GREAT DESIGNS IN STEEL

MODELING OF RESISTANCE SPOT WELDS IN 3RD GENERATION AHSS FOR USE IN CAE SIMULATIONS OF VEHICLE CRASH

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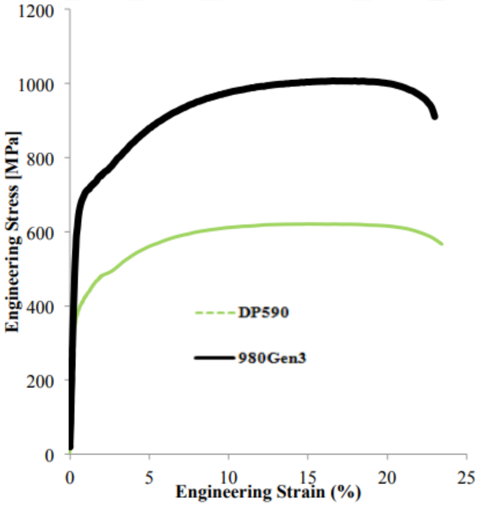
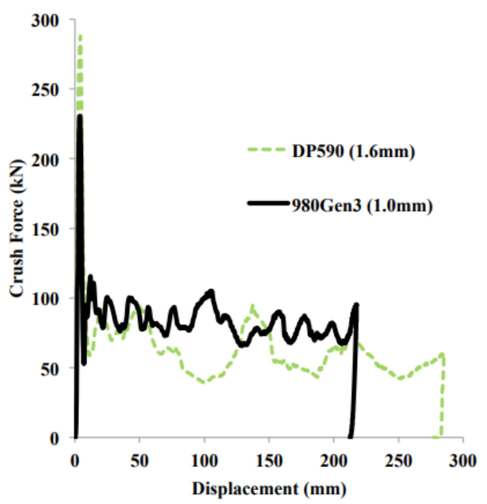
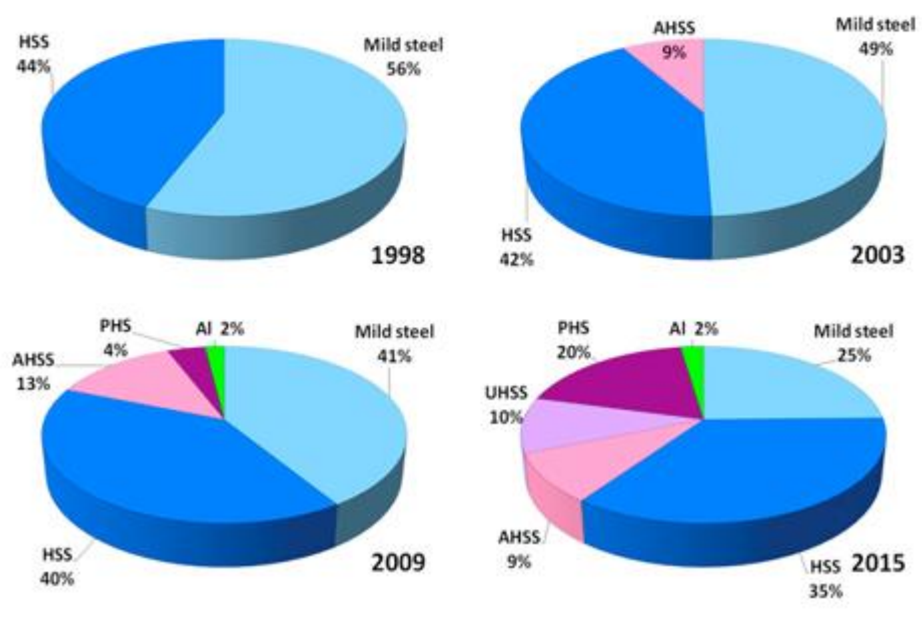
INTRODUCTION AND MOTIVATION

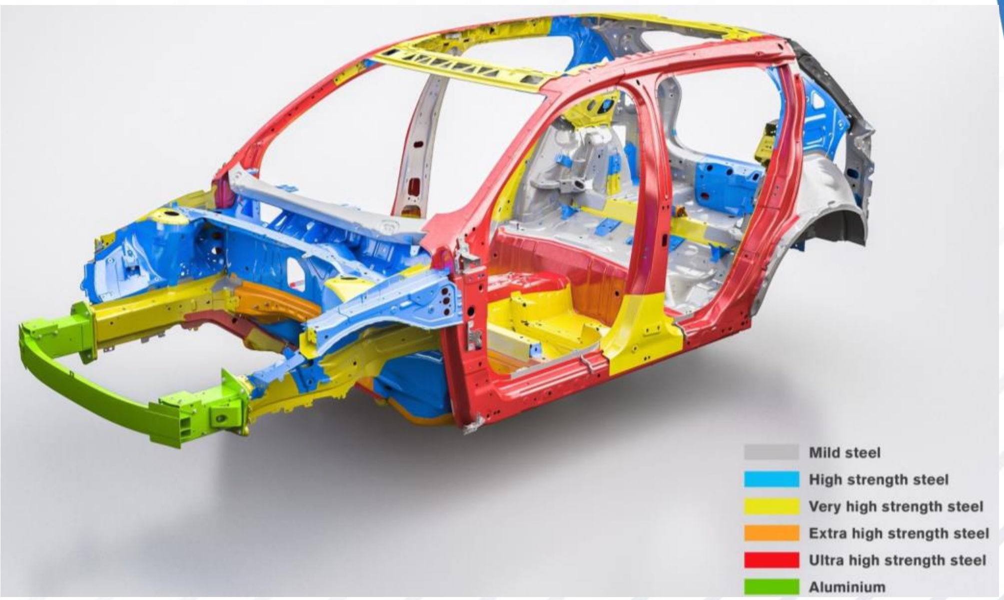
Substituting 1G AHSS with 3G AHSS in A and B pillars could save from 10% to 20% weight.

3G-980 steel offer 66% higher strength, and 25% shorter crush distance in comparison to DP590.









[1] Michael Davenport, "Third-generation advanced high-strength steel emerges," Stamping Journal, 2017
[2] M. Davenport, "Generation 3 Steels - A Guide to Applications of Gen3 AHSS," USS, Presentation, August 25th, 2016.
[3] https://www.repairerdrivennews.com/wp-content/uploads/2019/09/ice-and-bev-volvo-xc40.jpg

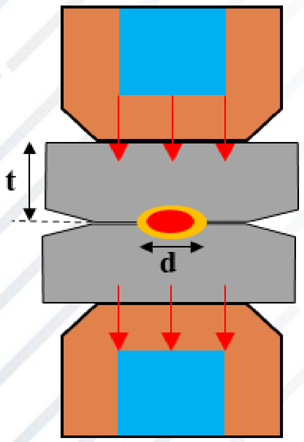
RSW PROCESS PARAMETERS

RSW Process Parameters

Welding Current [kA]

Welding Time [ms]

Low welding current/time

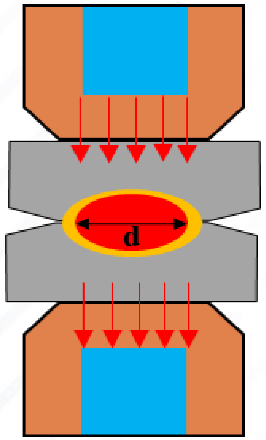


$d < 4\sqrt{t}$

Nugget too small

✗

Suitable welding current/time

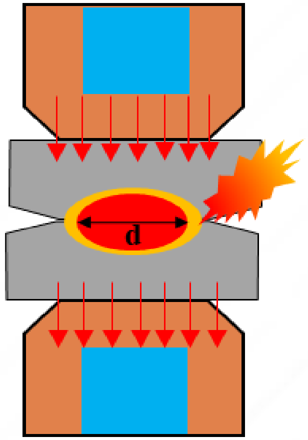


$d > 4\sqrt{t}$

FDWS

✓

Excessive welding current/time

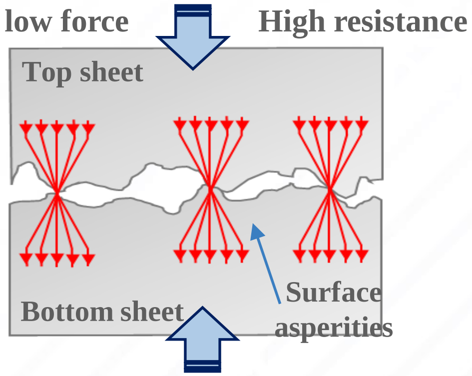


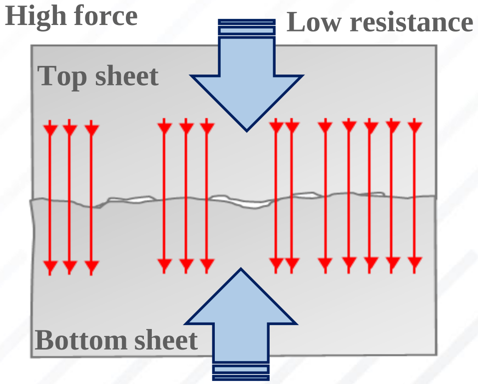
$d > 4\sqrt{t}$

Expulsion

✗

Welding Force [kN]





Other Parameters

- Material strength
- Sheet thickness
- Surface coating
- Stack-up ratio
- Electrode size/shape
- Part fit-up
- Water flow

Note: In HSR weld, we should check all sheet-sheet interfaces and measure nugget size, ensure good penetration into the thin sheet

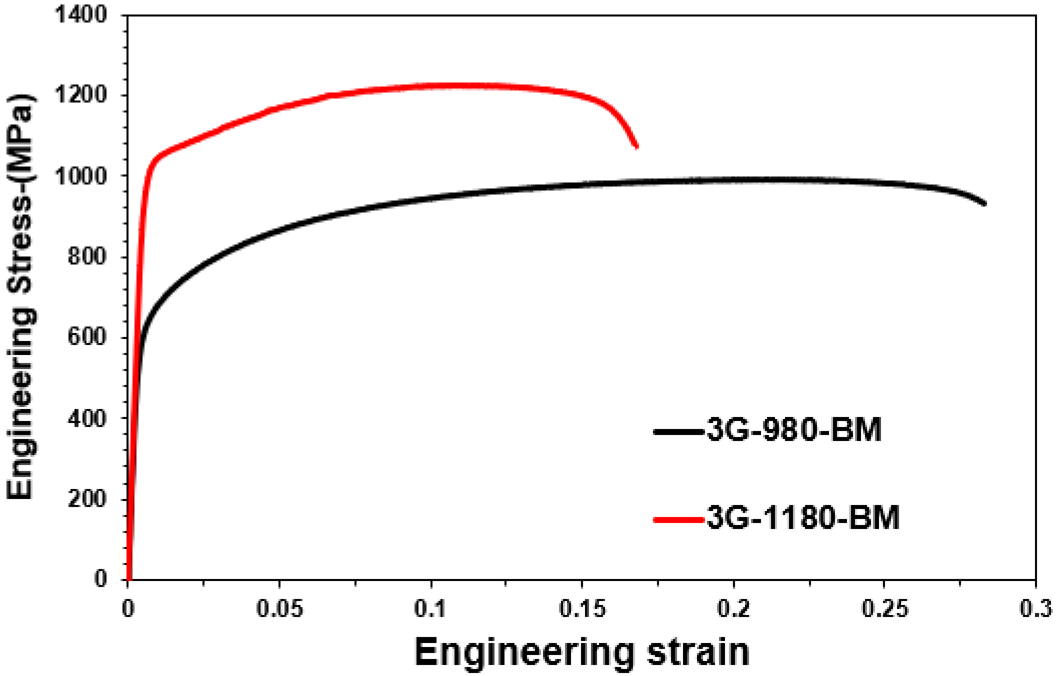
OBJECTIVES

- Develop welding lobe for third-generation AHSS materials (3G-980 and 3G-1180)
- Characterize the mechanical properties of RSW single spot weld through different mechanical testing (Lap shear, Cross tension, Coach peel, and KS-II)
- Build fracture surface using the single spot weld mechanical properties
- Weld structural components using the developed schedule and test them under different loading orientations (tension versus shear)
- Develop and calibrate a CAE model able to predict the unzipping behavior of multiple spot welds using the single spot weld fracture surface

MATERIALS

- The material investigated in this study was two grades of third-generation of AHSS (3G-980 and 3G-1180)
- Both materials were uncoated with a nominal thickness of 1.4 mm
- The carbon equivalent for the 3G-980 material is 0.638 and for the 3G-1180 is 0.696.
- JIS rectangular tensile coupons were machined from the base materials parallel to the rolling direction, and the engineering SS curves, and the summary of the tensile test are reported.

