GREAT DESIGNS IN STEEL

TWENTY YEARS

A NOVEL TECHNIQUE TO MEASURE THE LOCAL MECHANICAL PROPERTIES OF 3RD GEN AHSS SPOT WELDS

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On Behalf of Auto/Steel Partnership

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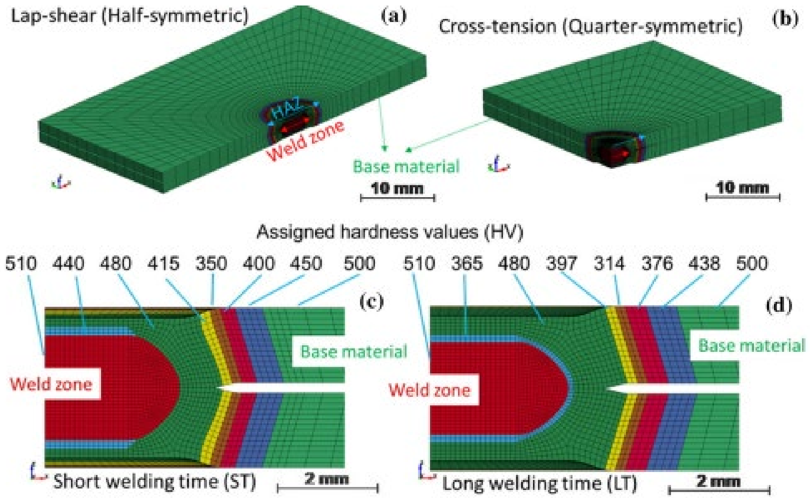
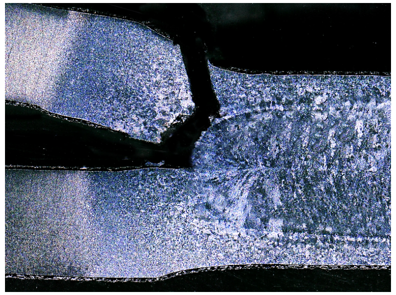
PRESENTATION OVERVIEW

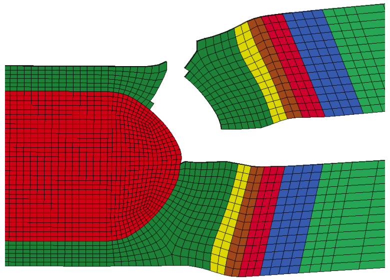
- **Introduction and Motivation**
- **Objective**
- **Materials and Methodology**
- **Results and Discussion**
  - **Novel technique to estimate the mechanical properties**
    - Mini-tensile test for AHSS spot welds
    - Mini-shear test for AHSS FZ
    - Hardness scaling approach
    - Comparison between Hardness and tensile/mini-shear approach
- **Conclusion and future work**

USING HARDNESS SCALING APPROACH VS. GLEEBLE THERMAL SIMULATION

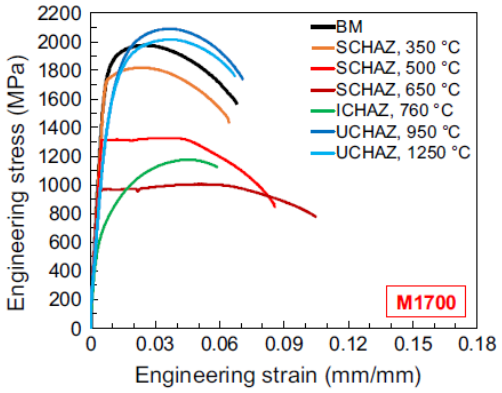
- Recent studies by Sherepenko *et al.* utilized the hardness scaling approach to predict the failure behavior of PHS RSW.

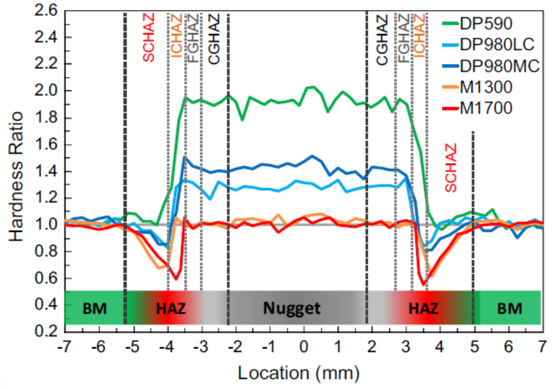


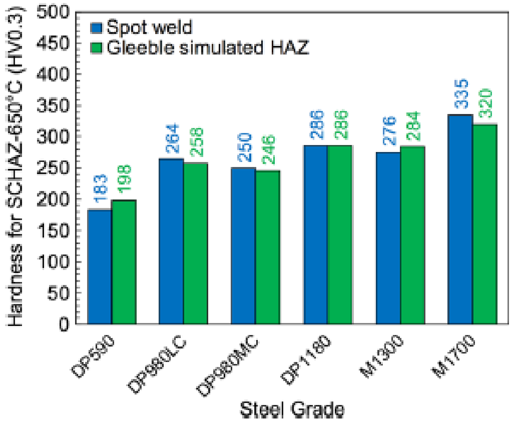




- Rezayat *et al.* highlighted uncertainty regarding utilizing the hardness scaling approach







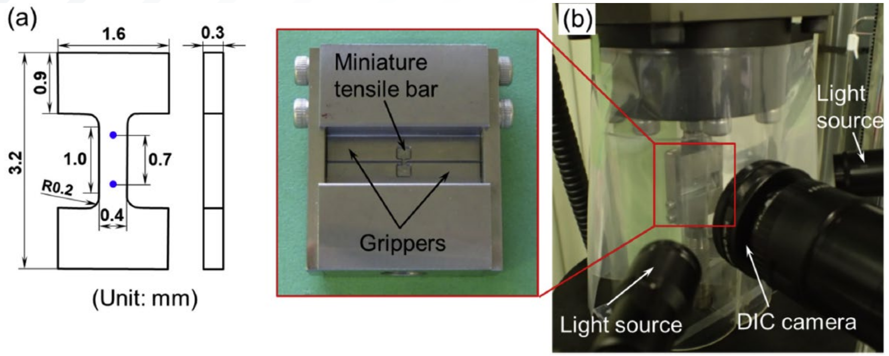
[1] A. Sherepenko et. al. Determination of resistance spot weld failure path in ultra-high-strength press-hardened steel by control of fusion boundary transient softening 2021

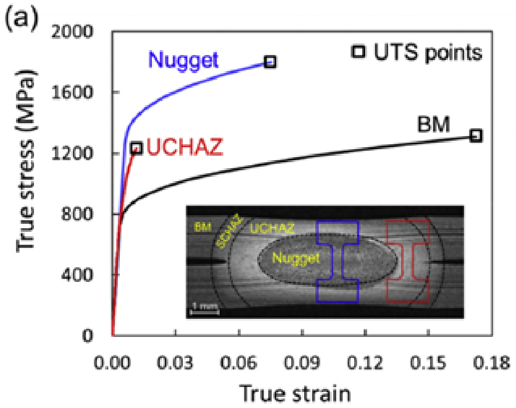
[2] Hassan Rezayatet.al. "Effects of Heat Affected Zone Softening Extent on the strength of Advanced High Strength Steels Resistance Spot Weld" Trends in welding research, proceedings of the 10th international conference,

[3] H. Rezayat et. al. "Constitutive properties and plastic instabilities in the heat-affected zones of advanced high-strength steel spot welds", J Mater Sci (2019) 54:5825–5843

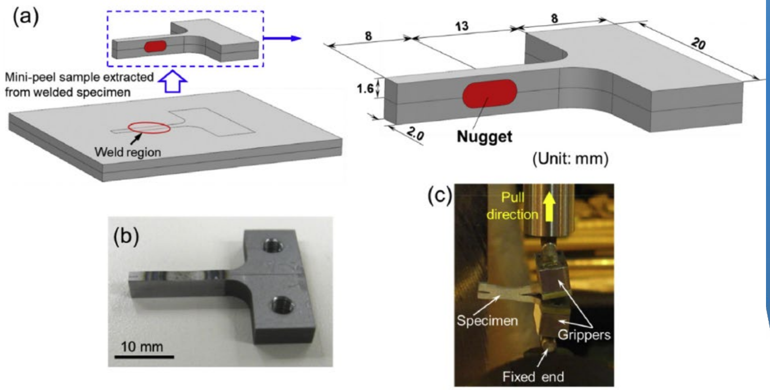
COMMON APPROACHES TO EXTRACT LOCAL RSW PROPERTIES IN LITERATURE

Miniature tensile

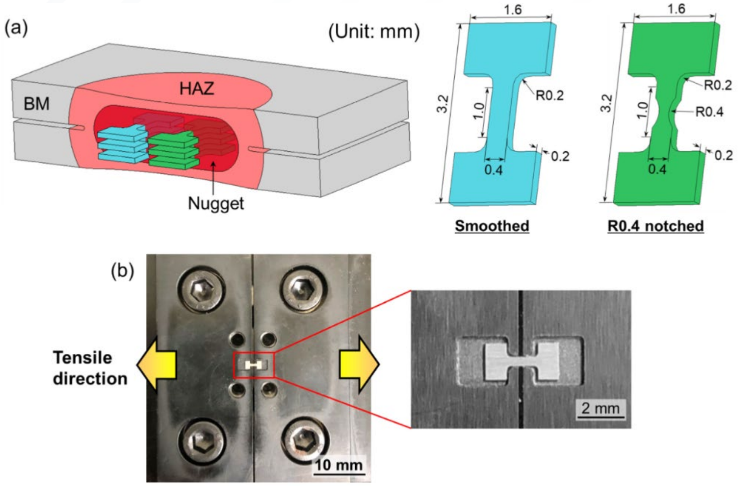




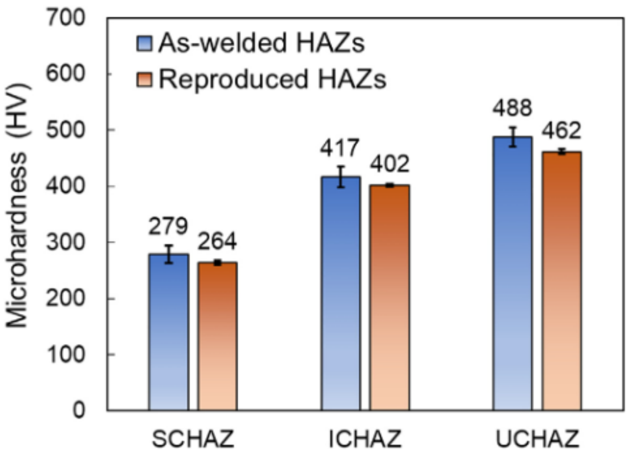
Miniature coach peel



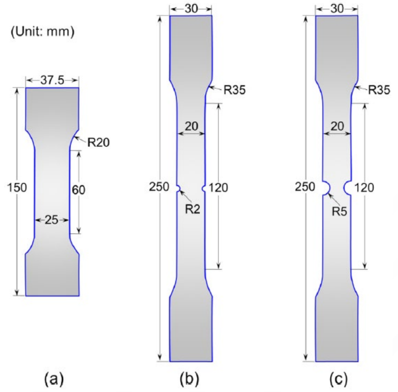
Miniature tensile for the FZ

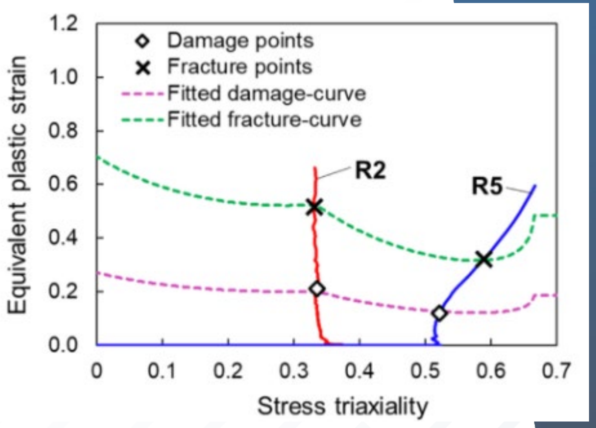


Heat treatment to reproduce HAZ hardness



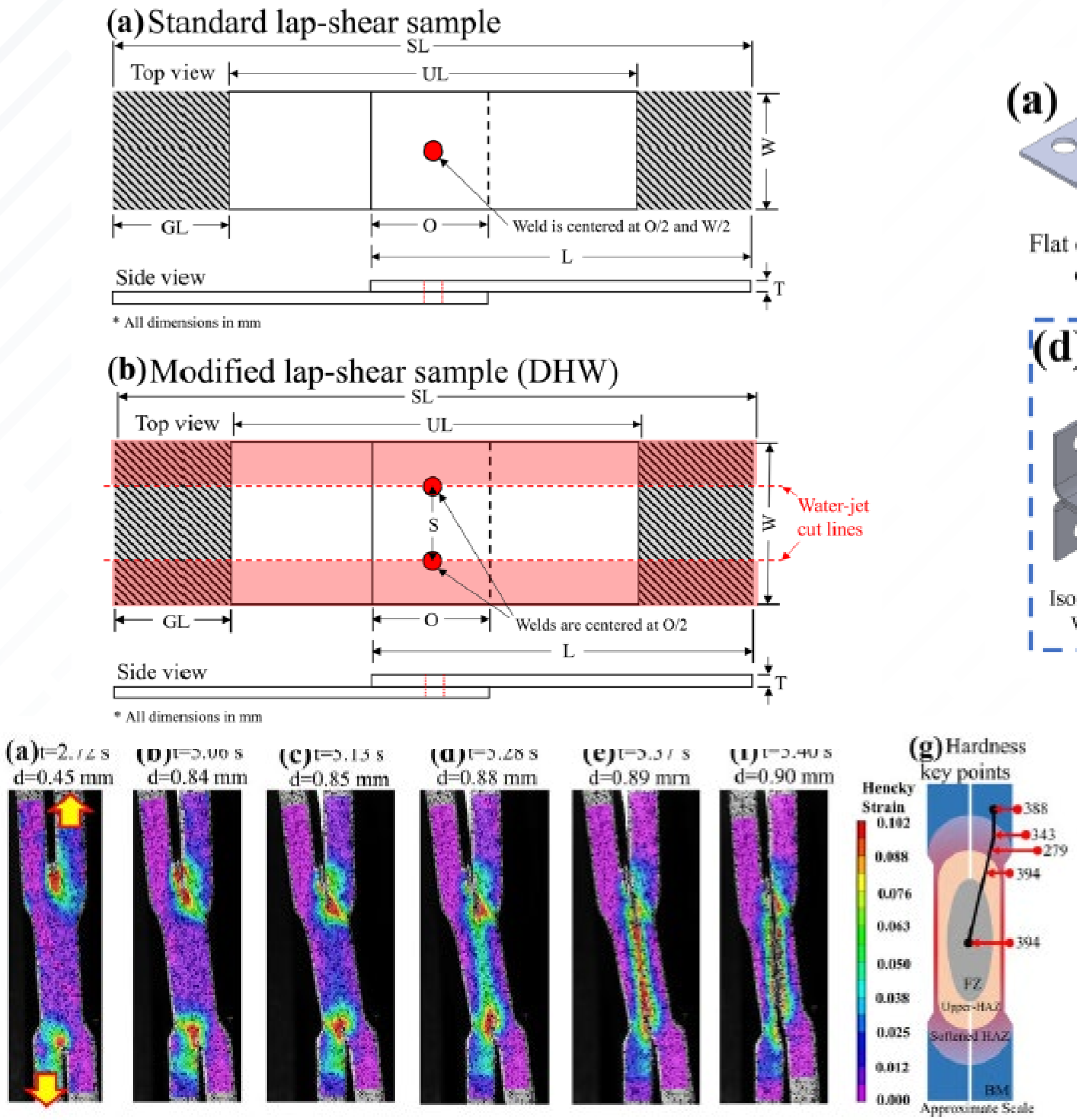
Development of fracture loci for different zones

