GREAT DESIGNS IN STEEL

TEMPERING OR RECRYSTALLIZATION? A MORE VIABLE TECHNIQUE TO IMPROVE THE MECHANICAL PERFORMANCE OF PRESS-HARDENED STEEL SPOT WELDS

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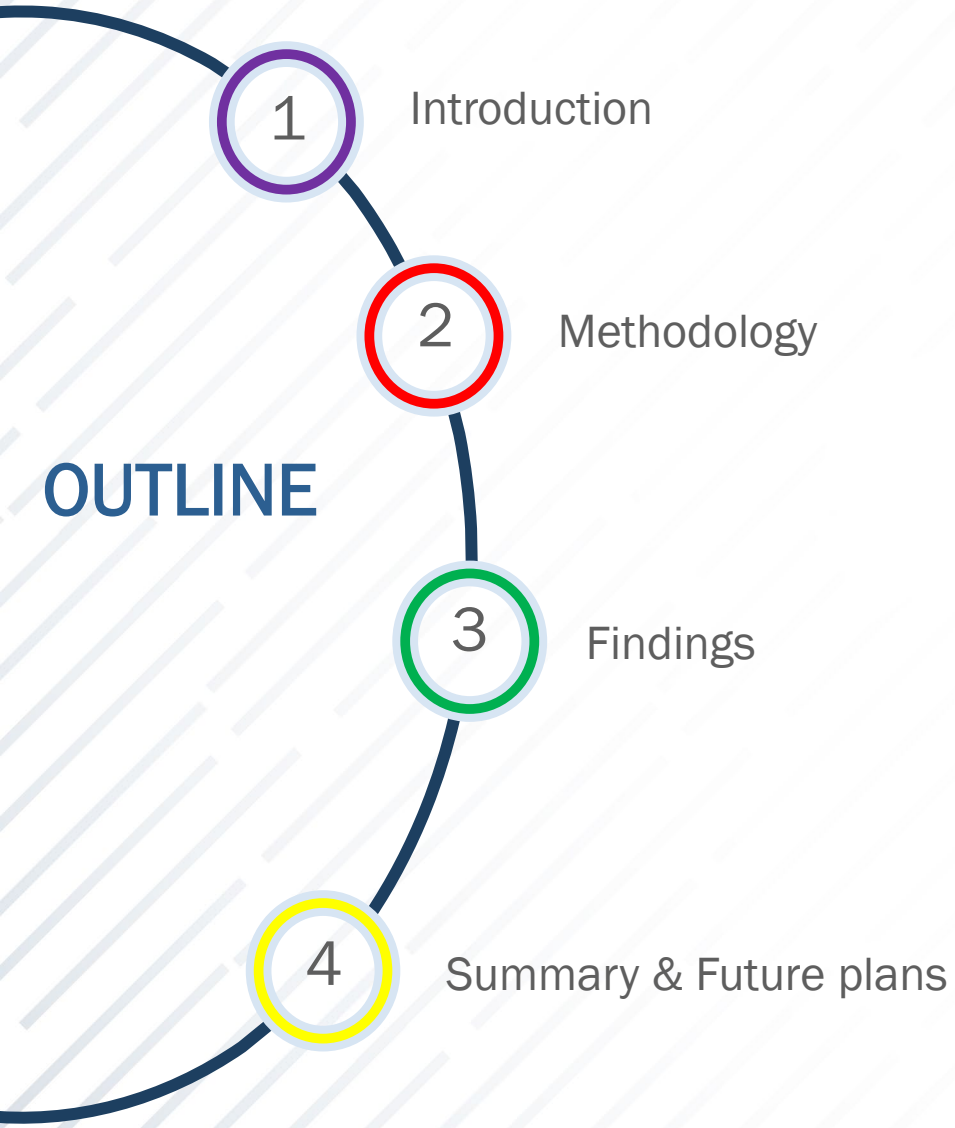
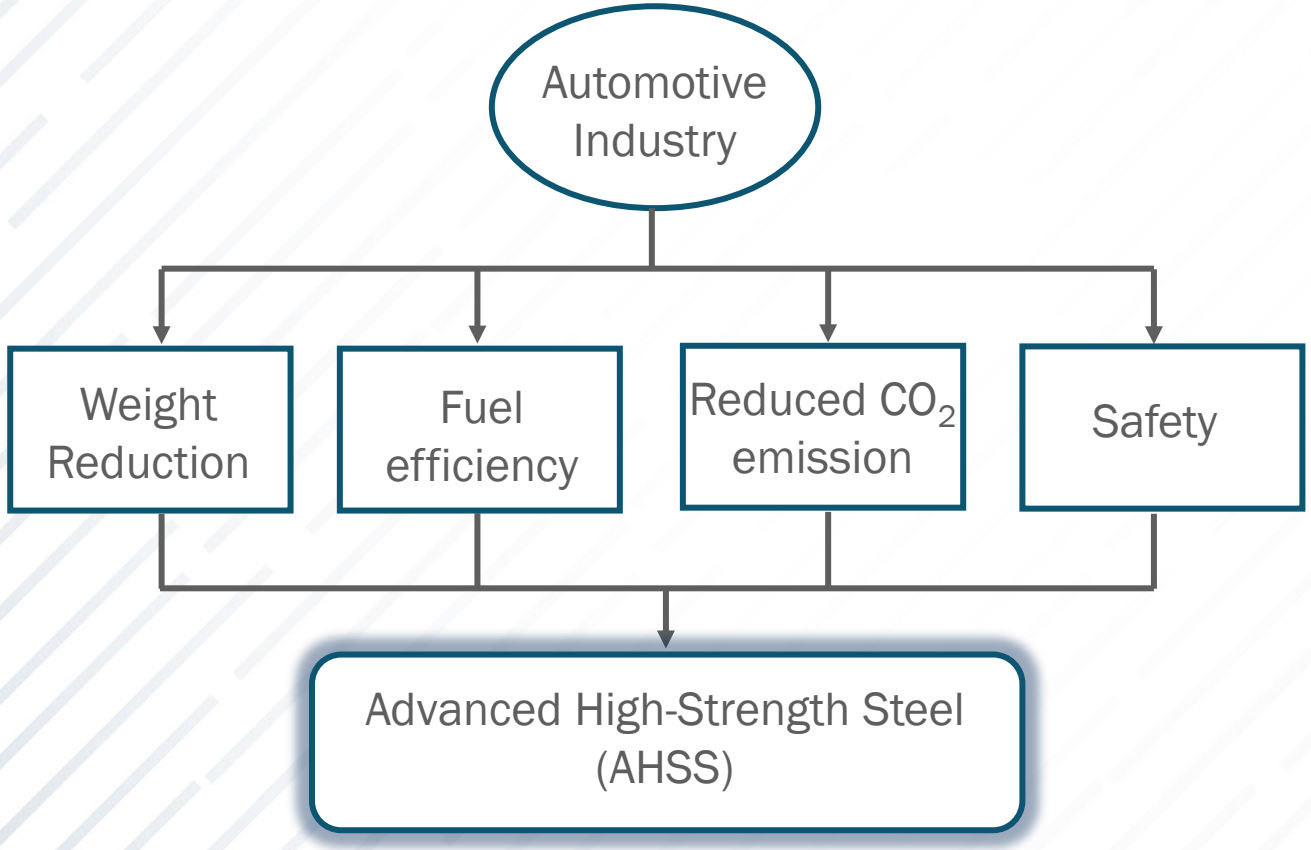
2023