Representative engineering stress-strain curves



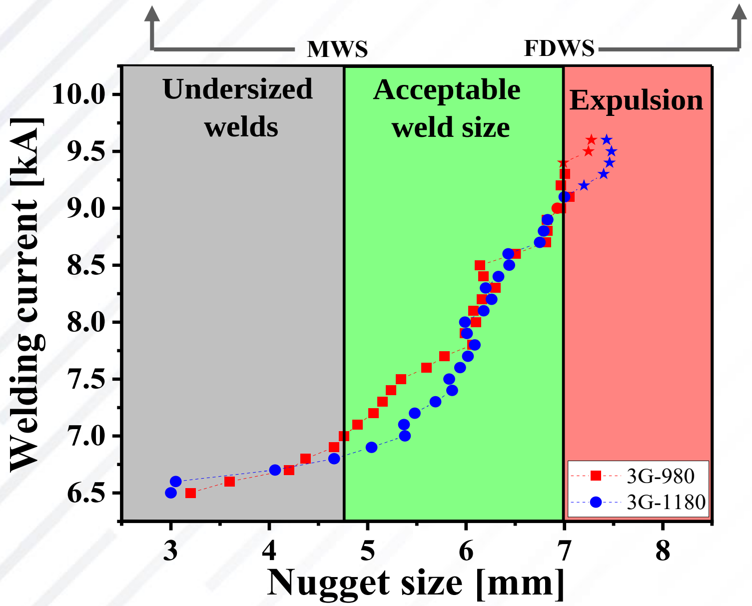
Summary of the mechanical properties of the investigated materials in the rolling direction

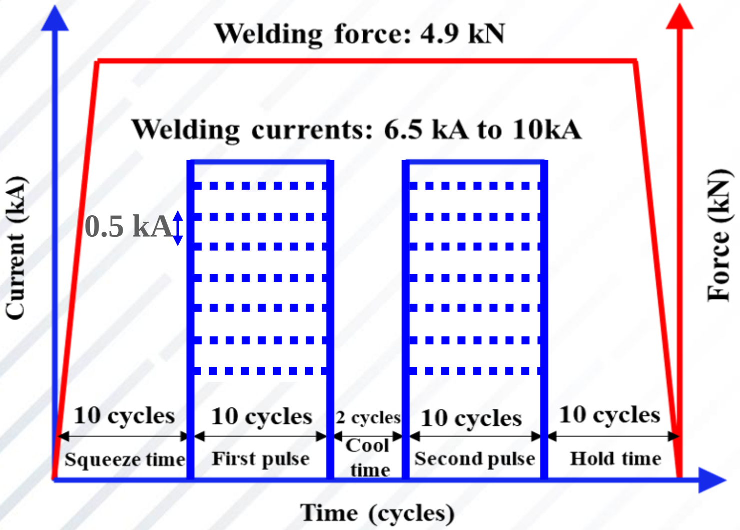
Material	0.2% YS [MPa]	UTS [MPa]	Uniform El. [%]	Total El. [%]	R Value
3G-980	650±8	1003±8.5	20±1	28±0.4	0.912±0.05
3G-1180	993±17	1230±4.4	11±0.1	16.5±0.4	0.85±0.06

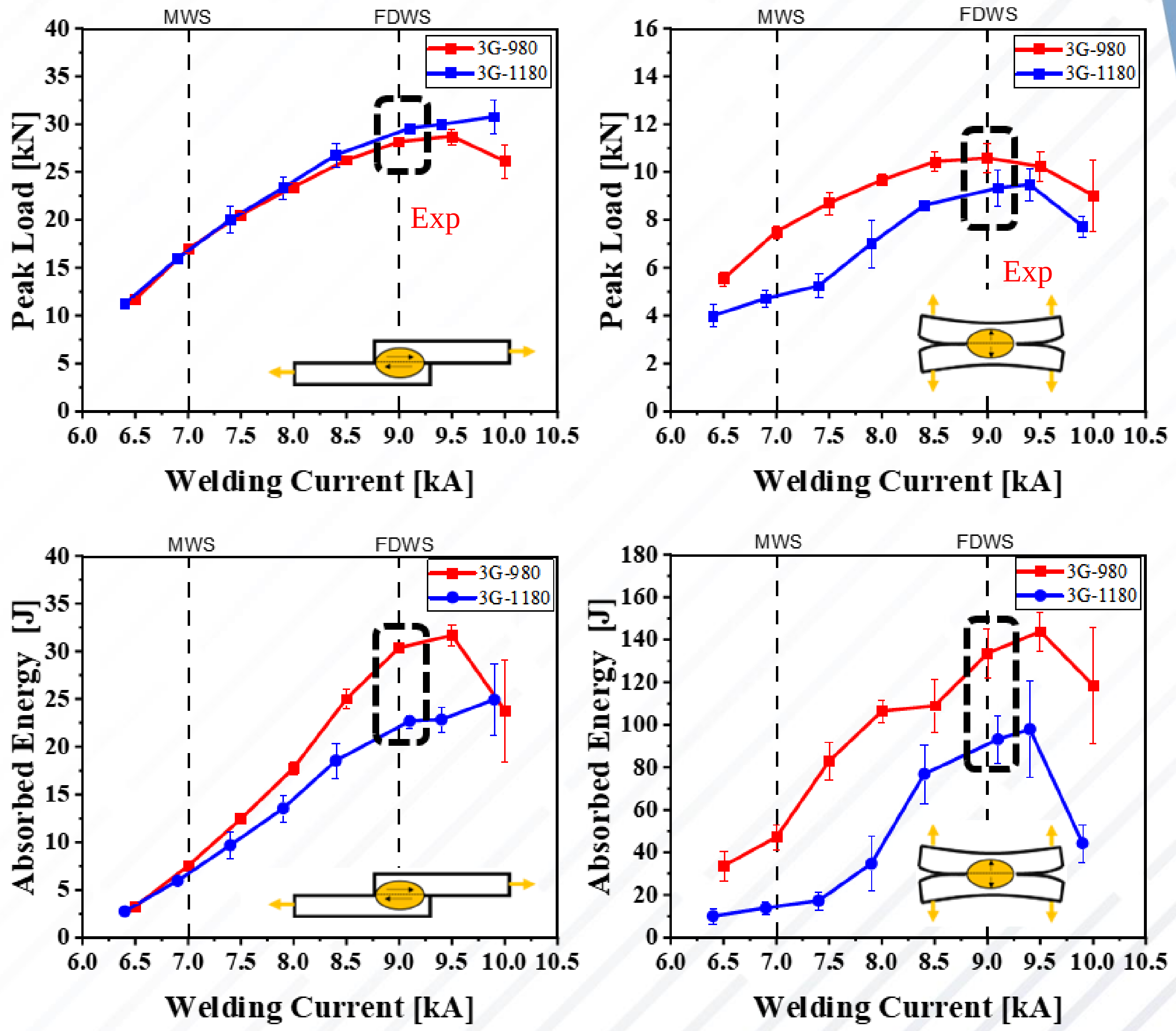
RSW PROCESS OPTIMIZATION

Minimum Weld Size (4√t ≈ 4.8 mm)

Electrode Face Diameter Weld Size (≈ 7 mm)







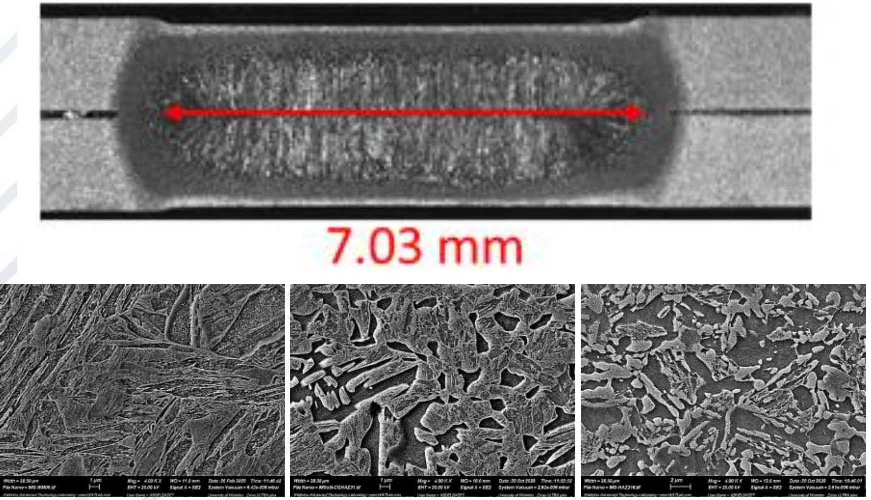
WELDING SCHEDULE

- The welding schedule was developed according to AWS D8.9-2012 standard
- The current that led to forming FSWD (7 mm) was chosen to perform the mechanical testing

Material	Current-kA	Squeeze time- Cycle	Welding time-Cycle	Electrode force- kN	Holding time-Cycle
3G-980	9.2	10	10-2-10	4.9	10
3G-1180	9.0				

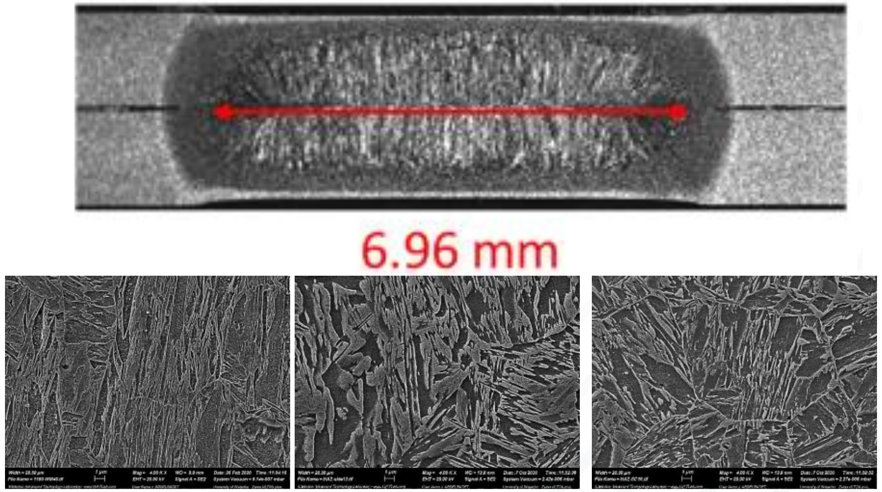
- FSWD weld size (7 mm) was measured from the cross-section