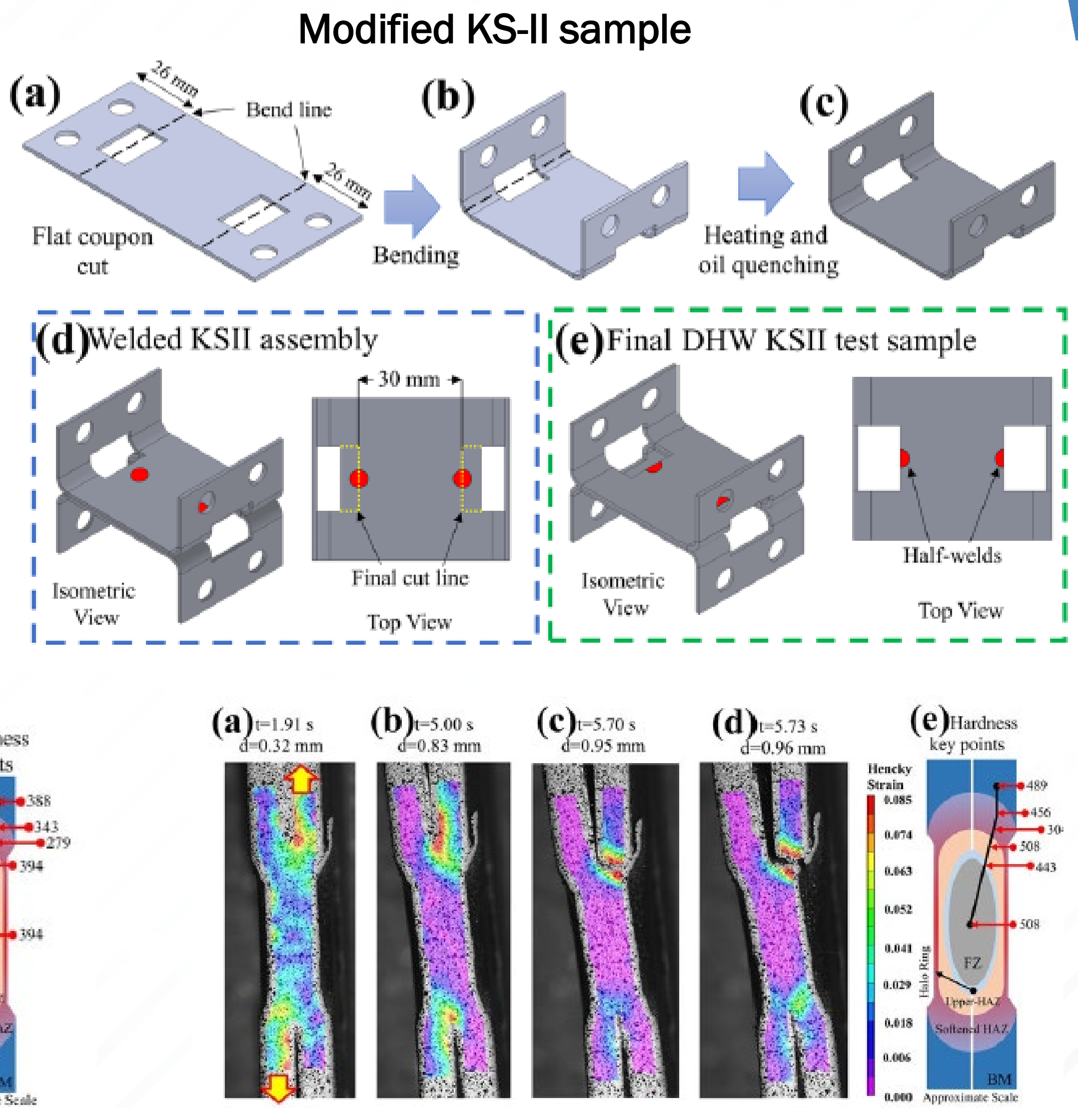




Yunwu Ma, Akira Takikawa , Jun Nakanishi , Kazuyoshi Doira , Tetsuo Shimizu, Yongxin Lu , Ninshu Ma" Measurement of local material properties and failure analysis of resistance spot welds of advanced high-strength steel sheets" Materials and Design 201 (2021) 109505

TWO HALF SPOT WELD TESTING APPROACH TO MONITORING THE DAMAGE PROGRESS AND FAILURE IN AHSS WITH DIFFERENT NUGGET SIZES





A. Mohamadizadeh· E. Biro· M. Worswick,” Novel Double-Half Spot Weld Testing Technique For Damage Progress And Failure Analysis Using Digital Image Correlation Techniques”, Experimental Mechanics (2021) 61:1405–1418

OBJECTIVE

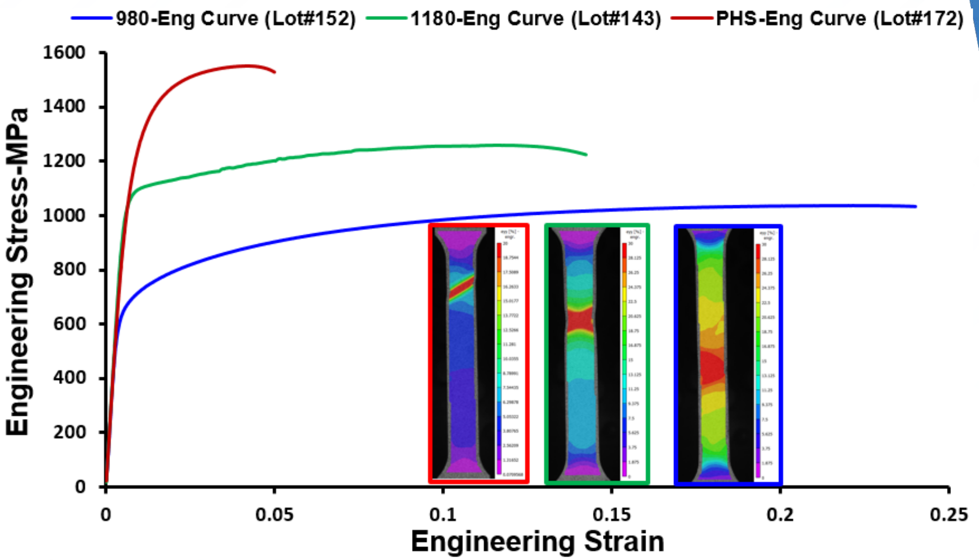
20 YEARS GDIS

- Develop an experimental technique to measure the local mechanical properties of the spot weld using DIC
- Compare the DIC results with the hardness scaling approach
- Extract the fusion zone mechanical properties using mini-shear geometry
- Verify the Gleeble experimental results (future work)

MATERIALS AND WELDING METHODOLOGY

MECHANICAL PROPERTIES / WELDING SCHEDULE

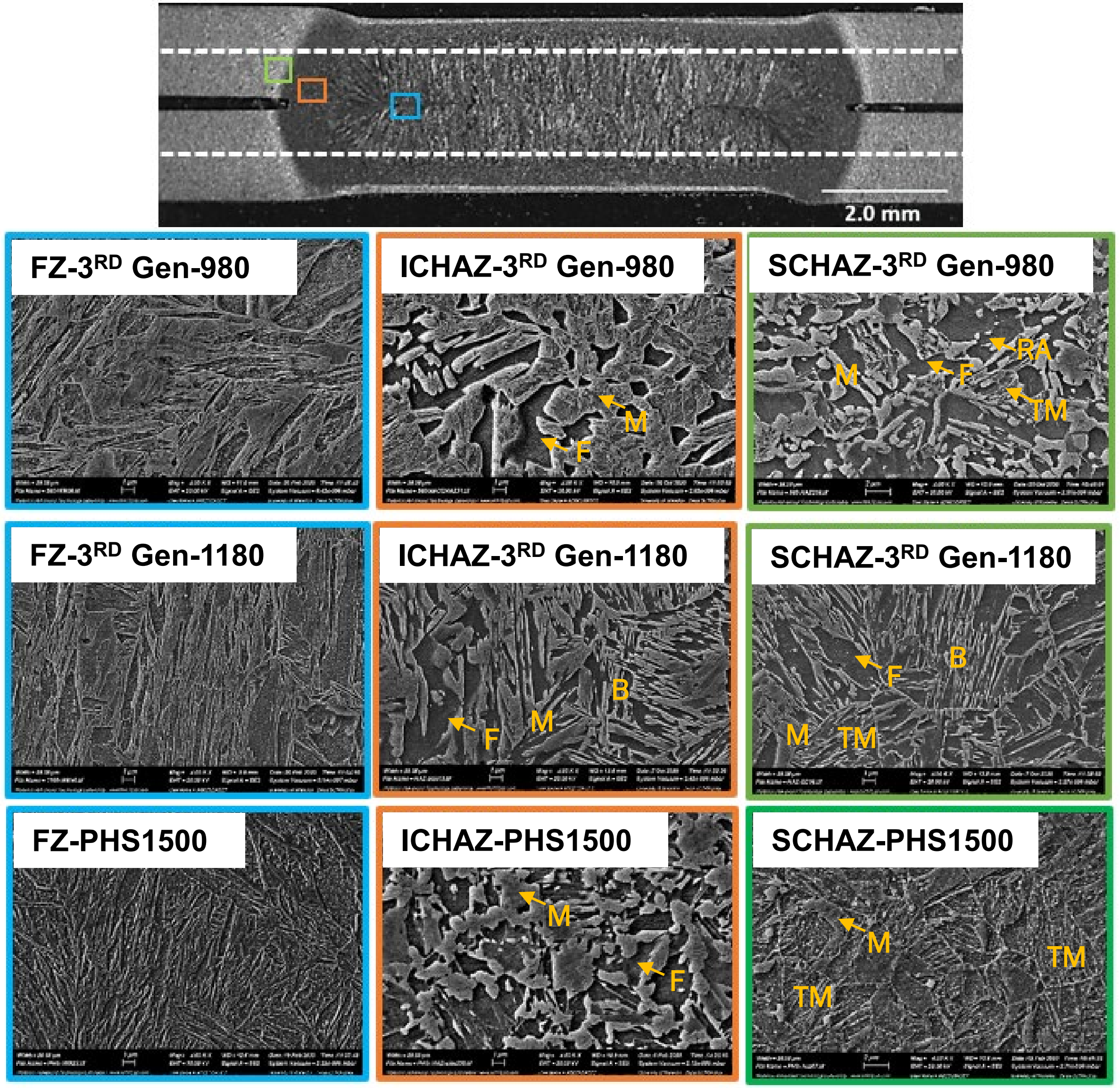
- **RSW conducted using Honda RSW robot**
- **Welding schedule according to AWS D8.9 standard**
- **BM tensile properties according to ASTM E8**

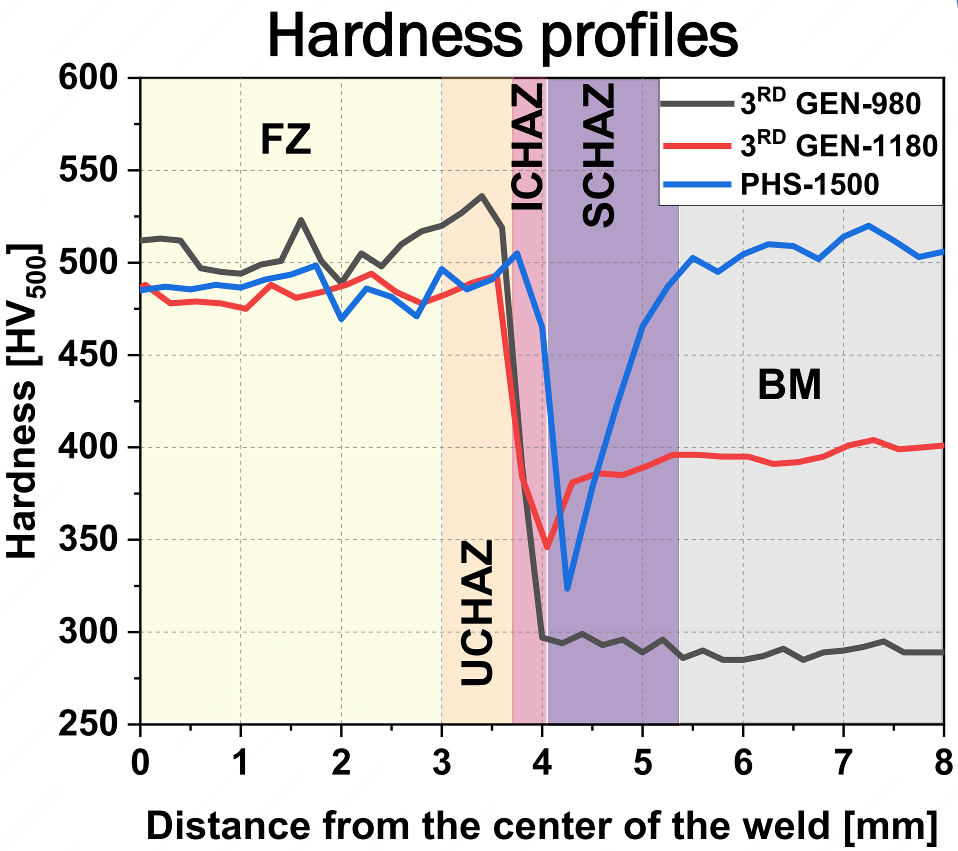


Welding schedule used to produce Face Diameter Weld Size

Material	Current-kA	Squeeze time- Cycle	Welding time-Cycle	Electrode force- kN	Holding time-Cycle
PHS-1500	8.0	10	10-2-10	4.9	10
3RD GEN-1180	9.0				
3RD GEN-980	9.1				

MICROSTRUCTURE AND MICROHARDNESS RESULTS





FZ: Fusion zone

UCHAZ: Upper-critical heat affected zone (above AC_3)

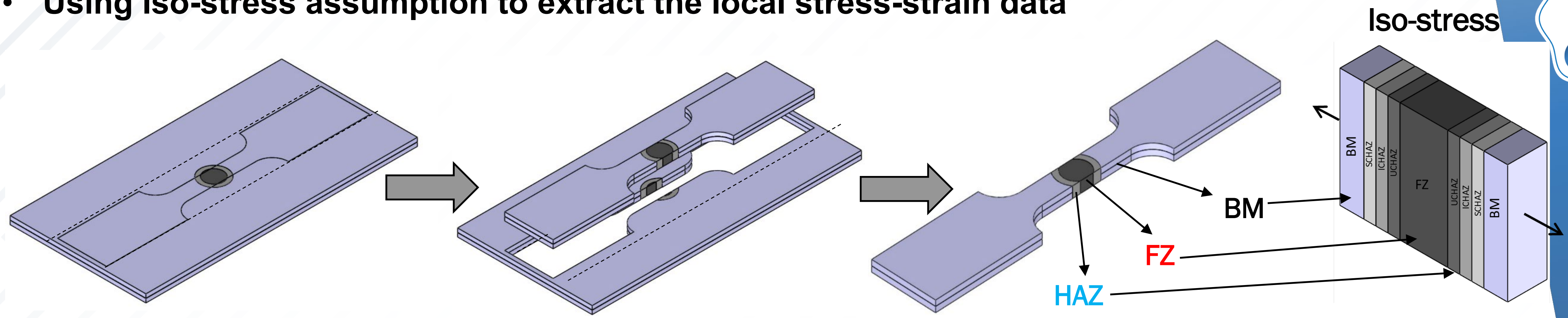
ICHAZ: Inter-critical heat affected zone (between AC_3& AC_1)

