GREAT DESIGNS IN STEEL

TWENTY YEARS

CHARACTERIZATION OF MECHANICAL PROPERTIES AND FAILURE BEHAVIOR OF 3RD GEN AHSS SPOT WELDS UNDER COMBINED LOADING MODE

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On Behalf of Auto/Steel Partnership

PRESENTATION OUTLINE

- Introduction
- Materials and methods
- RSW parameter optimization
- Microstructure and micro-hardness characterization
- KS-II combined loading results
- Conclusions

INTRODUCTION TO 3RD GEN AHSS

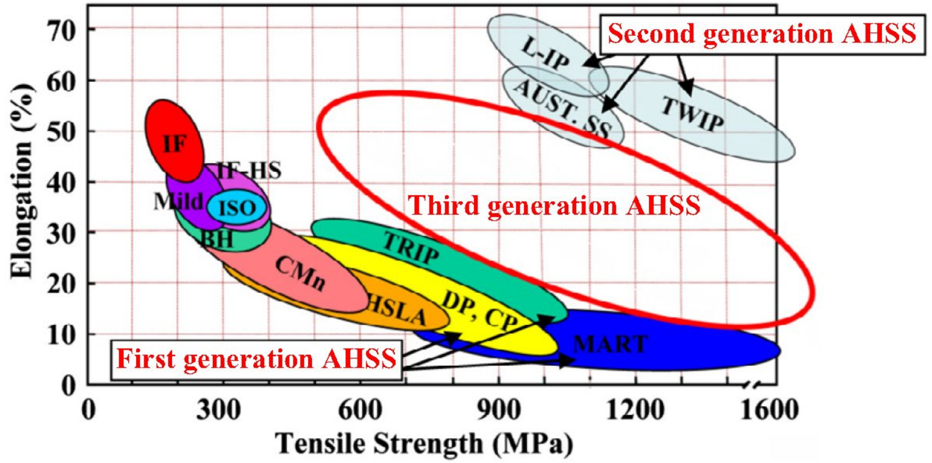
First generation AHSS: lean compositions, better strength and crash performance than HSS.

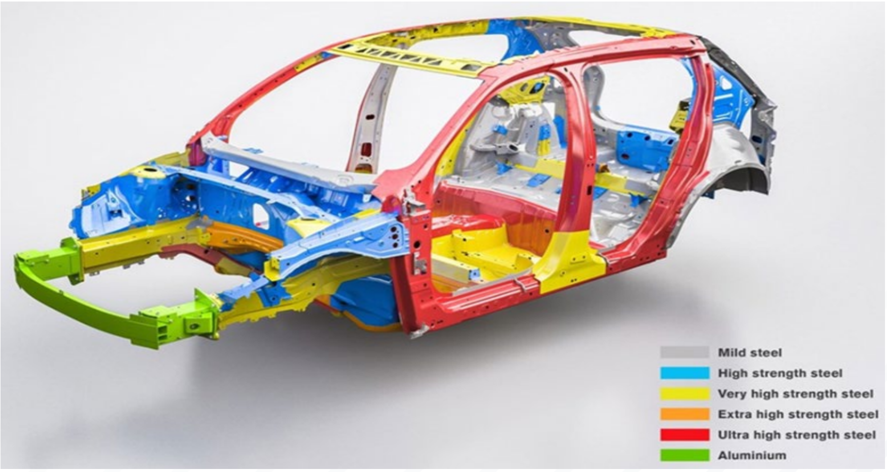
Second generation AHSS: Superior mechanical properties, elevated alloying additions, relatively expensive.

Third generation AHSS: Better strength/ ductility than 1G AHSS, lower allowing elements than 2G AHSS.

High strength to weight ratio of 3G-AHSS

- Weight reduction
- Reduced greenhouse emissions
- Better fuel efficiency
- Improved crash properties





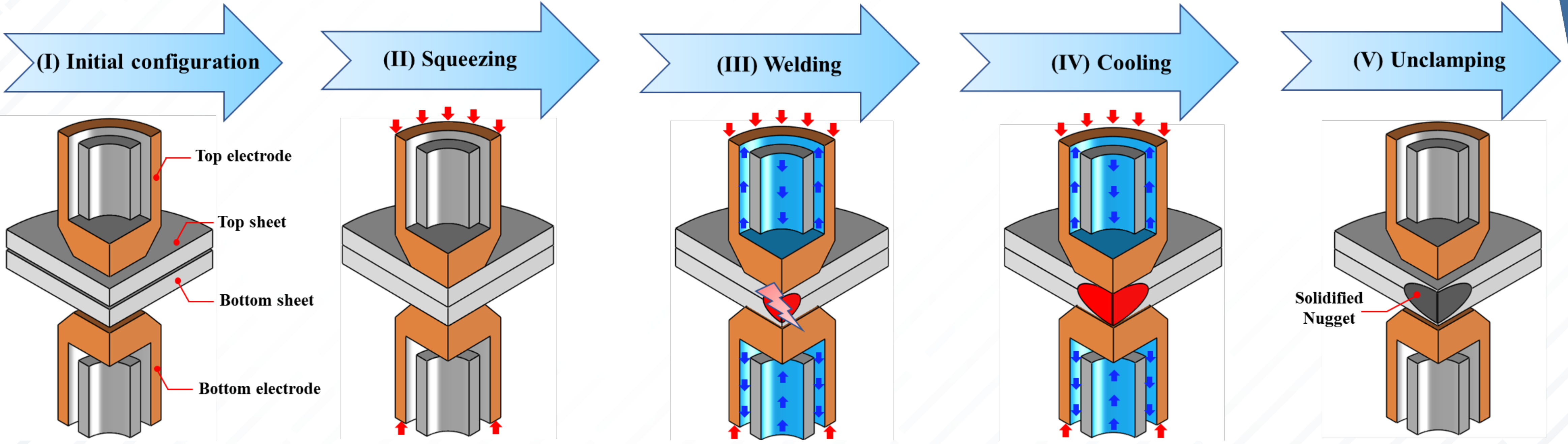
[1]WordAutoSteel. Advanced high strength steel (AHSS) application guidelines (version 4.1). WorldAutoSteel; June 2009.

[2]ArcelorMittal congratulates Volvo on XC40 winning Car of 2018 with AHSS - Automotive." [Online]. Available: https://automotive.arcelormittal.com/News/2018_news/Volvo-XC40-COTY-2018..

INTRODUCTION TO RSW PROCESS

Resistance Spot Welding is the most common joining technique in the automotive industry

2000-6000 Spot Welds in a typical BIW



OBJECTIVE

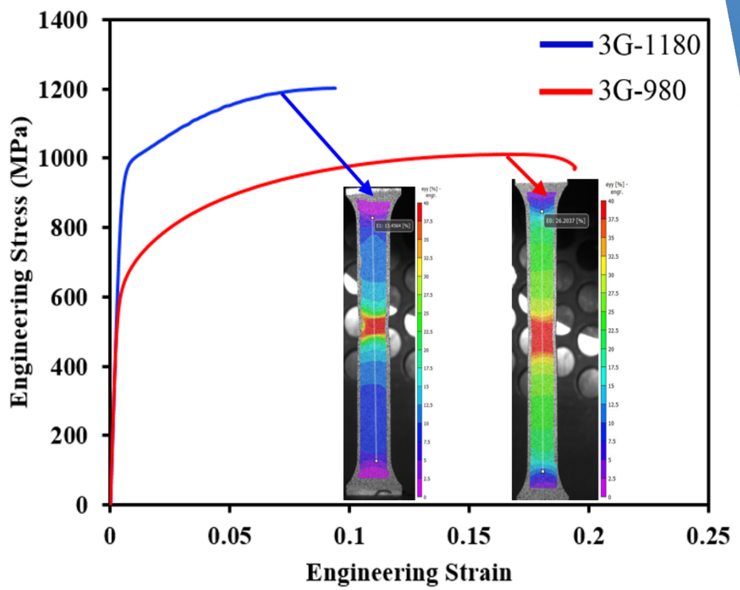
Characterize mechanical performance and failure behavior of 3rd Gen AHSS spot welded joints upon combined loading condition

- Load bearing capacities
- Energy absorption capabilities
- Failure response

MATERIALS AND METHODS

Material	Carbon equivalent	Nominal sheet thickness [mm]	YS [MPa]	UTS [MPa]	El [%]
3G-980 (uncoated)	0.64	1.4	616±2.64	1013±15.40	19.89
3G-1180 (uncoated)	0.7	1.4	967±7.05	1181±19.02	11.83

YS, yield strength; UTS, ultimate tensile strength; TE, total elongation; UE, uniform elongation;



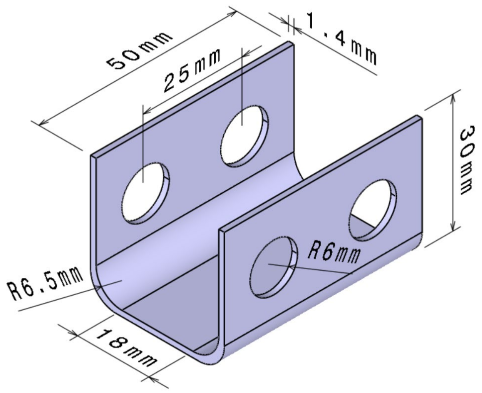
Welding schedule was selected based on recommendation of AWS D8.9 standard.