3G-980

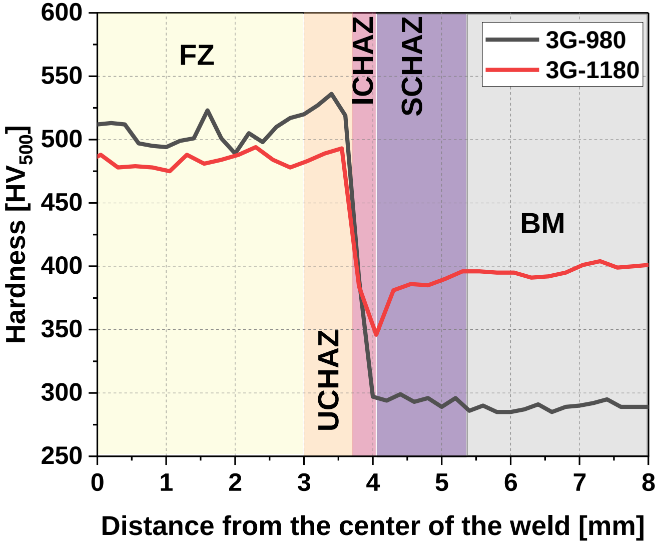


FZ ICHAZ SCHAZ

3G-1180

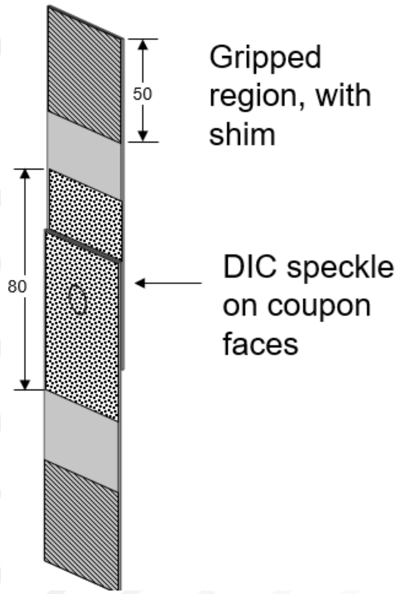


FZ ICHAZ SCHAZ



MECHANICAL TESTING

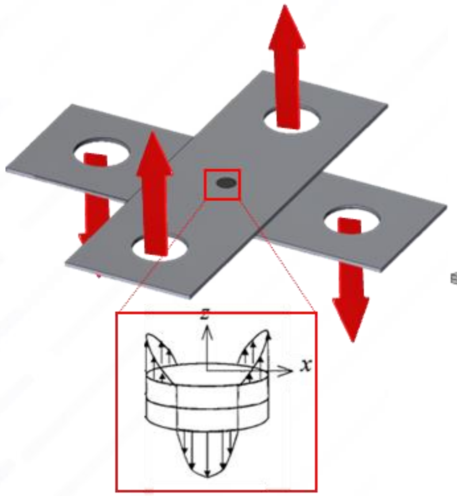
Lap shear



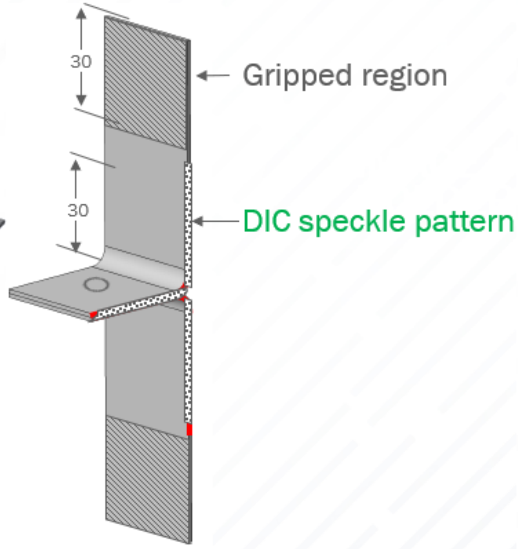
Gripped region, with shim

DIC speckle on coupon faces

Cross tension



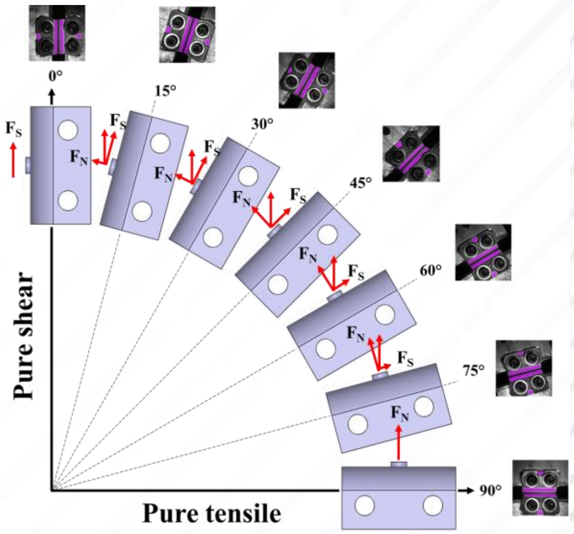
Coach peel

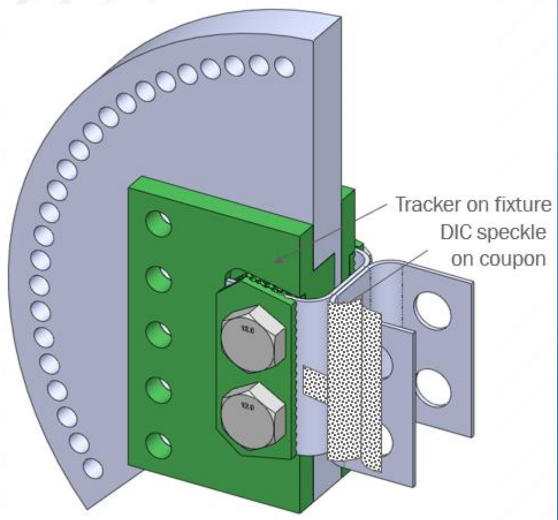


Gripped region

DIC speckle pattern

KS-II

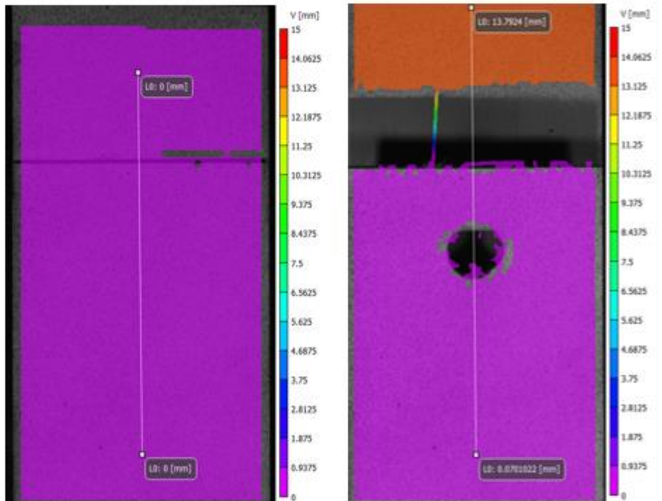


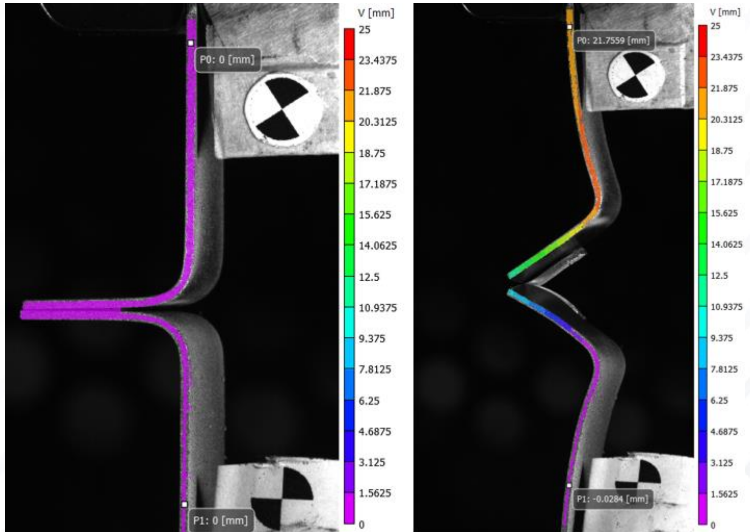


Tracker on fixture

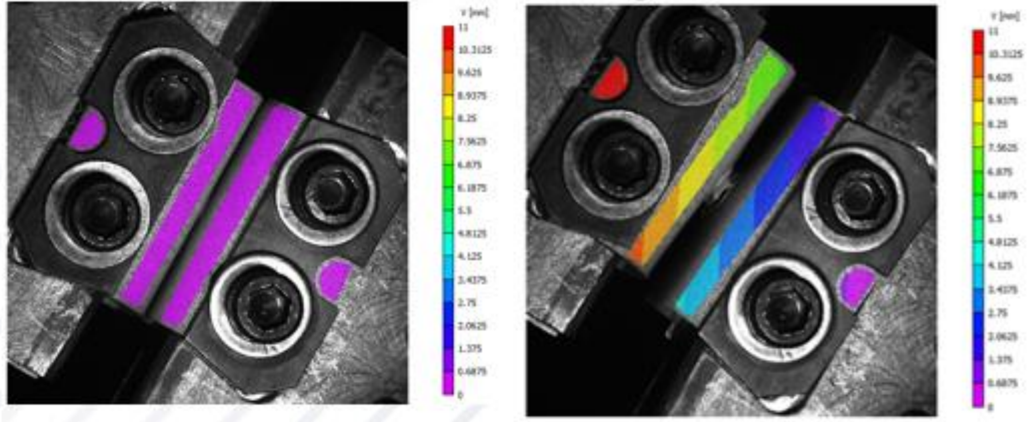
DIC speckle on coupon

Pullout failure



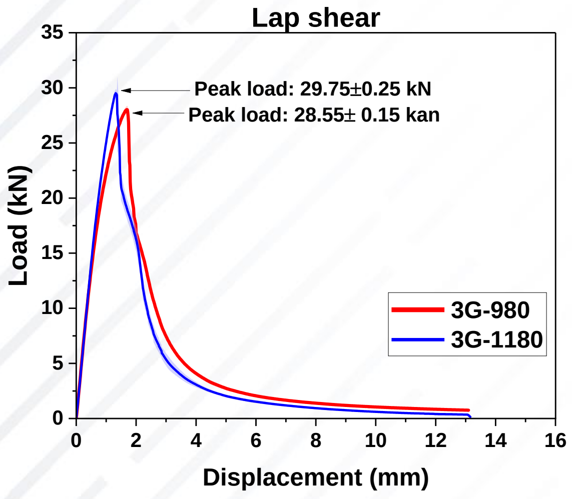


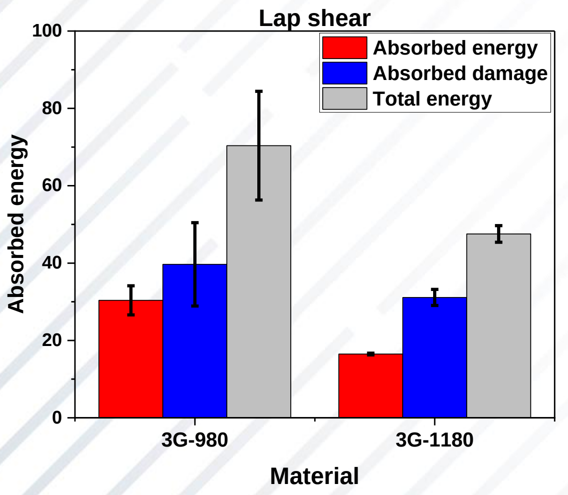
30 degree



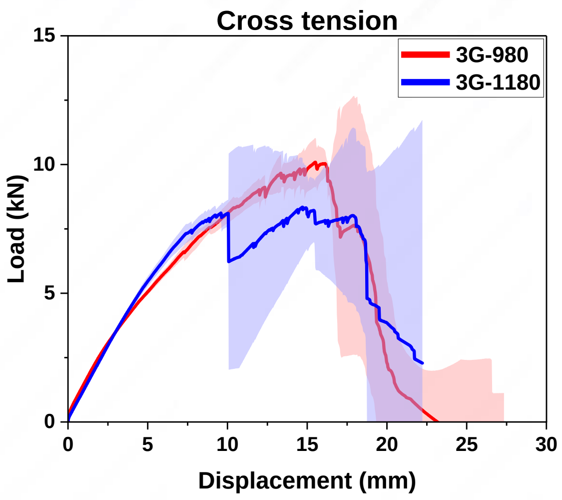
MECHANICAL TEST SUMMARY

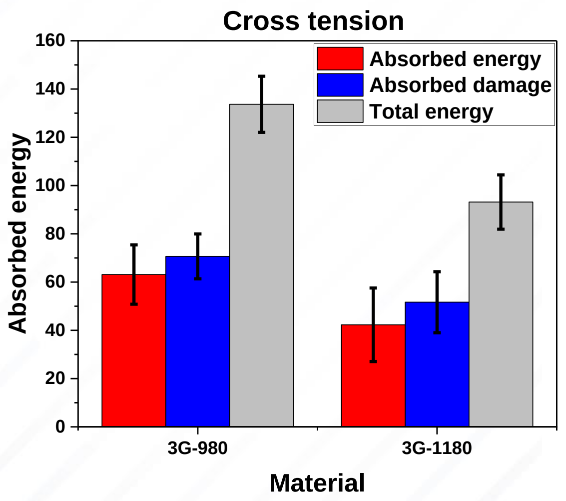
Lap shear



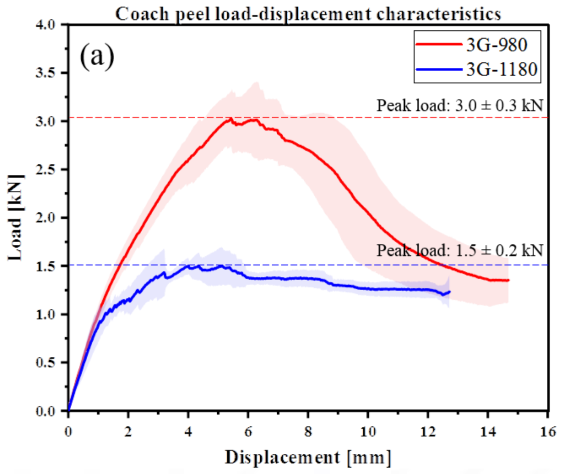


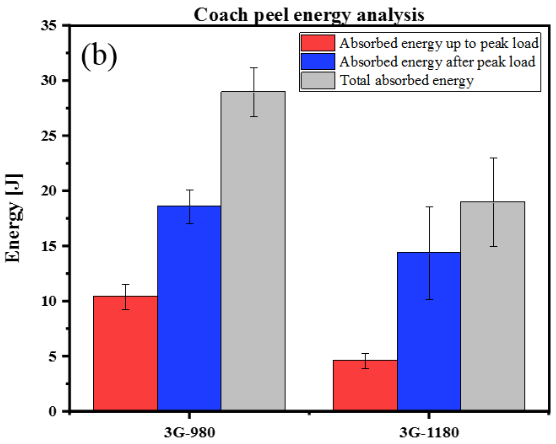