SCHAZ: Sub-critical heat affected zone (below AC_1)

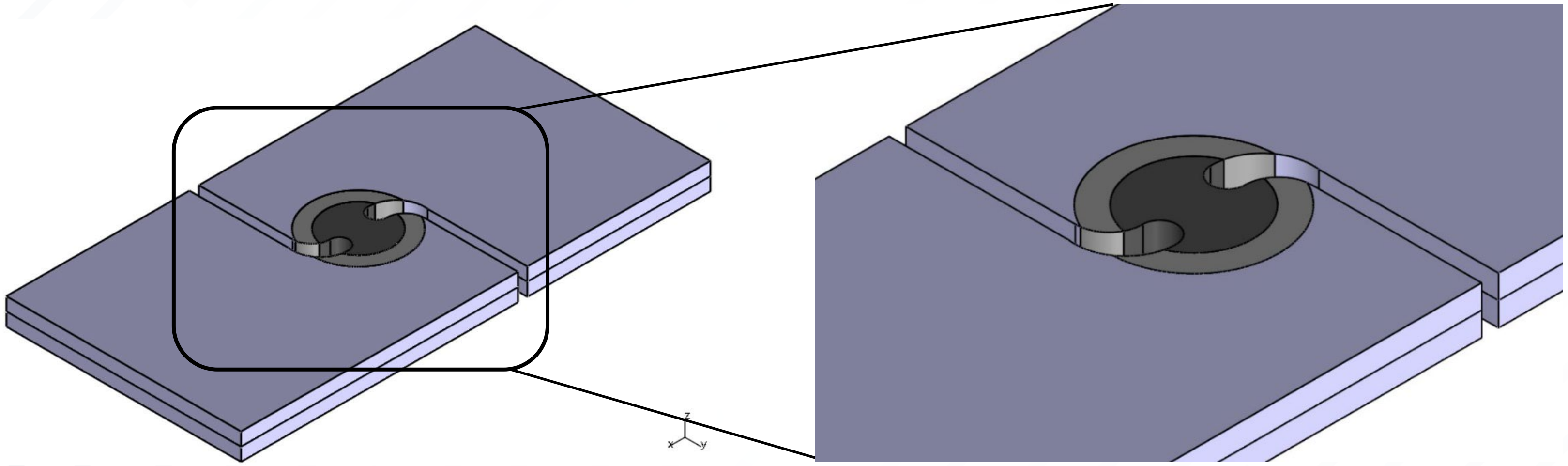
NOVEL TECHNIQUE TO ESTIMATE THE LOCAL MECHANICAL PROPERTIES FOR SPOT WELDS USING DIC

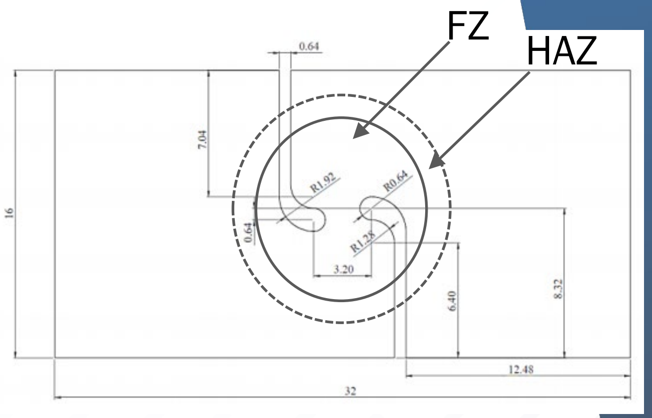
PROPOSED METHOD TO CHARACTERIZE THE LOCAL MECHANICAL

- **Using Iso-stress assumption to extract the local stress-strain data**

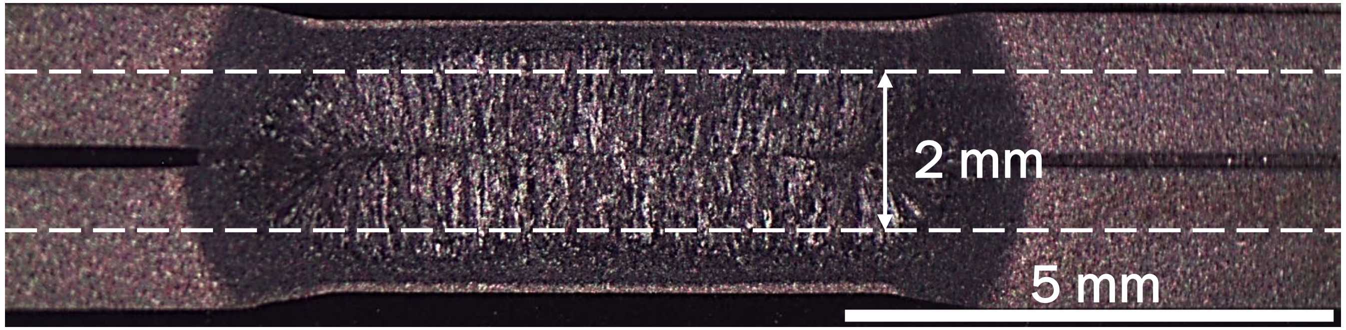


- **Due to the HAZ softening strain may localize in the softened HAZ, which will prevent deformation in the FZ. Therefore, a novel mini-shear coupon of the spot weld was used to extract the fusion zone properties**

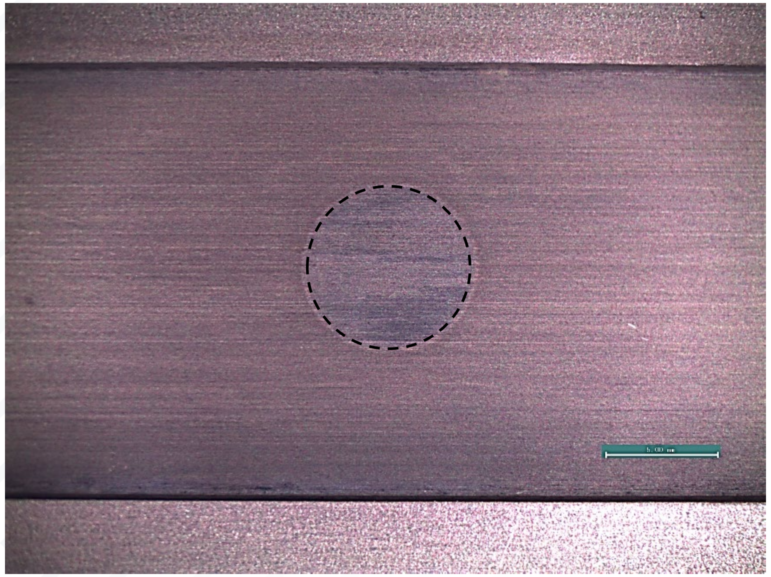


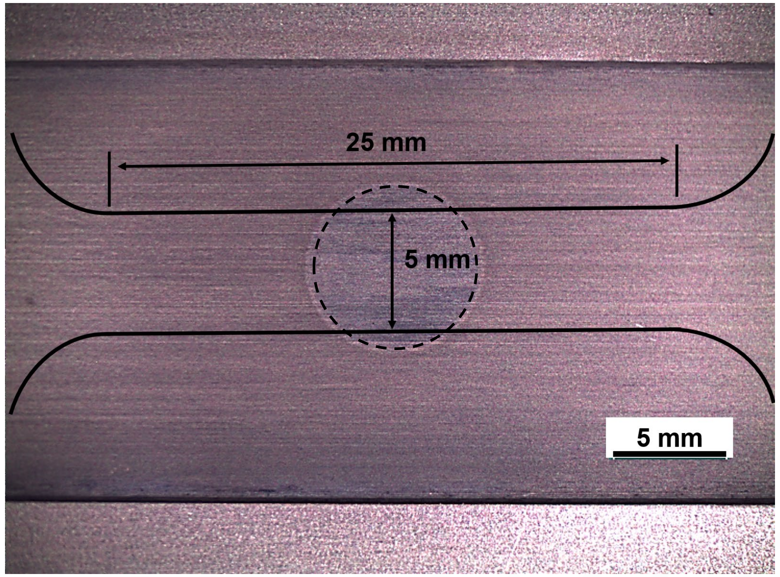


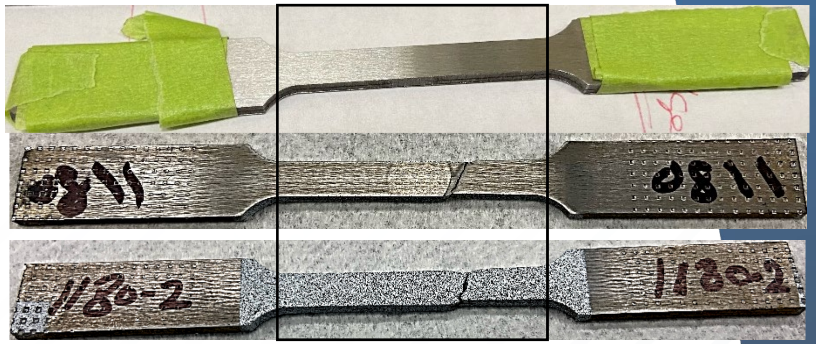
- **The top surface of the sample from both sides was *ground* to remove the corona bond HAZ layer, approximately 0.4 mm was removed from each side to reveal the nugget and HAZ.**



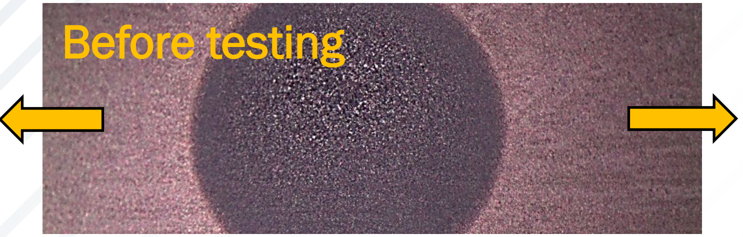
- **ASTM sub-size tensile coupons were machined from the welded coupons in order to perform DIC tensile test**