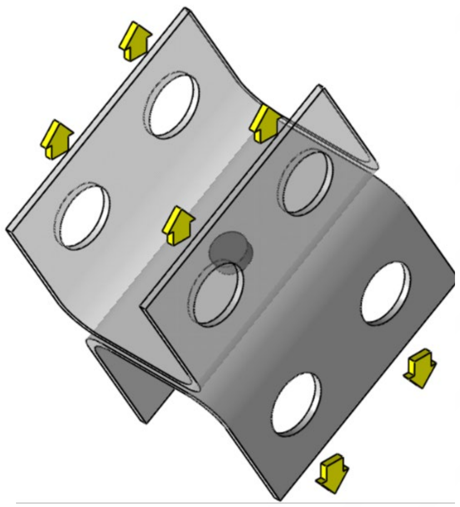
Material	**Number of pulses**	Total welding time (ms)	Squeeze time (ms)	Hold time (ms)	Cooling between pulses (ms)
3G-980 (uncoated)	2	334	167	167	34
3G-1180 (uncoated)	2	334	167	167	34

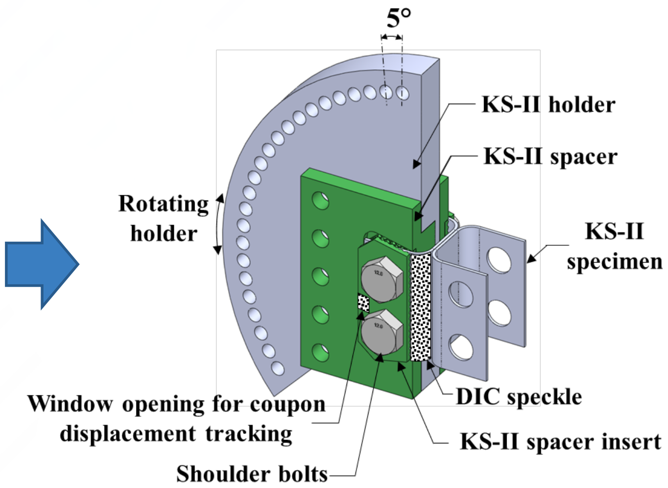
Honda RSW Robot

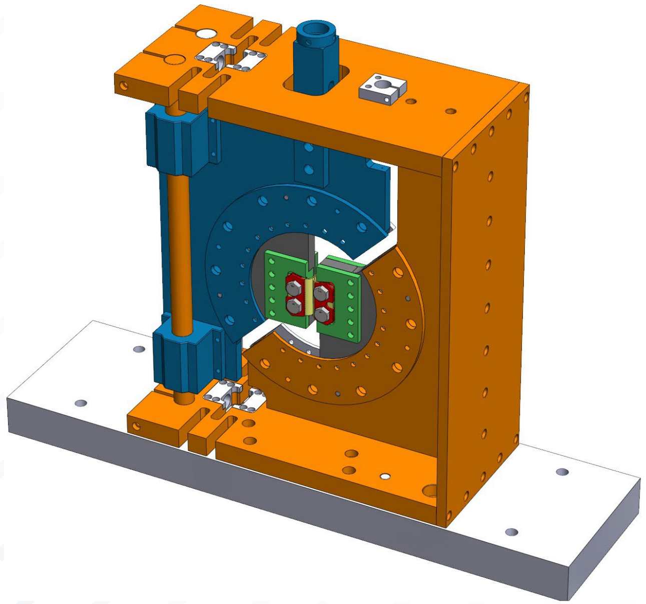
MATERIALS AND METHODS

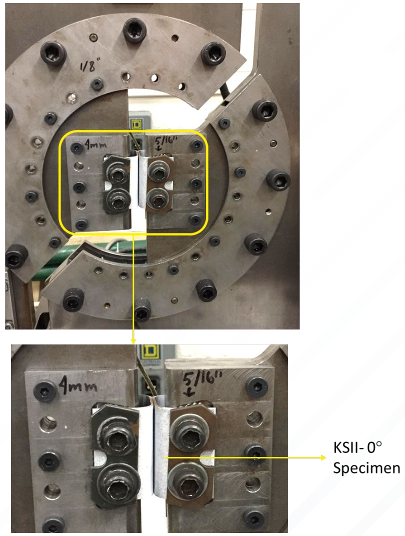
KS-II combined loading mechanical testing methodology:

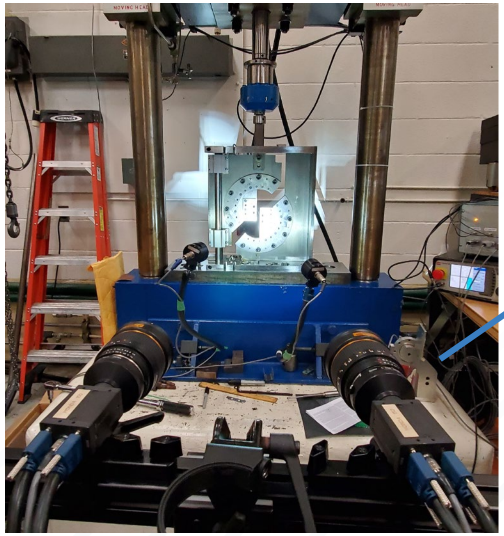










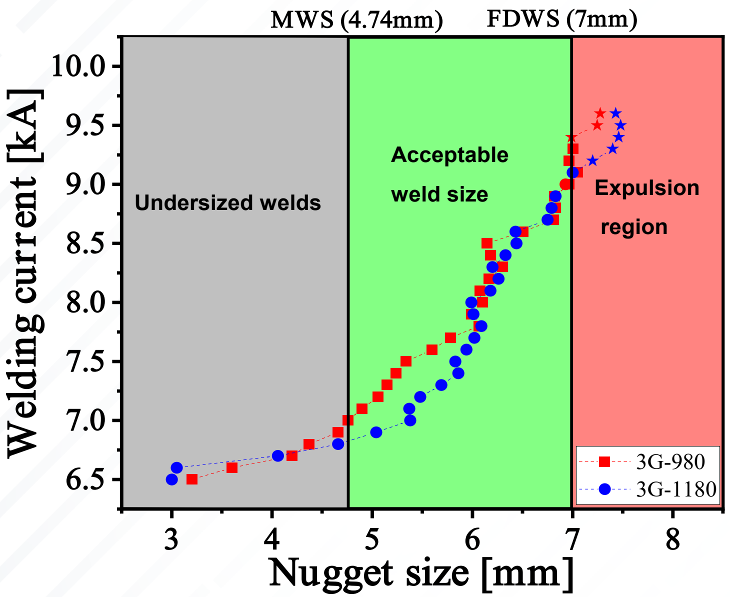


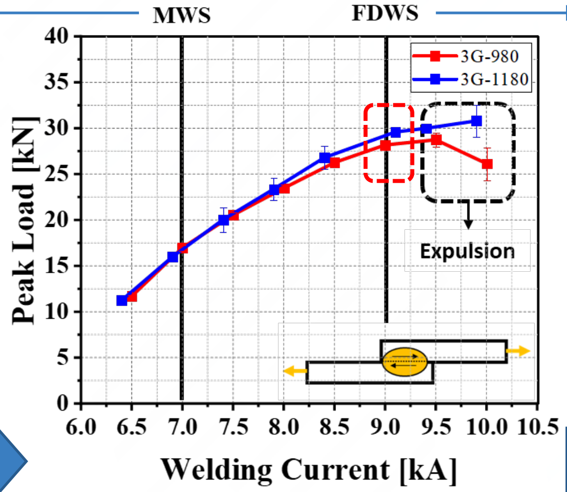
Tests were coupled with three dimensional Digital Image Correlation (DIC)

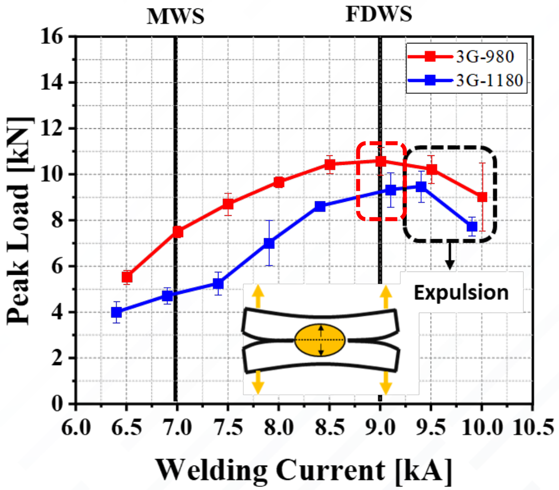
OPTIMIZED RSW PARAMETERS

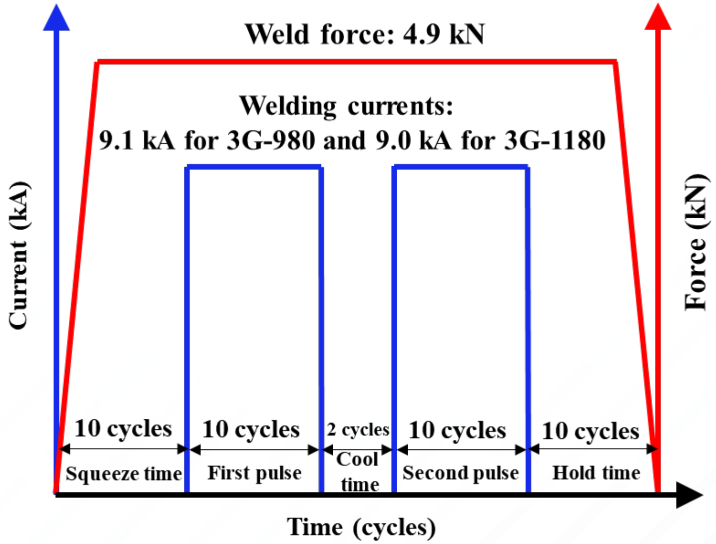
Welding current parameter was optimized by performing traditional Lap Shear and Cross Tension mechanical tests at 0.5 kA welding current intervals and selecting the highest load bearing capability without expulsion.