Cross tension



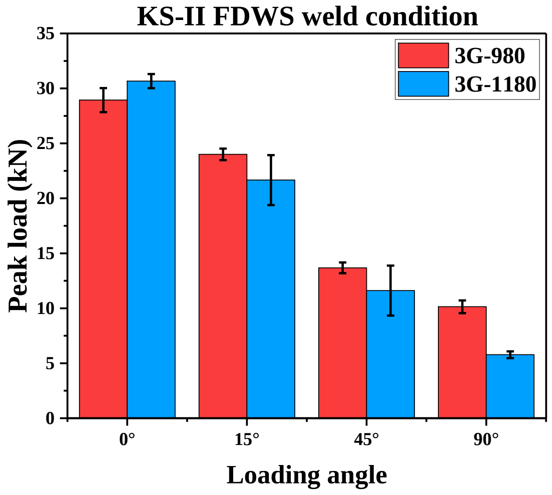


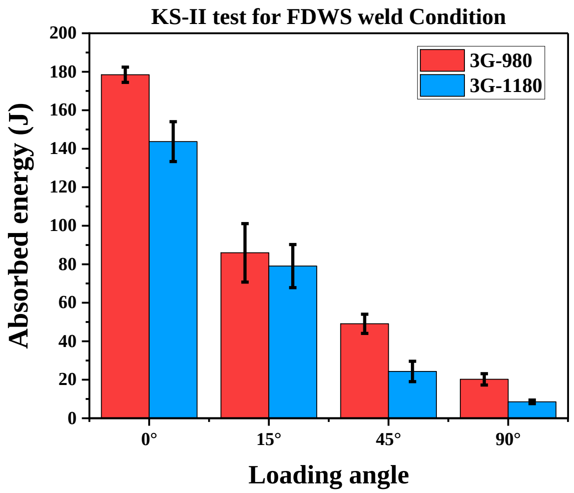
Coach peel



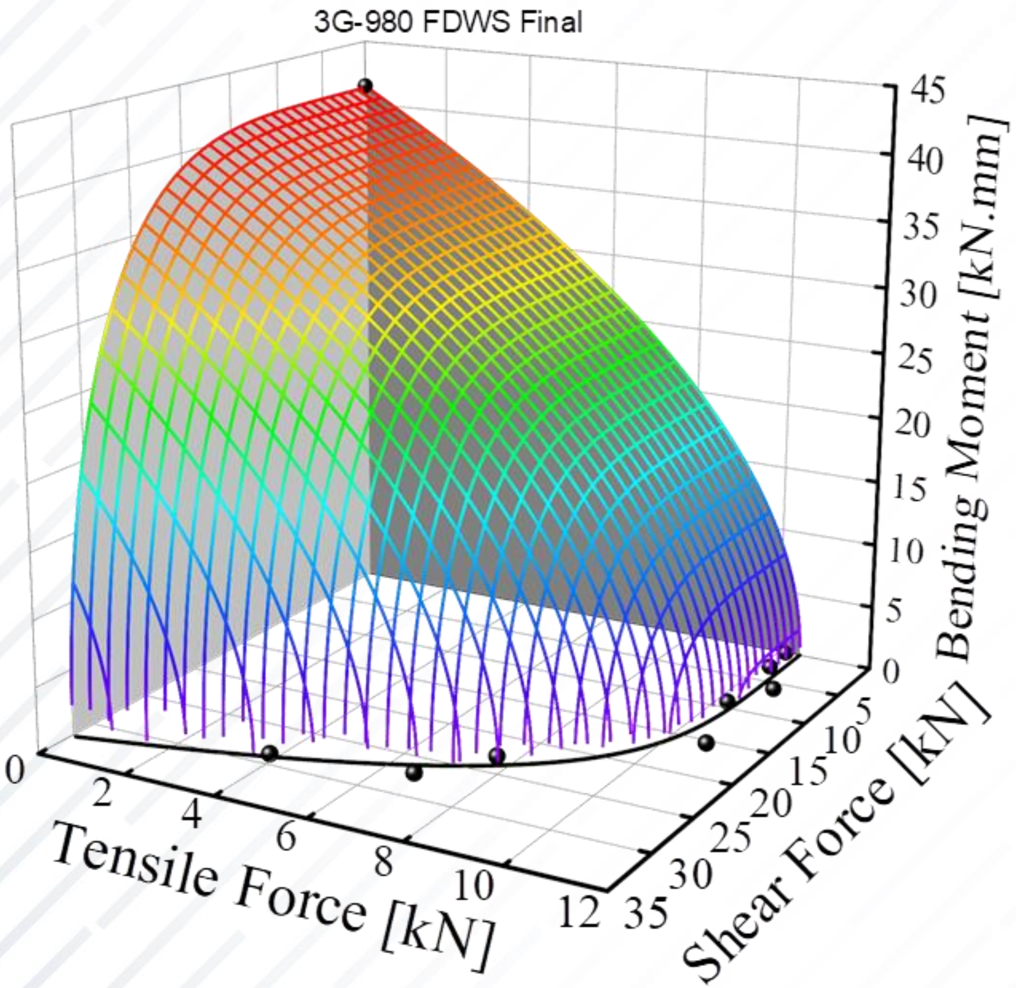


KS-II

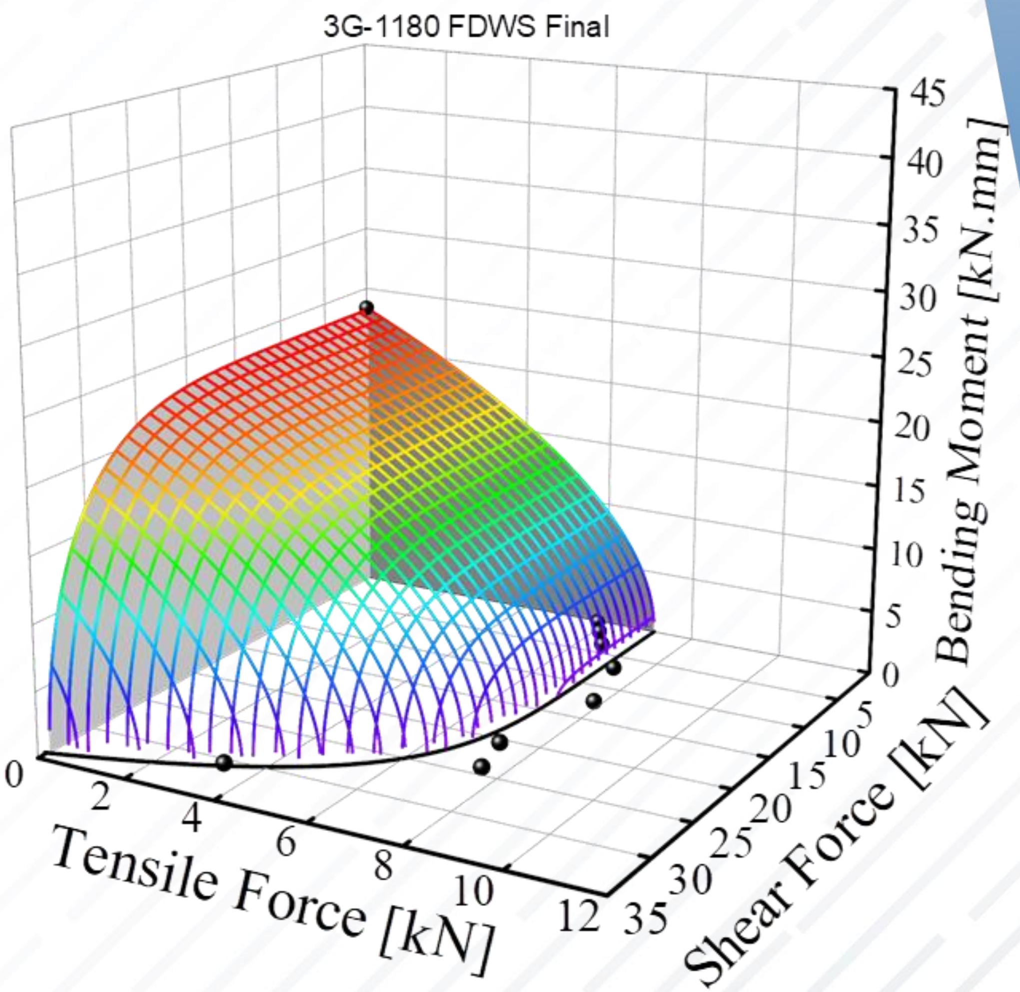




FAILURE SURFACE BASED ON SINGLE SPOT WELD RESULTS



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

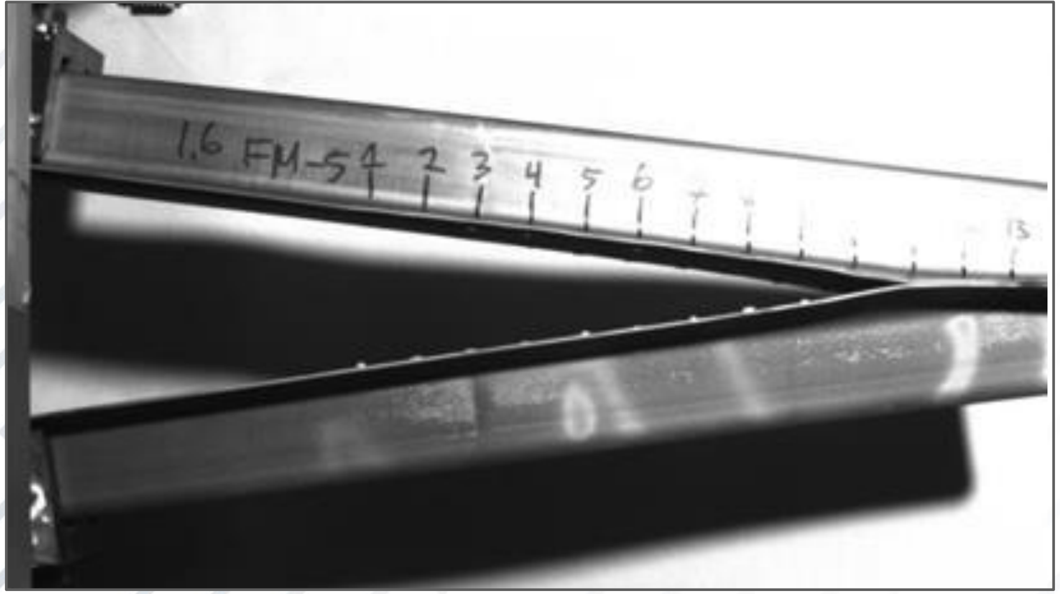


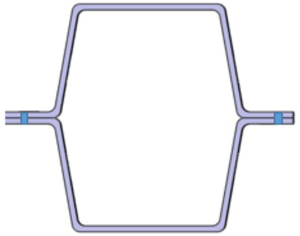
$$f = \left\{ \left(\frac{f_s}{34.160}\right)^{6} + \left(\frac{f_n}{7.116}\right)^{1} + \left(\frac{b_m}{23.359}\right)^{2} \right\} = 1$$

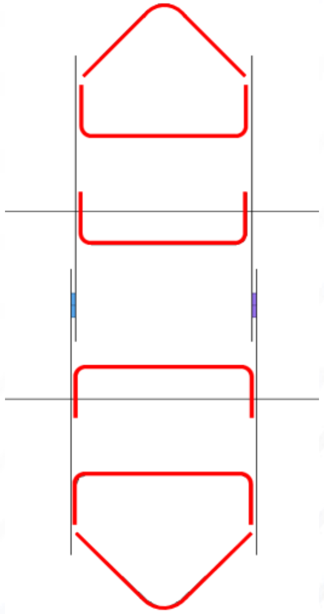
CAIMAN COMPONENTS TO TEST GROUP OF SPOT WELD FAILURE BEHAVIOR

SPOT WELD GROUP TEST

Caiman Mode-I (tension-dominated load)

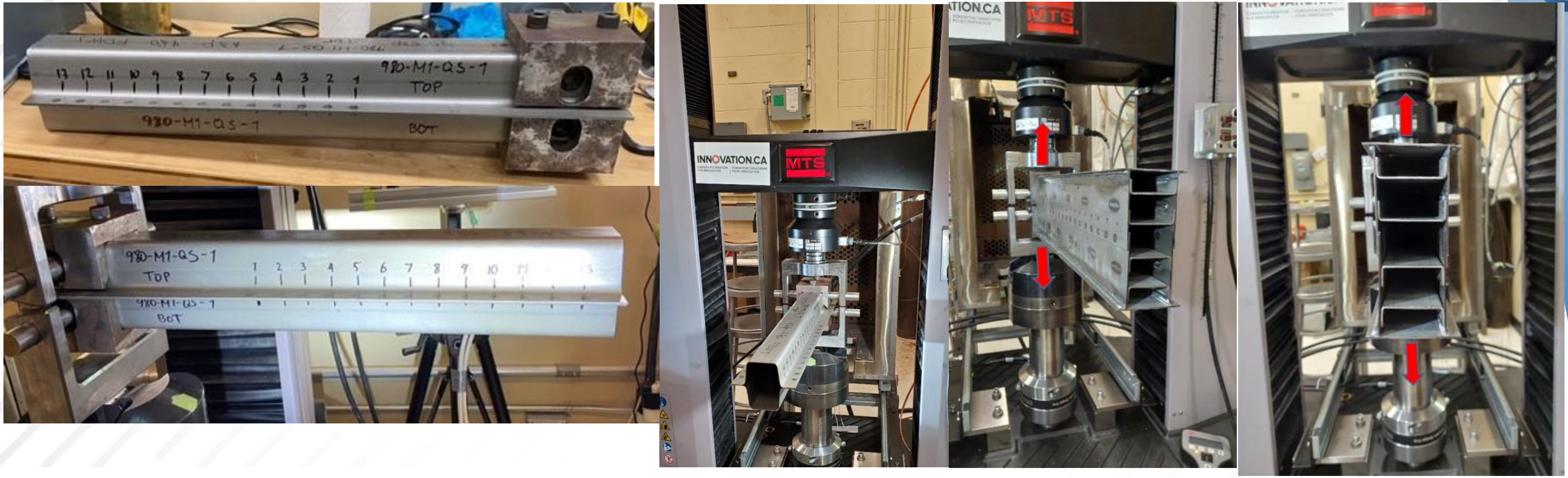


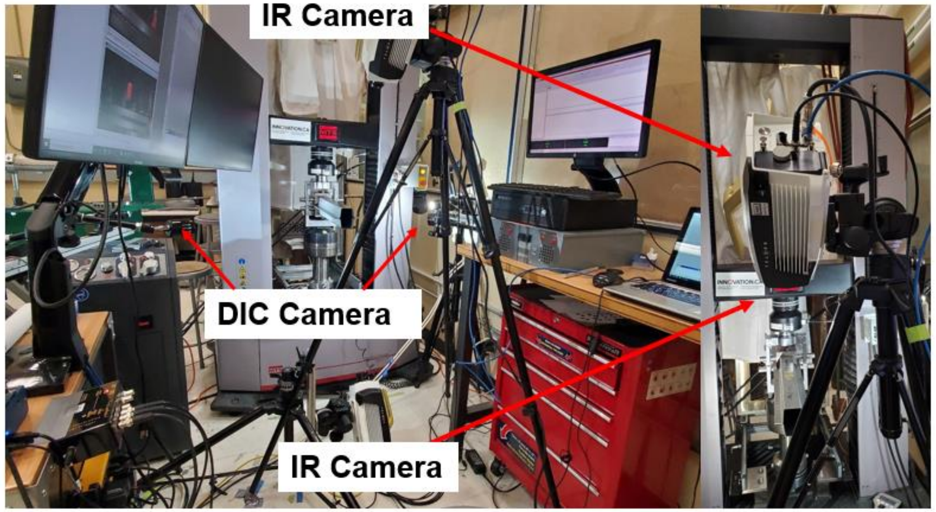


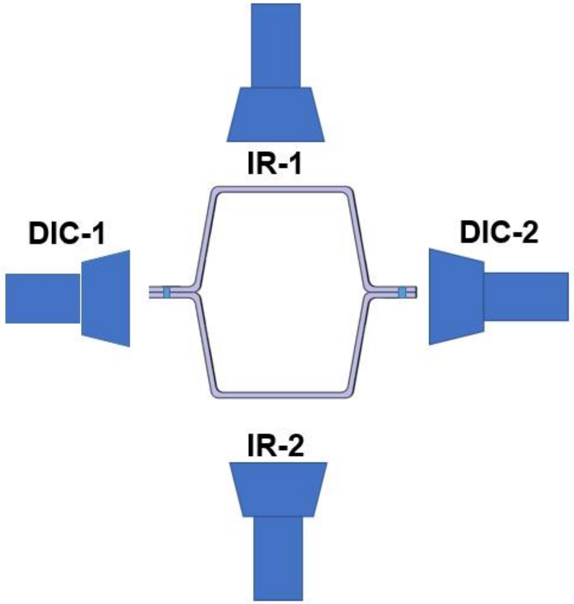


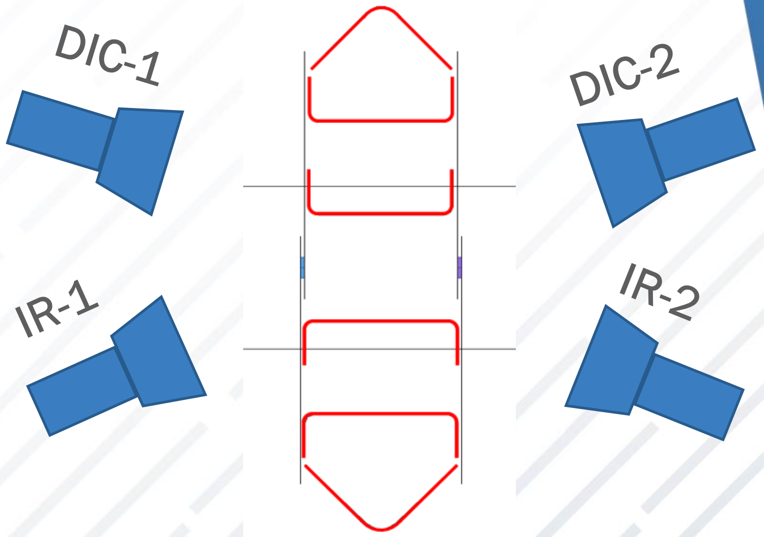
Caiman Mode-III (shear-dominated load)