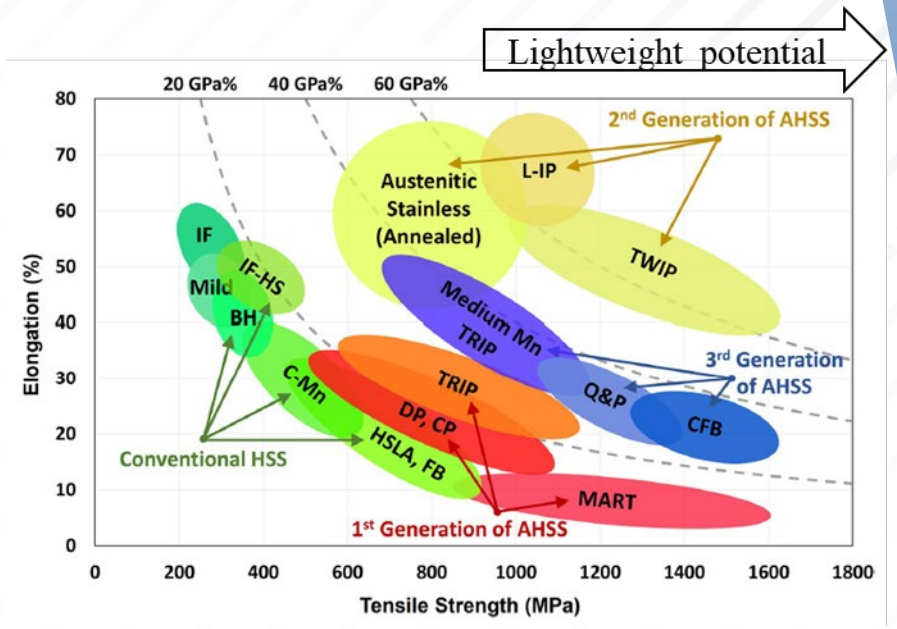
PRESENTATION OUTLINE



ADVANCED HIGH STRENGTH STEELS

- The need for **light weight materials** with **high strength** remains an increasing demand in the automotive industry





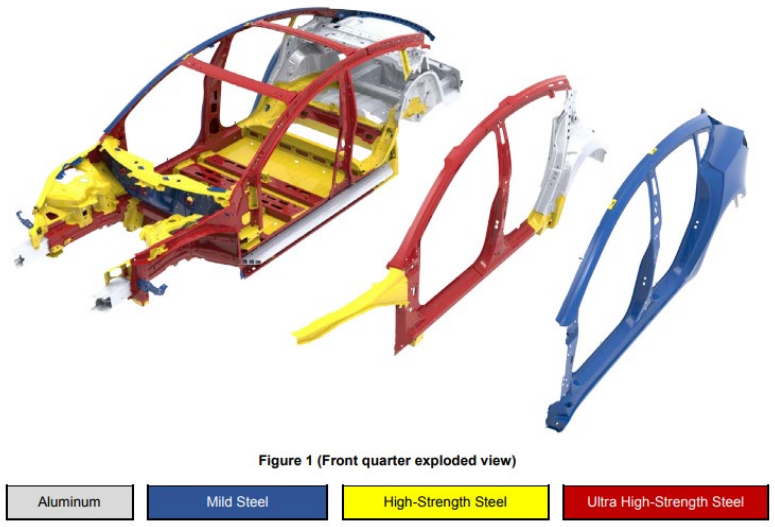
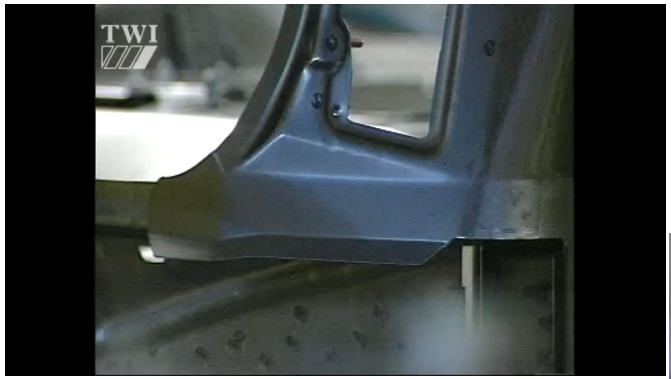


Image source: Kalhor et al, Archives of civil and mechanical engineering, 2020

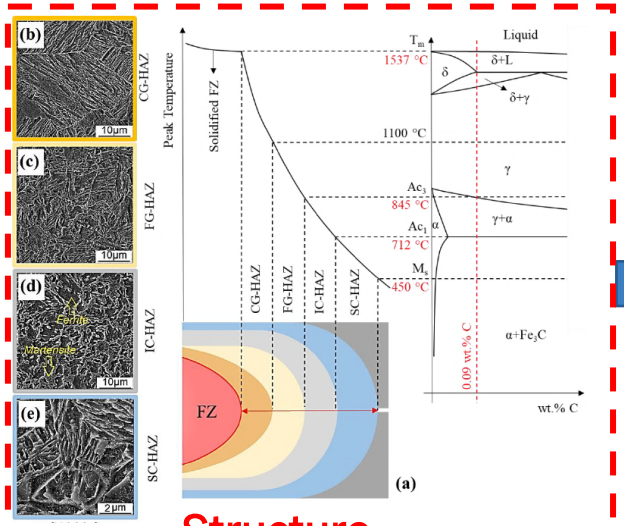
F. Lambert, Tesla Model 3: the alloy mix of model 3 body, 2017: https://electrek.co/2017/08/22/tesla-model-3-body-alloy-mix/ [Accessed 18/05/2021]