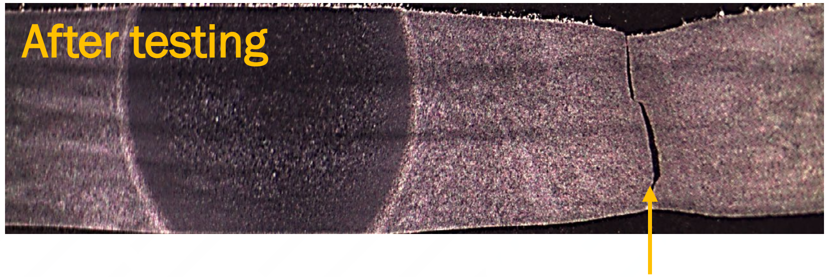






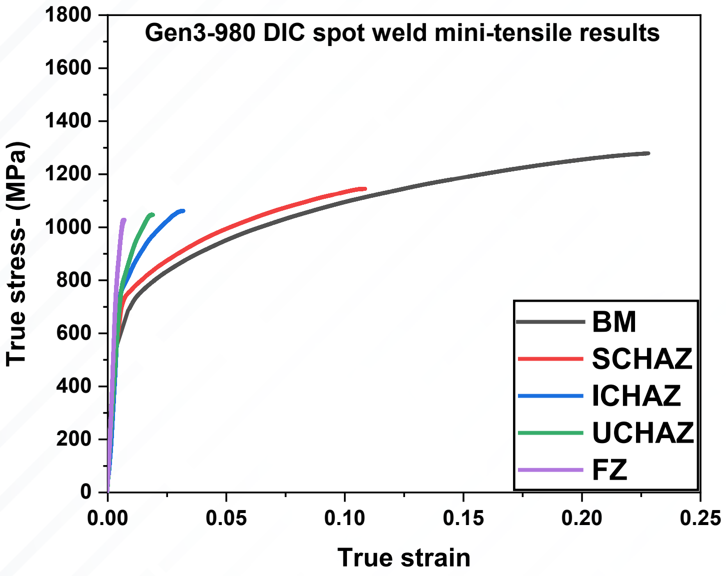
3RD GEN-980 TENSILE TEST RESULTS

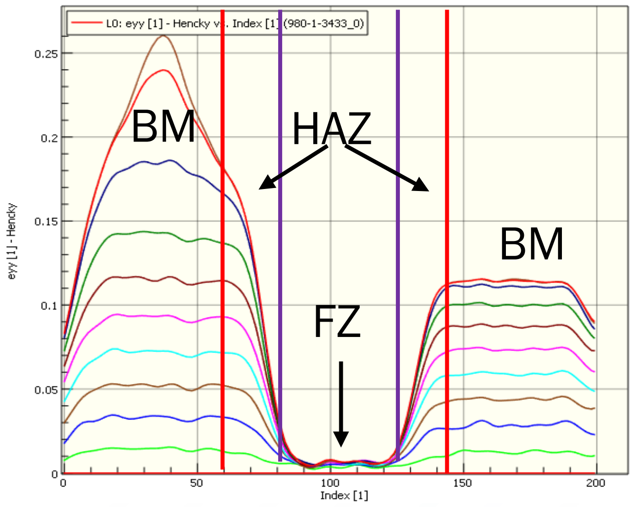


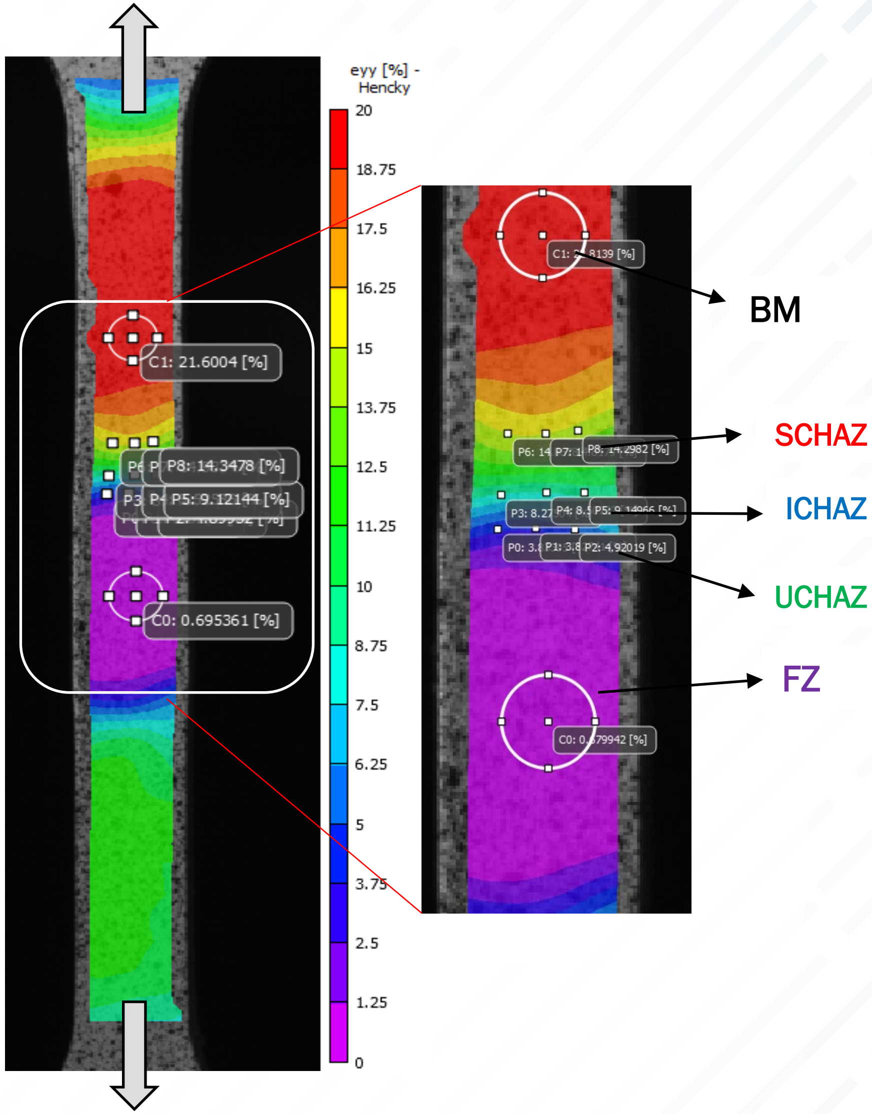


Fracture location in BM

Local SS-curves for 3RD Gen-980

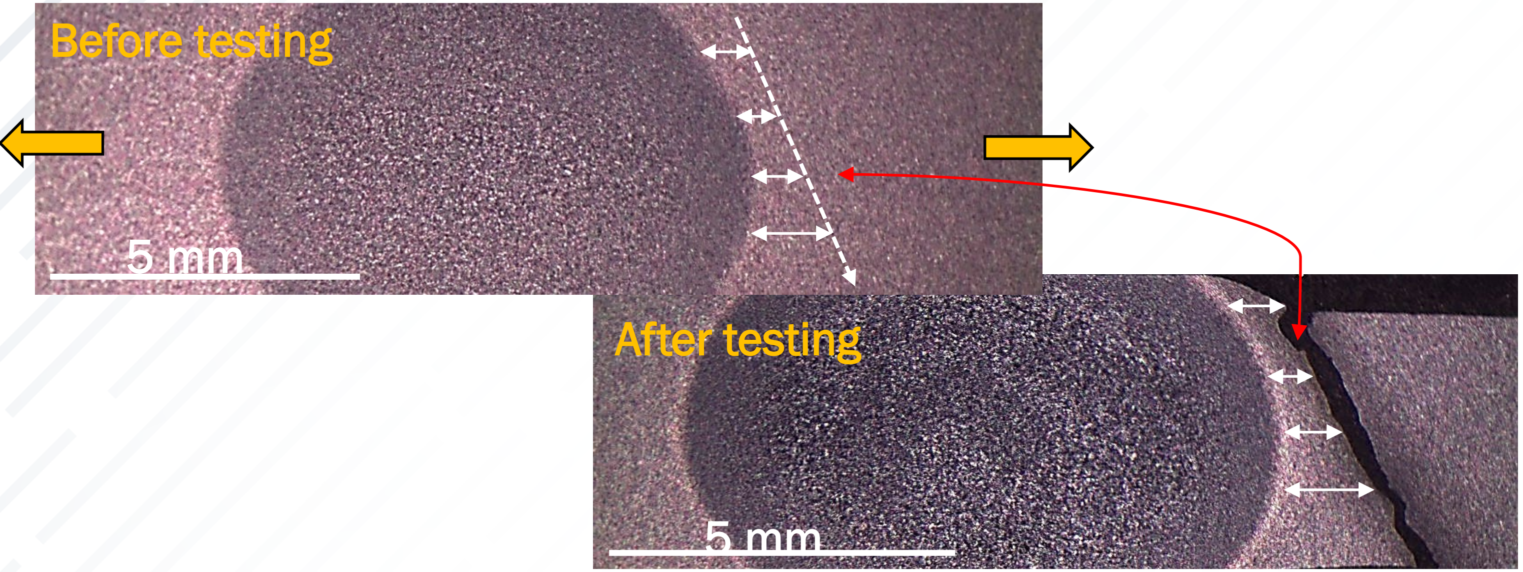




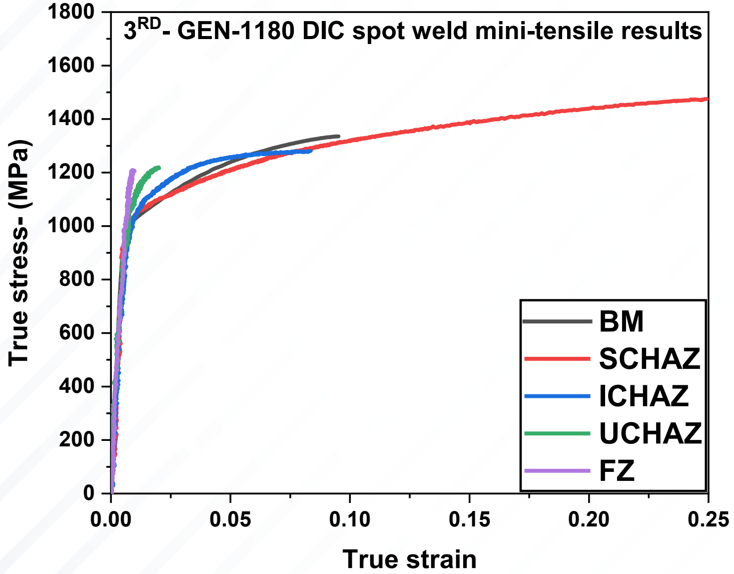


- Failure in the BM, SCHAZ showed higher mechanical properties these results were in agreement with the hardness profiles, secondary hardening was observed in the SCHAZ.
- No deformation was observed in the FZ and UCHAZ.

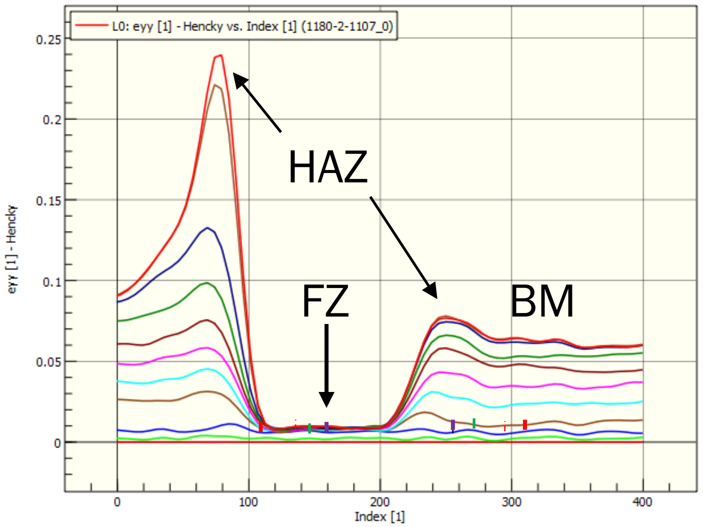
3RD GEN-1180 TENSILE TEST RESULTS

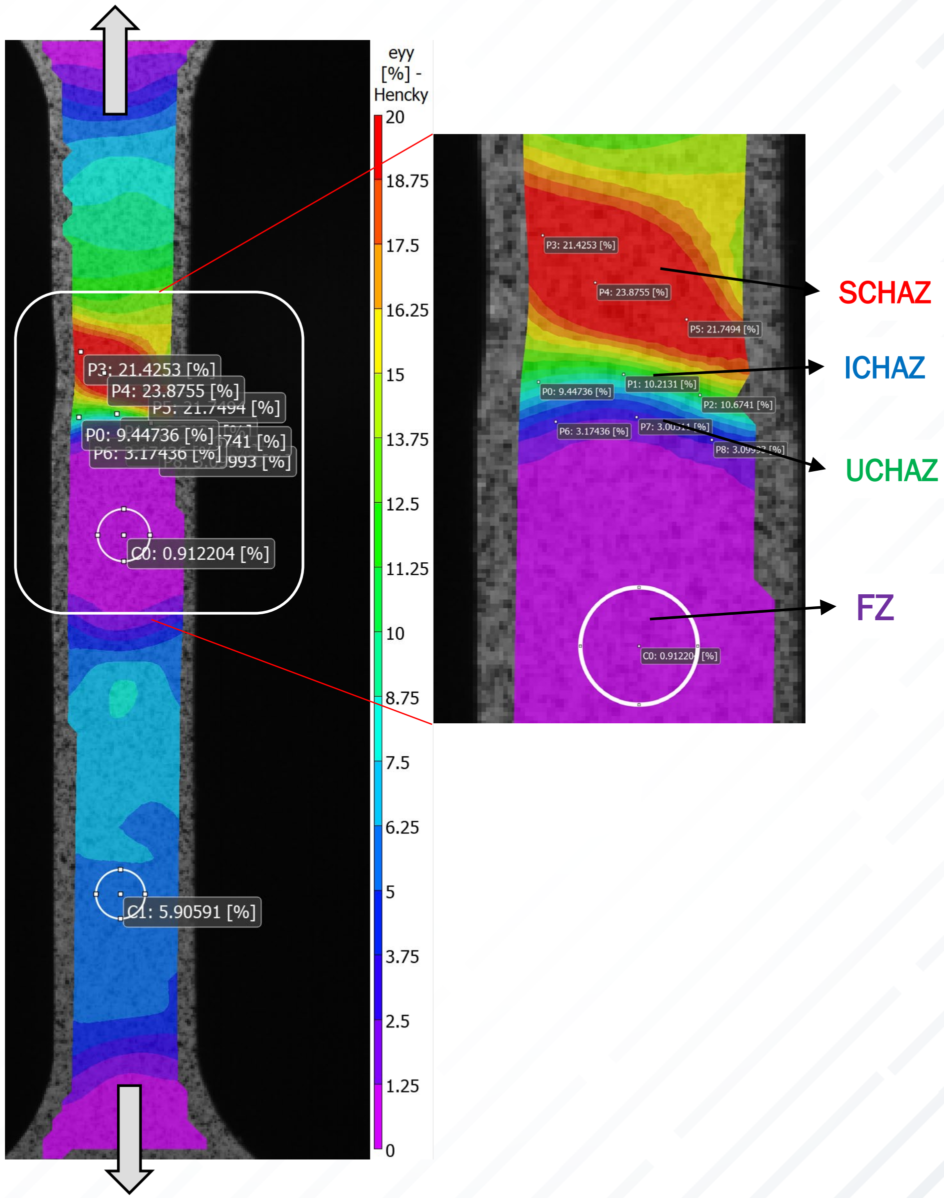


Local SS-curves for 3RD Gen-1180



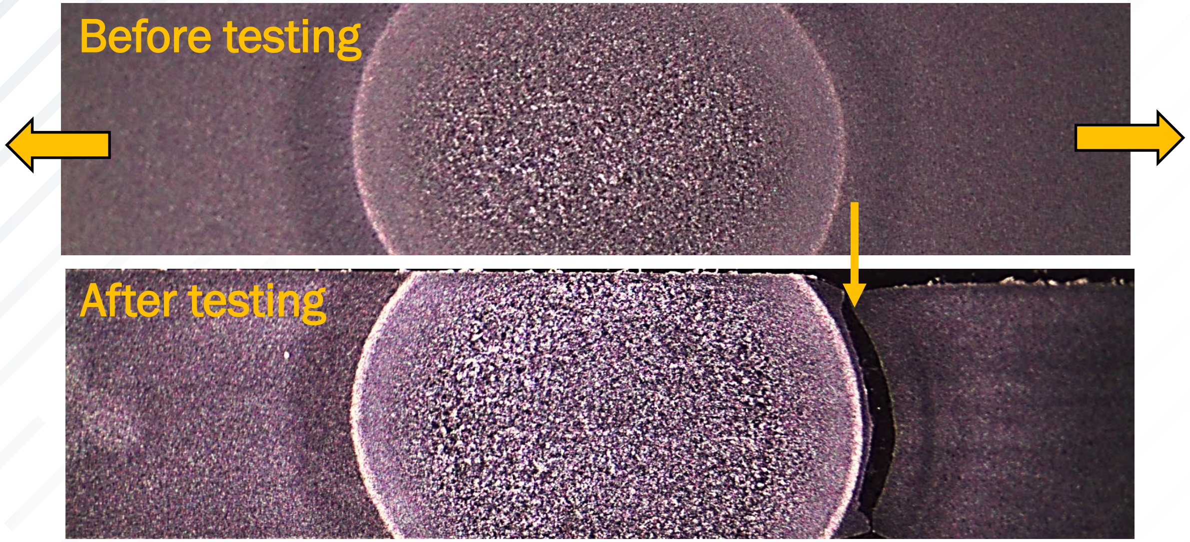
Fracture location in HAZ



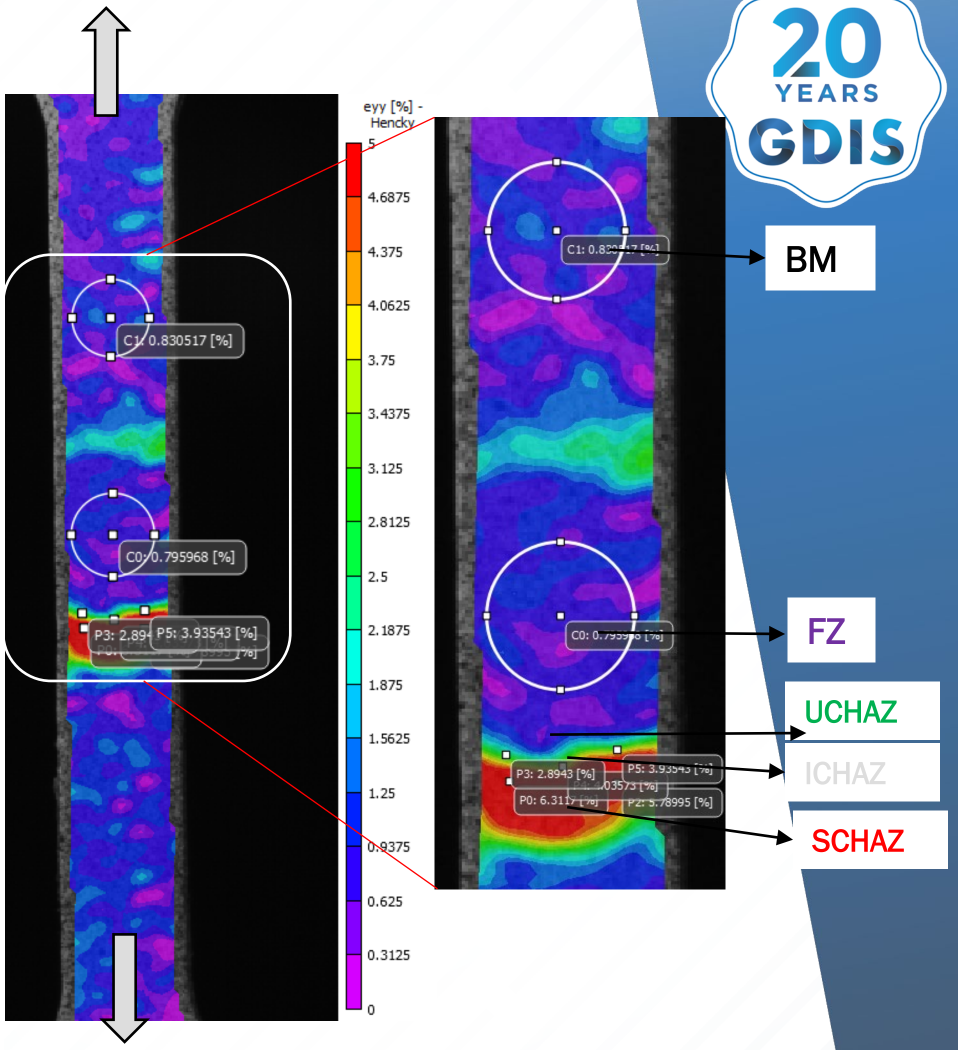


- Failure in the SCHAZ, there was some deformation was observed in the ICHAZ
- No deformation was observed in the FZ and UCHAZ.

