Precision in Spot Weld Simulation: Creating a Robust Material Card

GDIS

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- ❑ **Simulation Validation Results**
    - ❑ Nugget size & Hardness Validation
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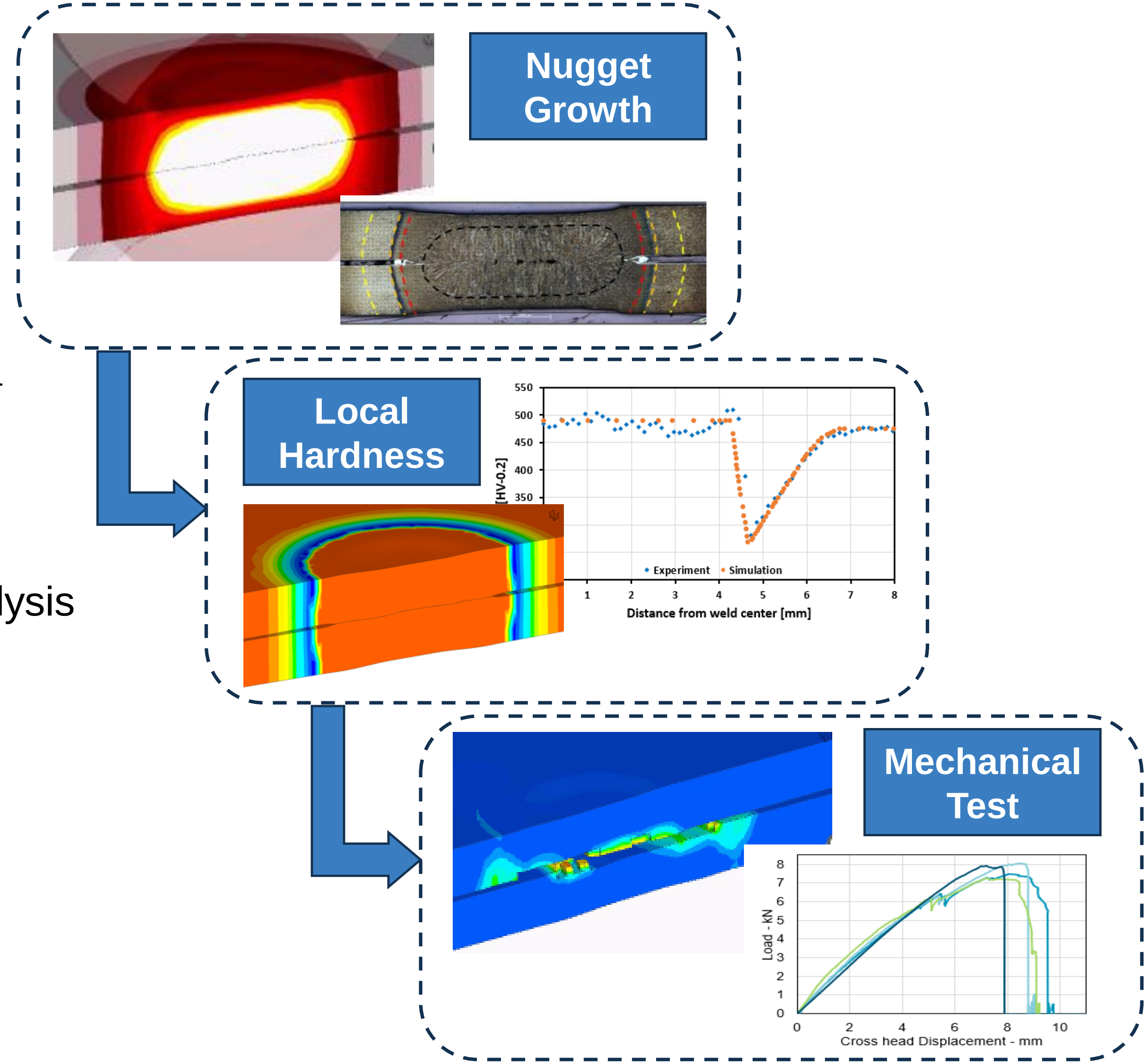


Introduction and motivation

CAE-level

- Ring of shell elements around spot weld
- Transitioning properties from nugget to BM

Meso-scale

- Mesh of fine solid elements
- Predict weld fracture location

HAZ is temperature time dependent and gradually change & can not be assumed as one zone with soft microstructure

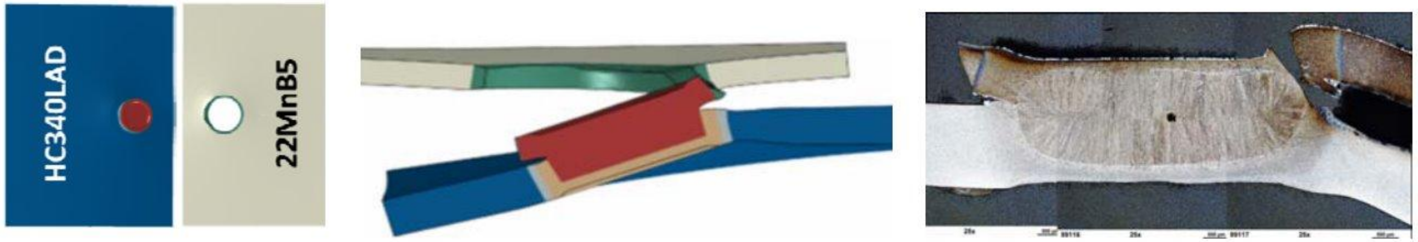
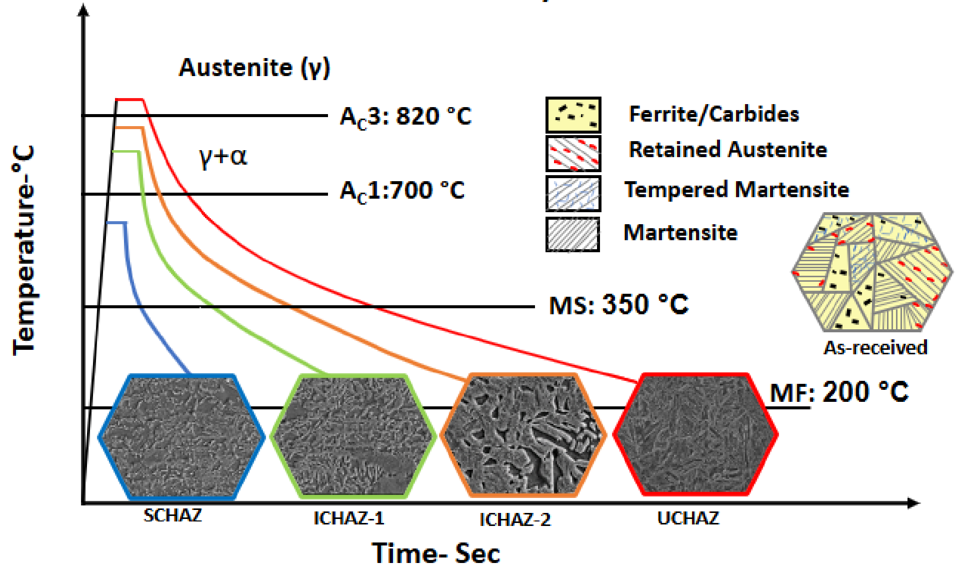


Figure 13. Calculated pull-out fracture of TS-specimen inside the softened HAZ of 22MnB5 (left and middle) Polished and etched cross-section of a tested TS-specimen showing pull-out fracture inside the SHAZ (right)

S. Burget and S. Sommer 2012 & 2013

Schematic shows the thermal history for different HAZ



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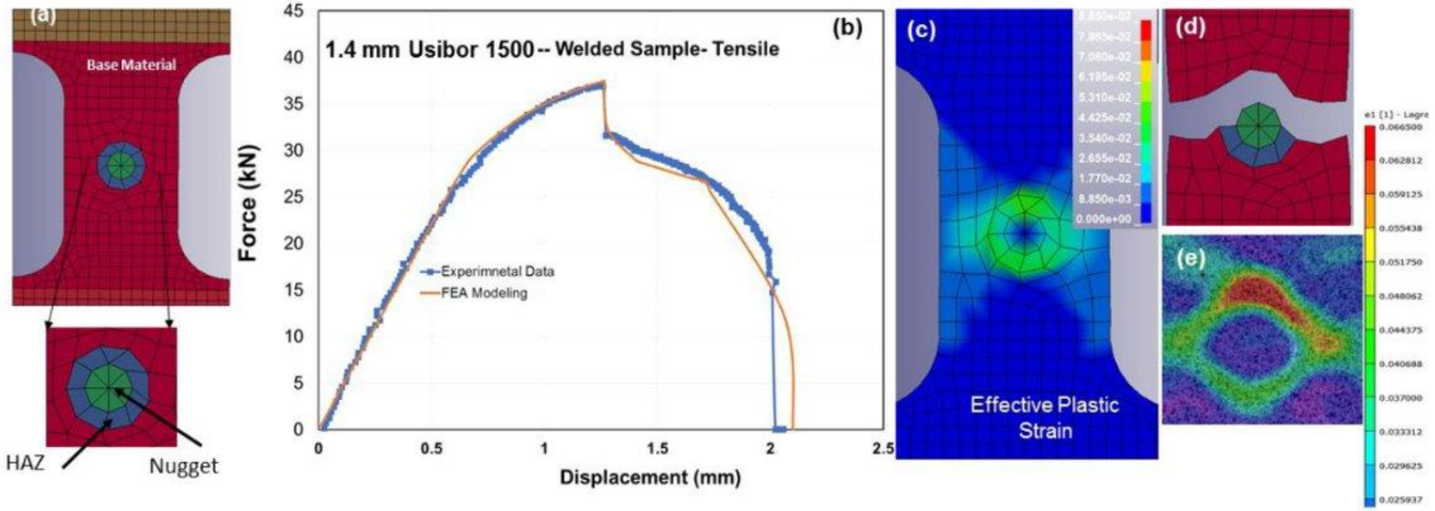
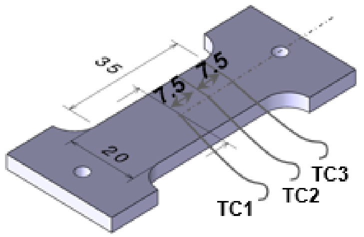


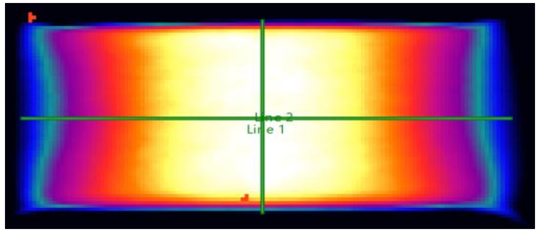
Fig. 14. For Usibor 1500 (a) Finite element model with 2 mm shell element size, (b) force-displacement from FE modeling and experimental measurement (c) effective plastic strain map right before failure, (d) & (e) failure of samples predicted by FE model and experimental observation, respectively. (Online version in color.)

H. Ghassemi-Armaki et al. 2017

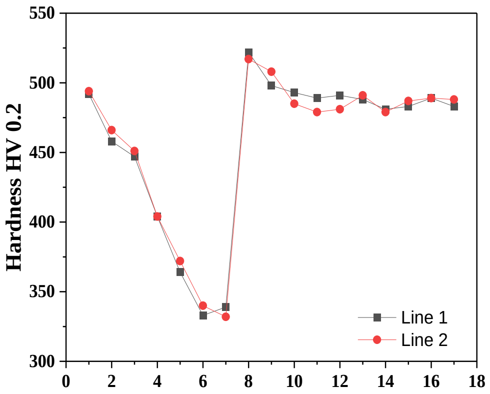
Introduction and motivation

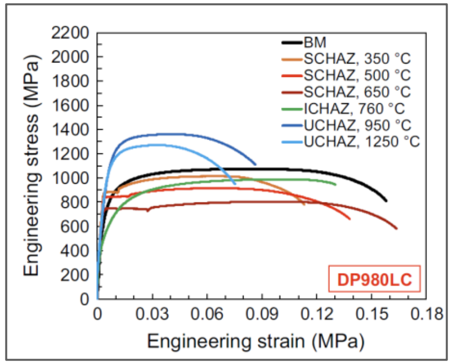
Meso-scale spot weld failure model approach need details of spot weld, microhardness, and local mechanical properties to be able to predict the failure behavior, which required extensive amount of work

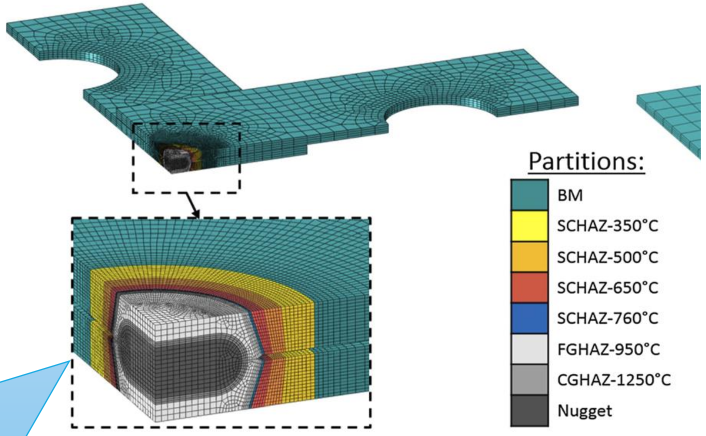




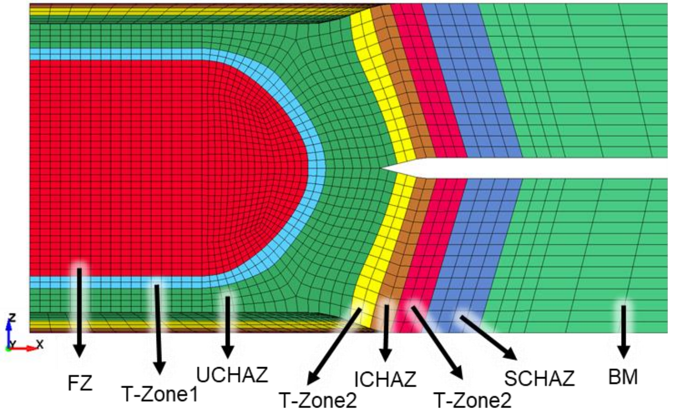
Hardening in some grades, softening due to tempering





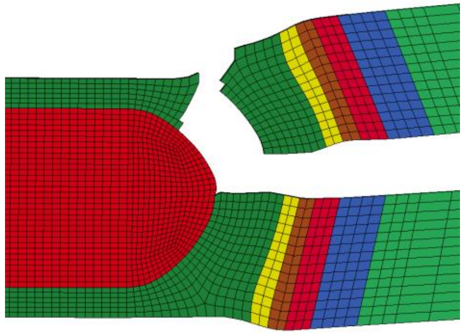


What happens if you change the weld schedule? More pulses? Less pulses? Higher current?