Caiman Mode-I and Mode-III fixture and component Quasi-static test set-up

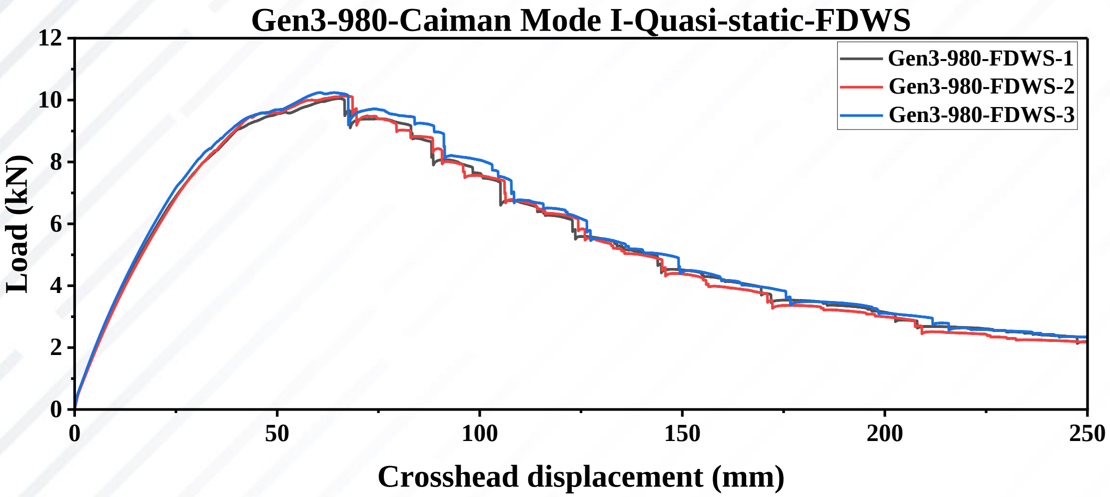


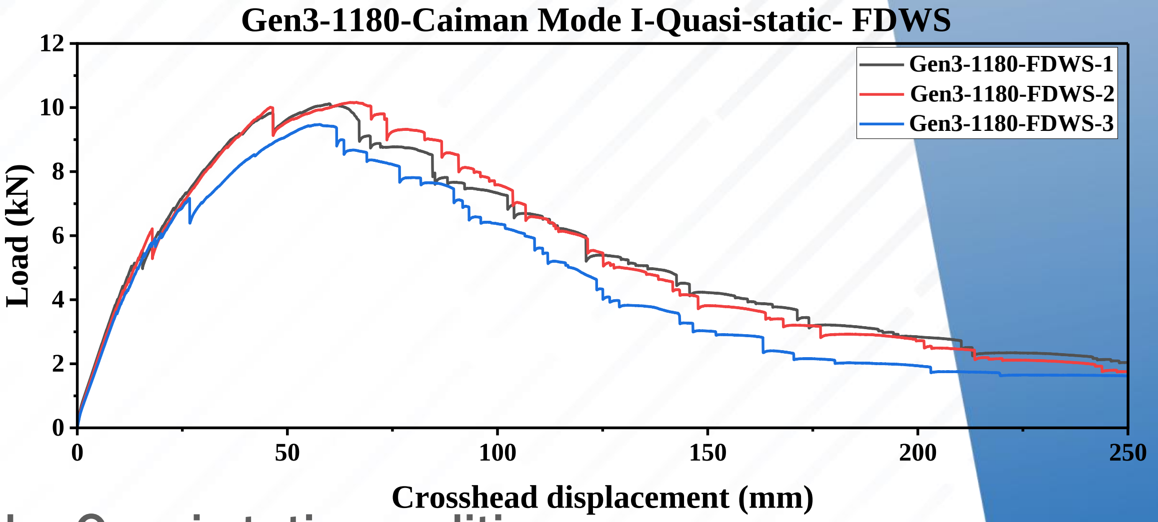






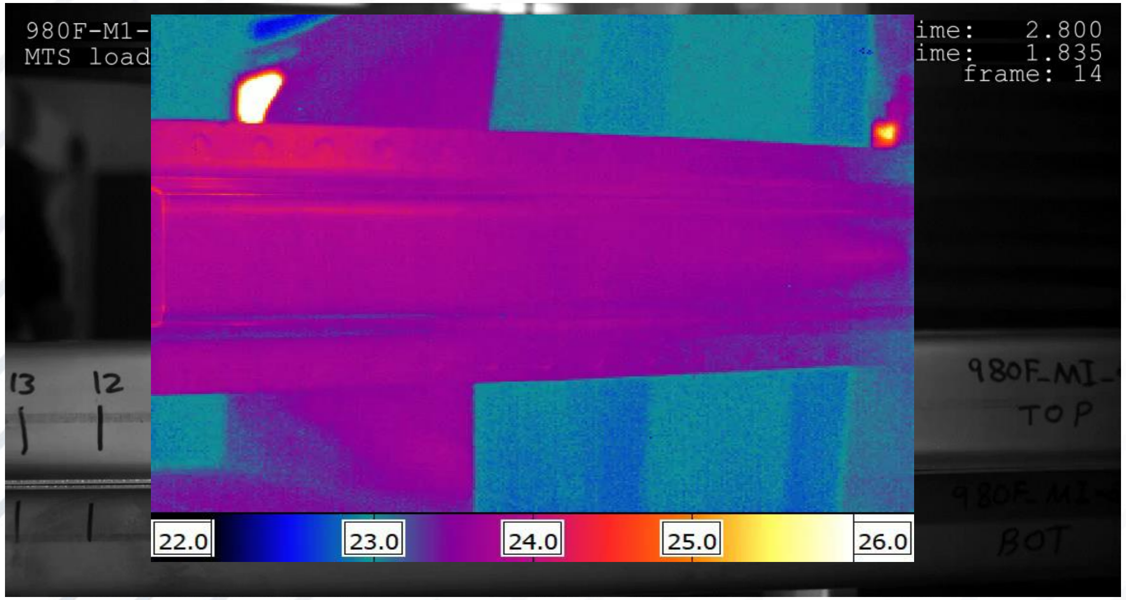
Load-displacement curves for Caiman Mode-I Quasi-static test

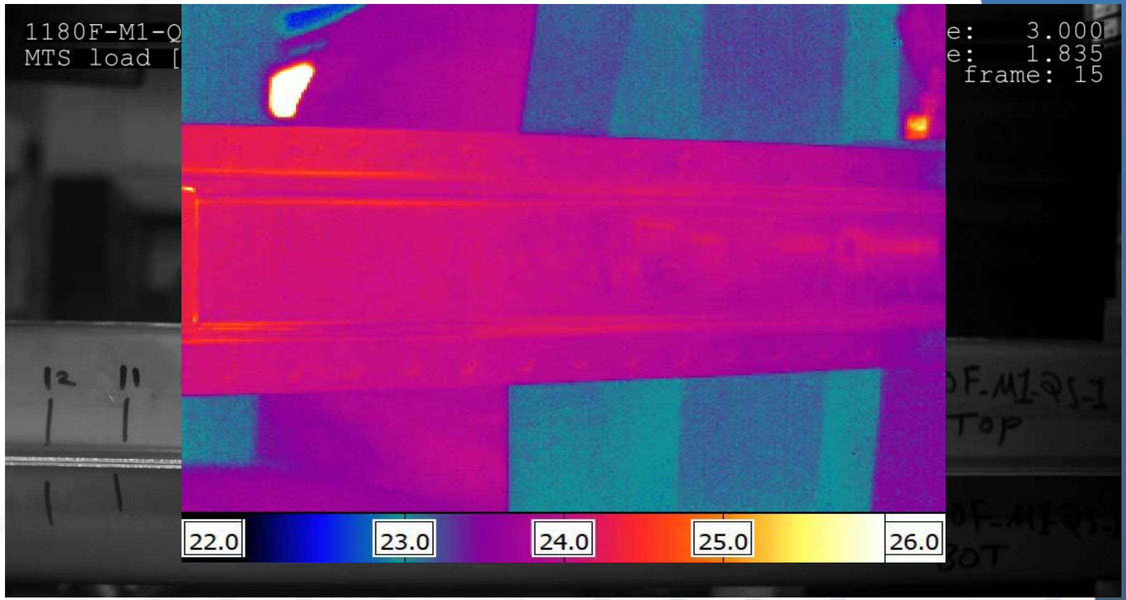




Videos show the failure behavior for Caiman Mode-I under Quasi-static condition

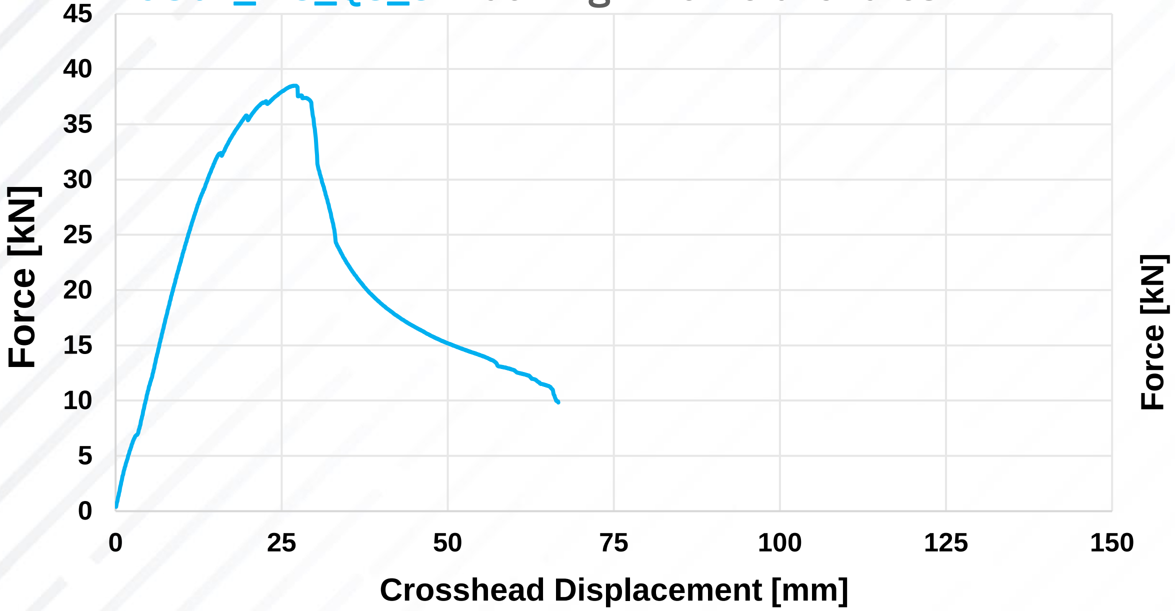
The thermal data will be processed in order to help for making the weld failure timing charts