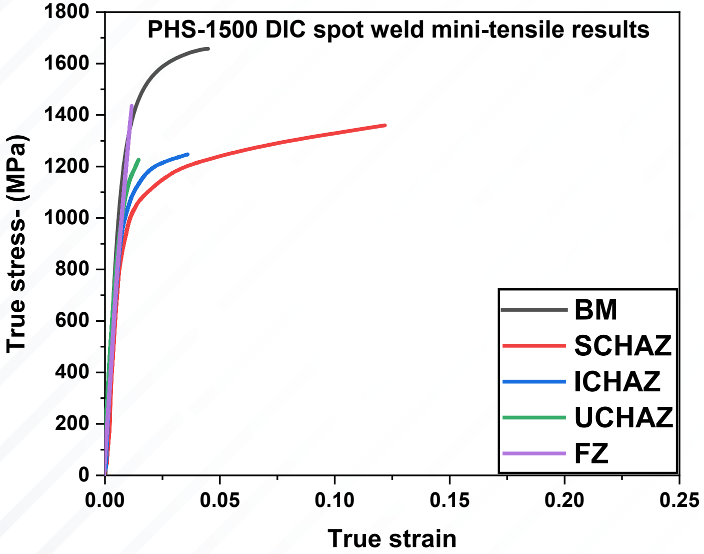
PHS-1500 TENSILE TEST RESULTS

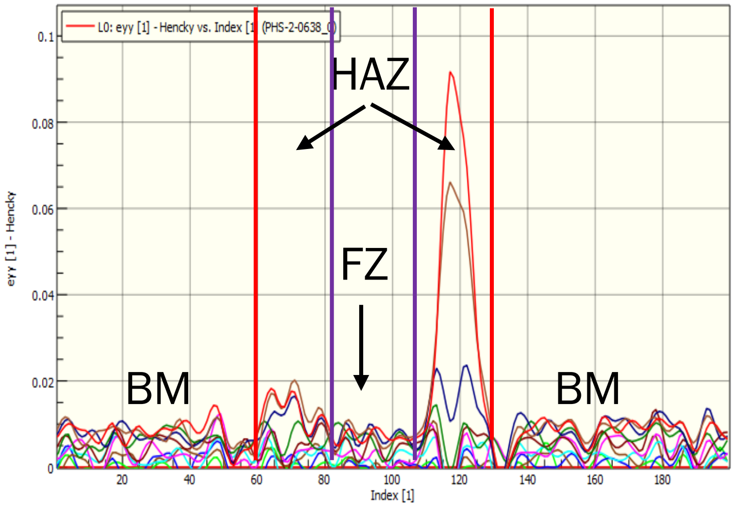


Fracture location in HAZ



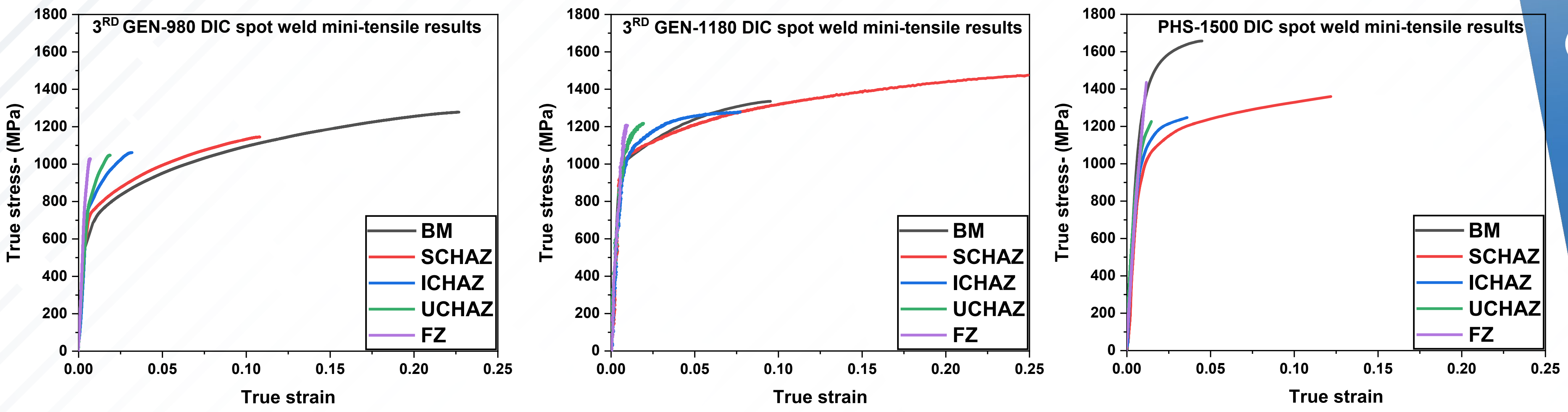
Local SS-curves for PHS-1500



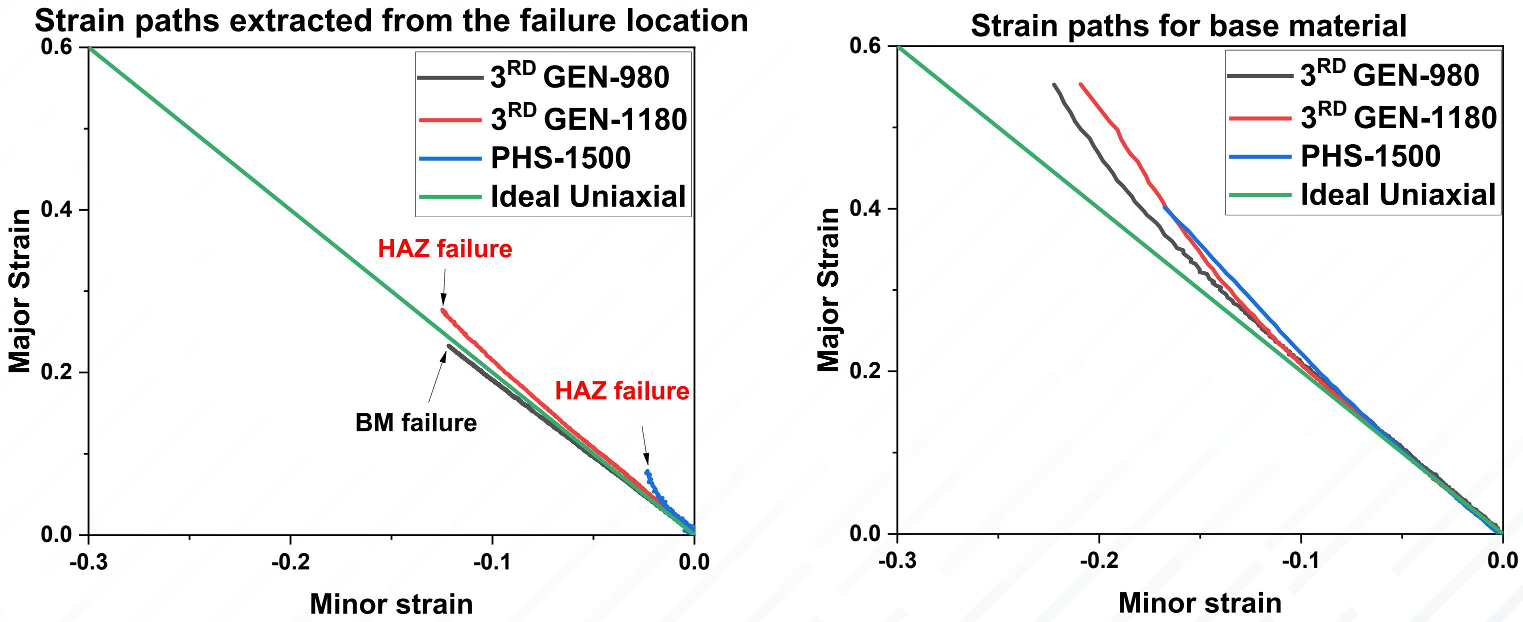


- Strain localized in the SCHAZ due to the severe softening in the microstructure (Martensite tempering)
- No deformation was observed in the FZ and UCHAZ.

LOCAL SS-CURVES FOR ALL MATERIALS EXTRACTED FROM THE DIC

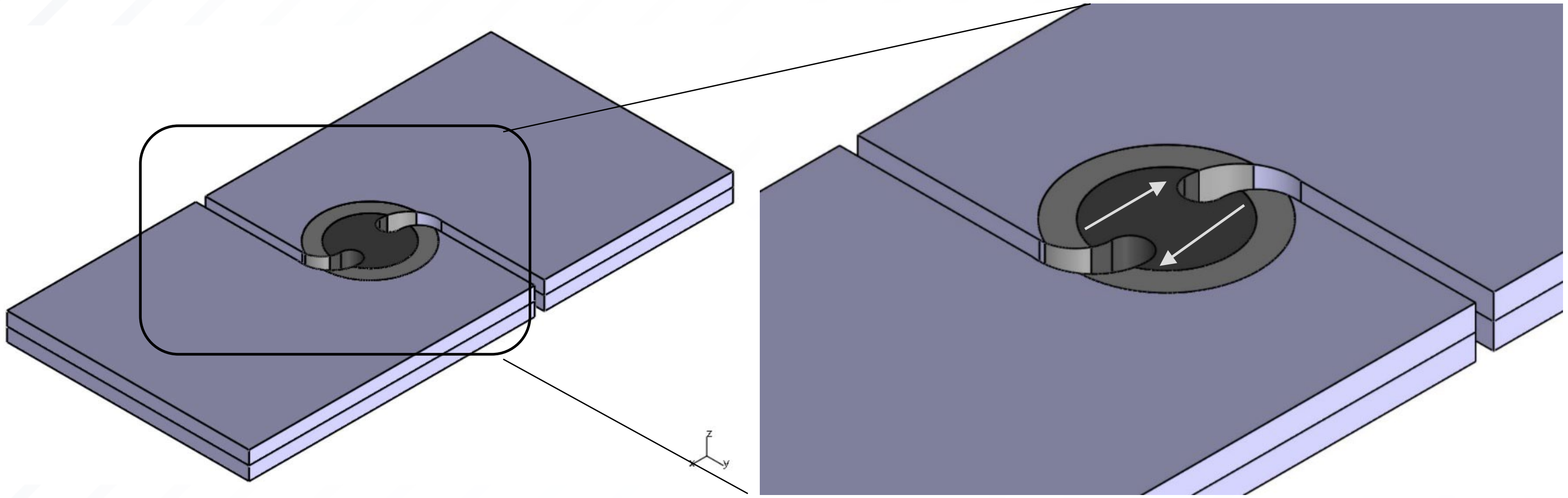


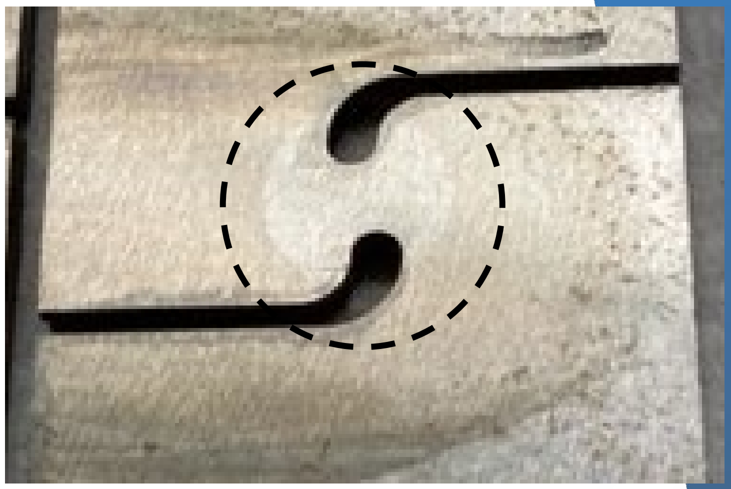
Strain path at fracture location and for BM



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

- **Two sheets with dimensions (25 mm by 50 mm) were welded together then machined to fabricate mini-shear spot weld coupons as shown:**

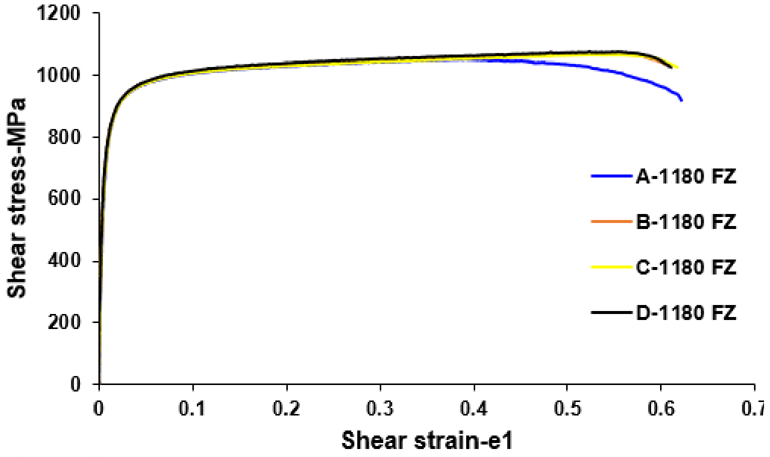




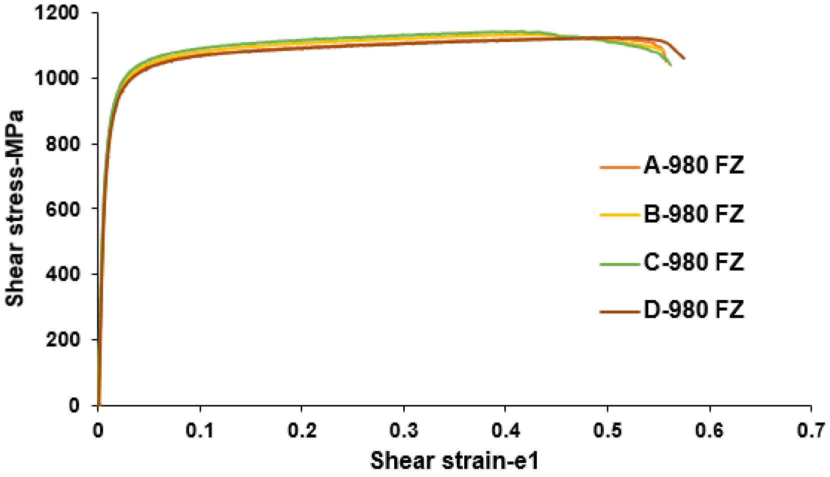
- **The samples were etched using a Nital etching solution to reveal the fusion zone area to make sure the weld is in the center of the sample**