Weld geometry and corresponding Microstructural Observations → Detailed spot weld FEA model

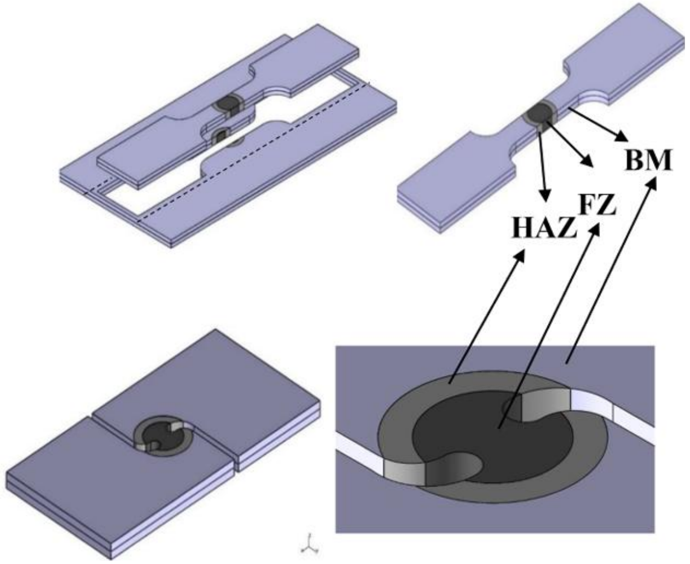
Miniature HAZ Gleeble coupon tests and simulation → Constitutive models with 3D Fracture loci

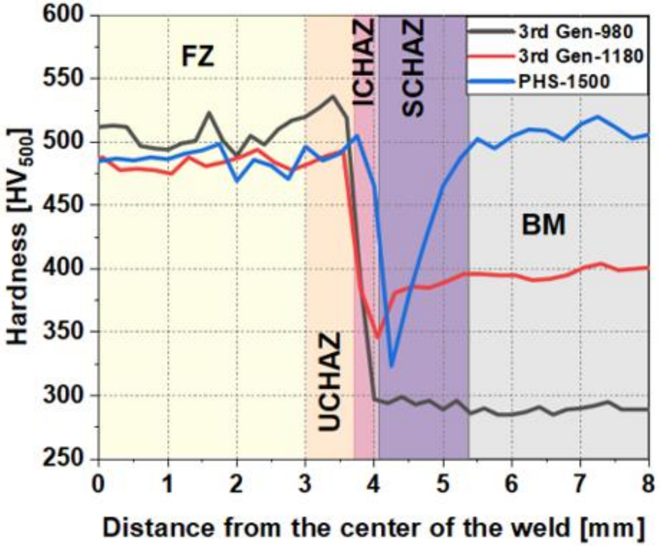


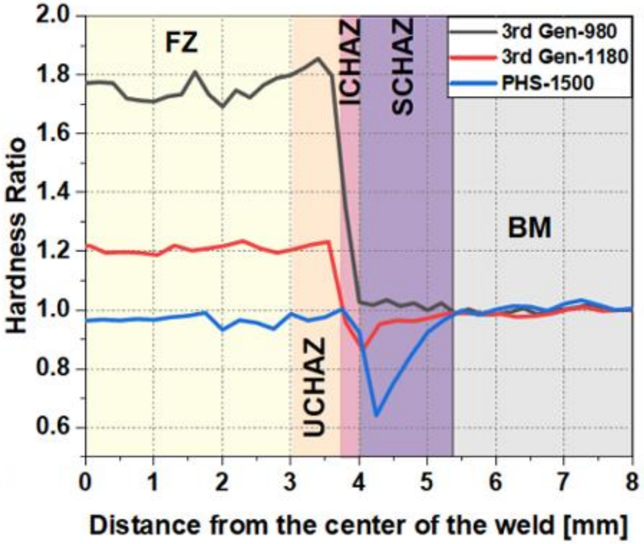
A. Mohamadizadeh et al. 2022

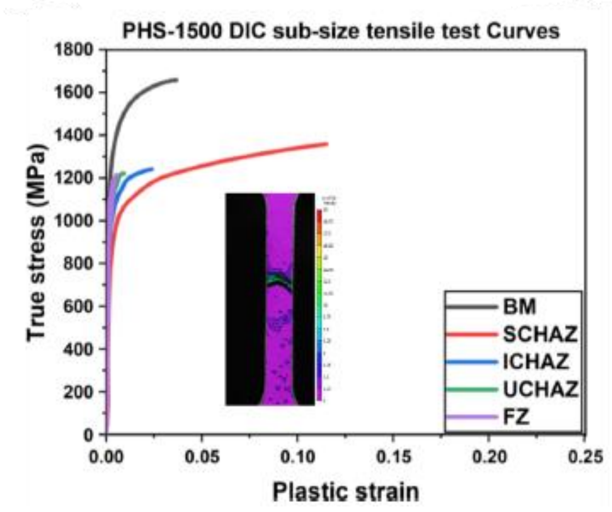
Introduction and motivation

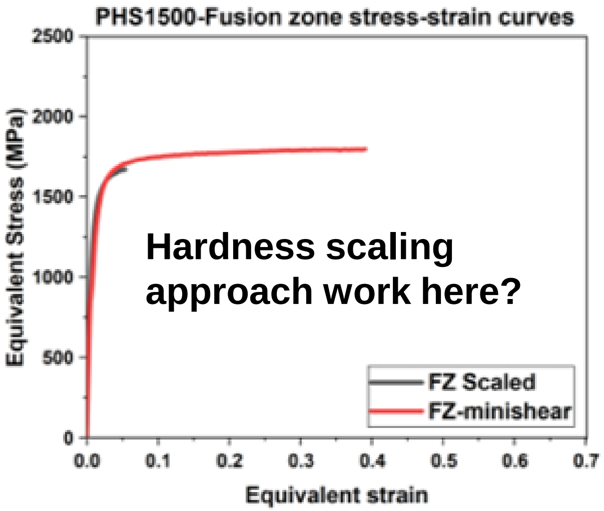
Using the local mechanical properties (mini coupons) to inform the spot weld model, which method is more robust?

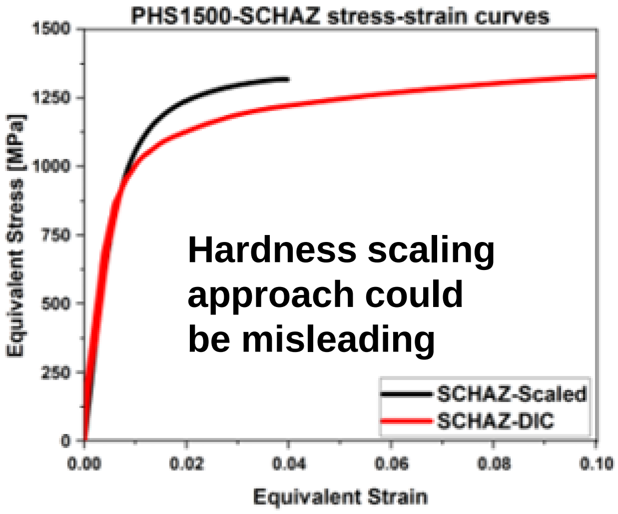


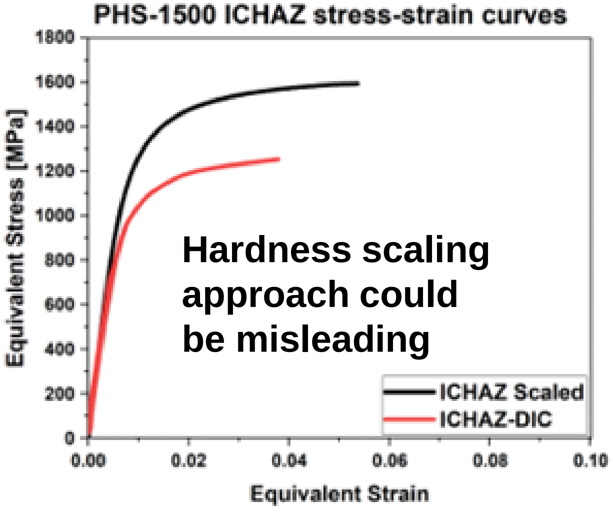












A. Midawi et al. 2022

Objective

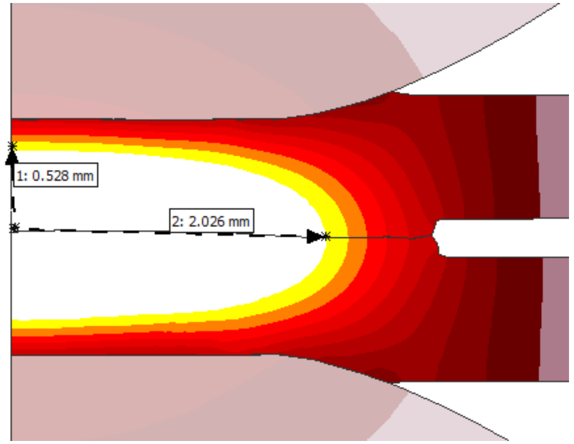
The main objective of this work is to develop a spot weld material card that can predict the spot weld process and mechanical behavior of the spot weld, and to achieve that:

- **Generate and characterize base material and spot weld data for 2 mm Usibor 1500 sheets**
- **Simulate the resistance spot welding (RSW) process using 2D and 3D-Simufact Forming software**
- **Incorporate a user-defined subroutine to predict phase transformations during welding and calculate local strength and failure.**
- **Improve the damage model to predict the mechanical test behavior and the failure mode in TSS & CTS**
- **Validate the simulation model by comparing weld size, hardness profiles, and mechanical test results with experimental data.**

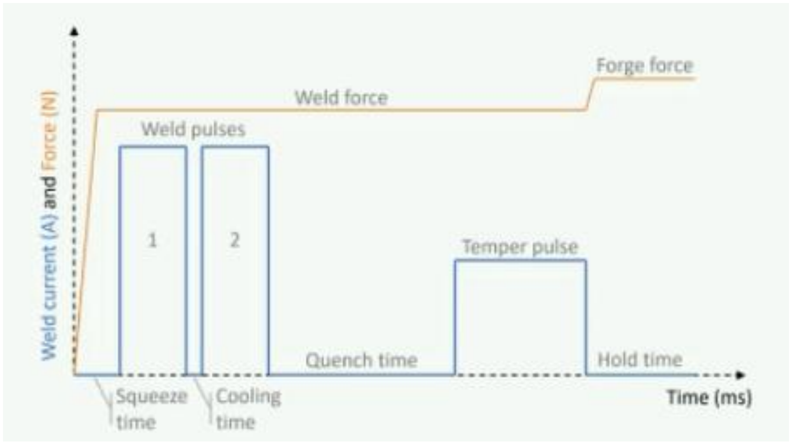
Simufact Spot Weld Model Procedure

Resistance Spot Welding – Single Spot Analysis

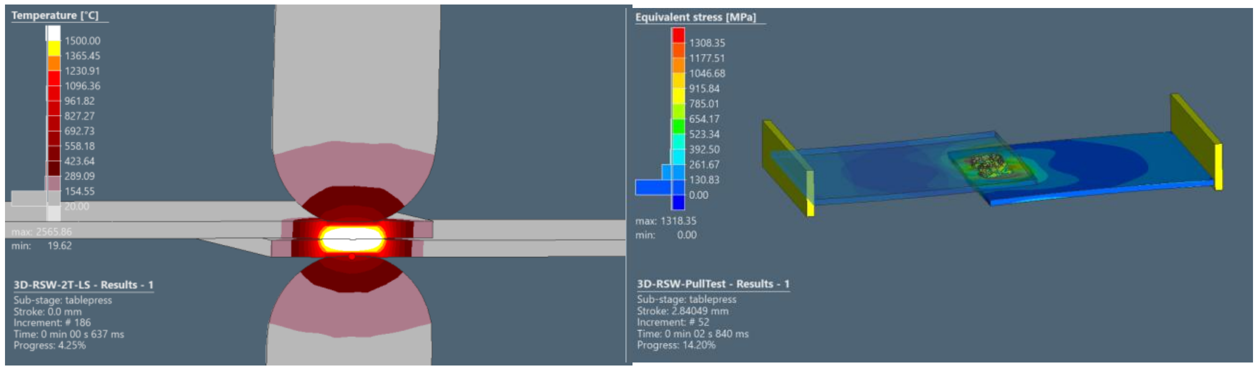
- **Thermomechanical Nonlinear Implicit FEA**
- **2D Axisymmetric or 3D analysis**
- **Thermal Dependent Material Properties**
- **Direct input of process parameters**
- **Calculation of key process results**