Minimum weld size of 4√t = 4.7 mm ← → Electrode face diameter weld size of 7mm



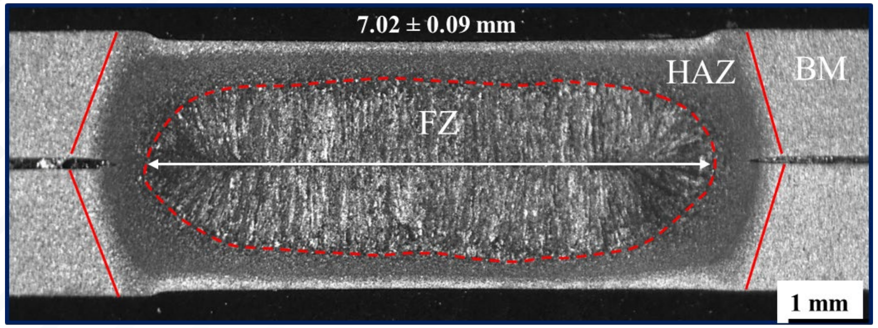


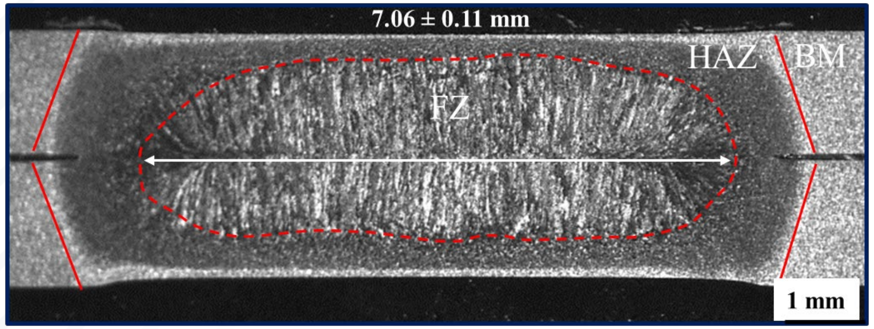


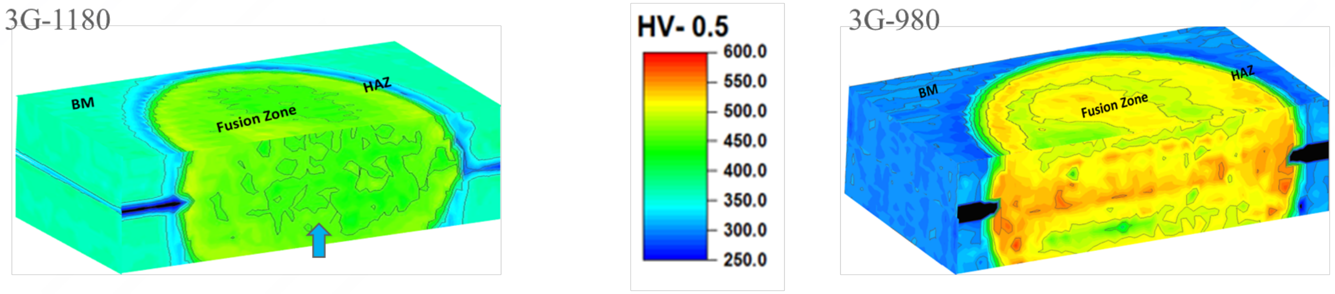


OPTIMIZED RSW CHARACTERISTICS

The optimized welding schedule resulted in a face diameter weld size (FDWS) of 7 mm for both materials.





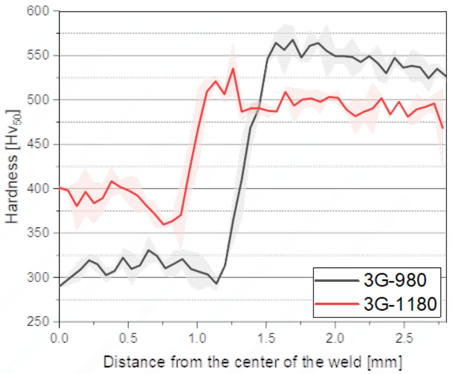


3G-1180:

Average FZ hardness of 490 HV

Min hardness in SCHAZ 340 HV

Average BM hardness of 380 HV



3G-980:

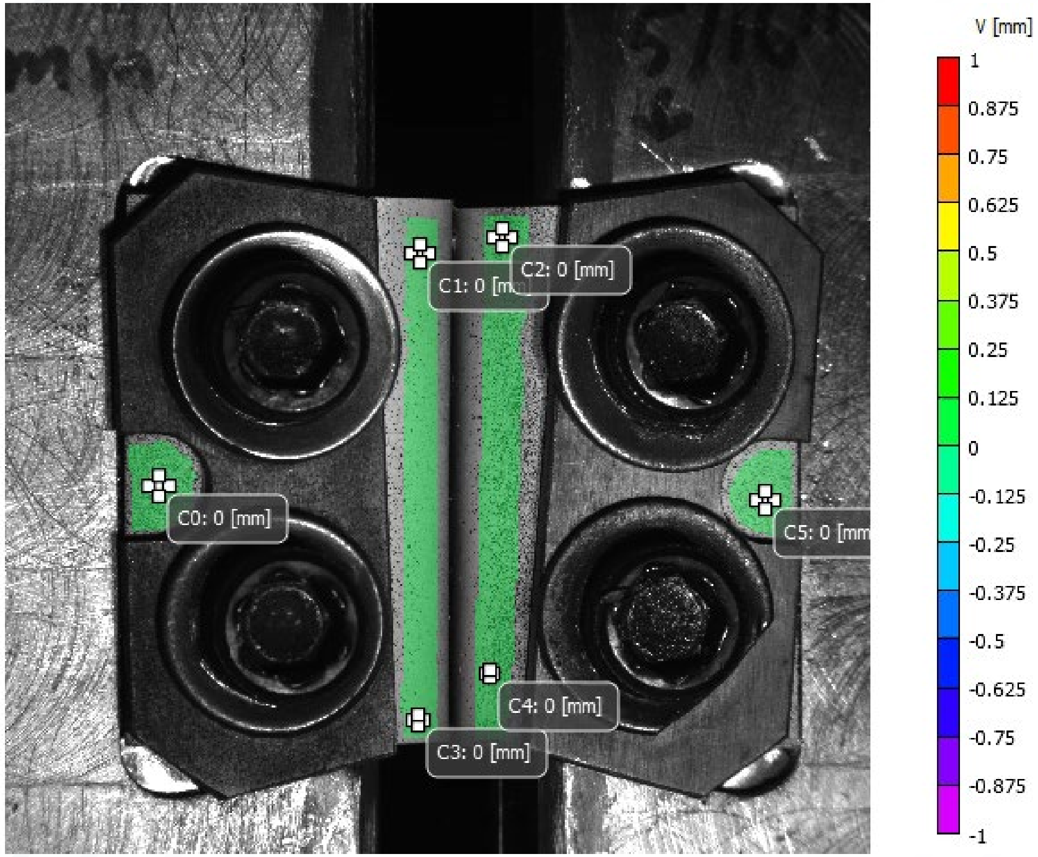
Average FZ hardness of 540 HV

No HAZ softening

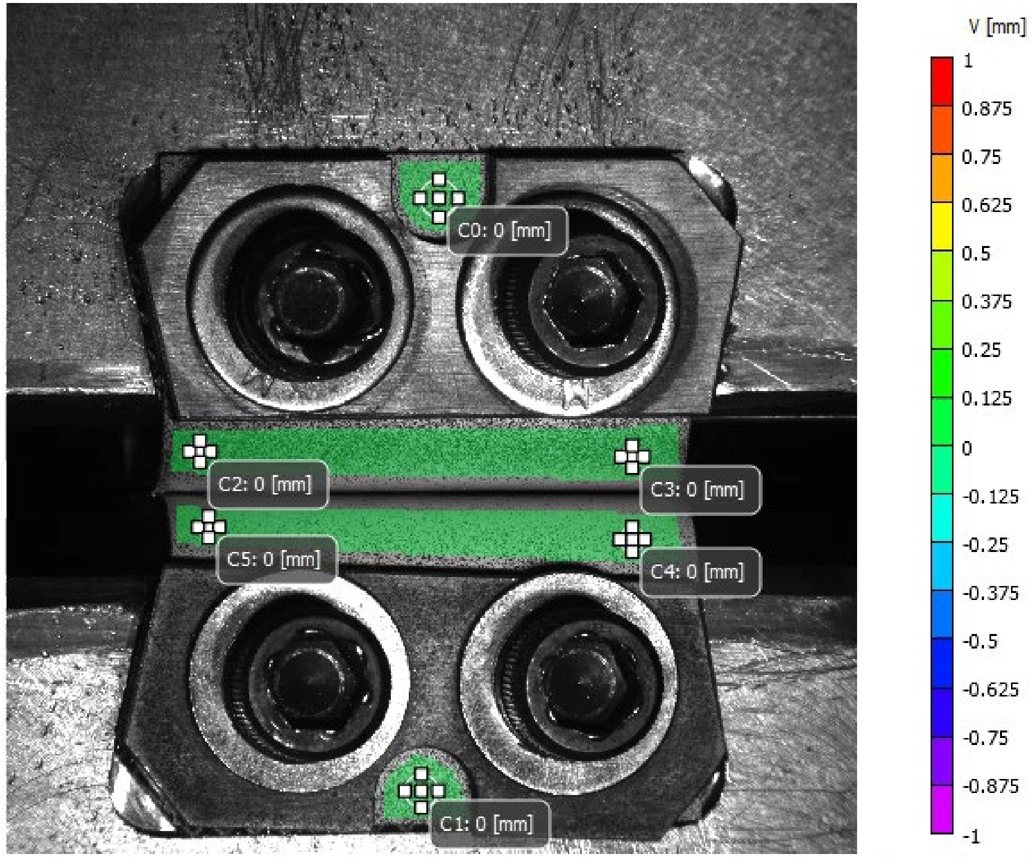
Average BM hardness of 300 HV

KS-II MECHANICAL TEST RESULTS

Noticeable slippage and rotation of specimen at shear-dominated loading orientations