MINI-SHEAR RESULTS

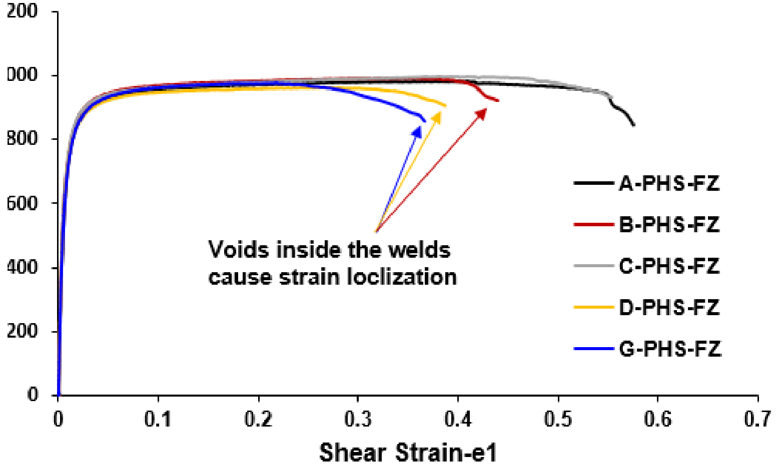
3RD Gen-980 FZ mini-shear

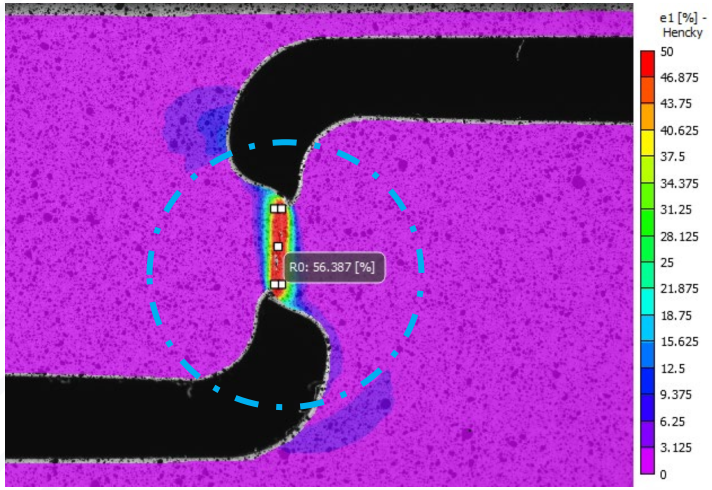


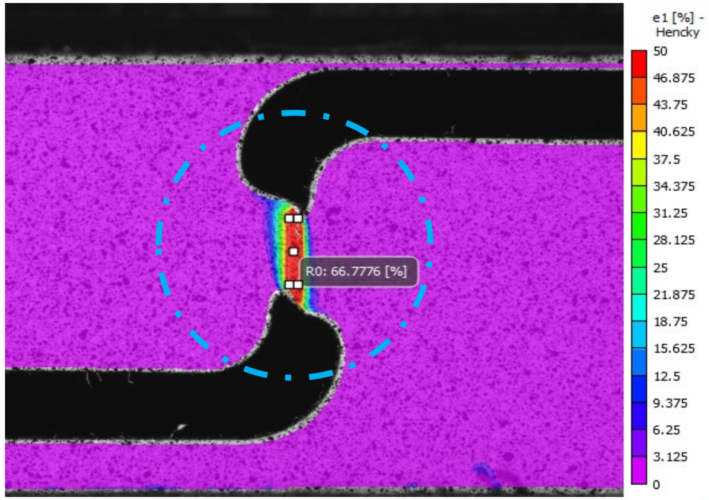
3RD Gen-1180 FZ mini-

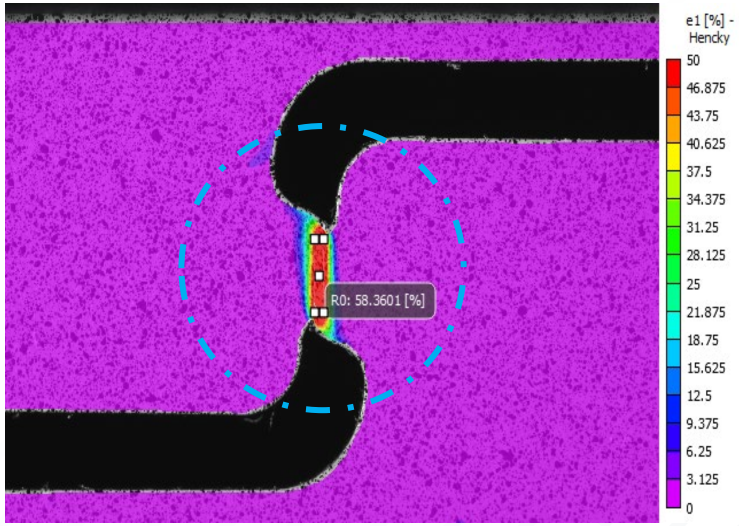


PHS1500-FZ mini-shear



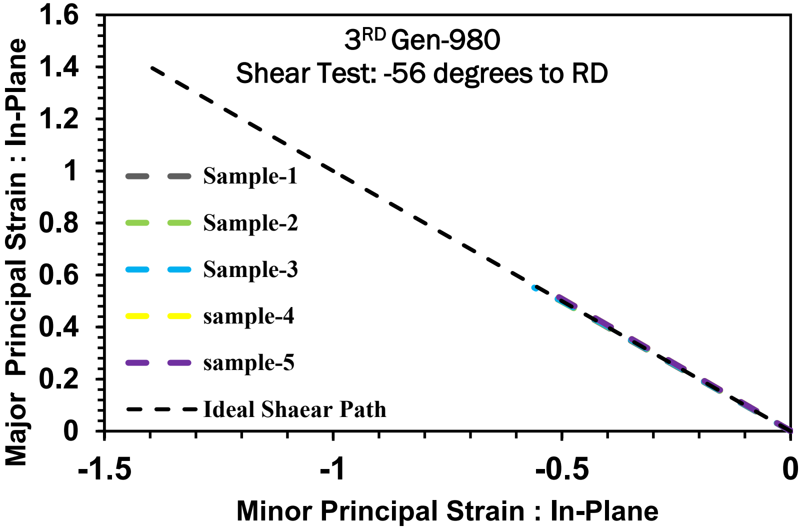


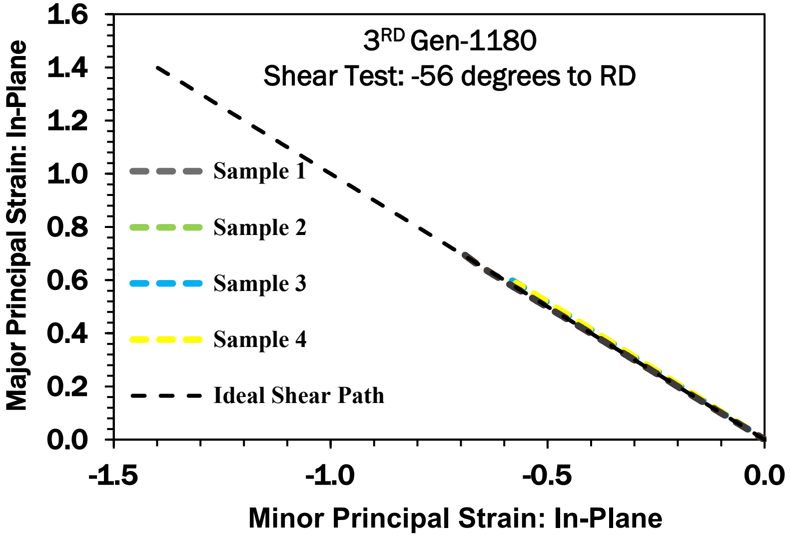


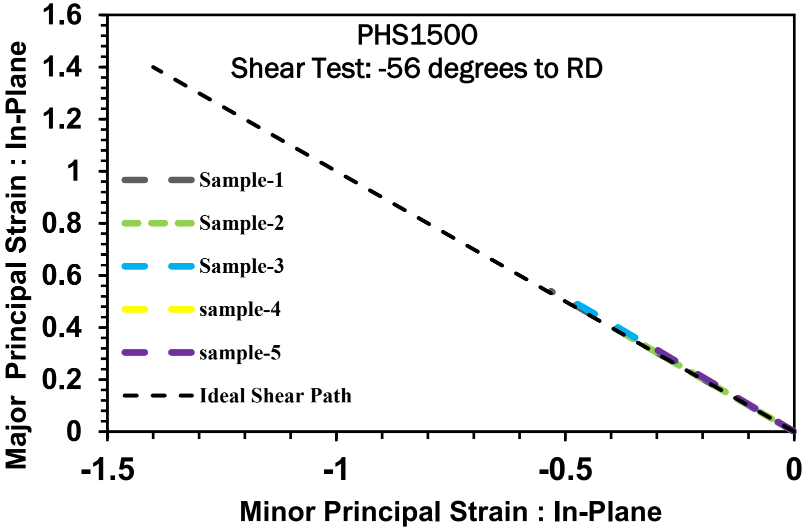


- Fusion zone mini-shear test data showed a consistent trend
- Voids in the PHS-1500 fusion zone led to strain localization and lower shear strain in some tests

STRAIN PATHS AND PLASTIC WORK for FZ







$$\sigma_{eq} = \tau \left(\frac{\tau}{\sigma_{eq}}\right)^{-1}$$

$$\varepsilon_{eq}^{p} = 2\left(\frac{\tau}{\sigma_{eq}}\right)\sinh(\varepsilon_1)$$

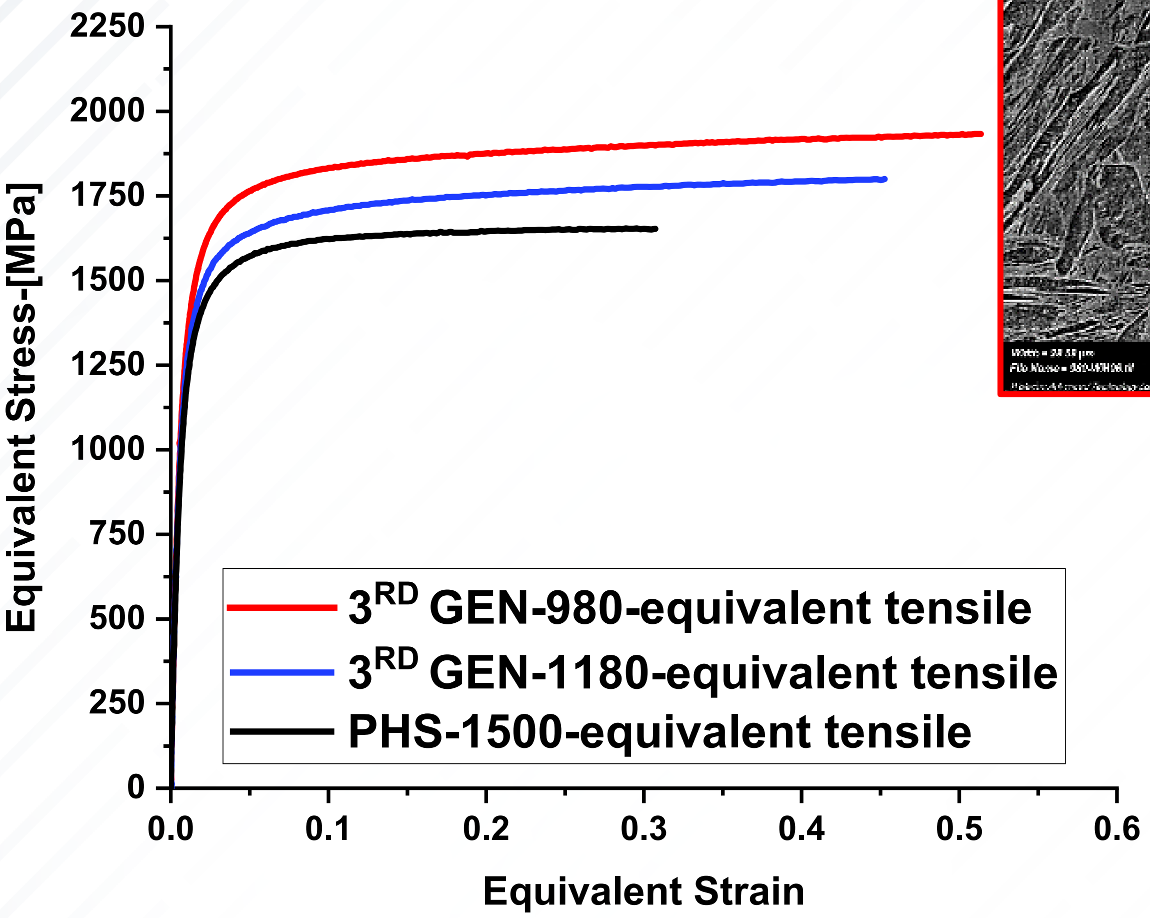
$$\left(\frac{\tau}{\sigma_{eq}}\right)^{Hosford} = \frac{1}{(1+2^{a-1})^{\frac{1}{a}}}$$

The stress ratio is assumed to be constant during deformation (0.558)

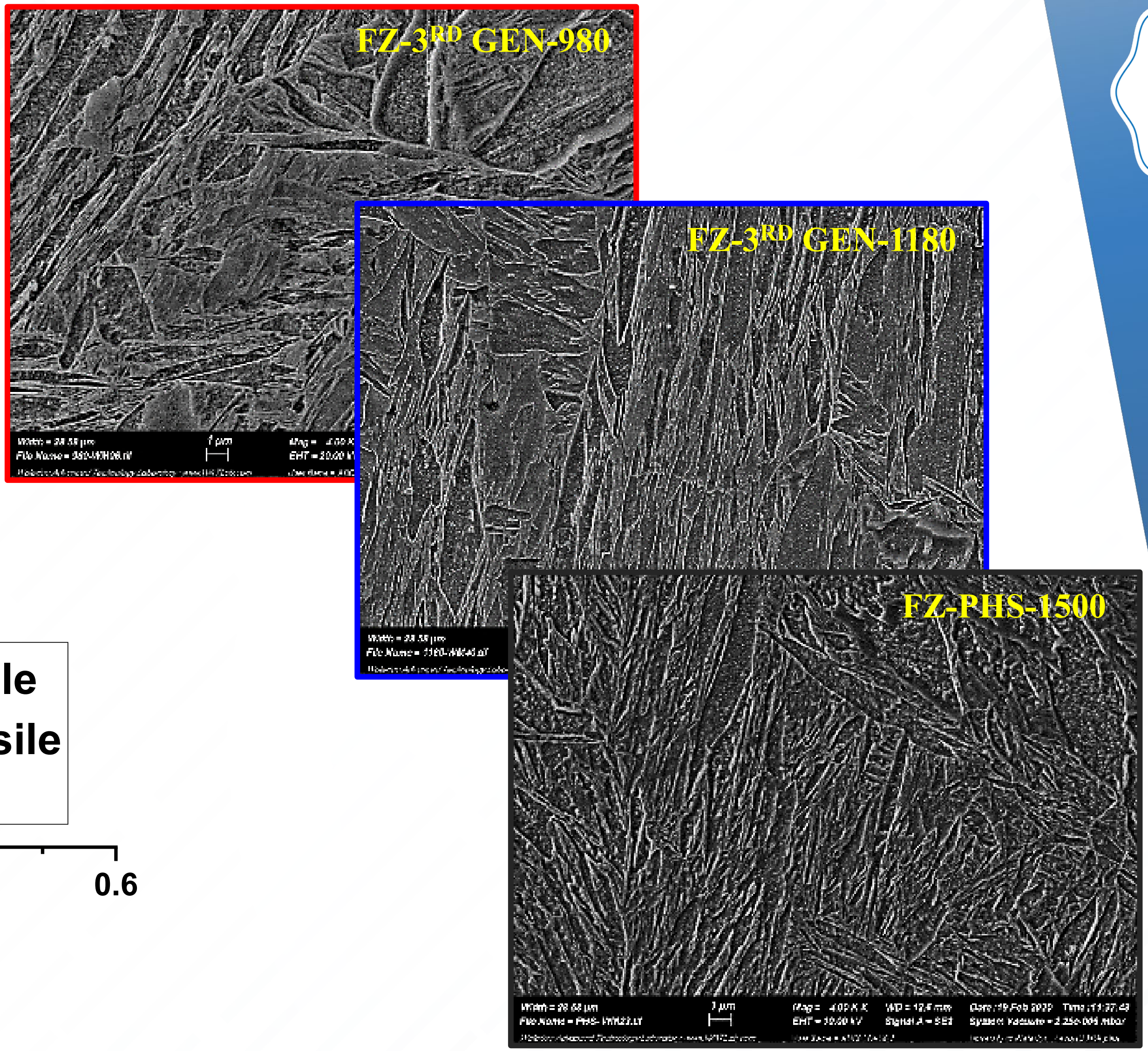
- Strain path of the mini-shear tests for the three materials matched the ideal shear strain path

A. Abedini, J. Noder, C. P. Kohar, and C. Butcher, “Accounting for shear anisotropy and material frame rotation on the constitutive characterization of automotive alloys using simple shear tests,” *Mechanics of Materials*, vol. 148, p. 103419, 2020.