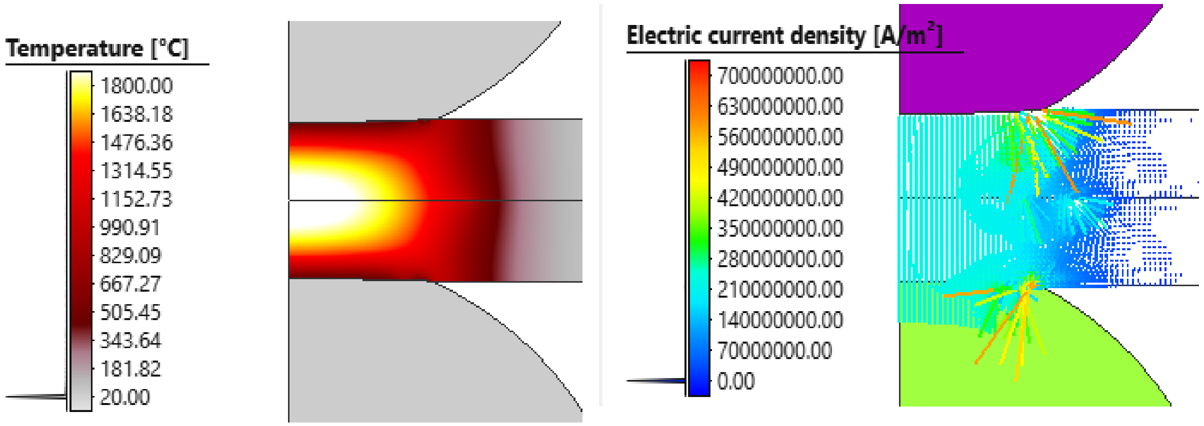
Weld nugget size



Weld schedule planning



3D model for TSS

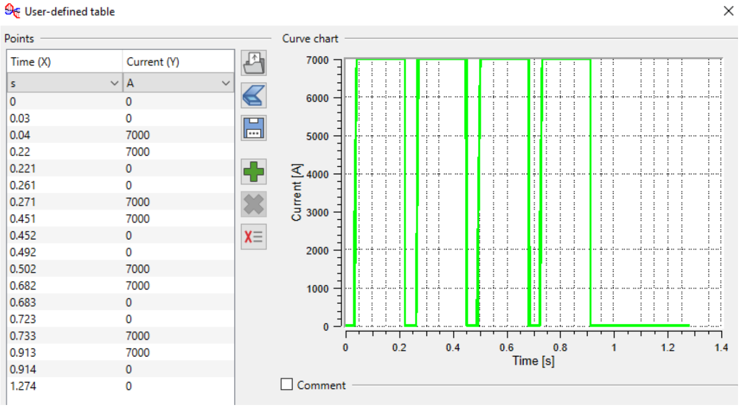


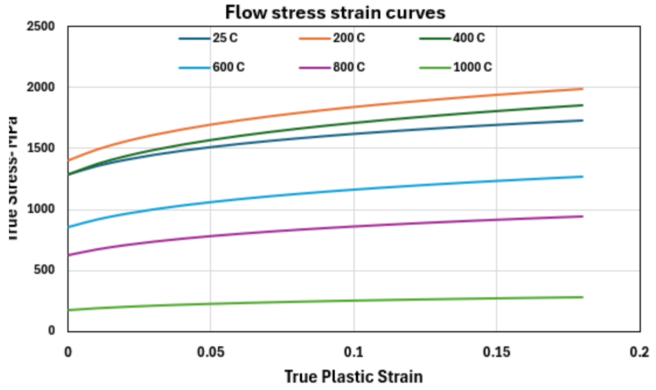
Temperature evolution and electric current density

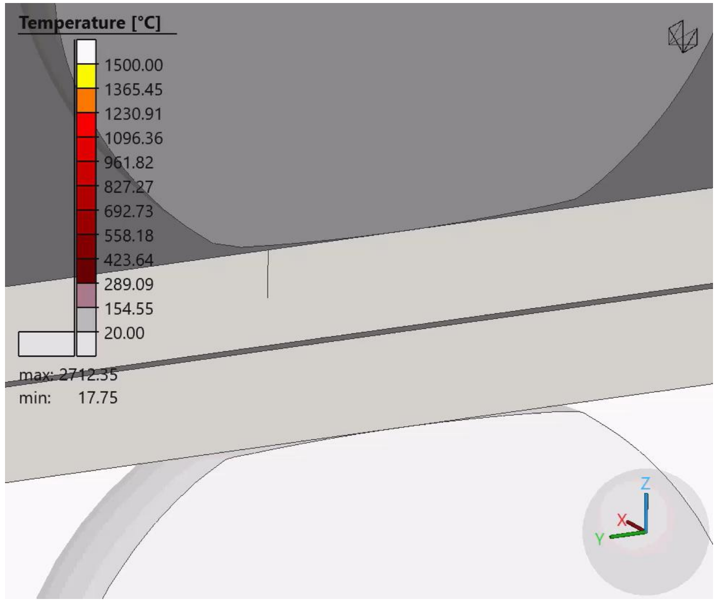
Simufact Spot Weld Model Procedure

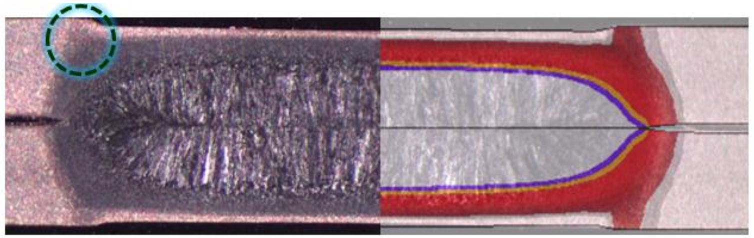
- **Direct input of process parameters:**
  - Weld schedule (current, weld time, # of pulses, cool time, and hold time)
  - Electrode class, force, and welding gun type
  - Thermal conductivity & Specific heat capacity
  - Flow stress strain curves
  - Microstructure (phases and hardness value for each phase in the base material)
  - Critical temperatures for phase transformation
  - Coating type and resistance model
- **Calculation of key process results:**
  - Nugget diameter/height
  - Indentation depth
  - Current density
  - Expulsion prediction
  - Plastic strain
  - Residual stresses
  - And many more…

User Defined weld schedule









Simufact Spot Weld Model Procedure

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Modeling of post-weld material properties

Kinetic strength of heat cycles

$$I = \int \exp\left(-\frac{Q}{RT}\right) dt$$

$$I' = 2.0 \cdot 10^{6} \cdot (I + 1.25 \cdot 10^{-9})$$

$$I_2 = 80 + \ln\left(\int \exp(-\frac{Q}{RT})\, dt\right)$$

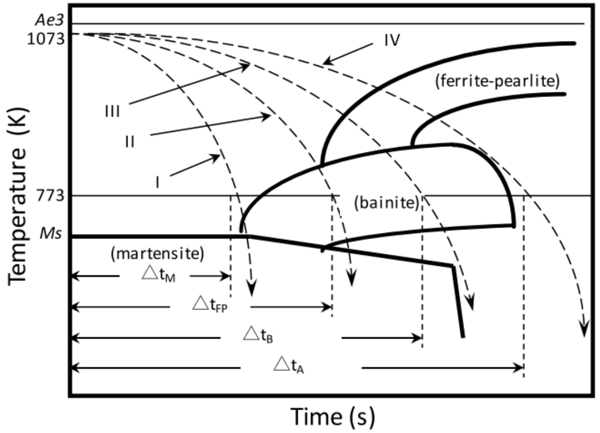
Critical cooling times

$$\Delta t_B = \exp(6.2 \cdot CE_B + 2.0)$$

$$\Delta t_A = \exp(0.99 \cdot CE_A + 4.5)$$

$$\Delta t_{FP} = \exp(8.74 \cdot CE_{FP} - 1.5)$$

$$\Delta t_M = \exp(10.6 \cdot CE_M - 3.5)$$



Tempering parameter

$$P = \frac{T_P - AC1}{AC3 - AC1}$$

Mechanical properties

$$Y_s = 2.5 \cdot H_v - 0.0015 \cdot H_v^2 \text{ (MPa)}$$

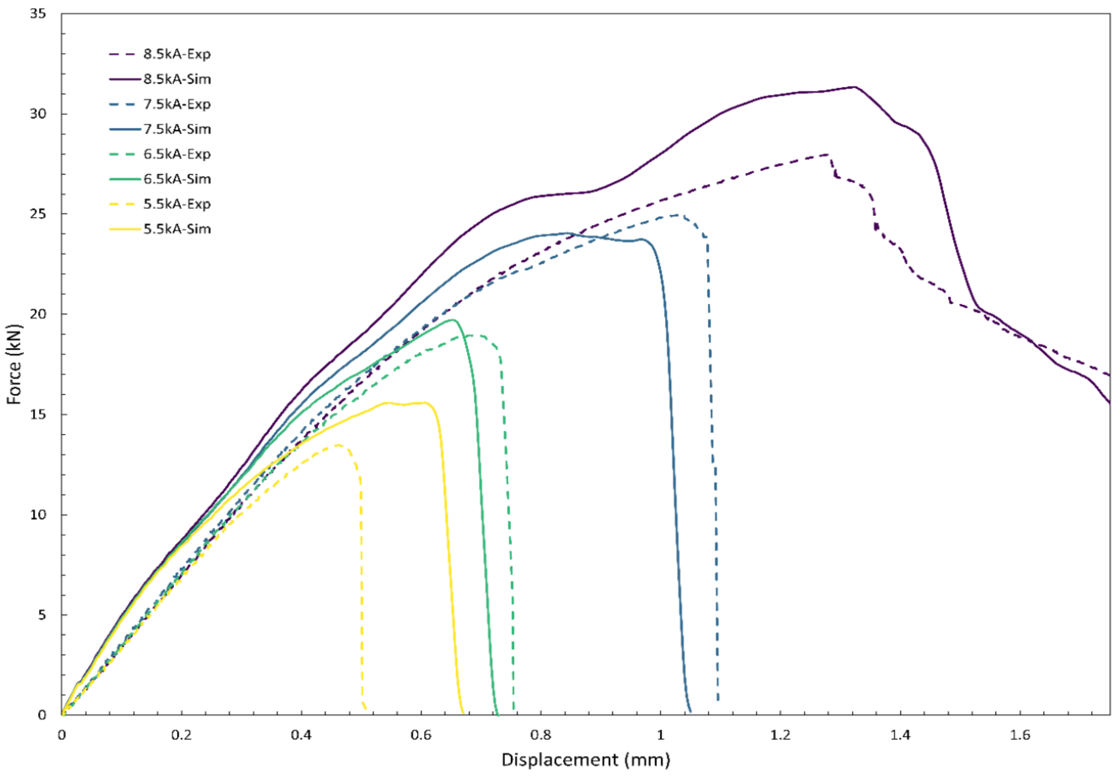
$$T_s = 3.5 \cdot H_v - 0.0018 \cdot H_v^2 \text{ (MPa)}$$

Hui Wang et al. 2022

Not all equations are listed here

Simufact Spot Weld Model Procedure

Identify a suitable damage model that is aware of local HAZ properties



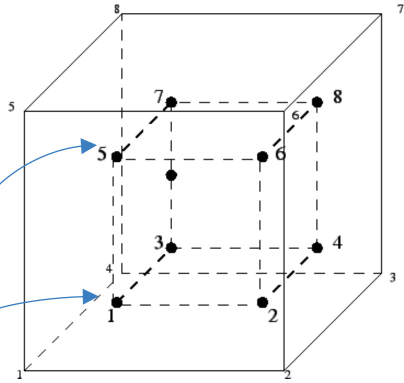
Brizes, E. (2022).

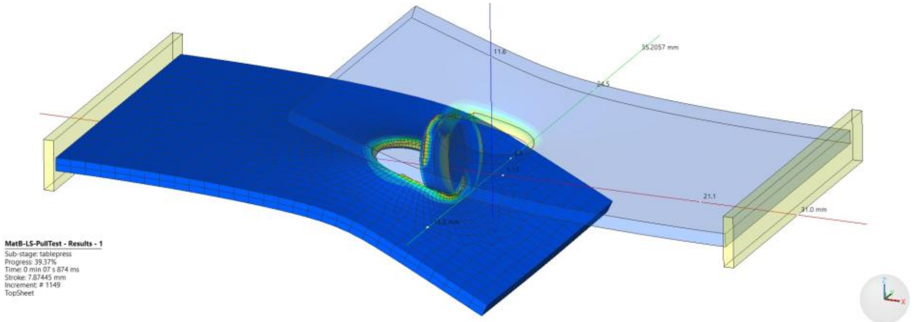
True fracture strain

TFS= f (phase fraction, plastic strain of the phases, local hardness)