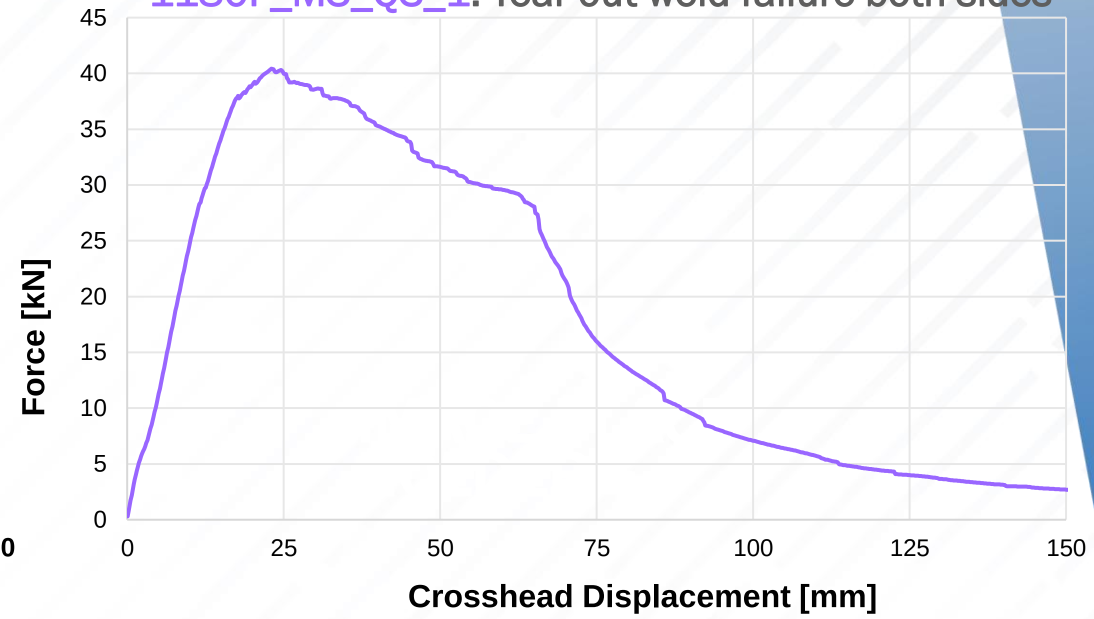


Load-displacement curves for Caiman Mode-III Quasi-static test

980F_M3_QS_3: Buckling – no weld failures

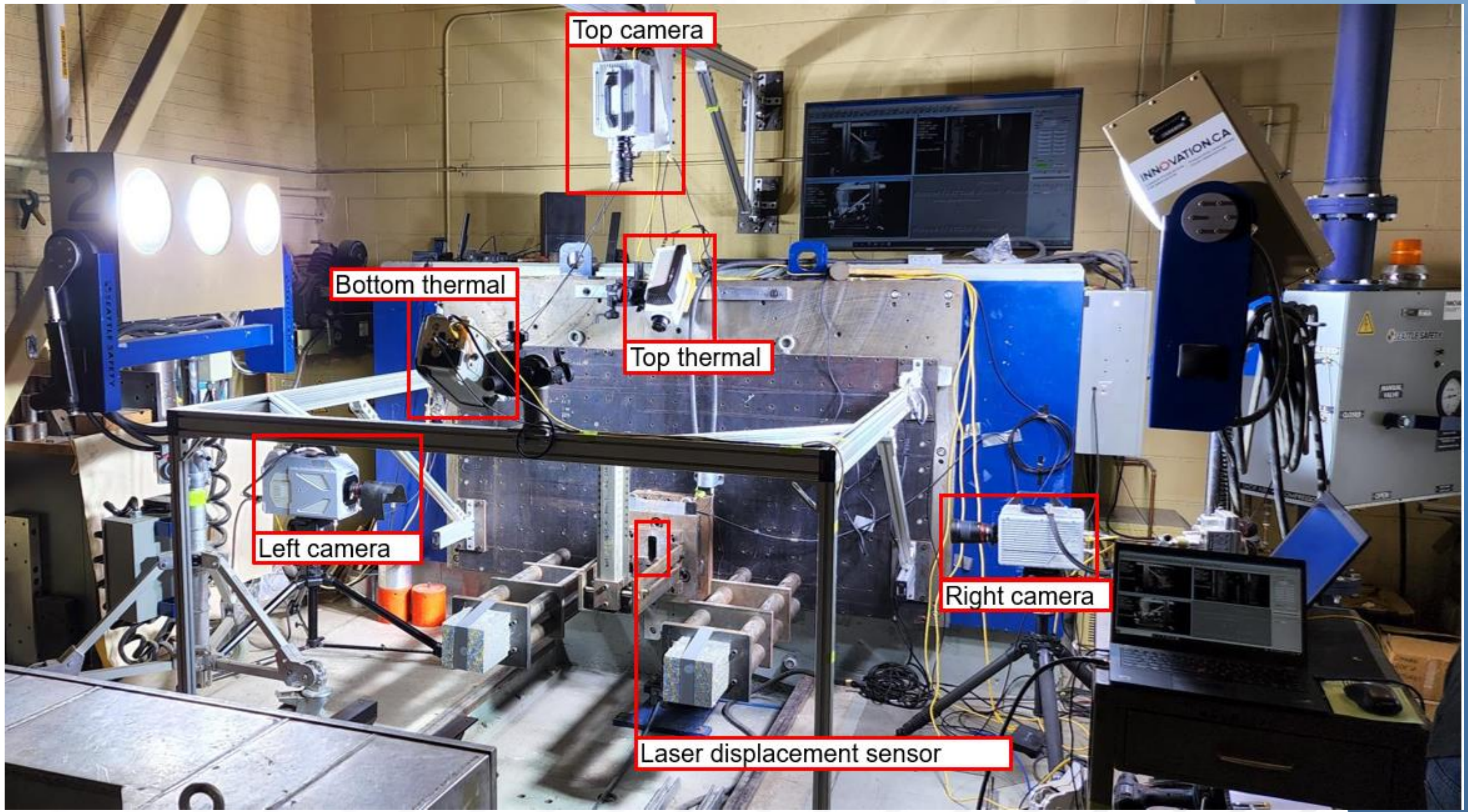


1180F_M3_QS_1: Tear out weld failure both sides



CAIMAN MODE- I DYNAMIC TEST SETUP

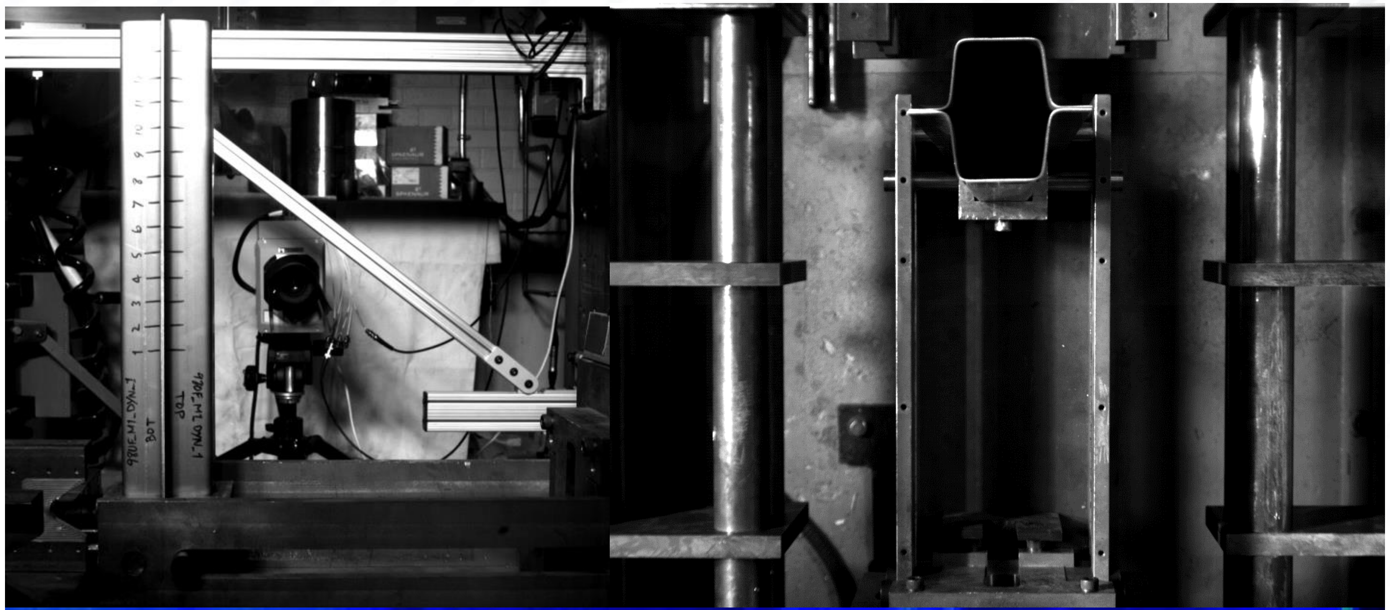
- Three High speed Photron cameras (left, right, top) – 5000 fps
- Two thermal cameras (top and bottom of parts) – 5000 fps
- Initial sled velocity – 7 m/s (25 km/h)
- Laser-displacement sensor measures part boss displacement
- 215 mm sled travel before the honeycomb
- 250 mm total measurement range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



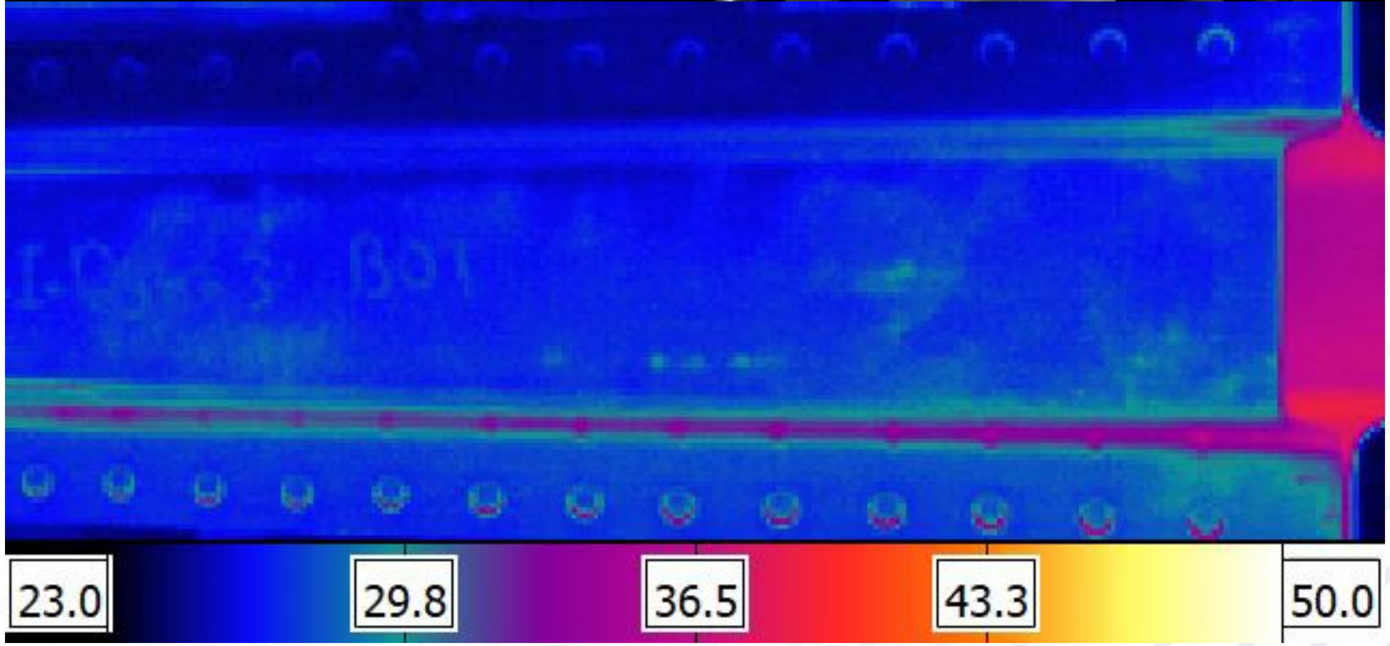
Caiman Mode 1 Dynamic Optical Video

980F_M1_DYN_1

Video speed reduced
5000 fps > 30 fps (0.006x)