EQUIVALENT STRESS-STRAIN FOR FZ



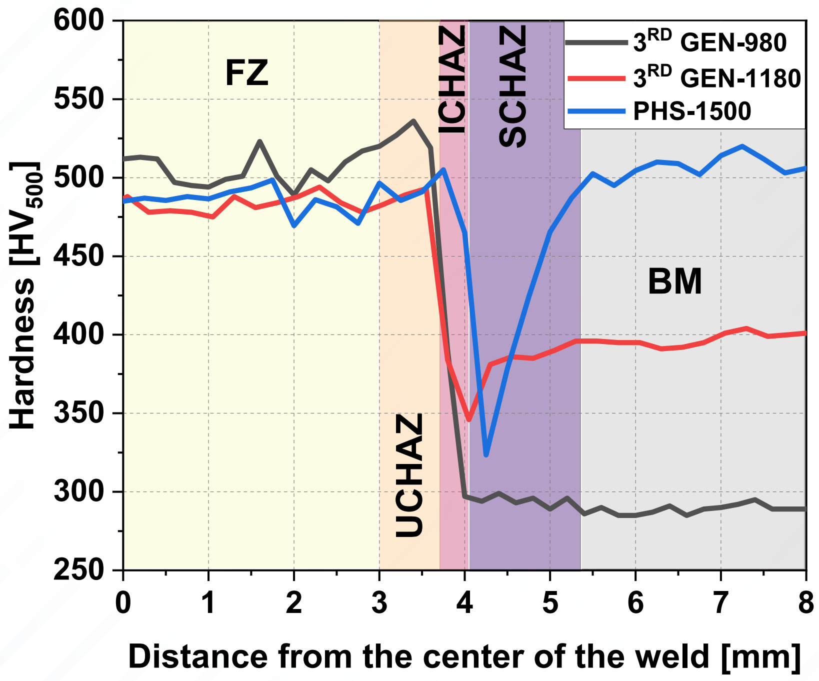
FZ-microstructure

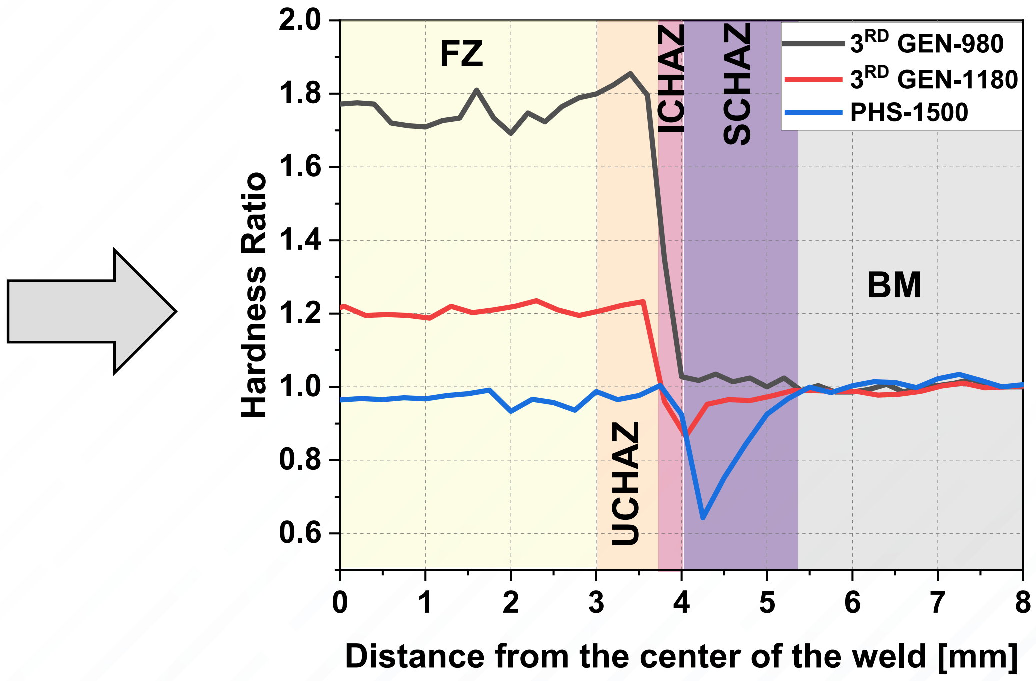


- All FZ showed a martensitic microstructure; however, the C_{eq} is different, which will lead to the variation in the mechanical properties.
- The fusion zone properties can be used in the UCHAZ

MICROHARDNESS SCALING APPROACH

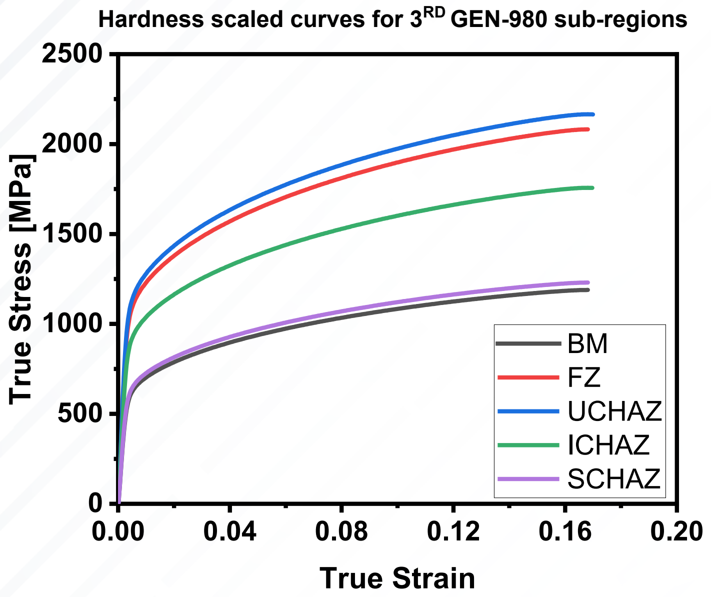
Material/Zone	BM	FZ	HAZ-1 (UCHAZ)	HAZ-2 (ICHAZ)	HAZ-3 (SCHAZ)
3RD Gen-980	289±3	530±11	527±13	427	300±5
3RD Gen-1180	406±3	488±5	487±6	420	377±23
PHS-1500	502±9	498±6	494±13	465	323±2

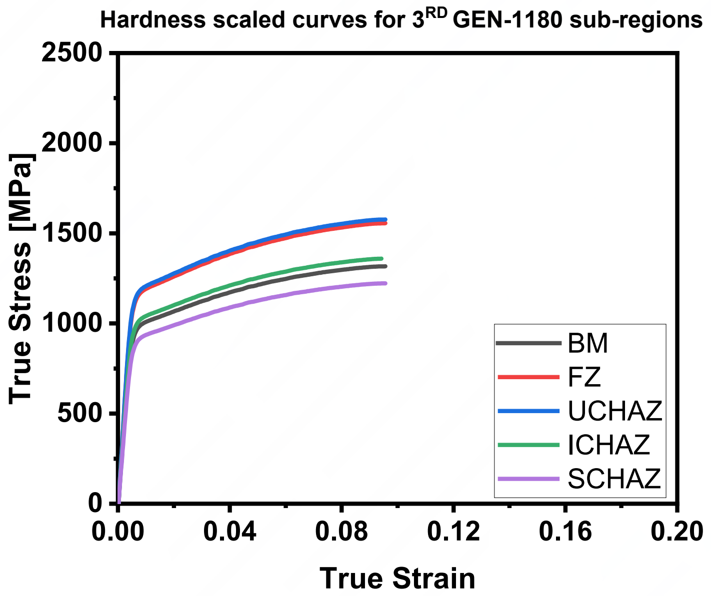


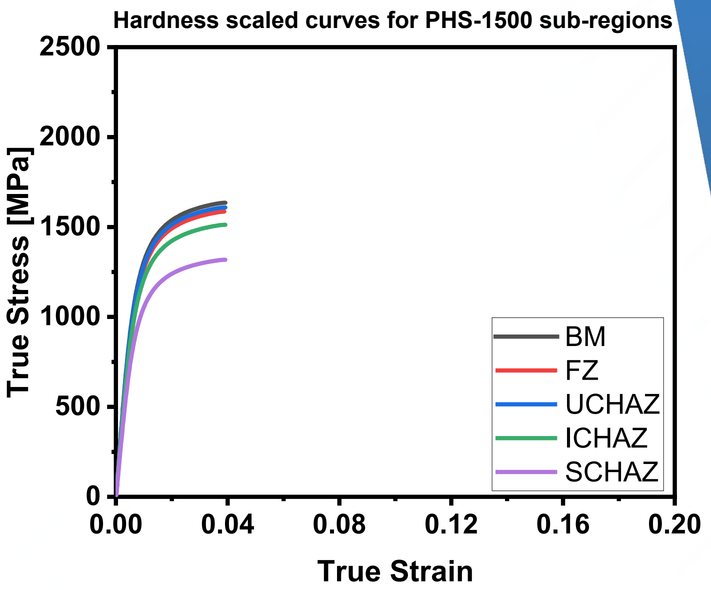


STRESS-STRAIN CURVES GENERATED USING THE HARDNESS RATIO METHOD

- This method assumes the hardening behavior of different zones across the weld similar to the BM.

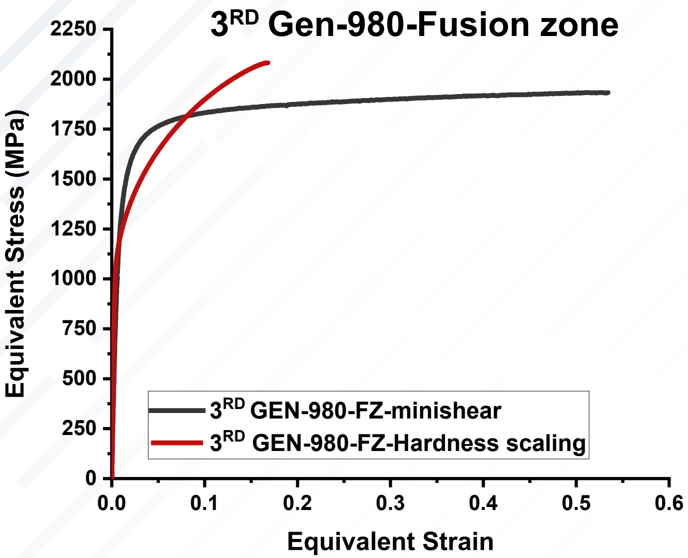


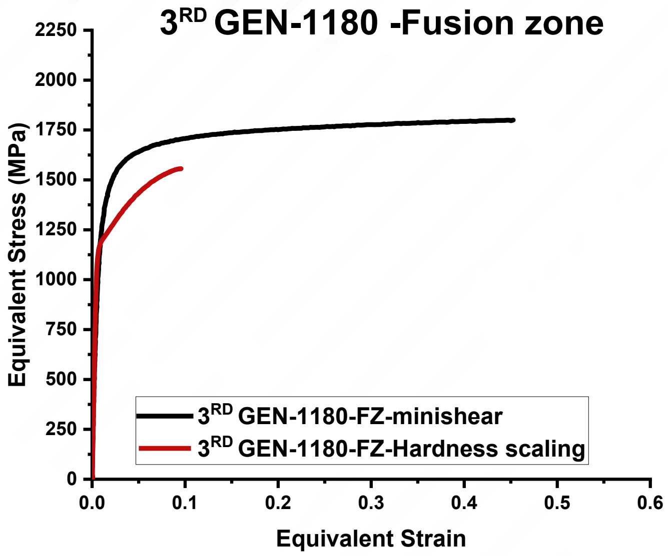


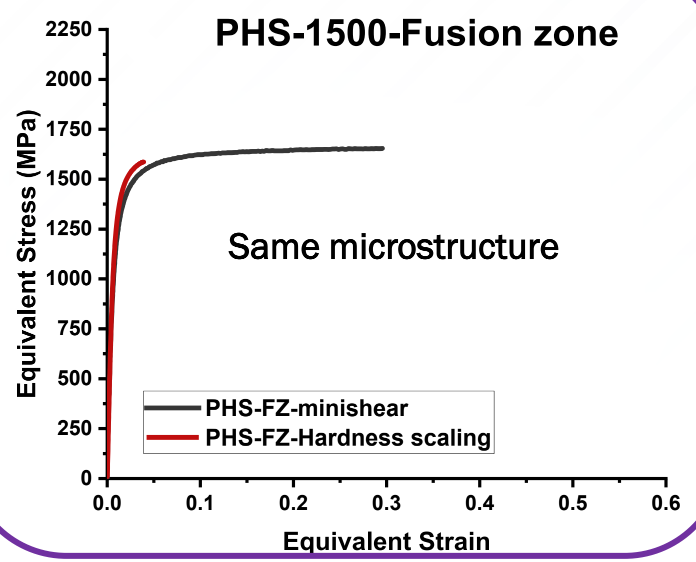


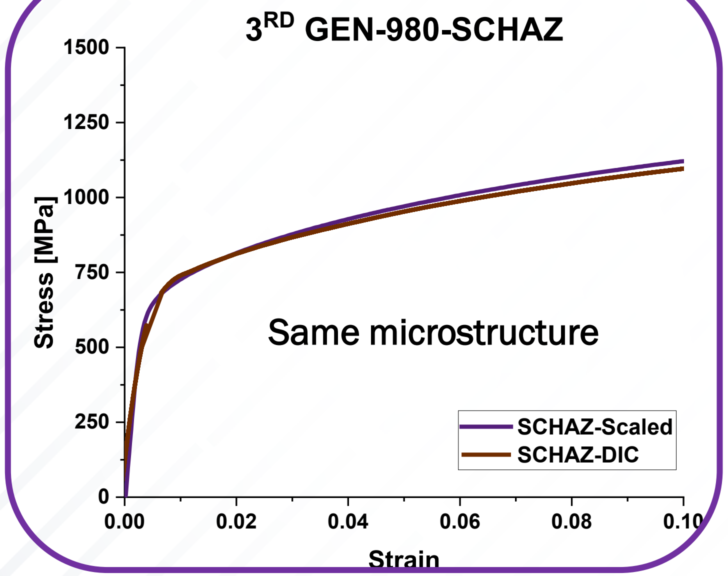
The representative SS curves obtained from the hardness scaling approach will be compared to the tensile data were extracted from the mini-shear and mini-tensile test