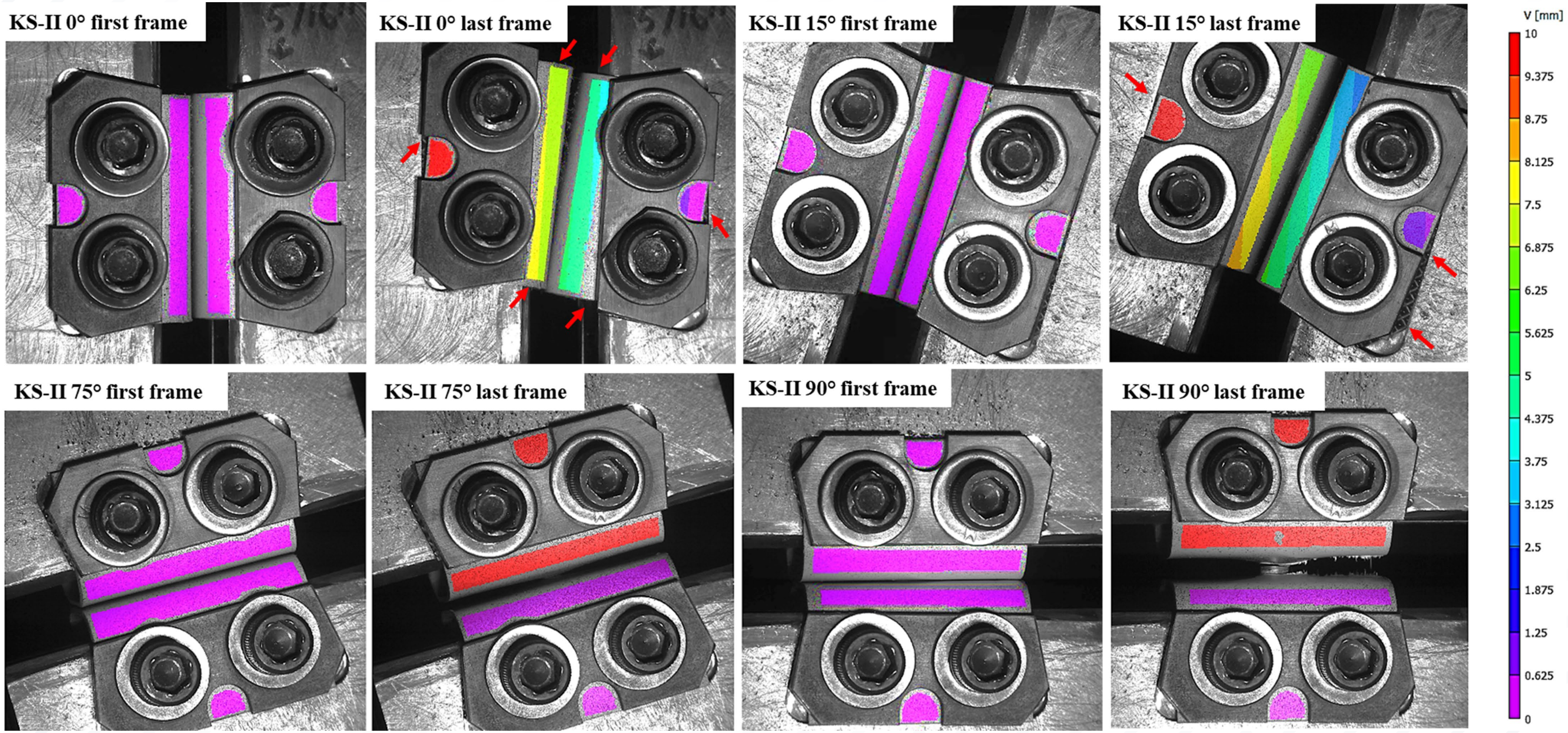


Negligible slippage and rotation of specimen at tensile-dominated loading orientations



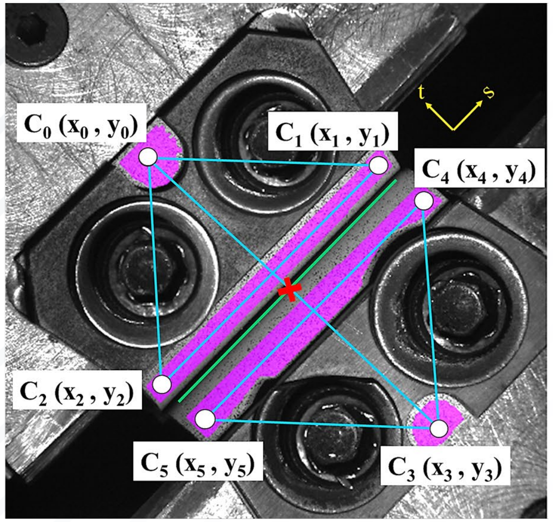
KS-II MECHANICAL TEST RESULTS

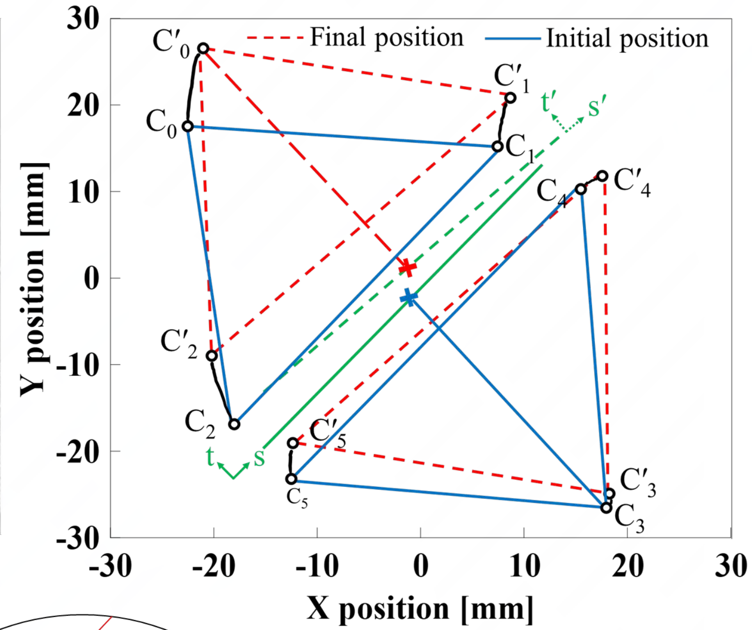
Snapshots of different loading orientations showing a combination of rotation and slippage at shear-dominated loading orientations.