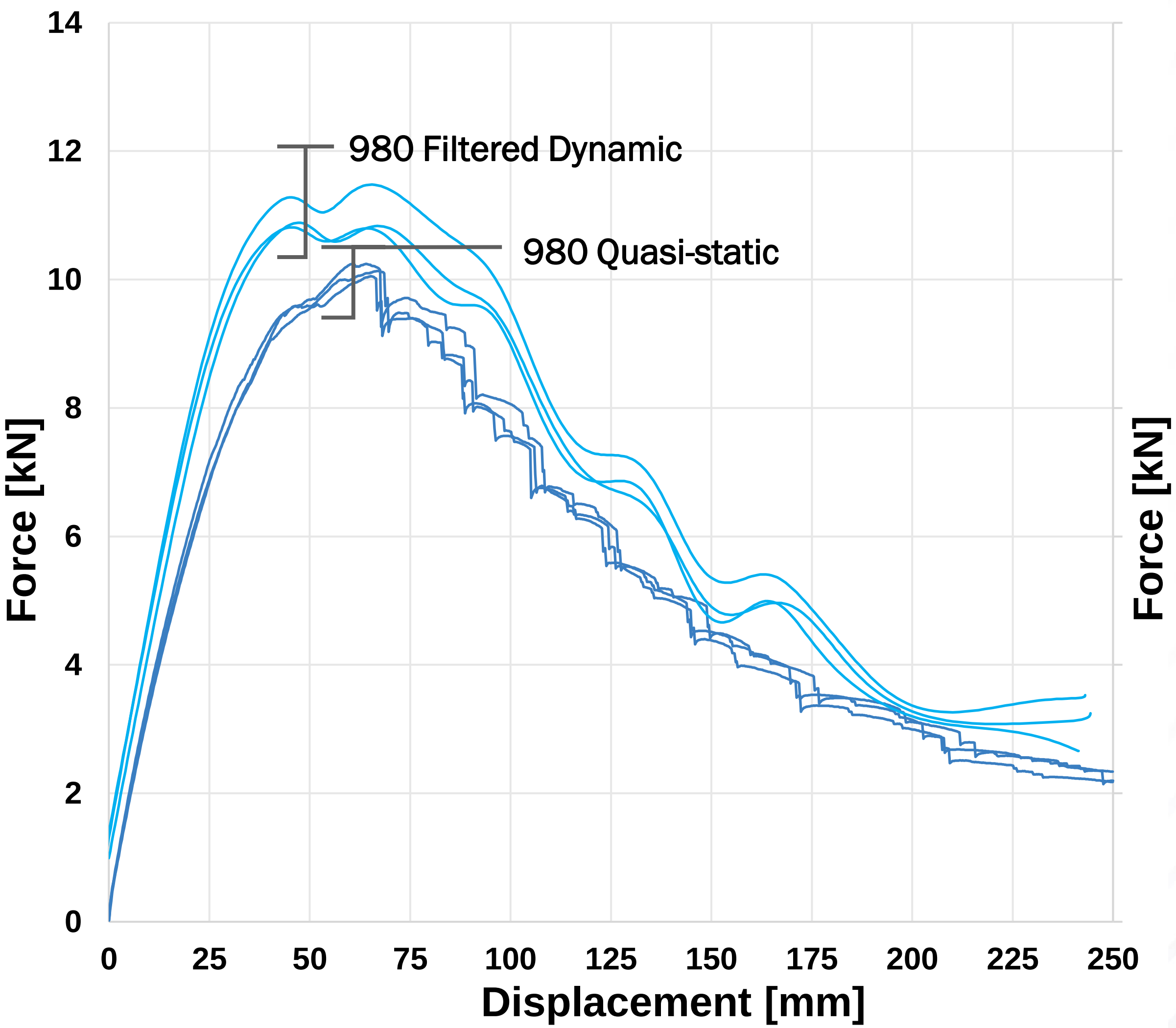


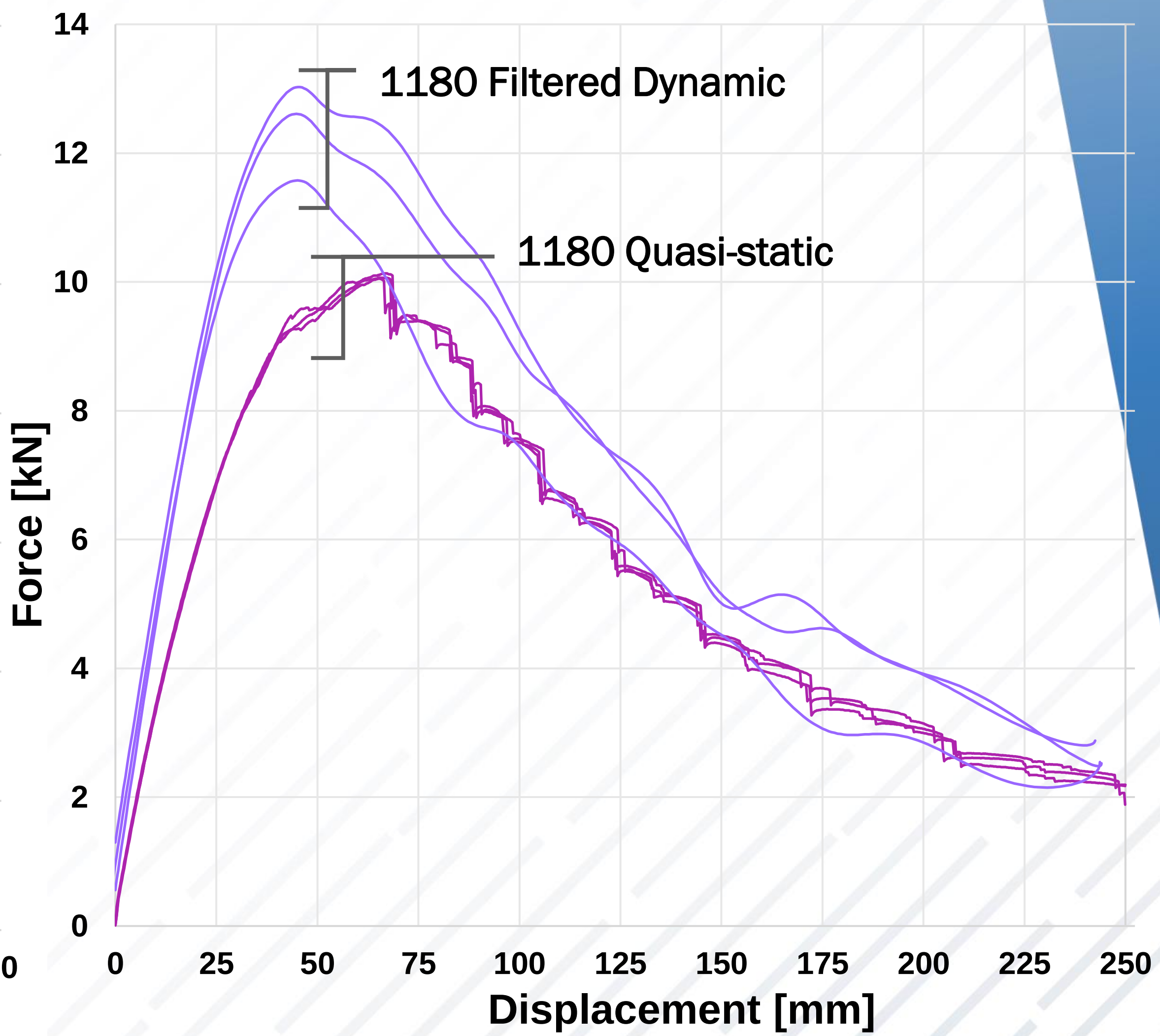
Video speed 0.006x actual
(5000 fps > 30 fps)



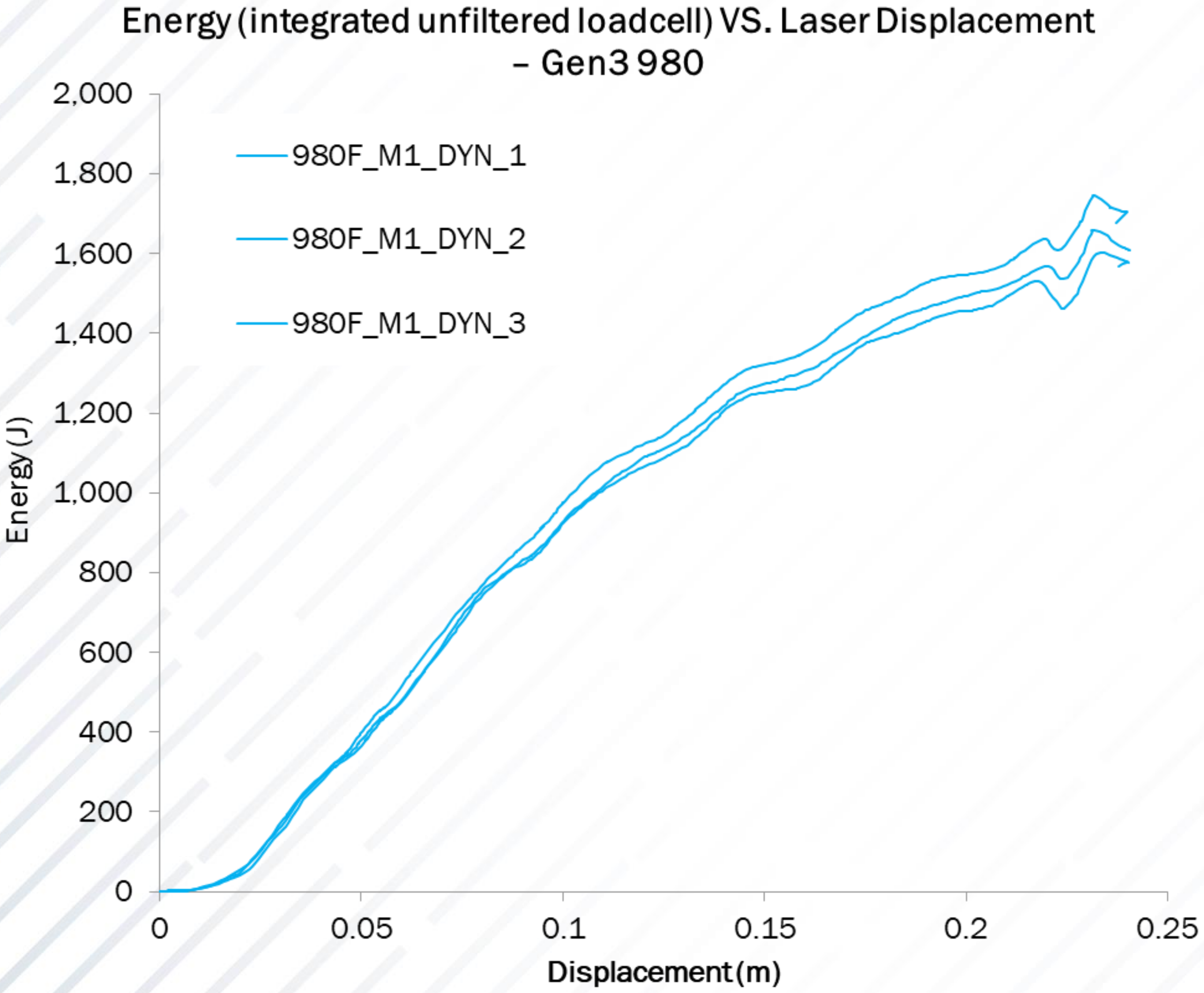
Caiman Mode 1 Dynamic test compared to Quasi-static test Force-Displacement

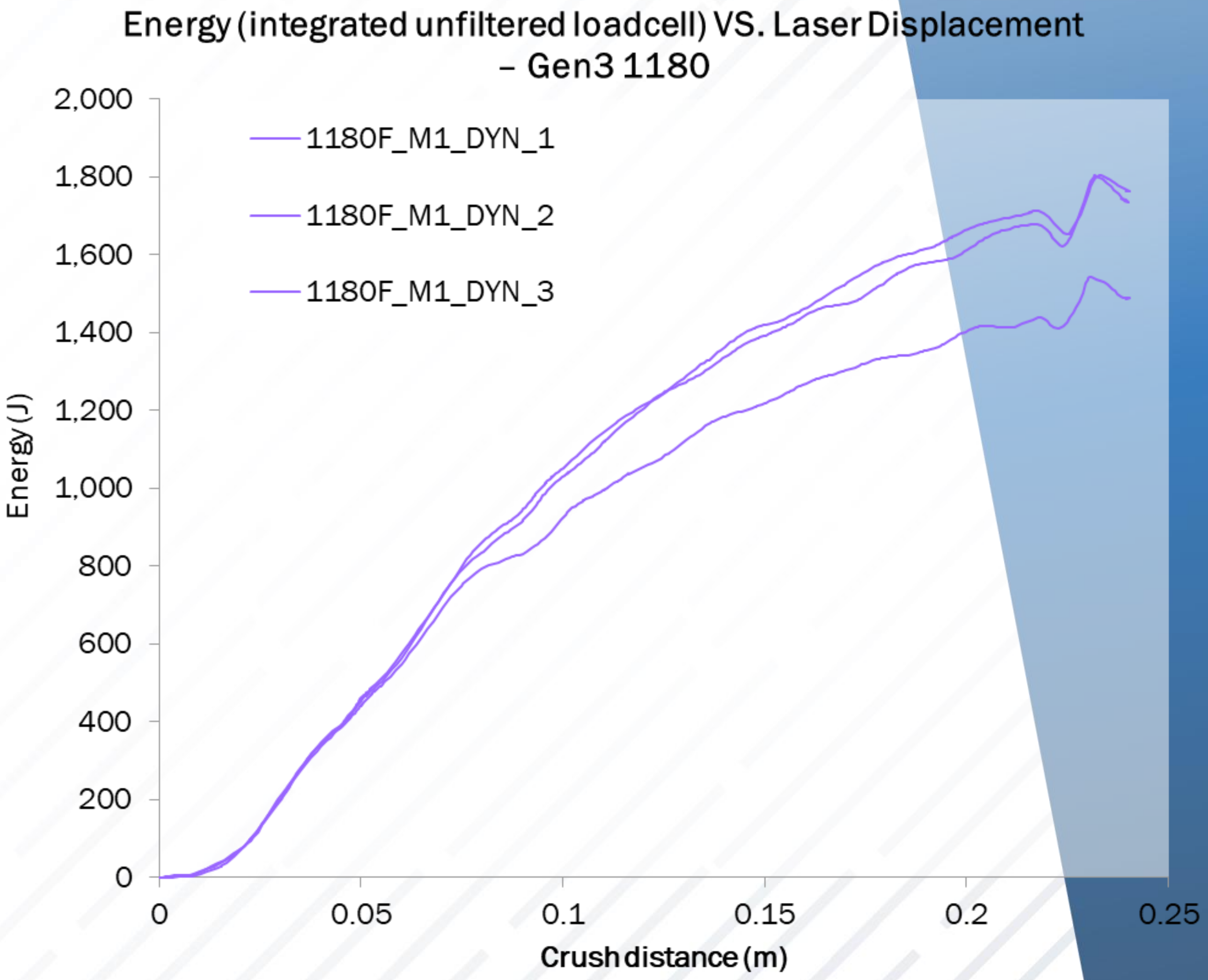
Comparing the filtered dynamic test load cell data to the quasi-static load cell data





Caiman Mode 1 Dynamic Energy-Displacement





MODELING OF CAIMAN SPOT WELD GROUP TEST

Caiman Mode I and Mode III – LS-Dyna Simulations

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

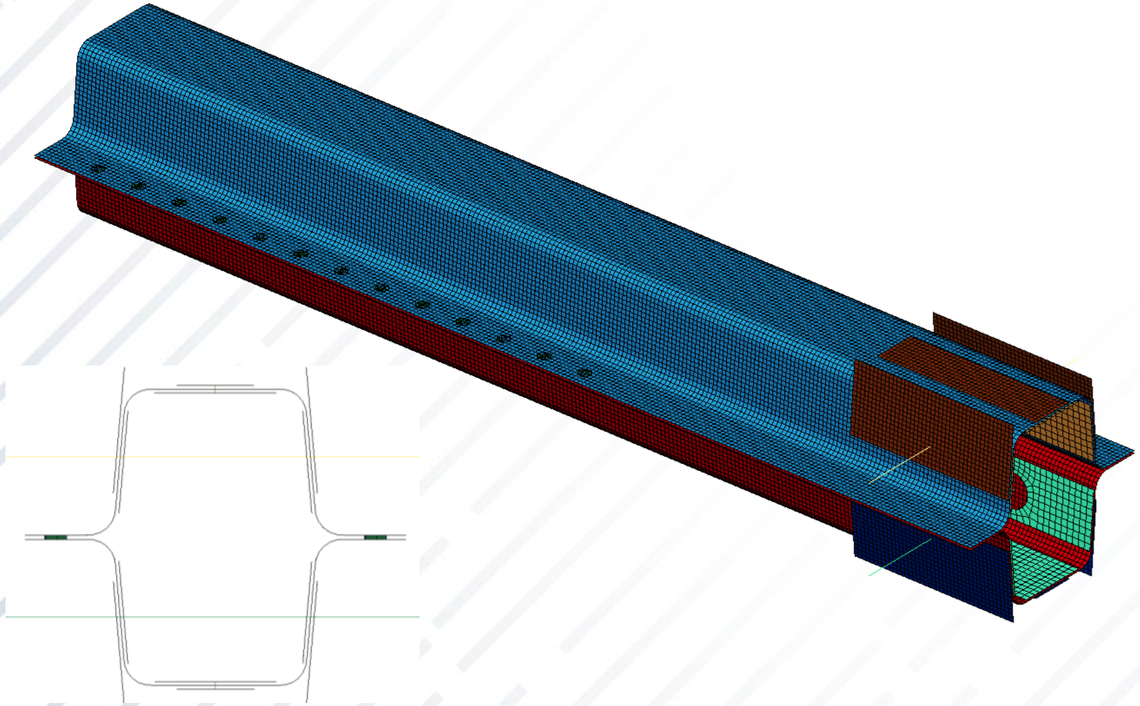
- Brick elements – 8 element assembly
- Cross section area equiv. to experimental spot welds
- Tied to parent metal shell midplanes
- **MAT_100, MAT_100DA, and MAT_240**
- Weld models fit from single-spot weld lap shear experiments

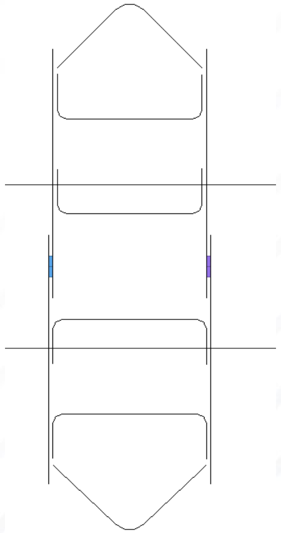
Caiman Mode 1:

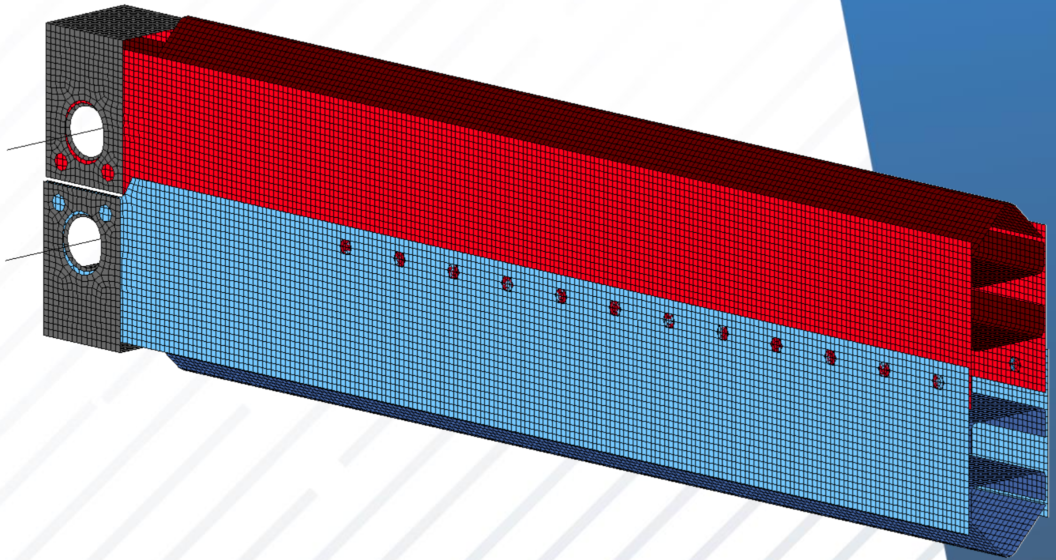
- Fixtures/bosses are rigid shells
- Lower pin (beam) fixed in x, y, and z space
- Upper pin (beam) prescribed to displace up (+Y)
- Bosses constrained to rotate about pins
- Tensile failure through the spot welds (FE data)

Caiman Mode 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)

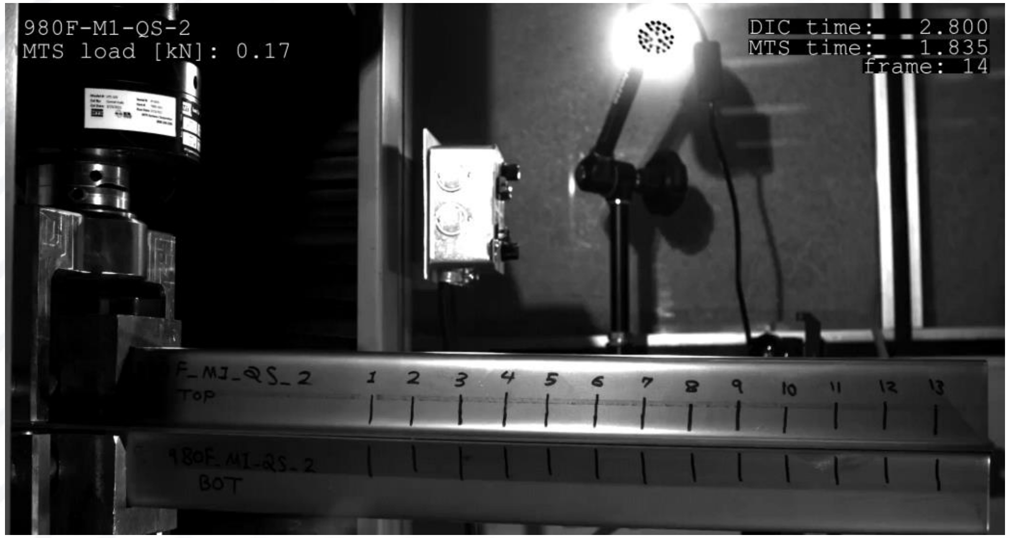




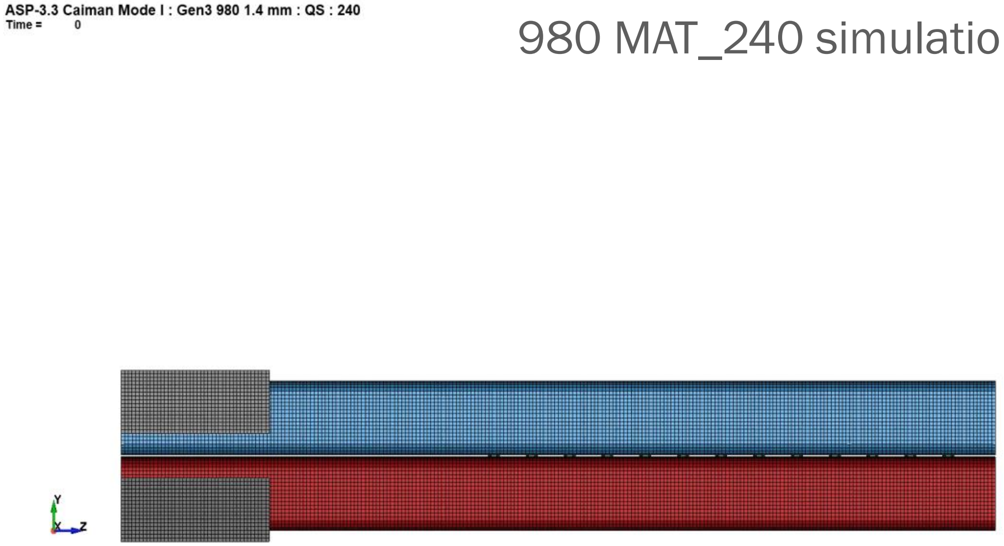


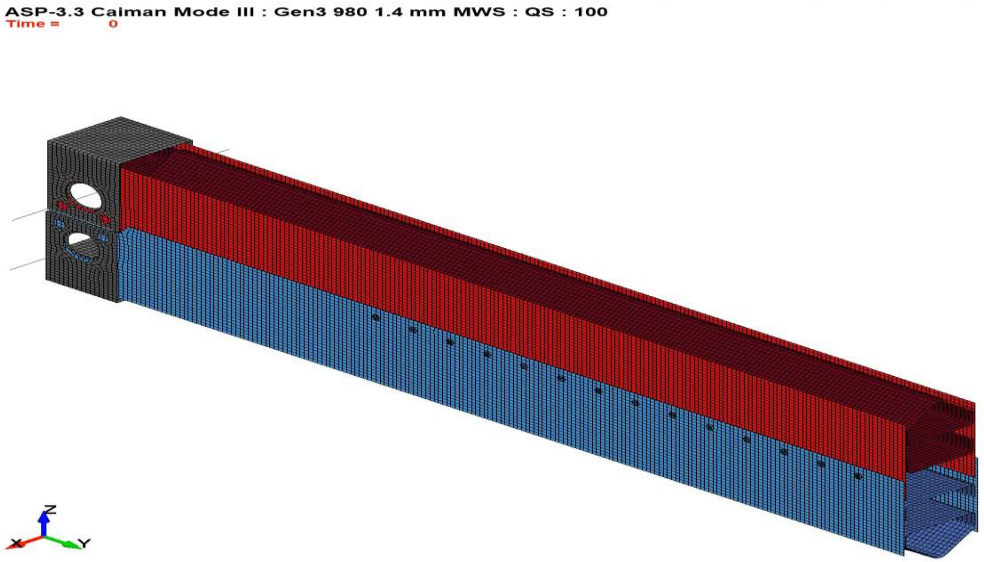
Caiman Mode-I and Mode-III – LS-Dyna Simulations

980F_M1_QS_2

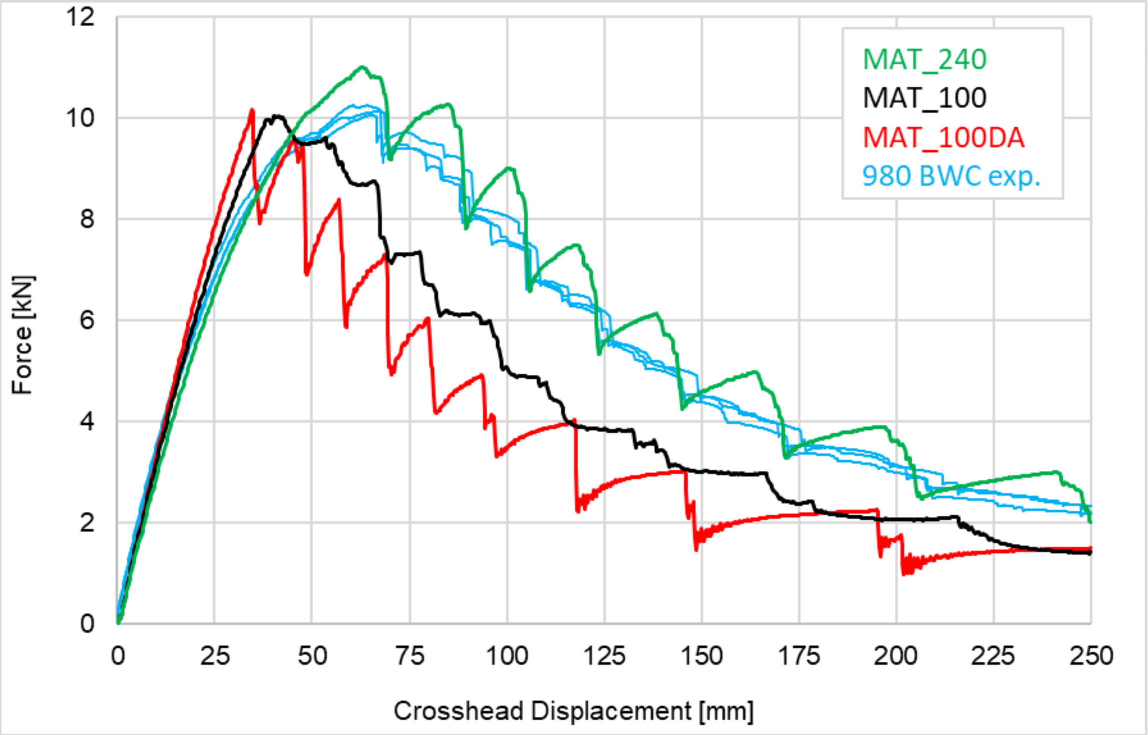


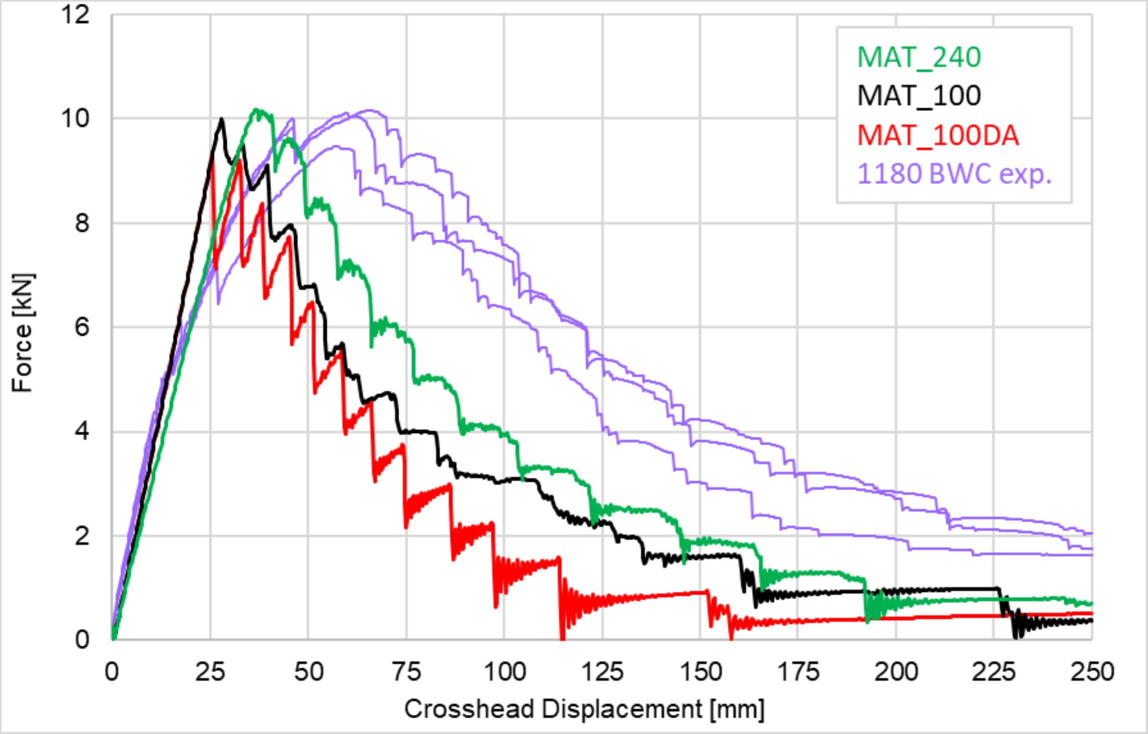
980 MAT_240 simulation





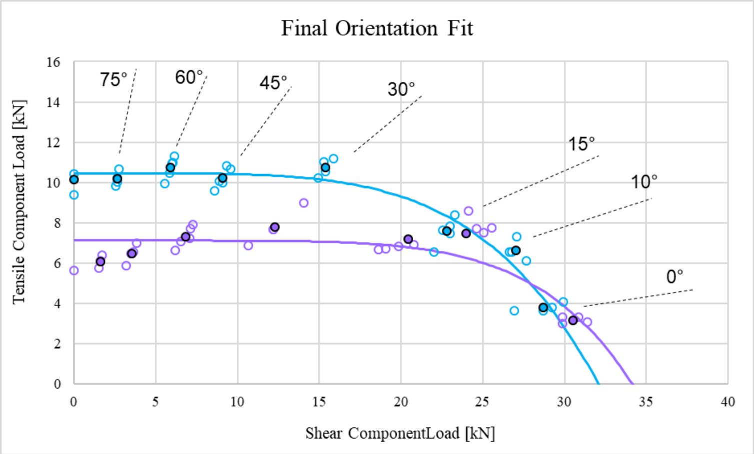
Caiman Mode 1 – LS-Dyna Simulations





Initial calculation for model bending parameter:

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



- 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

CONCLUSION AND FINAL REMARKS

- 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 behaviour 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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