Local hardness

FE element local hardness value

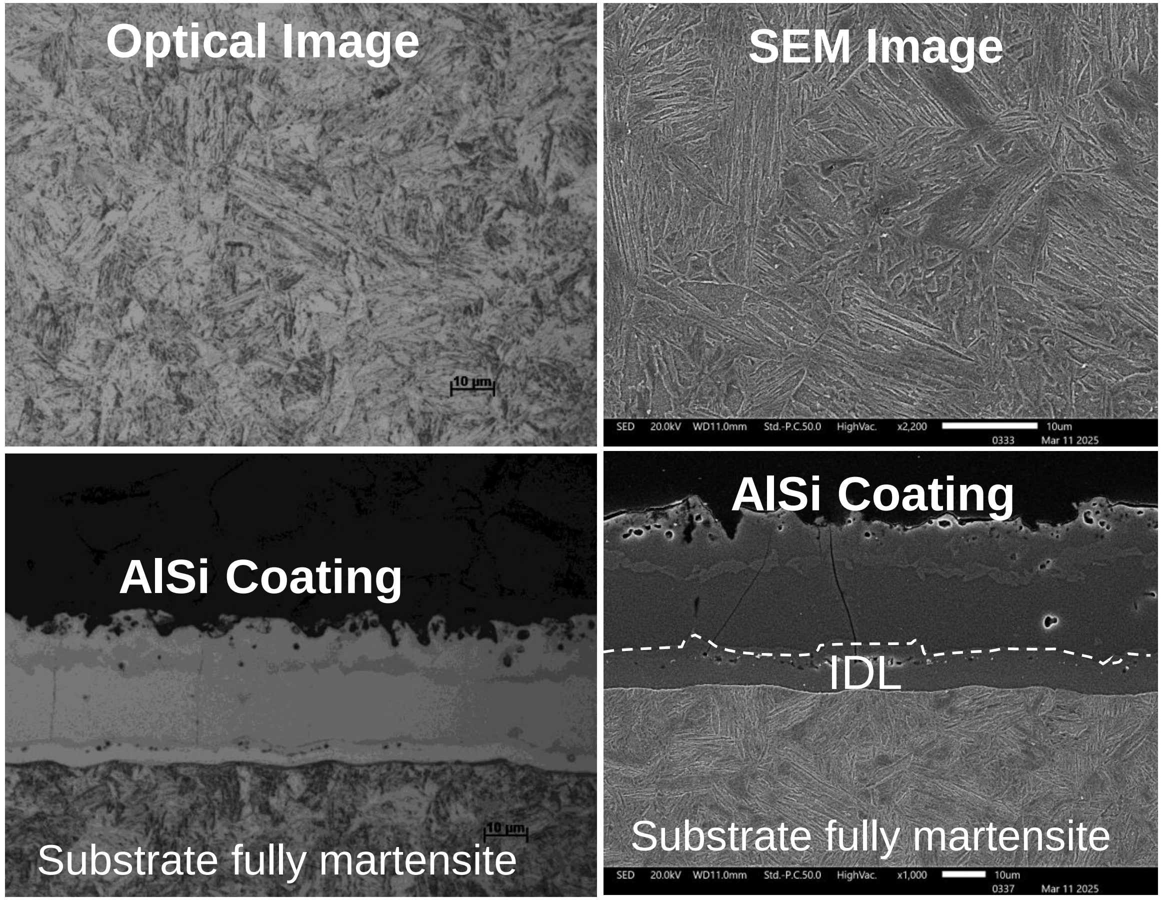


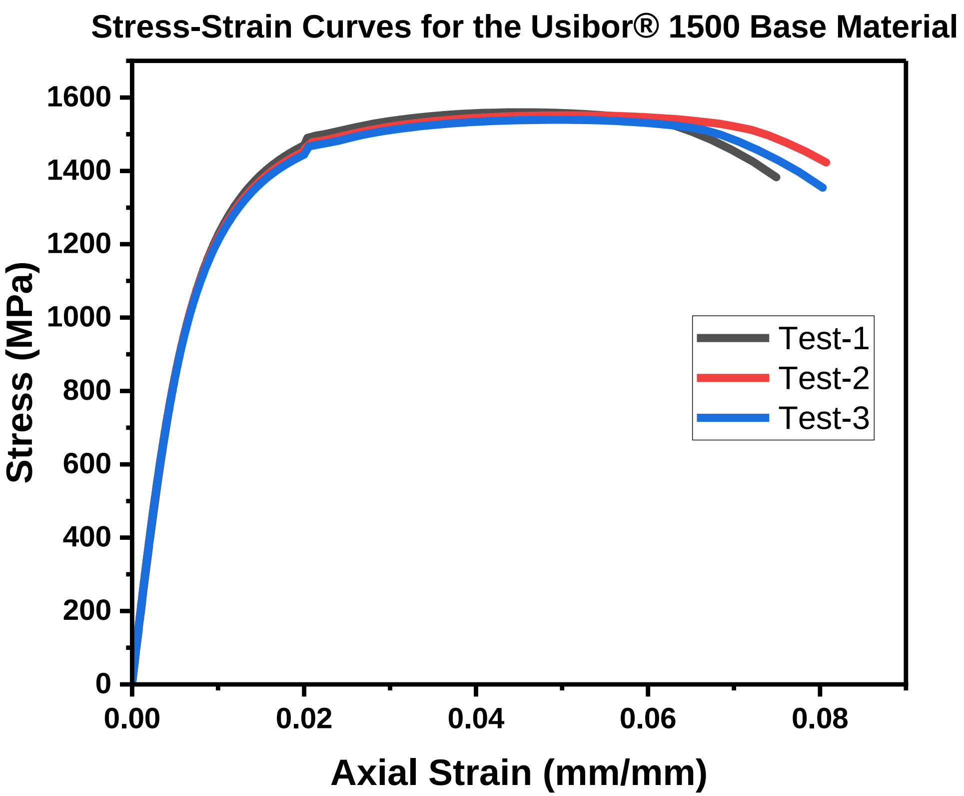


Failure criteria: The **true fracture strain value** will be calculated from the FE model and compared to the local fracture strain value, which is dependent on the local hardness value and individual phases plastic strain if the TFS exceed the local strain value the element will be deleted.

Material & Methodology

Microstructure & Mechanical Properties





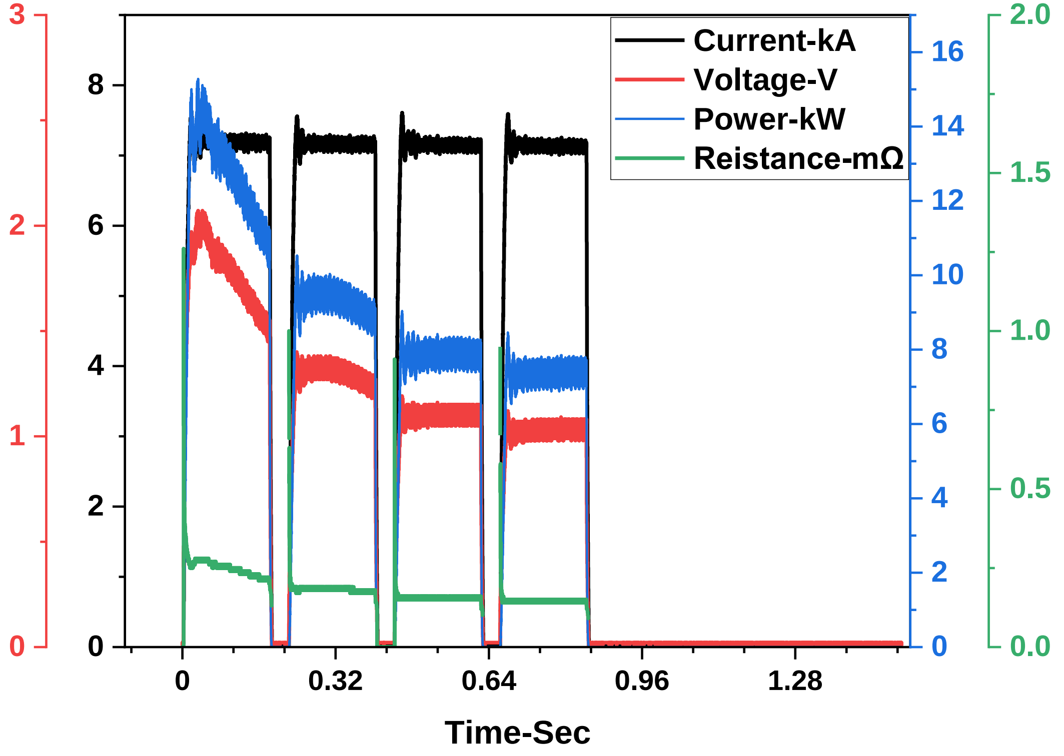
Material Thickness-mm	Yield Strength-MPa	Tensile Strength-MPa	U. Elongation-%	T. Elongation-%
2.0±0.05	1056±7.5	1542±6.4	5.0±0.10	8.3±0.16

Material & Methodology

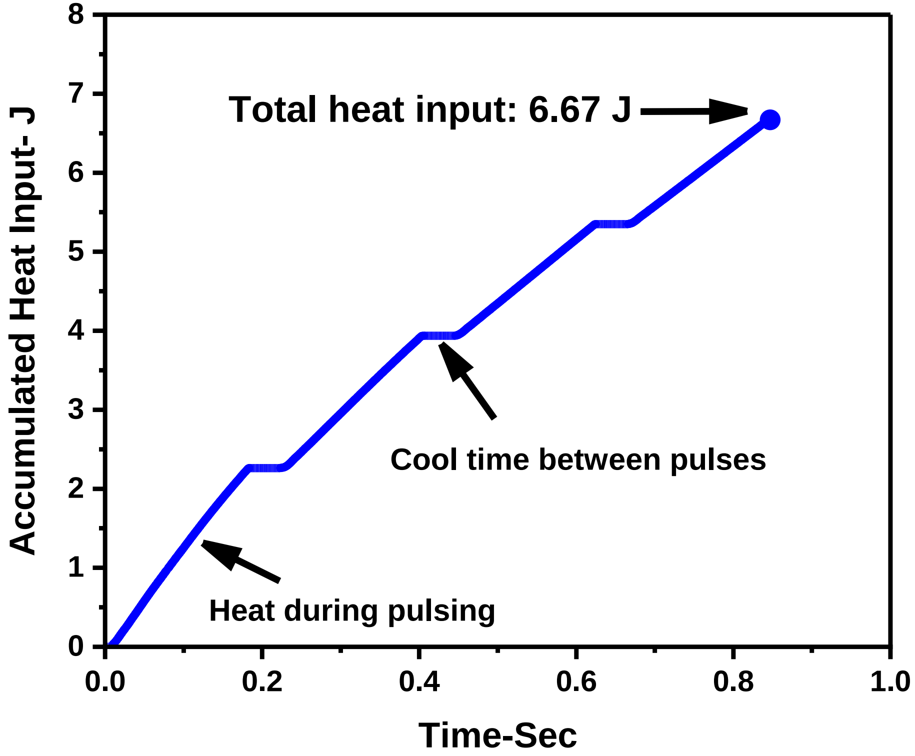
Welding Procedure: An ISO welding schedule were used in this study to weld the material

Tip face diameter -mm	Force - N	# of Pulses	Weld time per pulse - ms	Cool time per Pulse -ms	Hold time -ms	Current range - kA
8.0-R50	5000	4	180	40	360	7.0-10.2 (0.4)

Example of weld schedule at 7kA current

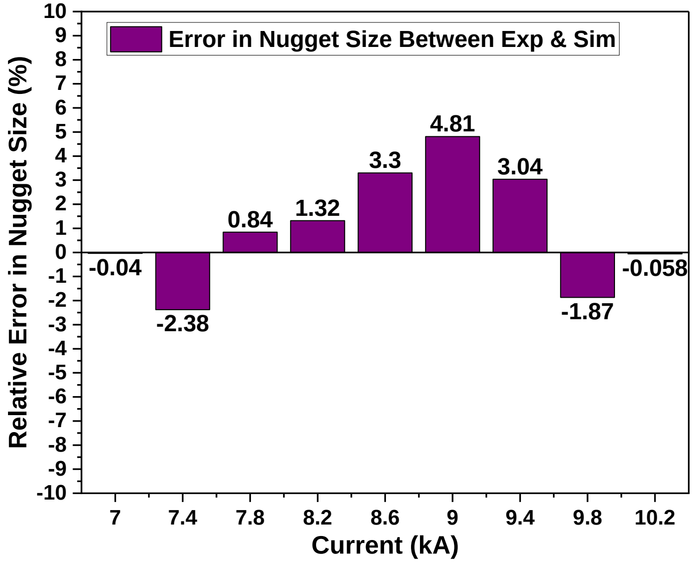


Integration of the power at 7kA current

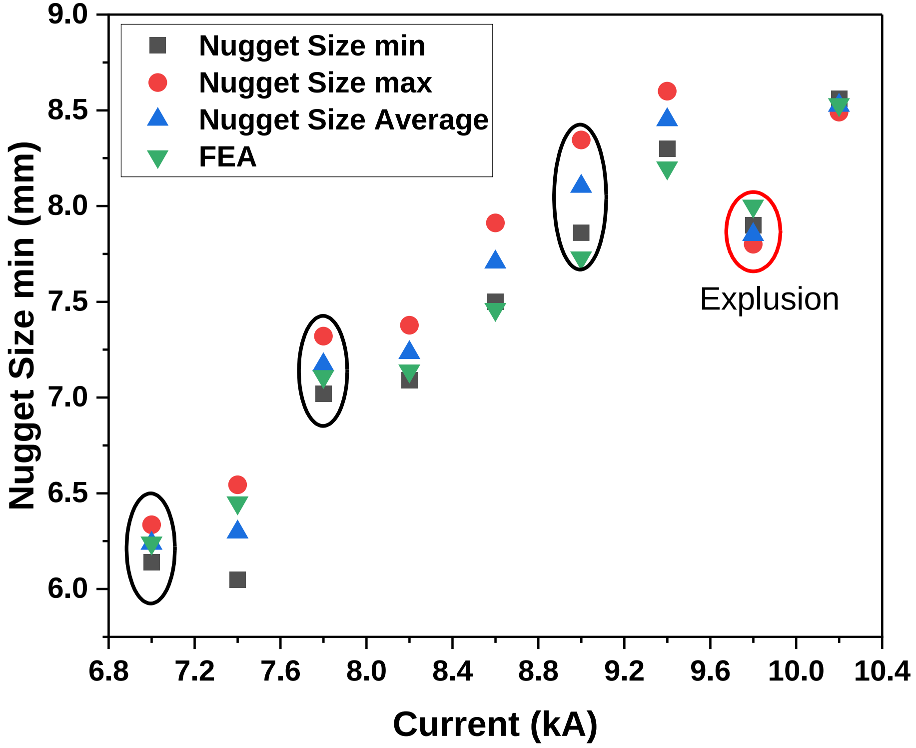


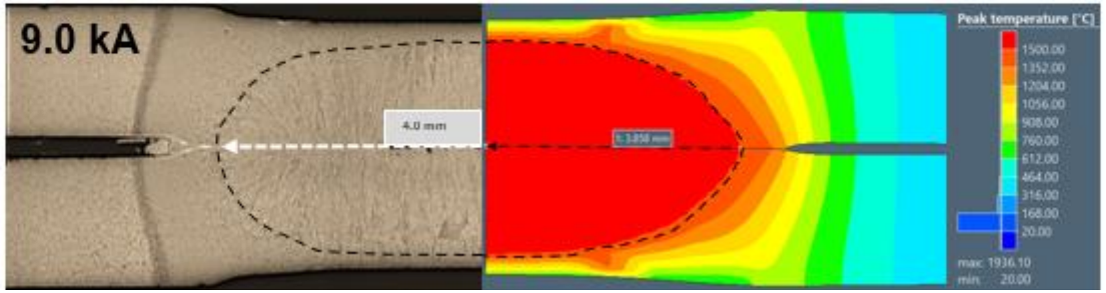
Spot weld nugget size data comparison

The nugget size measurements was validated against the experimental data (Chisel test or cross section measurements), in the first stage the 2D model was used to validate the nugget size at different weld current levels.
The maximum relative error between the experimental and the simulation data was calculated, The magnitude of the relative error is bounded by 4.8%, note that the error was calculated based on the average value.