MOTIVATION

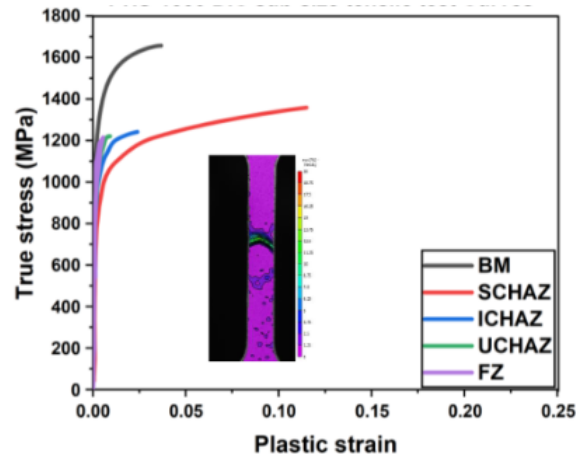


In simple terms, two sheet metals are joined

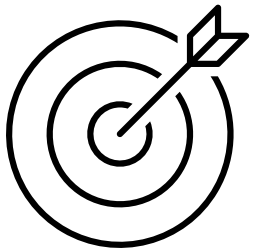
Processing



Structure



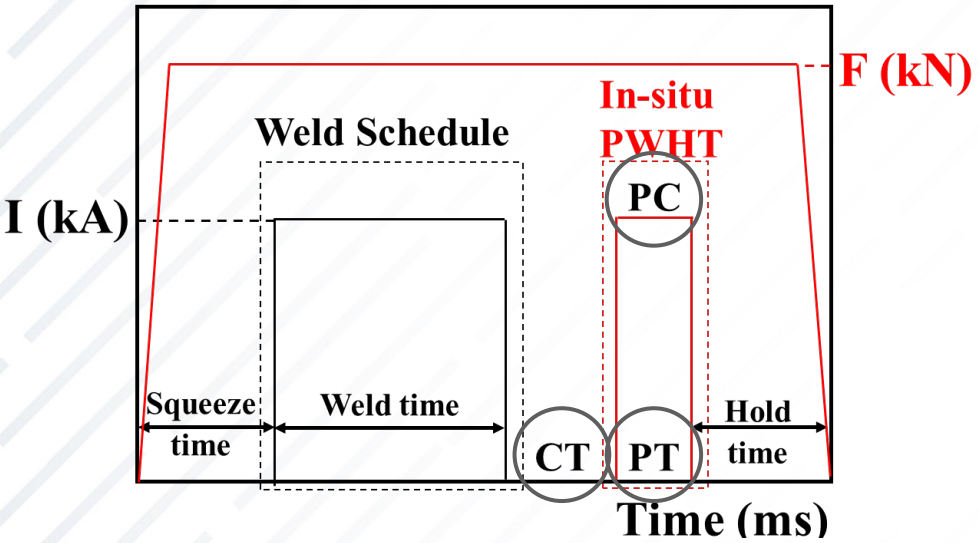
Properties



Apply an in-situ post weld heat treatment to improve joint properties

Midawi et al., Forces in Mechanics, 2022.