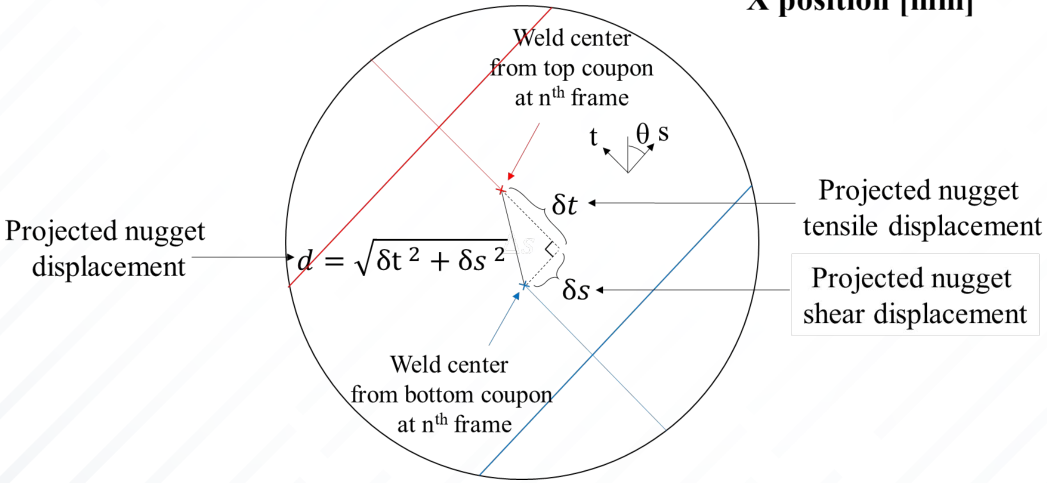


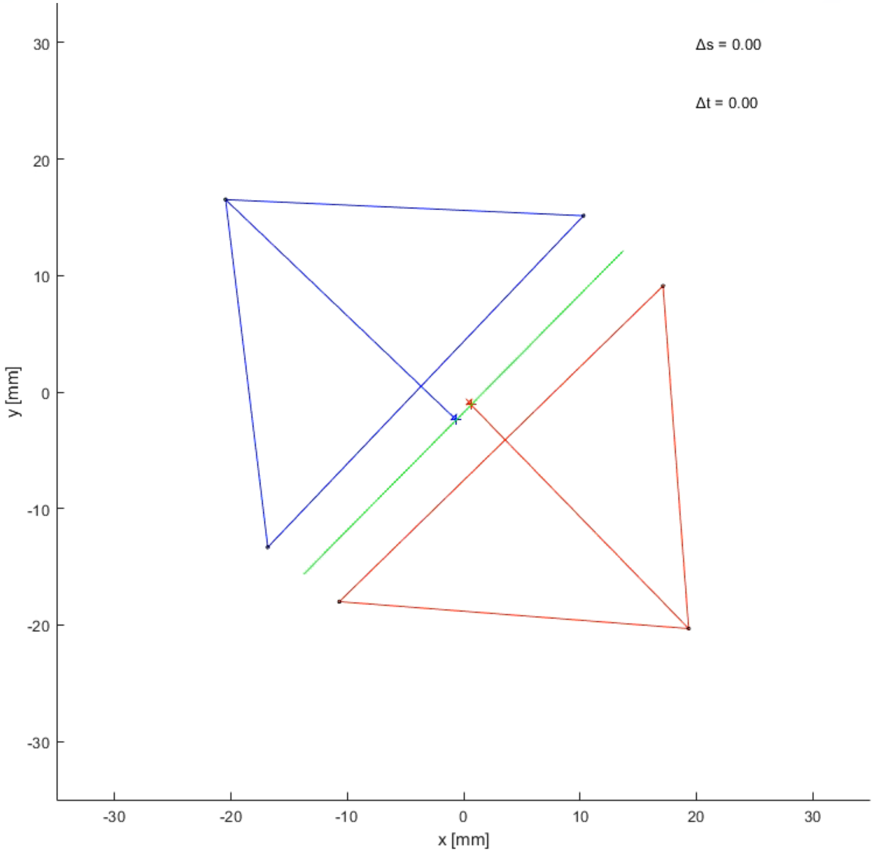
KS-II MECHANICAL TEST RESULTS

Novel local nugget displacement methodology proposed to minimize influence of coupon rotation and slippage on spot weld performance indices.

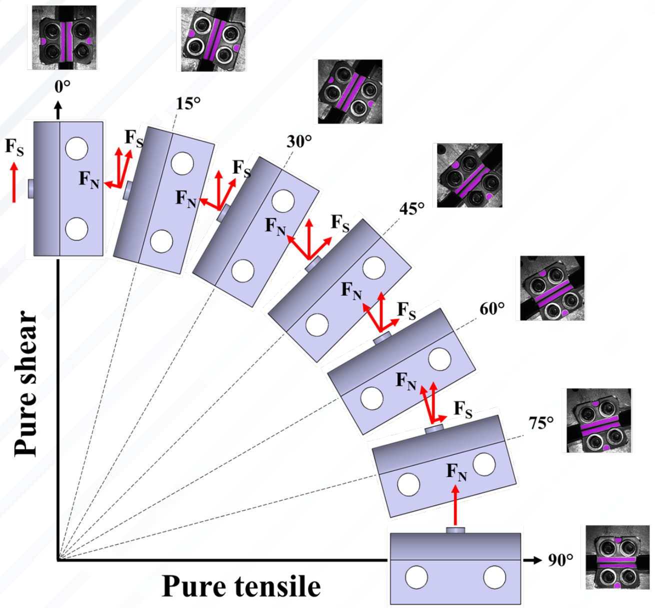


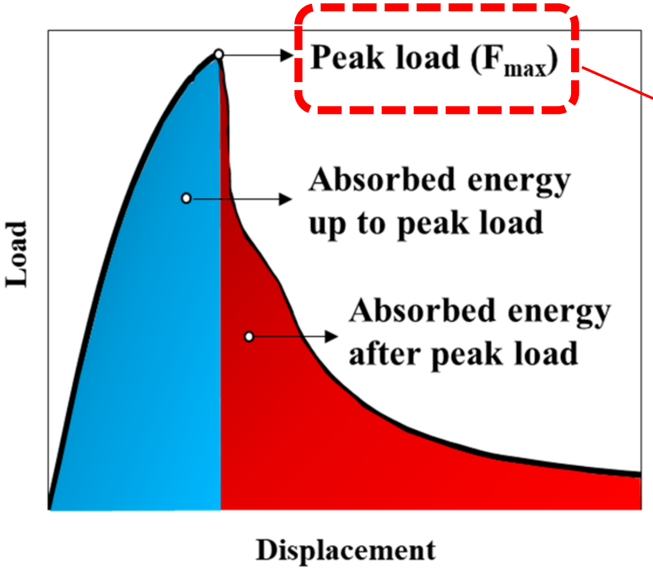


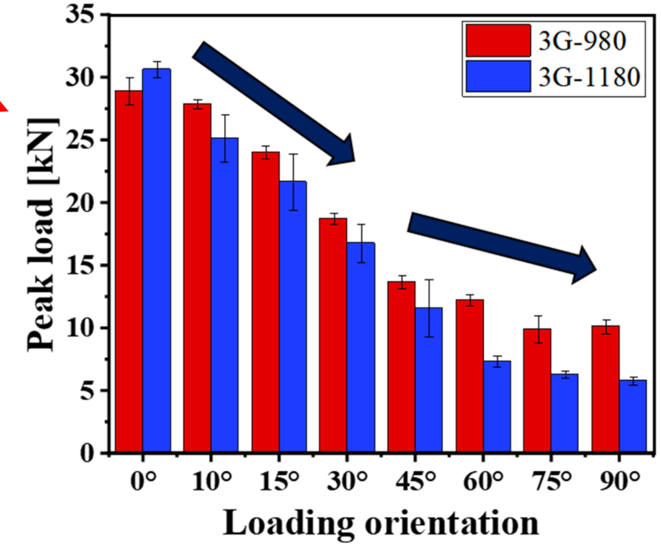




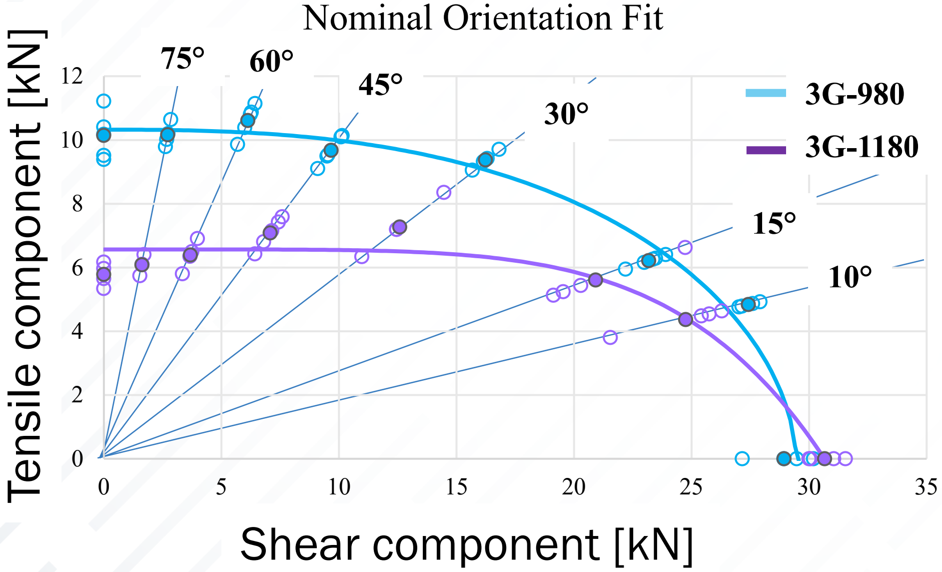
KS-II MECHANICAL TEST RESULTS





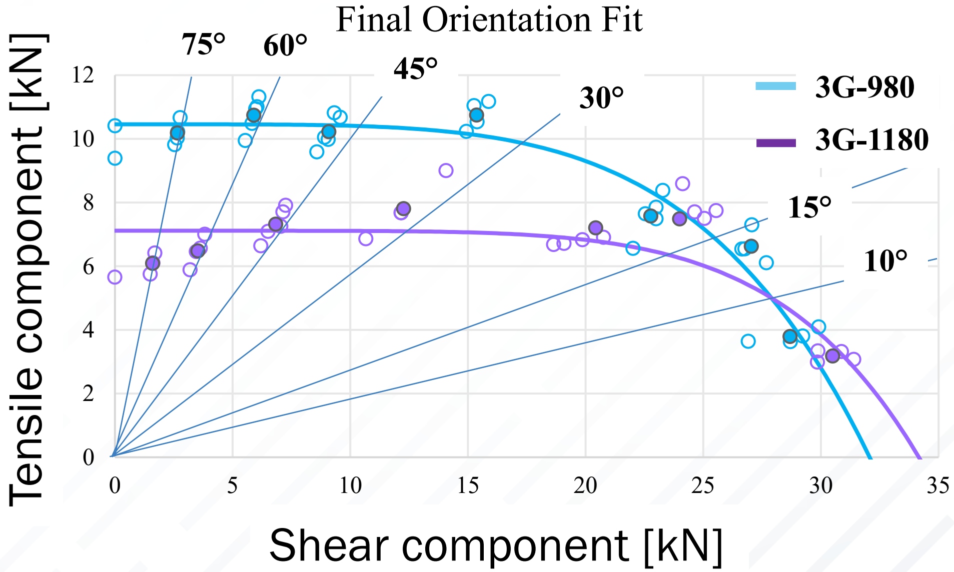


First benefit of local nugget displacement: more accurate calibration of force-based failure criterion