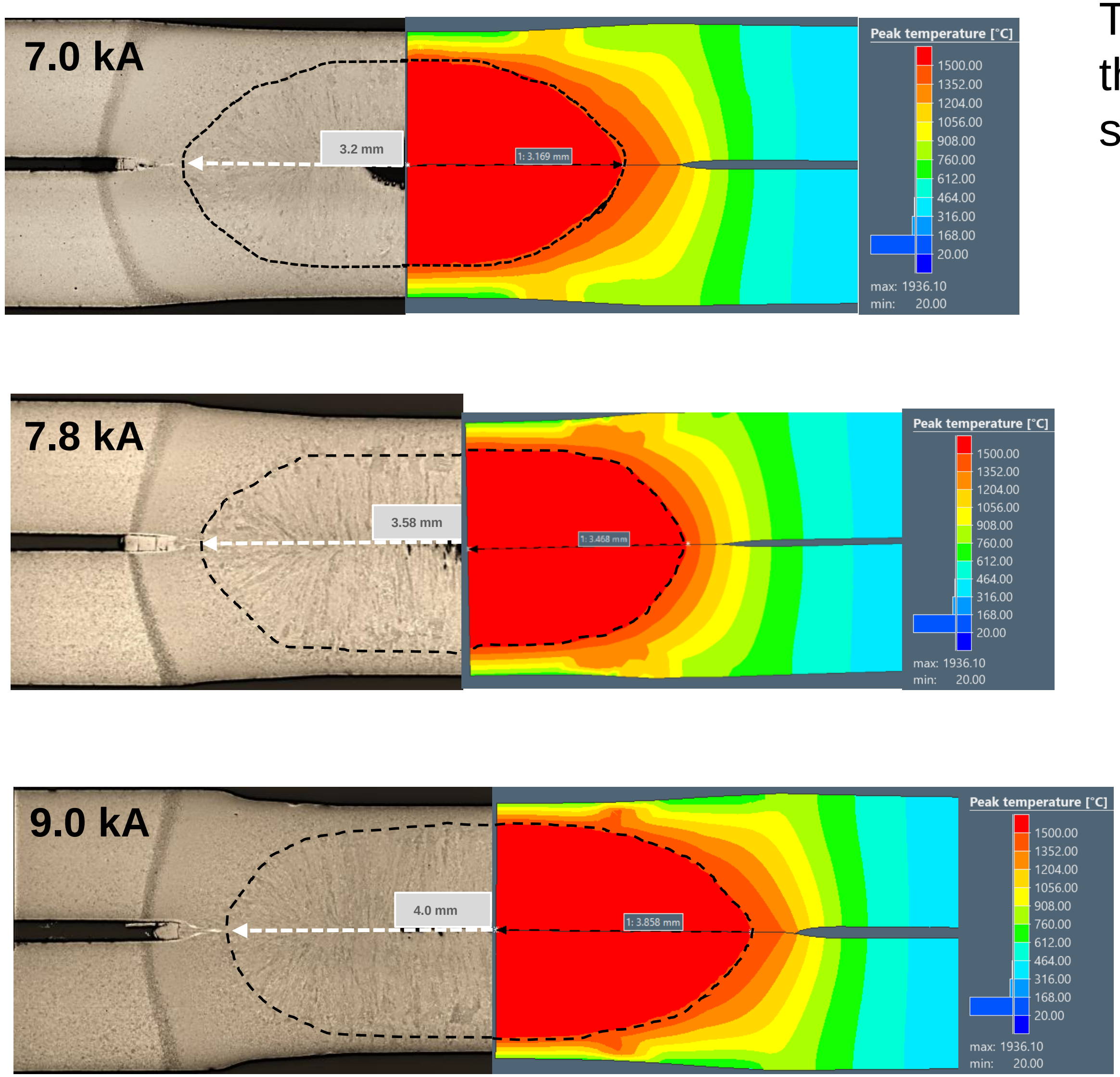


Comparison between nugget size from experimental & Simulation

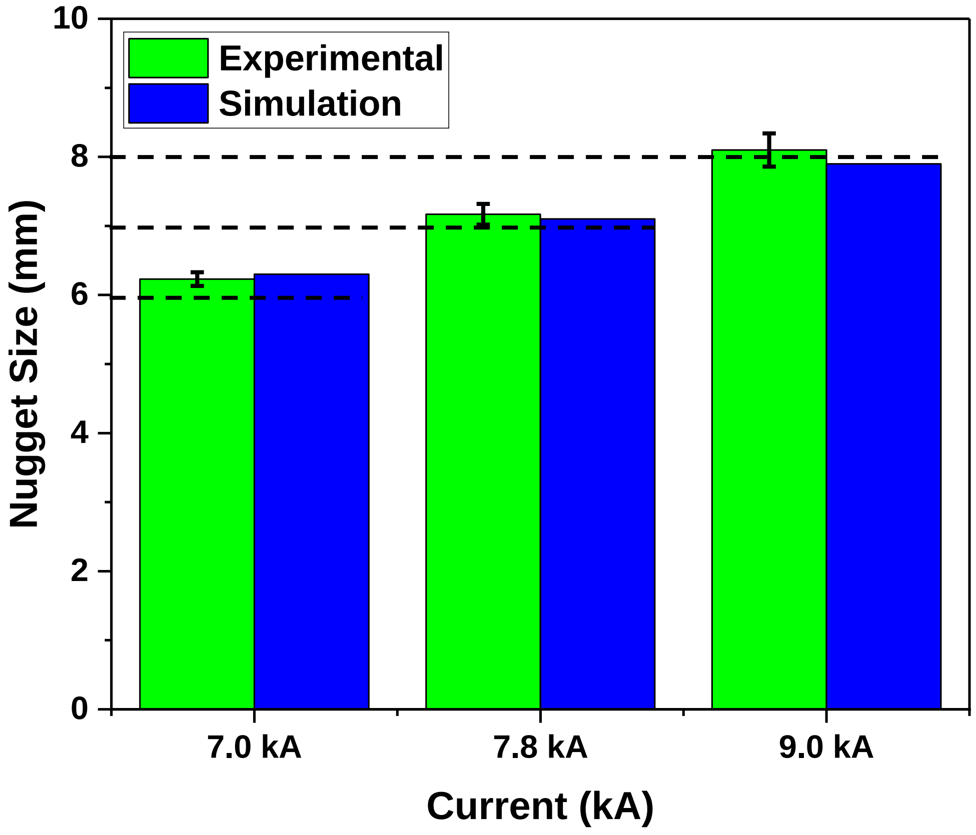




Nugget Size Validation



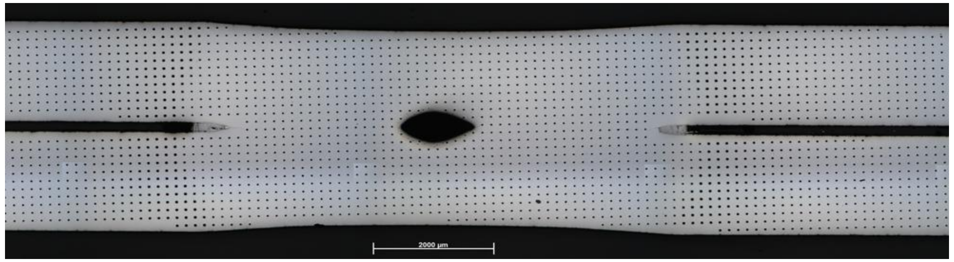
The nugget sizes were matched with the experimental results, the images show the temperature profile for the targeted weld size: 6mm, 7mm, and 8mm.

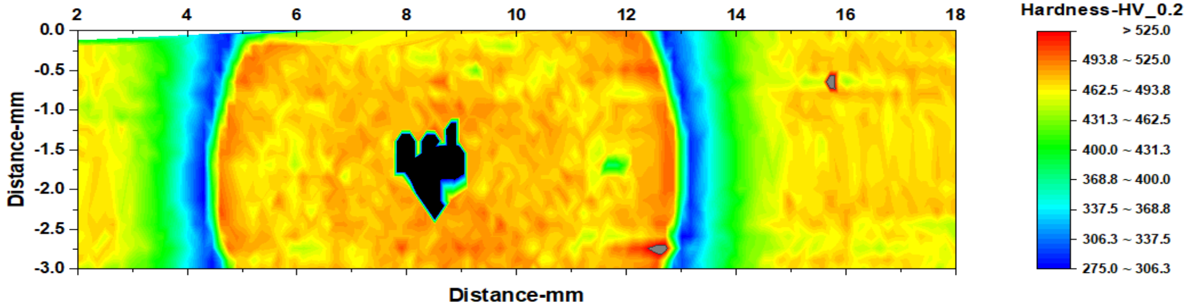


Microhardness Analysis

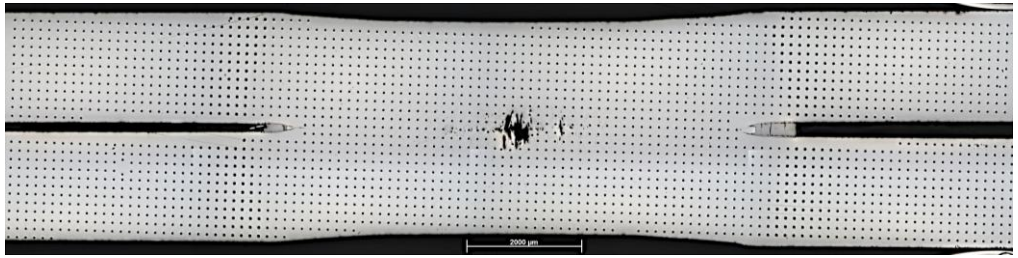
The hardness map and hardness evolution during the welding cycle