IN-SITU POST WELD HEAT TREATMENT



In-situ PWHT Parameters

- *CT: Cool time*
- *PT: Pulse time*
- *PC: Pulse current*

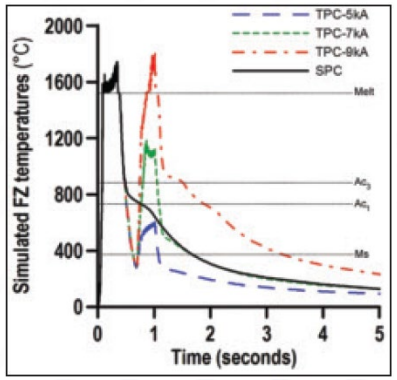
Control

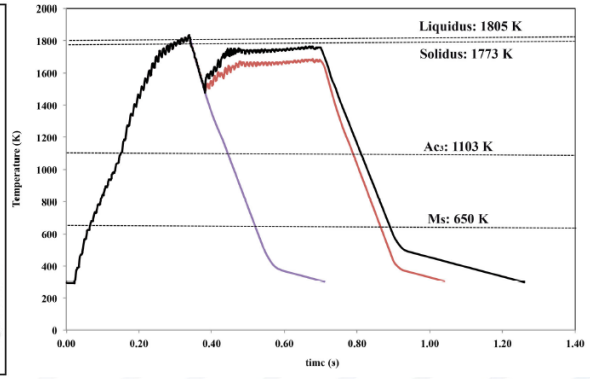
Metallurgical techniques

✓ Tempering

✓ Recrystallization

- Martensite **tempering** of the FZ
  - General consensus on **cool time**
  - **post weld current and time** depends on material chemical composition and/or thickness.
- **Recrystallization** (in-situ grain refinement)
  - Unknown relationship between process parameters needed to induce the transformation?





- Microstructural evolution?
- Influence on overall joint mechanical properties?

Hernandez et al., Welding journal, 2012

Khan et al., SEA technical paper series, 2007

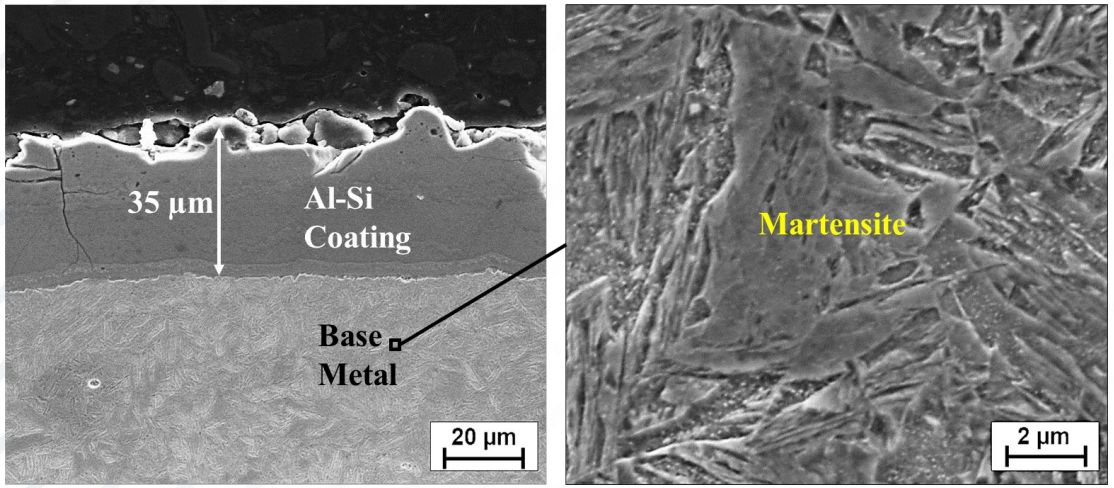
Eftekharimilani et al, STWJ, 2017

AIM

This research aims to investigate the influence of various microstructural changes in the weld on the resulting mechanical performance of the joint.

MATERIAL & METHOD

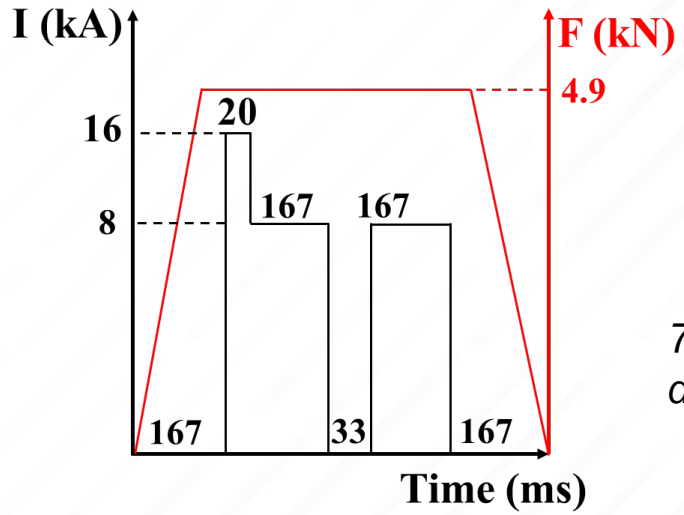
Material: Press-Hardened Steel



Microstructure after hot stamping

Material	Sheet thickness (mm)	Carbon equivalent	YS (MPa)	UTS (MPa)	T.E (%)	U.E (%)	Base metal hardness (HV)
PHS	1.4	0.47	1228±14	1623±13	6.89±0.50	4.66 ± 0.15	491 ± 4