Considering final orientation of the nugget

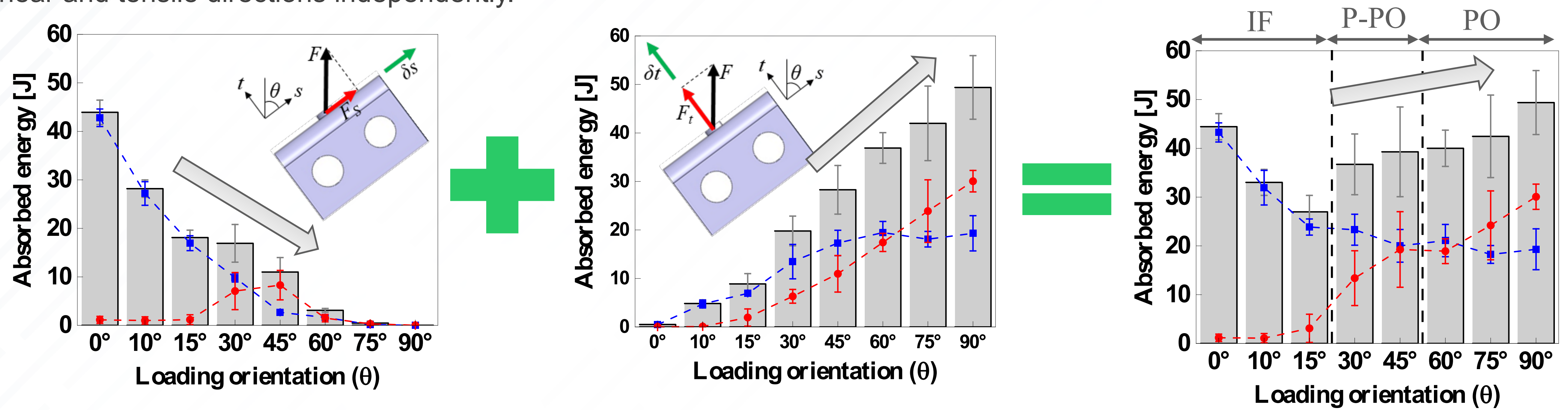
Instead of nominal orientation at the beginning of the tests



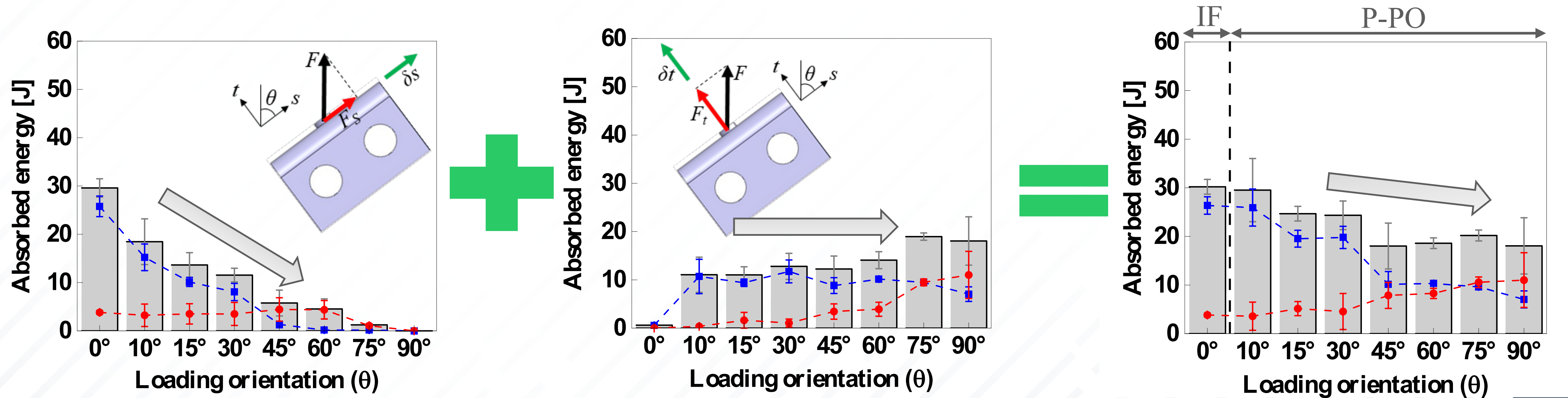
KS-II MECHANICAL TEST RESULTS

Second benefit of local nugget displacement: Capability to calculate spot weld energy absorption capability in shear and tensile directions independently.