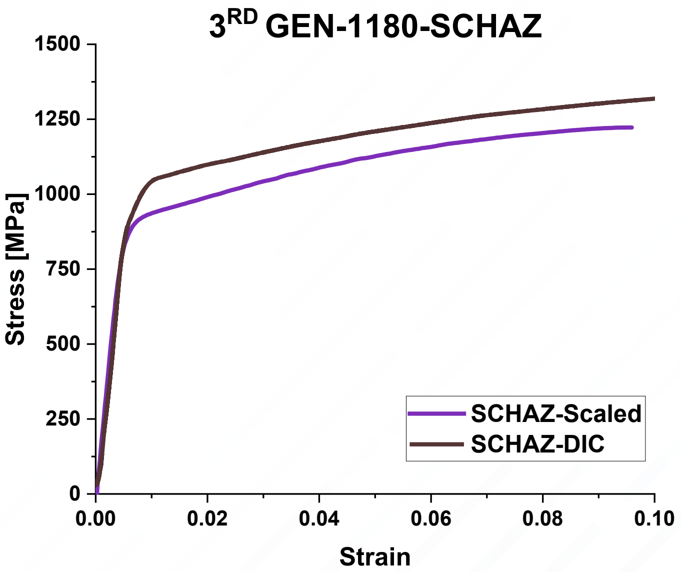
COMPARISON BETWEEN HARDNESS APPROACH AND SHEAR TENSILE STRESS-STRAIN CURVES

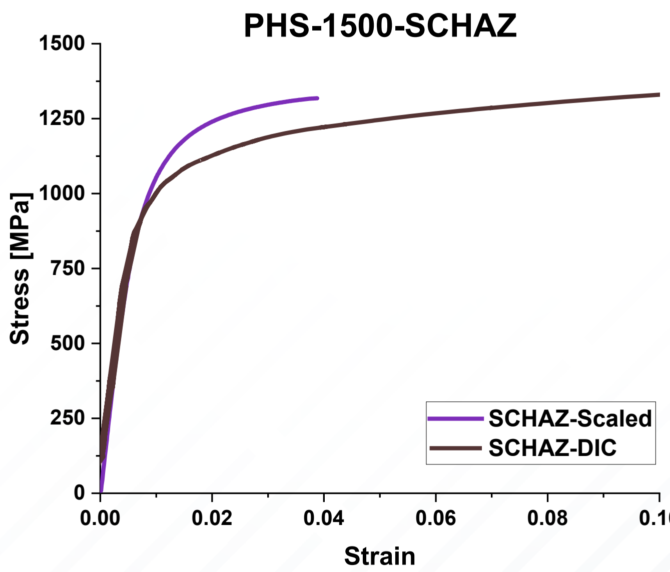






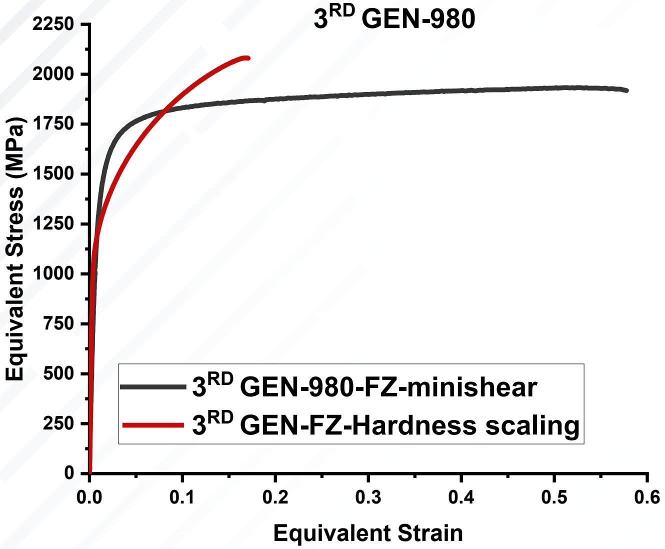


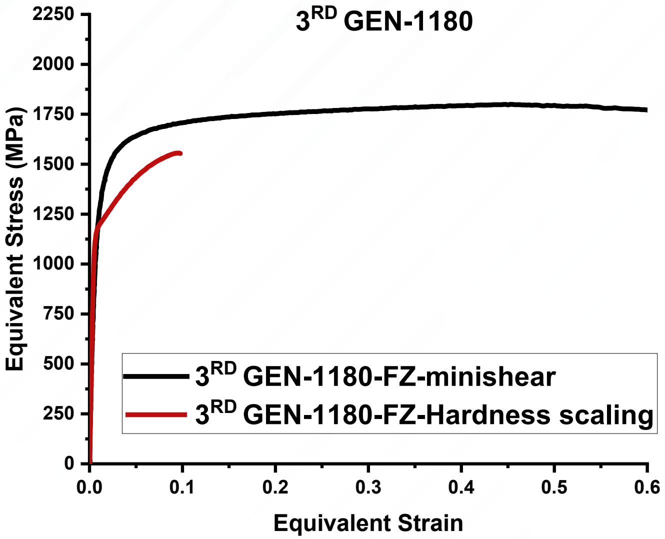


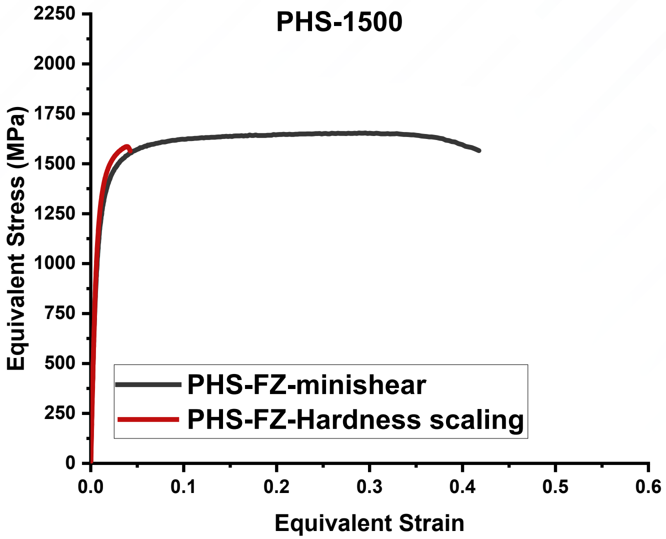


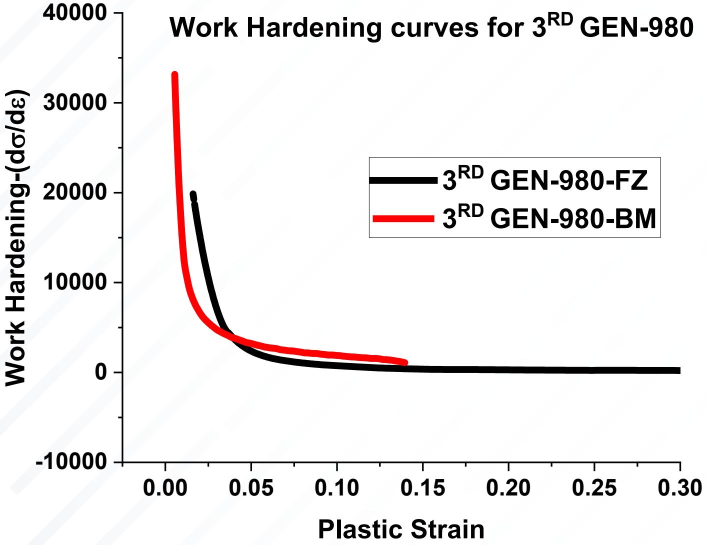
The hardness scaling approach can estimate the stress-strain curves of different zones across the weld as long as the sub-zone has a similar microstructure as the BM.

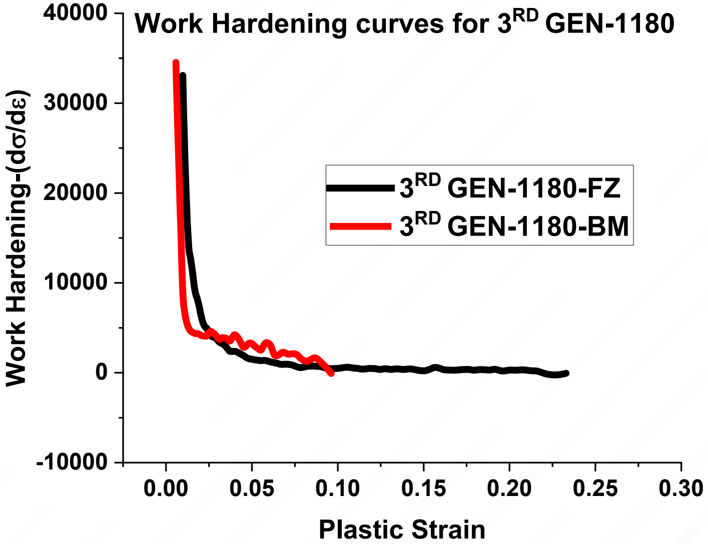
WORK HARDENING

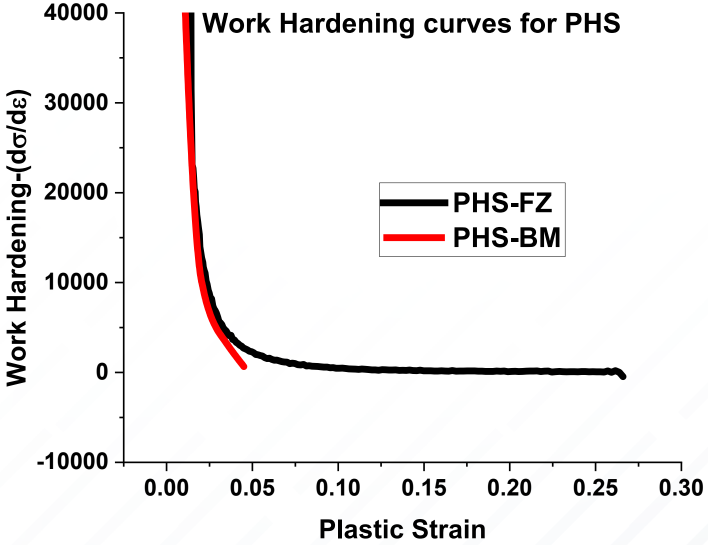








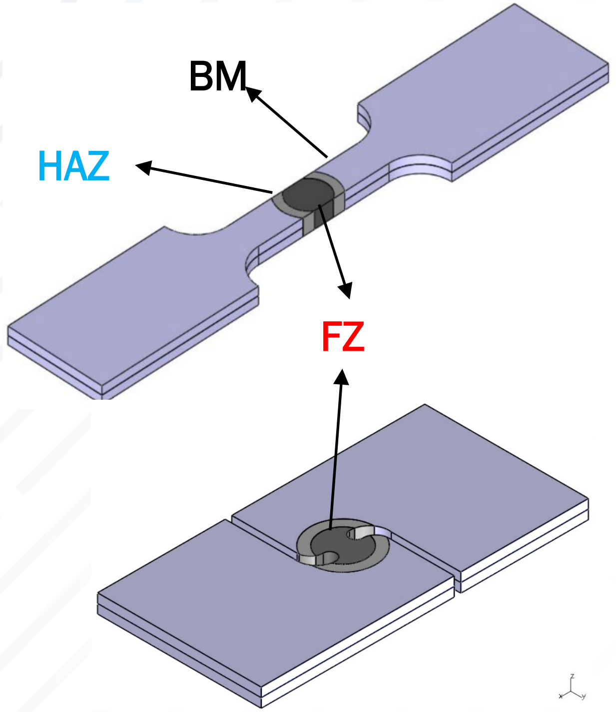




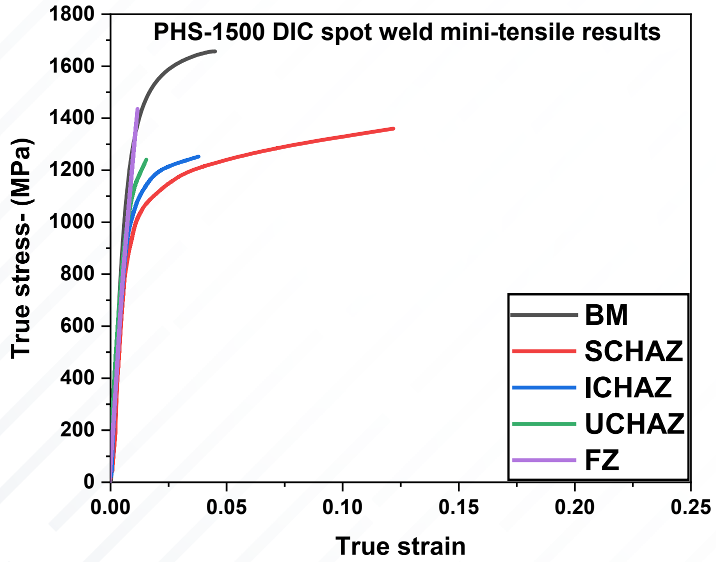
The hardness scaling approach could only estimate the mechanical properties if the microstructures across the weld result in a consistent strain hardening.

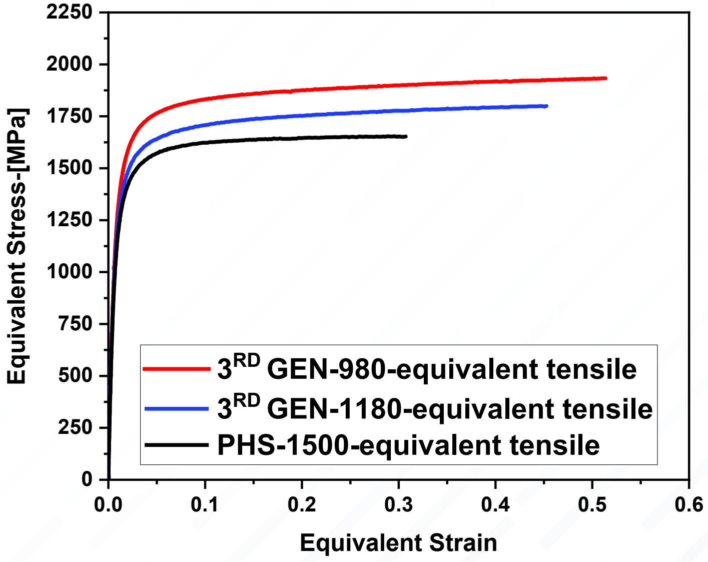
CONCLUSION & FUTURE WORK

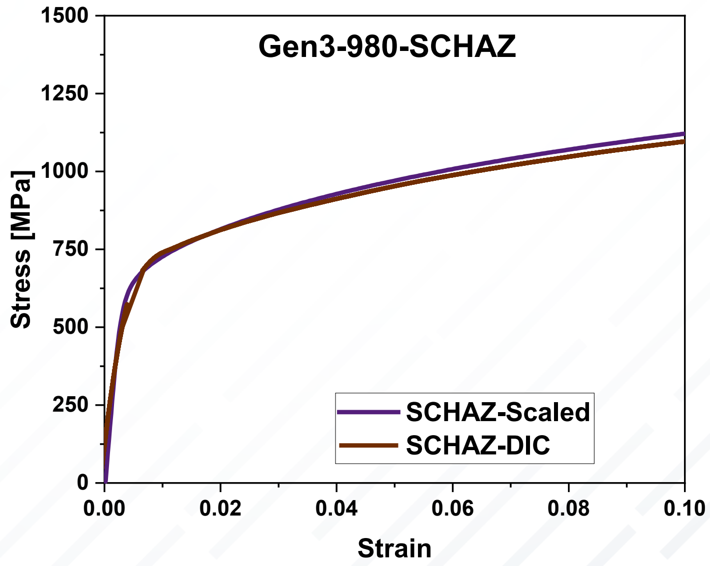
CONCLUSION/ RECOMMENDATIONS



- The novel technique of measuring local properties of spot weld fusion zone enables more accurate modelling of 3[RD] GEN AHSS spot weld performance.
- More work is required to further evaluate and develop the methodologies via FE modelling
- Modelling of spot weld can be improved by:
  - Estimate flow properties of different HAZ using mini-tensile welded samples
  - Directly measuring the stress-strain curves for FZ using a mini-shear coupon
  - Hardness scaling can be used to estimate the flow properties of HAZ and FZ as long as the microstructures of the target zone are similar to the BM.
  - Thermal simulation of the HAZ microstructure using Gleeble is another way to estimate the local properties.







THANKS FOR YOUR ATTENTION

FOR MORE INFORMATION

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