RSW Baseline Schedule

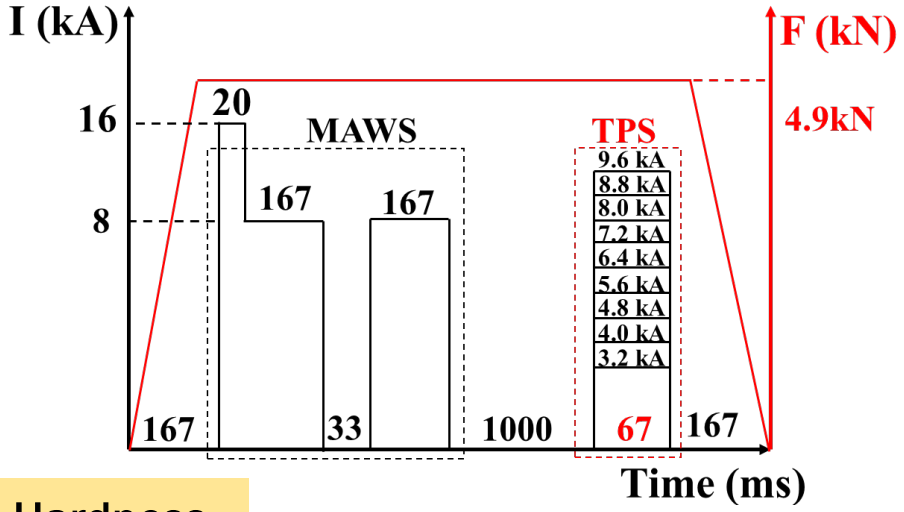


7 mm electrode diameter

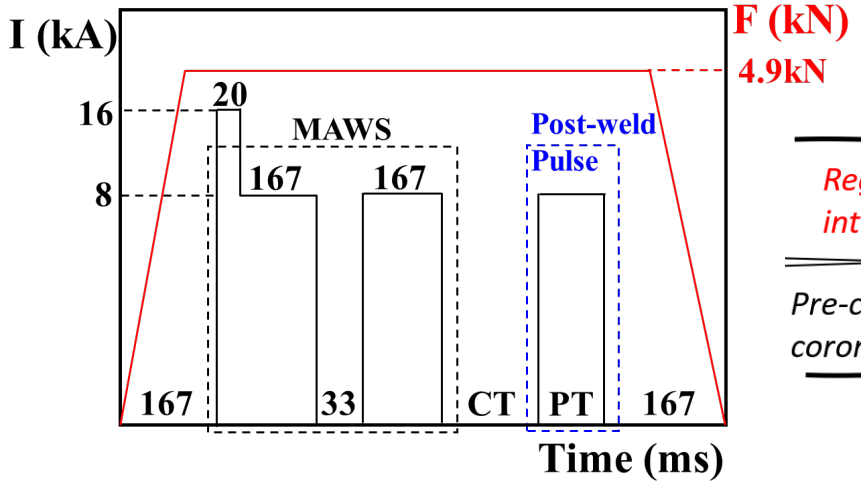
Honda RSW Robot

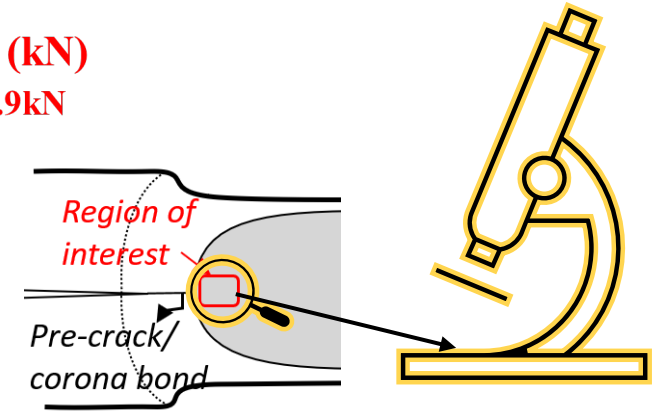
METHOD

Tempering



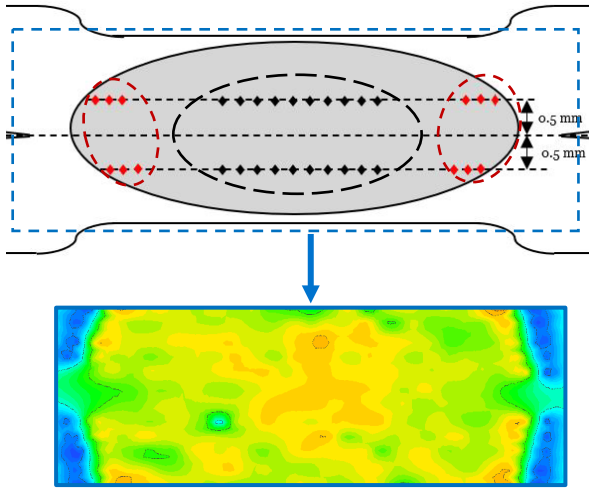