3rd Gen -980

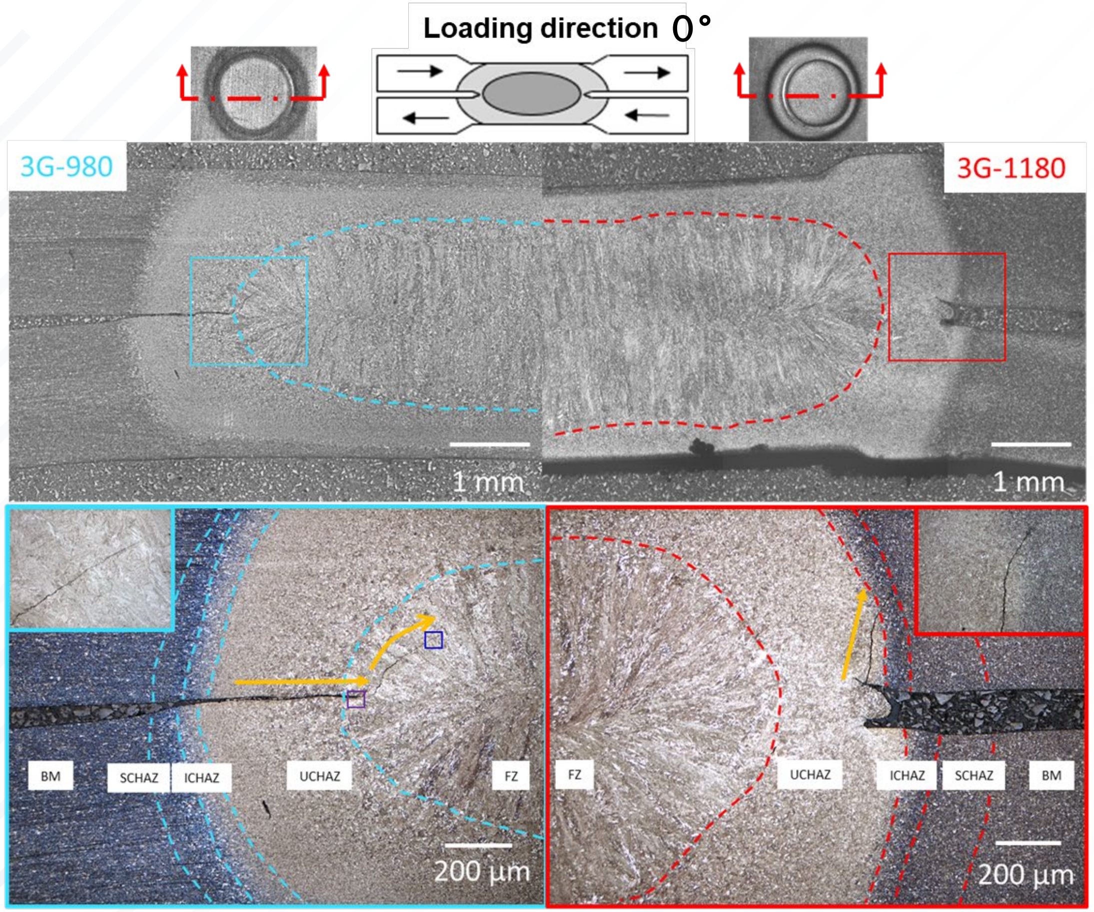


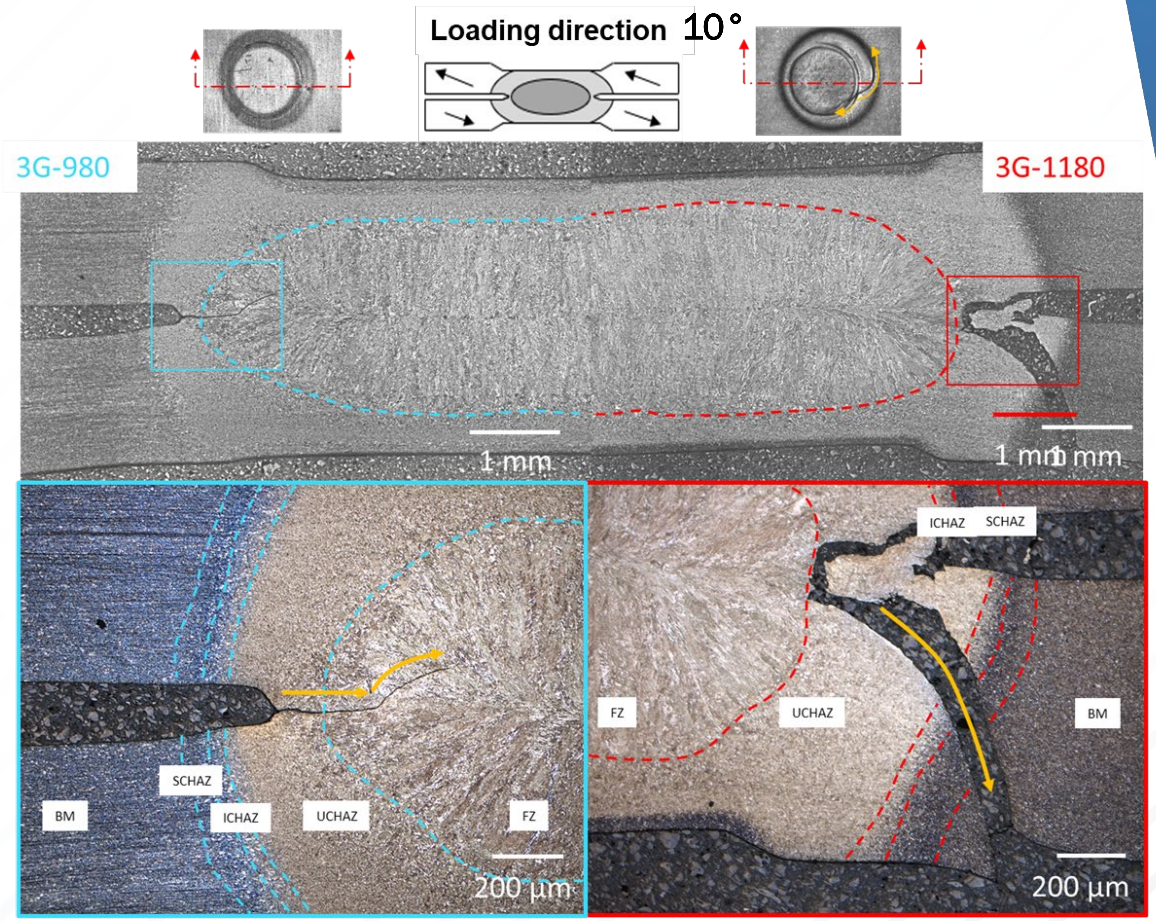
3rd Gen -1180



KS-II MECHANICAL TEST RESULTS

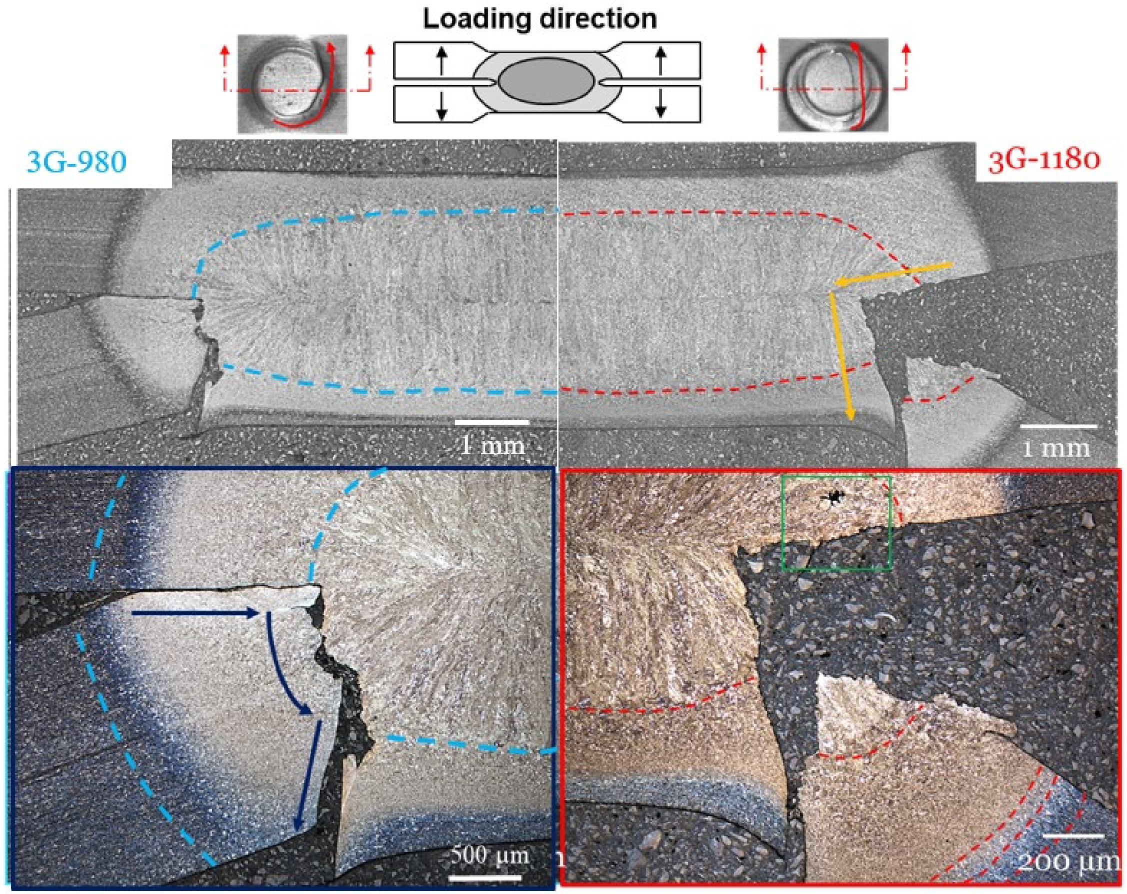
Failure analysis: Interrupted KS-II tests within shear-dominated loading orientations revealed tendency of failure through softened SCHAZ for 3rd Gen-1180 joints.

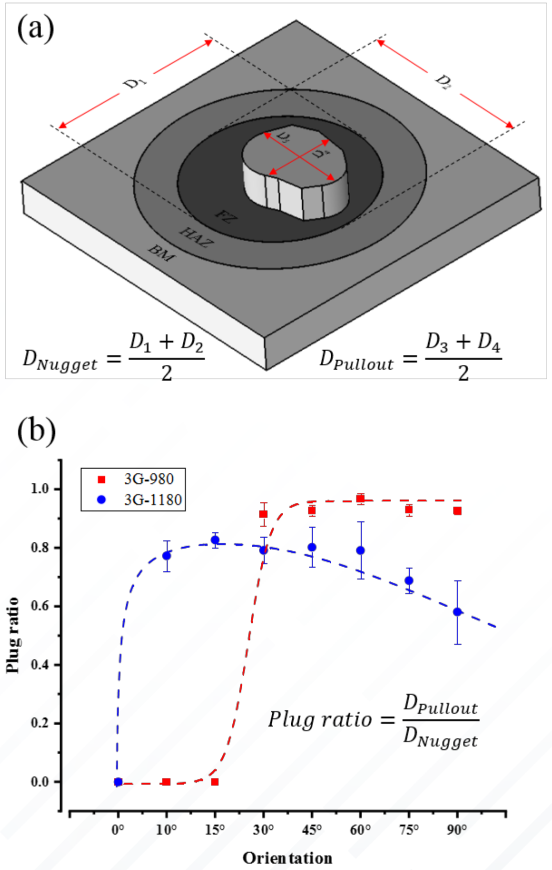




KS-II MECHANICAL TEST RESULTS

- Failure analysis: Interrupted KS-II tests within tensile-dominated loading orientations revealed tendency of crack propagation within the fusion zone of 3rd Gen-1180.
- Propagation of cracks into the fusion zone of 3rd Gen-1180 spot welds is causing limited post-failure energy absorption.





SUMMARY

- RSW process was optimized for investigated 3rd Gen AHSS by producing joints with optimum load bearing capacities during lap shear and cross tension tests.

- Mechanical properties (strength and energy absorption) and failure characteristics of 3rd Gen AHSS spot welds under combined loading conditions were investigated.

CONCLUSIONS

- A novel methodology **coupling digital image correlation with KS-II testing** was proposed.

The proposed methodology allows for

- more accurate calibration of strength-based failure criteria → instantaneous quantification of nugget orientation
- more precise measurement of nugget displacement → minimizing the influence of slippage and deformation
- increased accuracy for spot weld energy absorption calculation → Calculating in shear and tensile directions separately

- Propagation of the cracks into the fusion zone of the 3rd Gen-1180 spot welds is responsible for their inferior energy absorption and strength compared to 3rd Gen-980 spot welds within tensile-dominated loading orientations.