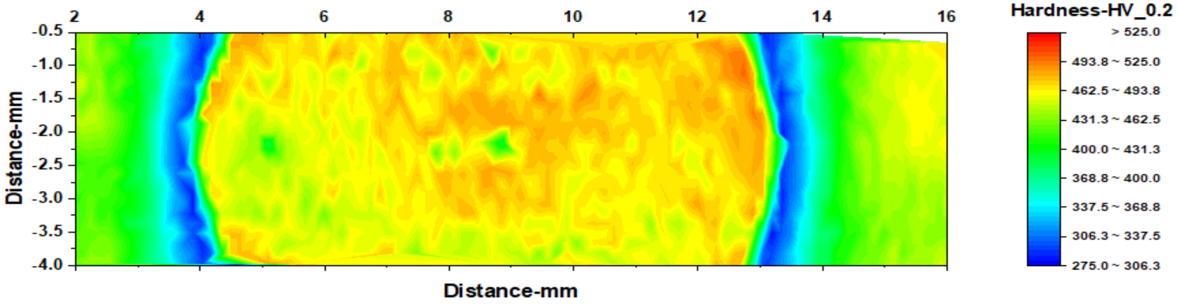
7.0 kA



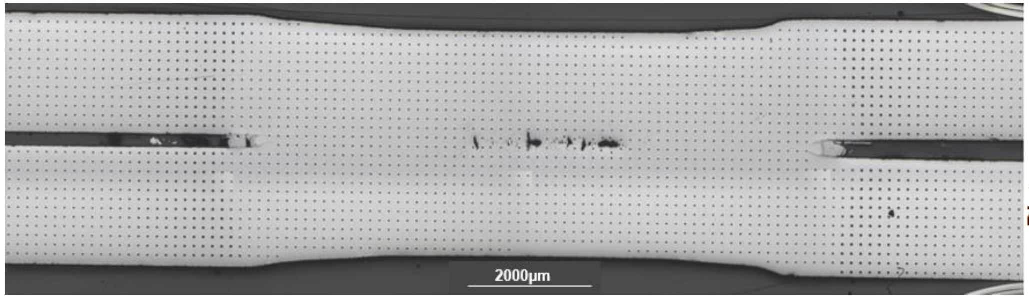


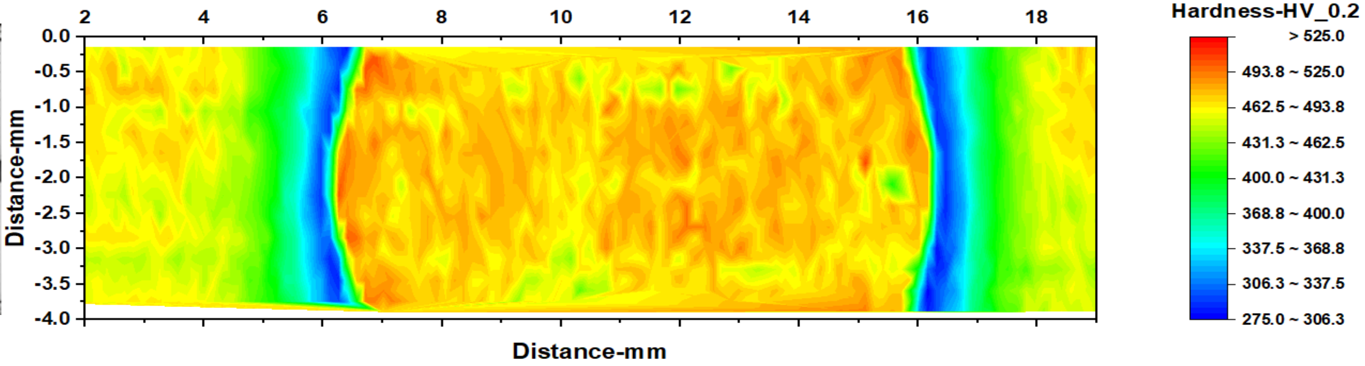
7.80 kA





9.0 kA

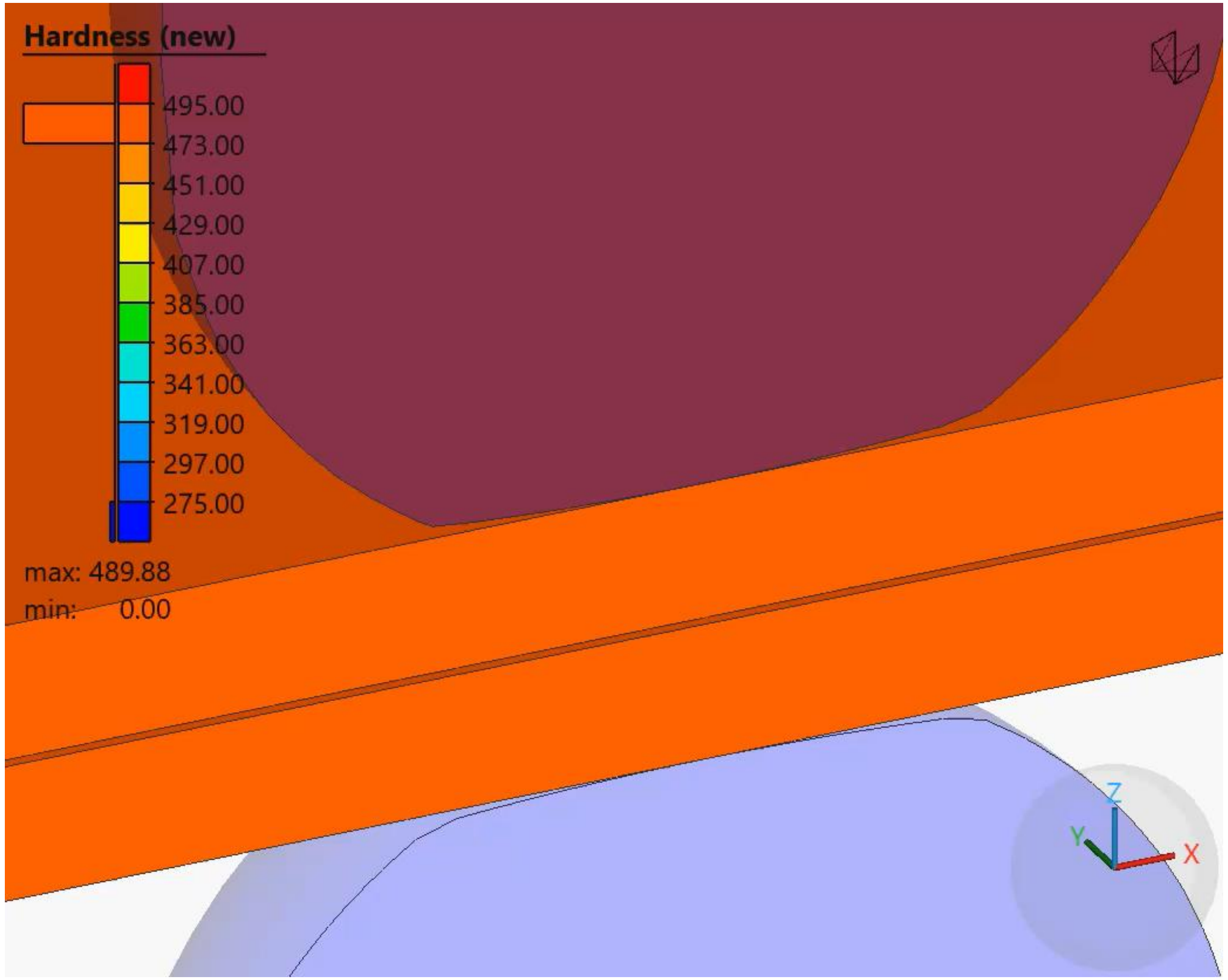


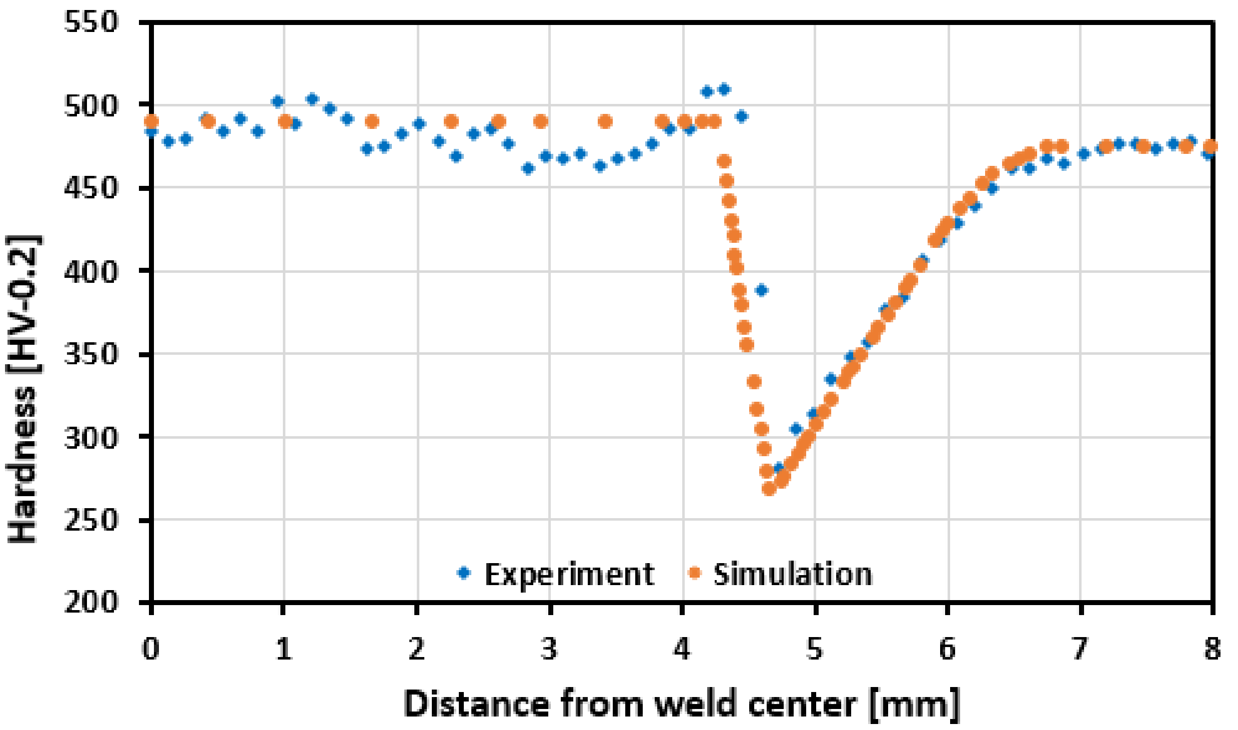


The experimental minimum hardness recorded in the SCHAZ was 275 HV

Microhardness Analysis

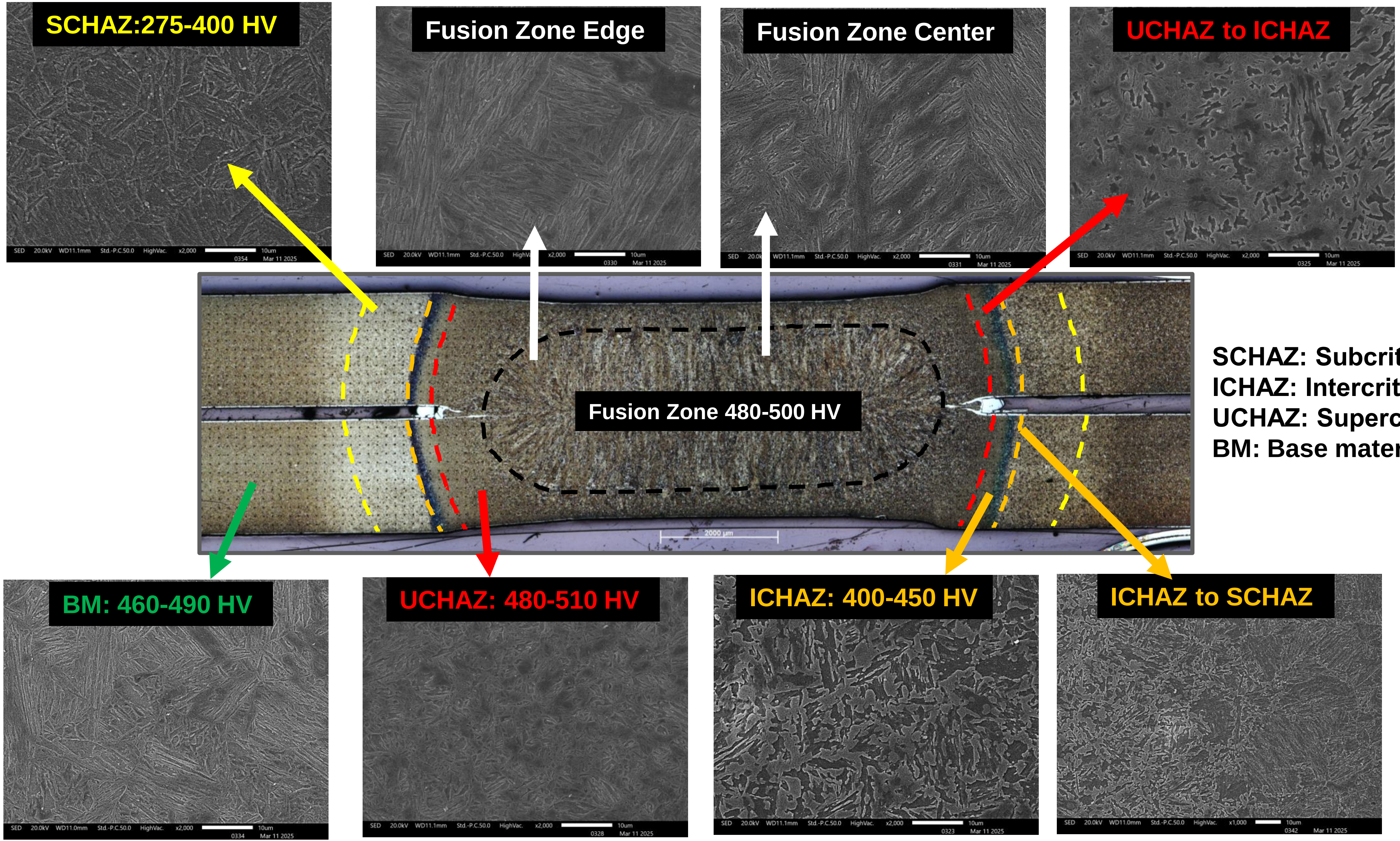
The hardness evolution during the welding cycle





The experimental hardness results was extracted from the 7.8 kA weld condition and compared to the simulation hardness profile

