1180 AHSS
- The weld was mechanically tested under different loading conditions, including tensile shear, cross tensile, KS-II (8 orientations), and coach peel. The peak load and absorbed energy were quantified.
- The single spot weld mechanical properties were used to build a failure surface that predicts the spot weld failure under combinations of load scenarios.
- The optimized welding schedule was then used to analyze the failure behaviour of a group of spot welds (Caiman Mode-I and Caiman Mode-III) under quasi-static and dynamic strain rates.
- LS-DYNA material cards were calibrated using single-spot weld experiments, including:
  - MAT_100 and MAT_100DA calibrated with weld failure surface equation fit
  - MAT_240 calibrated to lap shear and cross tension experiments
- MAT_240 was found to better capture the unzipping behavior of the components
- Models accurately predict peak load of experiments, identified shortcomings in models' ability to predict all of the post-failure absorbed energy

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Thanks for your attention!