FOR MORE INFORMATION

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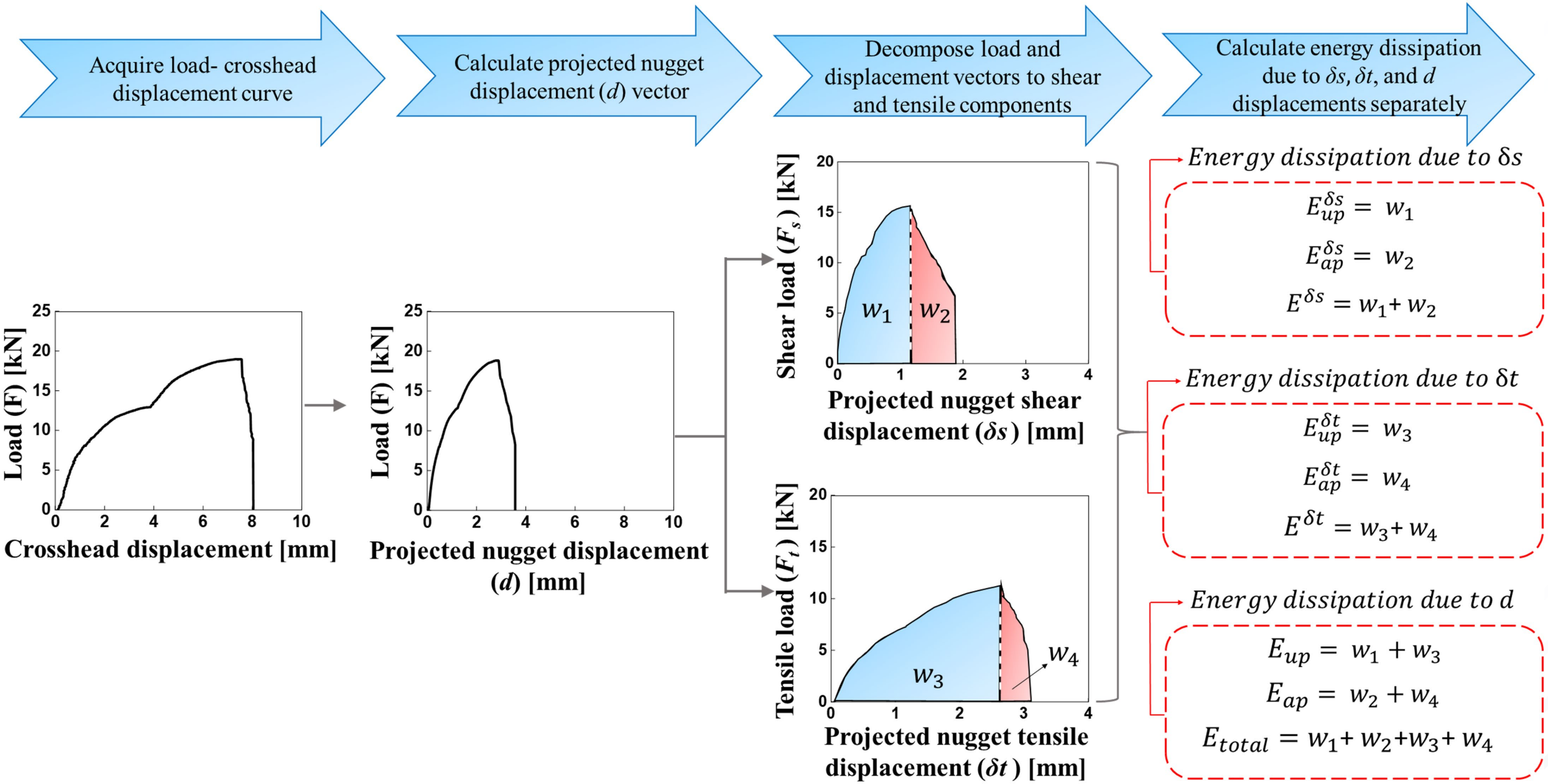
More Questions? Meet the speaker at the Auto/Steel Partnership booth after this presentation.

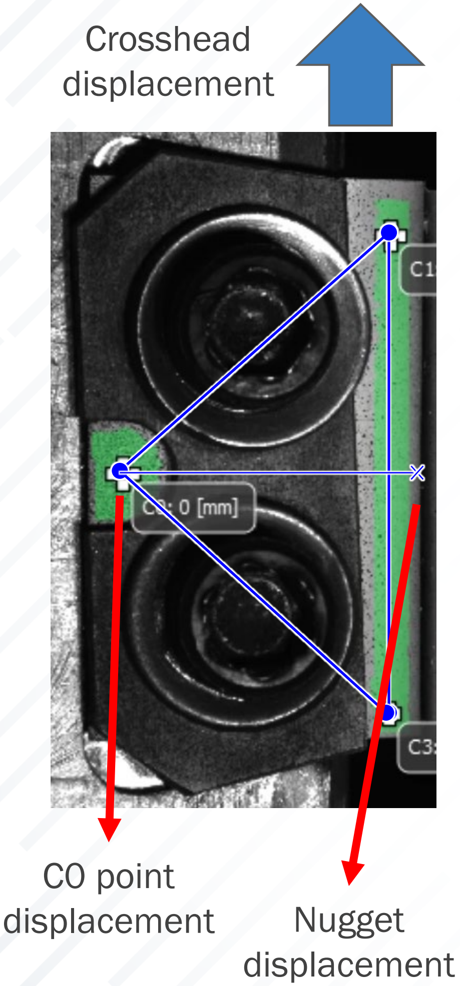
KS-II MECHANICAL TEST RESULTS

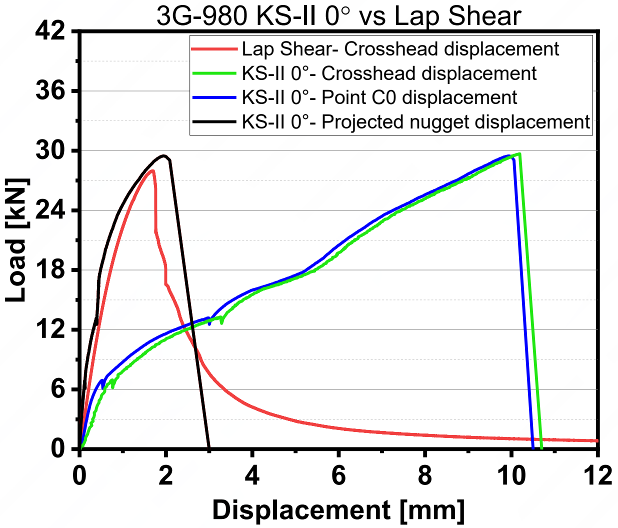
Second benefit of local nugget displacement: Capability to calculate spot weld energy absorption capability in shear and tensile directions independently.

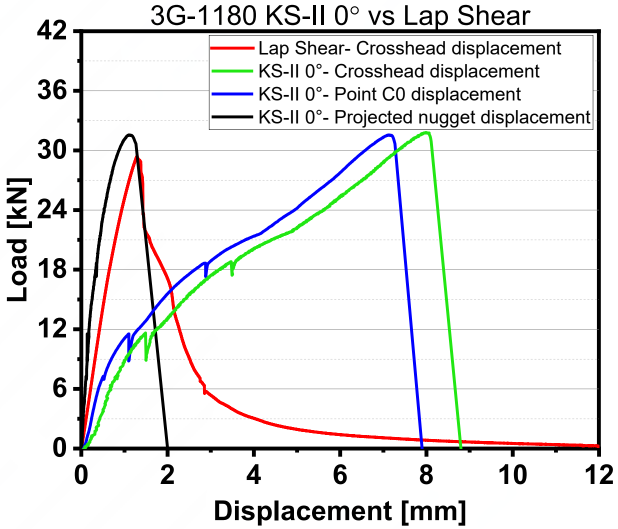


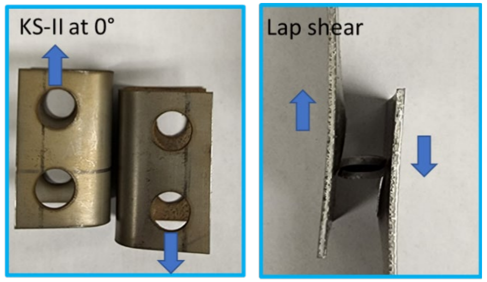
KS-II MECHANICAL TEST RESULTS

Third benefit of local nugget displacement: Exclusion of the influence of slippage and deformation at regions away from the spot weld on extracted load-displacement curves.



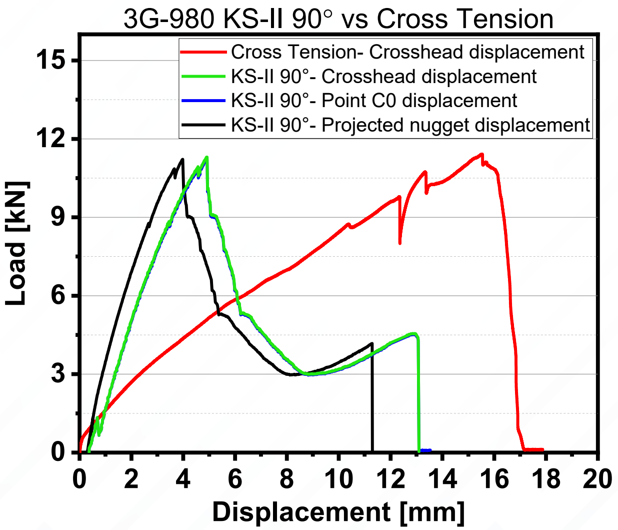


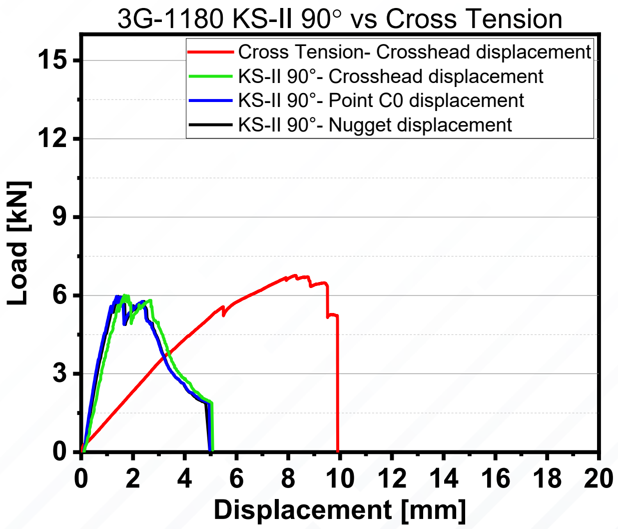


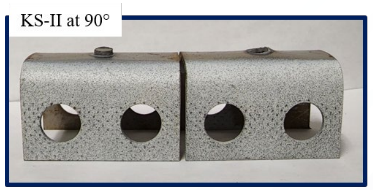


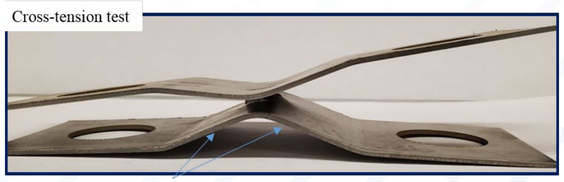
Interfacial failure with Limited deformation

Pullout with severe rotation and deformation









Noticeable plastic deformation around the nugget