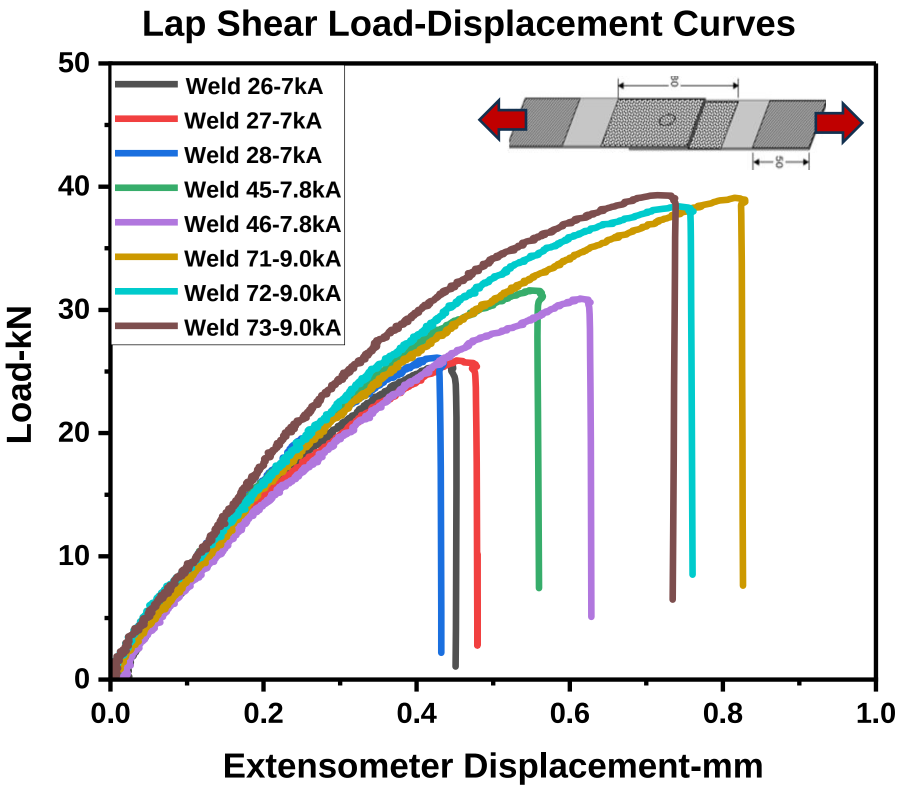
Microstructure Analysis of Spot Weld

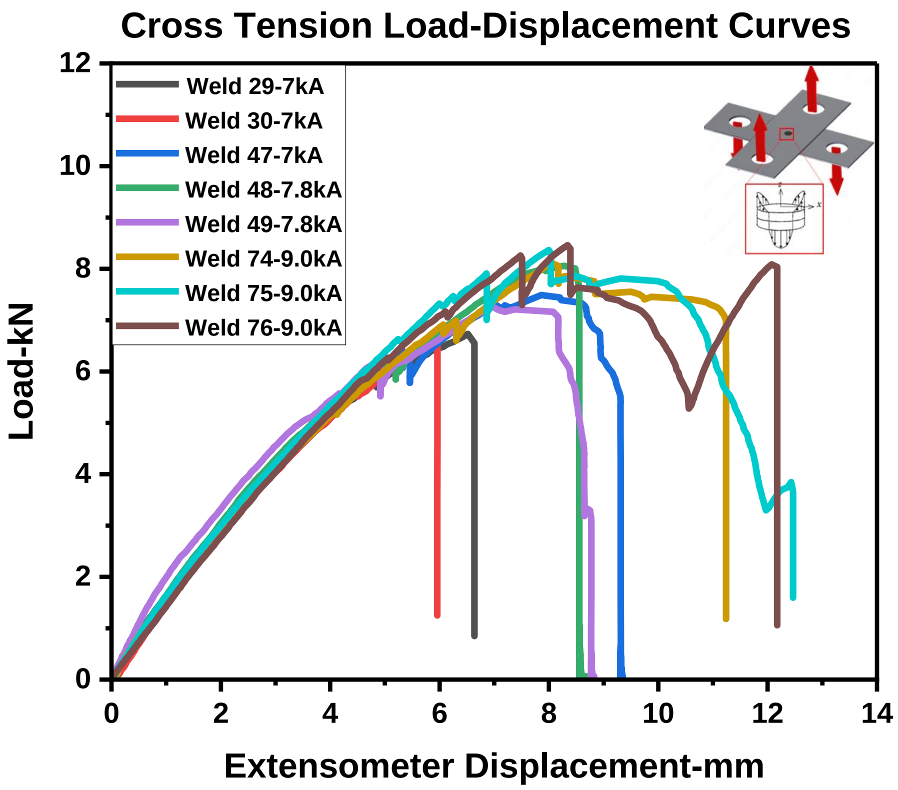


SCHAZ: Subcritical ≈ 350°C-700 °C
ICHAZ: Intercritical ≈ 700°C-900 °C
UCHAZ: Supercritical ≈ 900°C-1350 °C
BM: Base material

Summary of the experimental mechanical test

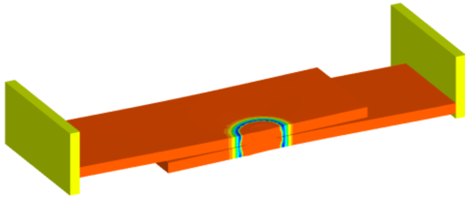
Target Weld Size - mm	Current - kA	Tension Shear - kN	TSS Failure Mode	Cross Tension - kN	CTS Failure Mode
6.0	7.0	25.8±0.23	Interfacial	6.70±0.03	Interfacial
7.0	7.8	30.9±0.45	Interfacial	7.60±0.33	Partial Interfacial
8.0	9.0	38.9±0.38	Interfacial	8.31±0.14	Button Pullout



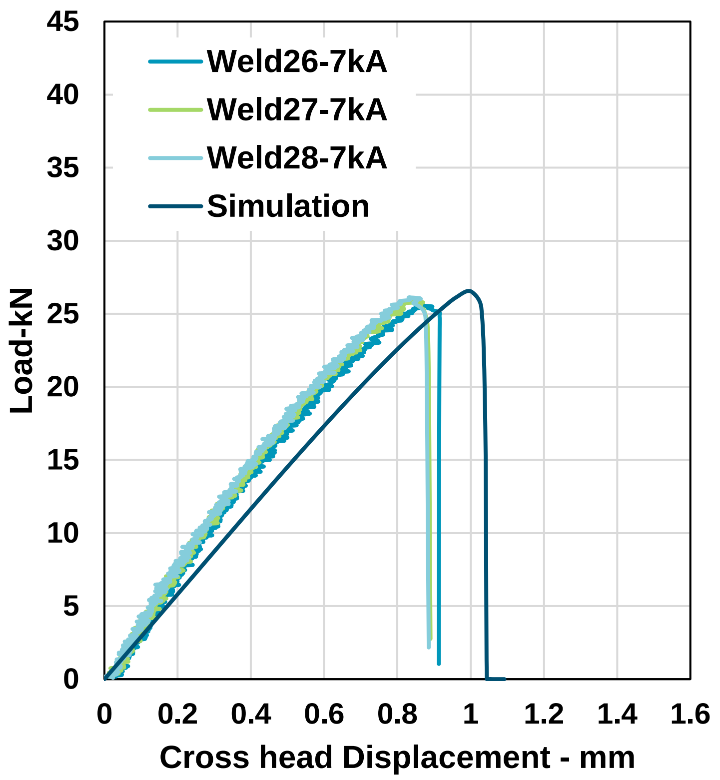


Tensile Shear test results comparison

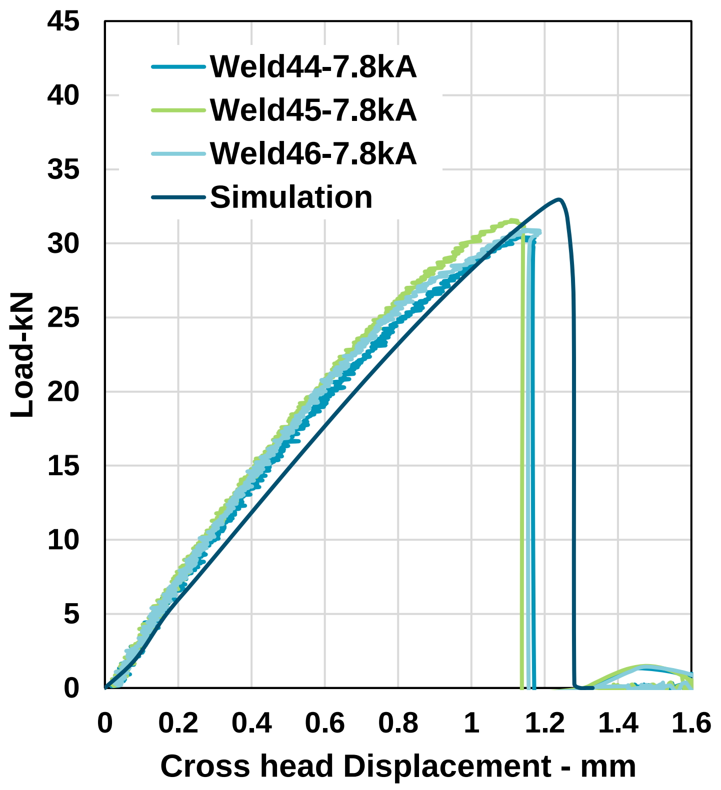
The maximum error in the peak load was 7.0%



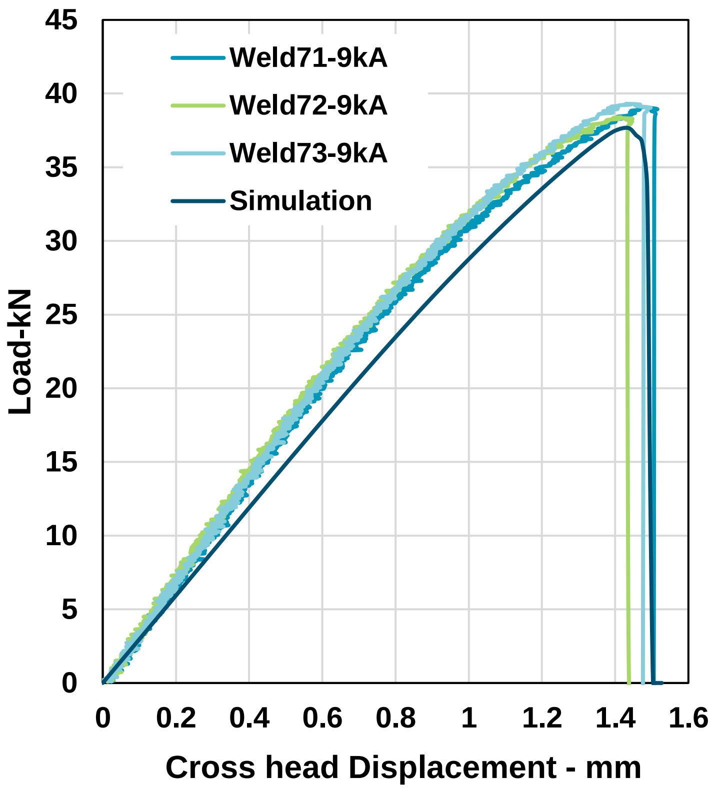
Nugget 6 mm, Current 7 kA



Nugget 7 mm, Current 7.8 kA



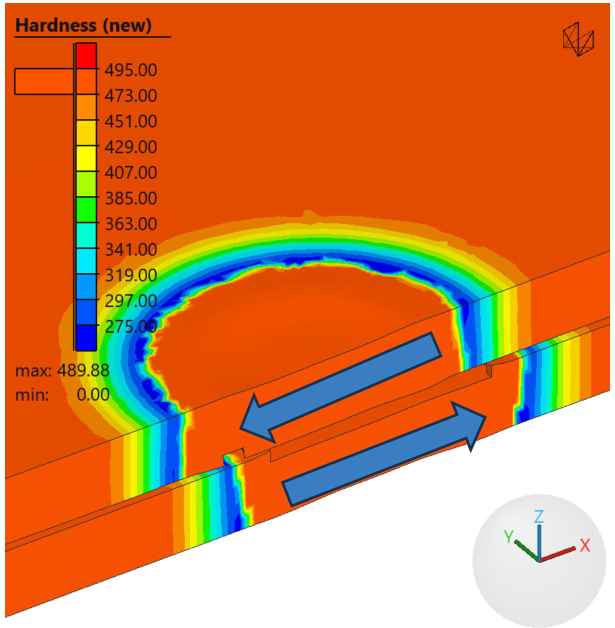
Nugget 8 mm, Current 9 kA

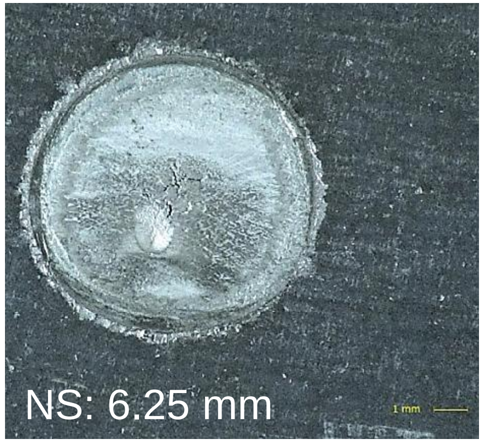


Machine compliance was modeled using a spring element in the direction of the movement

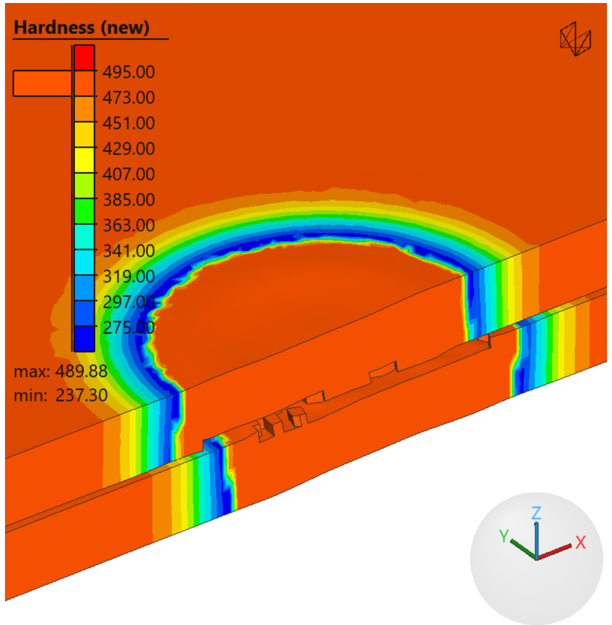
Tensile Shear test failure: Interfacial mode

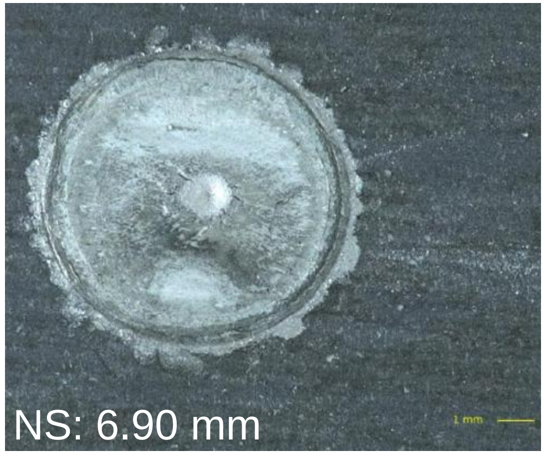
Nugget 6 mm, Current 7 kA



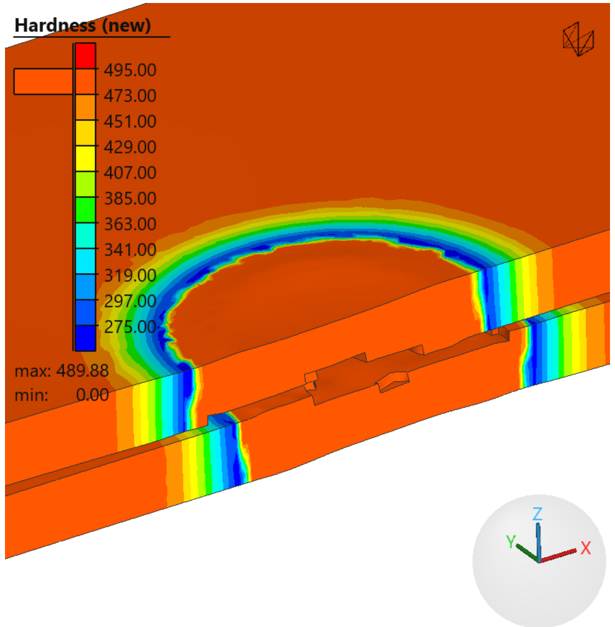


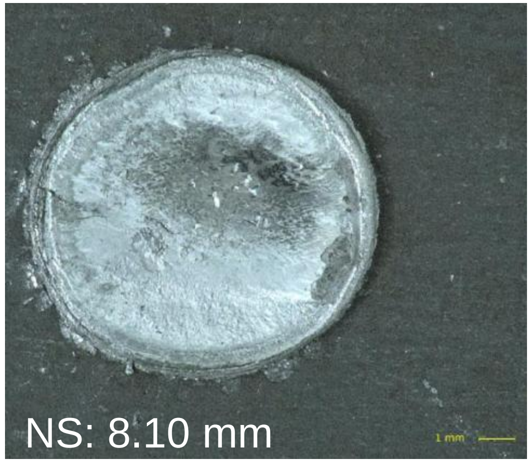
Nugget 7 mm, Current 7.8 kA



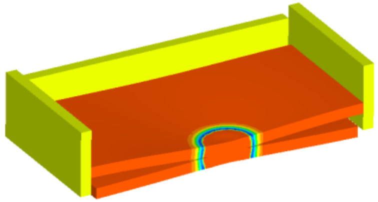


Nugget 8 mm, Current 9.0 kA



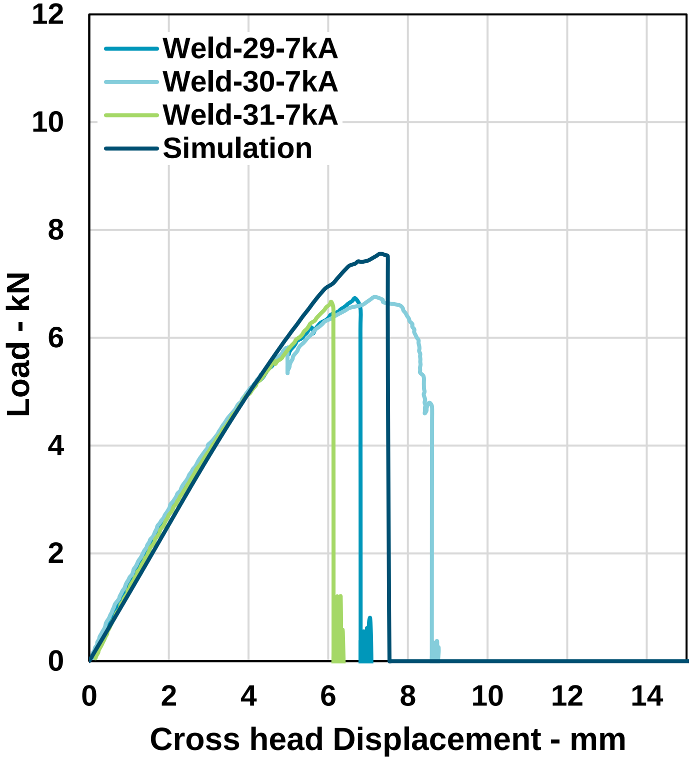


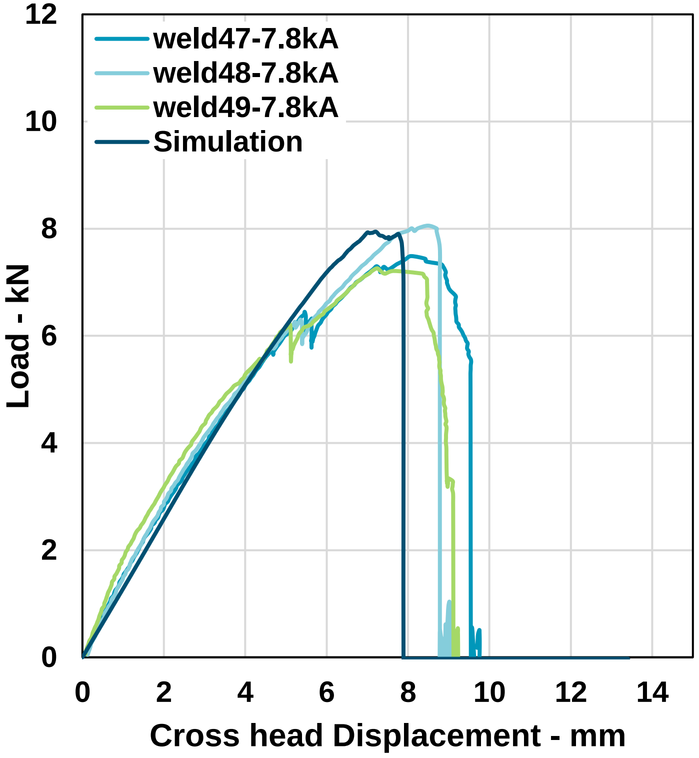
Cross tension test results comparison

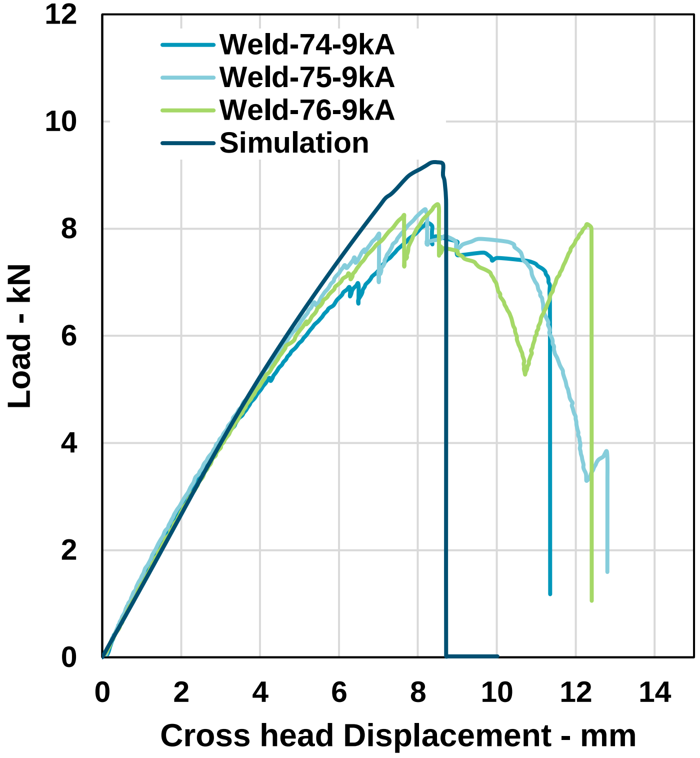


The maximum error in the peak load was 9.0%

Nugget 6 mm, Current 7 kA	Nugget 7 mm, Current 7.8 kA	Nugget 8 mm, Current 9 kA



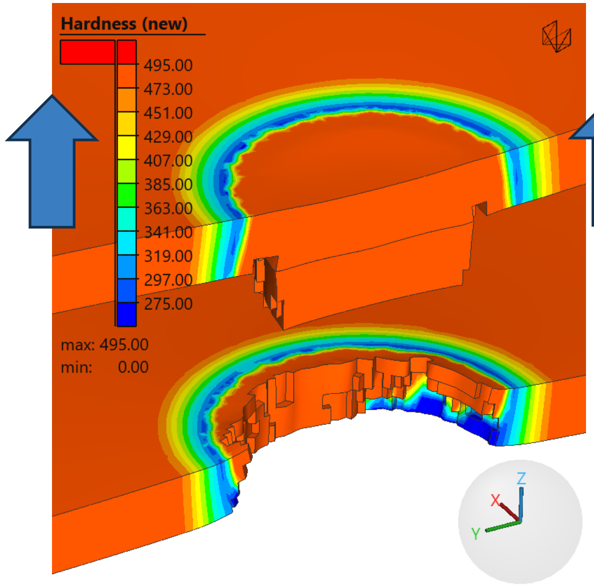


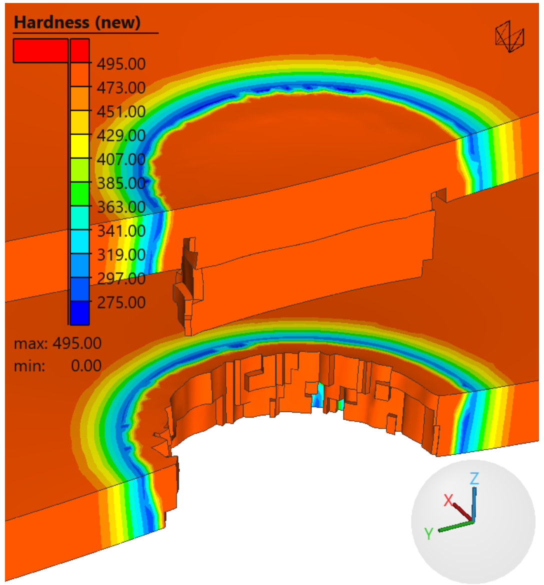


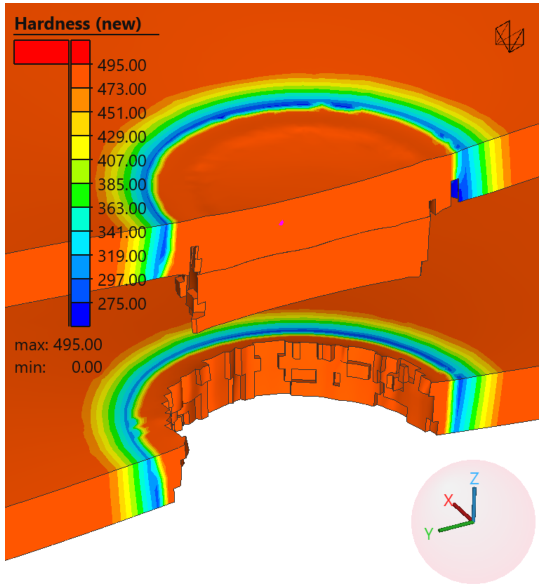
Machine compliance was modeled using a spring element in the direction of the movement

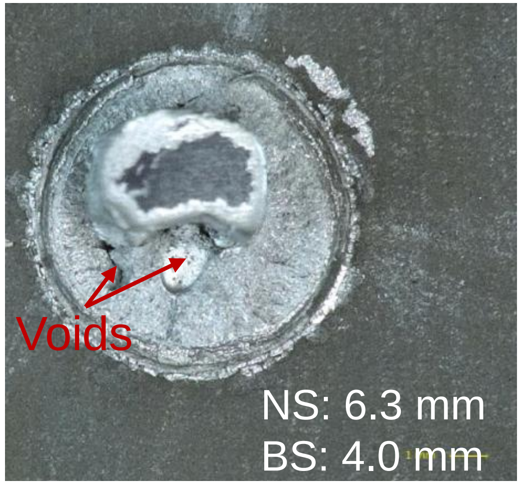
Cross tension test failure: Partial interfacial & Button pullout mode

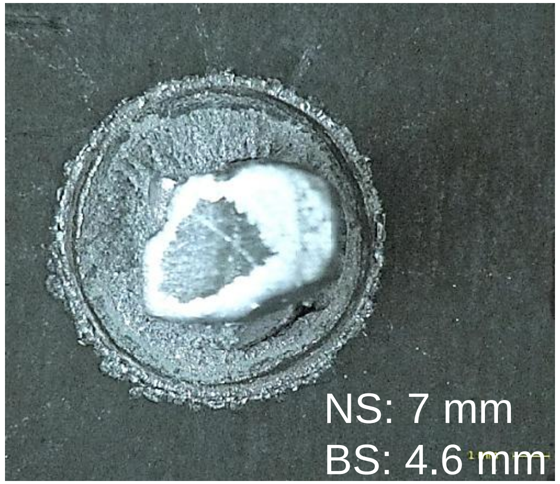
Nugget 6 mm, Current 7 kA	Nugget 7 mm, Current 7.8 kA	Nugget 8 mm, Current 9.0 kA

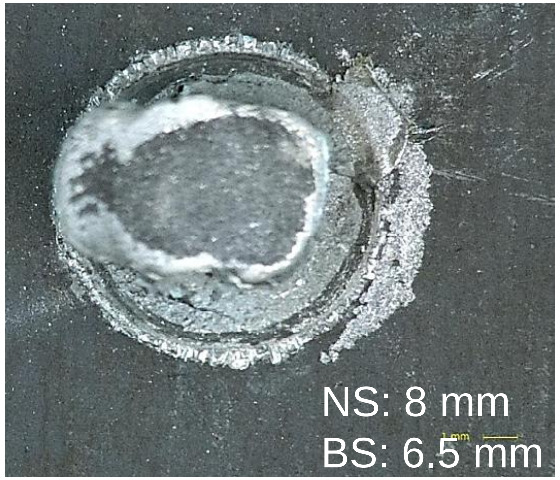












Final Remarks & Future Work

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➢ Final Remarks:

- Experimental data was generated for 2mm Usibor® 1500 with an AlSi coated to support model validation.
- A modified damage model that incorporating phase fraction and local hardness measurements led to improved failure predictions.
- Machine compliance was accounted for by implementing a spring element in the direction of movement, which results an improved prediction.
- The model accurately predicted weld size and hardness distribution, maintaining an error margin below 5%.
- The TSS and CTS load-displacement curves and failure modes were successfully captured in most cases with a maximum error bounded by 9.0%, with further fine-tuning expected to enhance model accuracy.

➢ Future work includes:

- Verifying the application of the method for other steel grades
- Fine tuning machine compliance values to better match stroke at peak load results
- Other mechanical tests such as KS-II and Coach peel coupons will be generated using same model to build a virtual failure surface that can be used in crash simulation.

Modeling of post-weld material properties

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For More Questions, please meet the speaker after this presentation.

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