Recrystallization





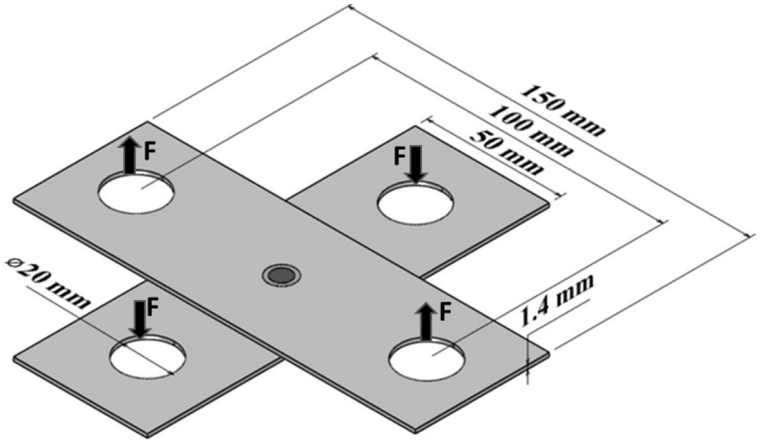
Microstructure (ASTM E112)

Hardness



Mechanical properties (CTT)

Failure mode & crack propagation path

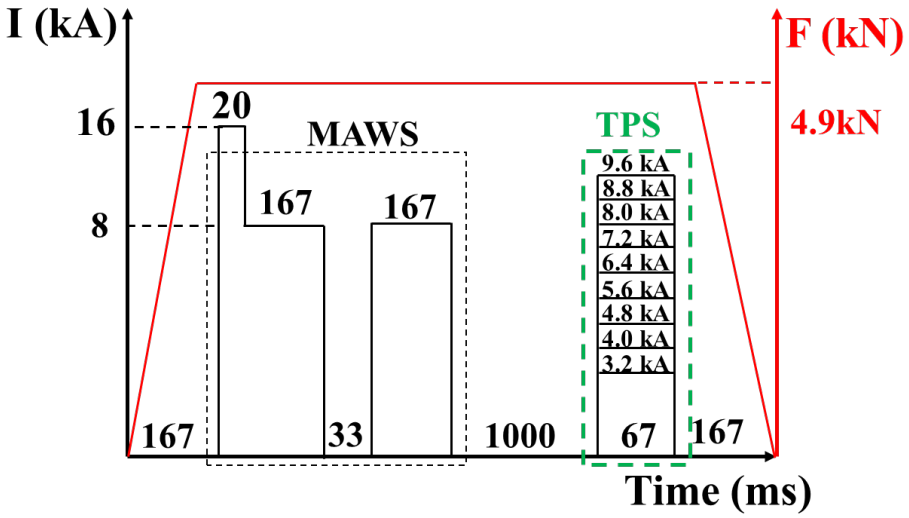


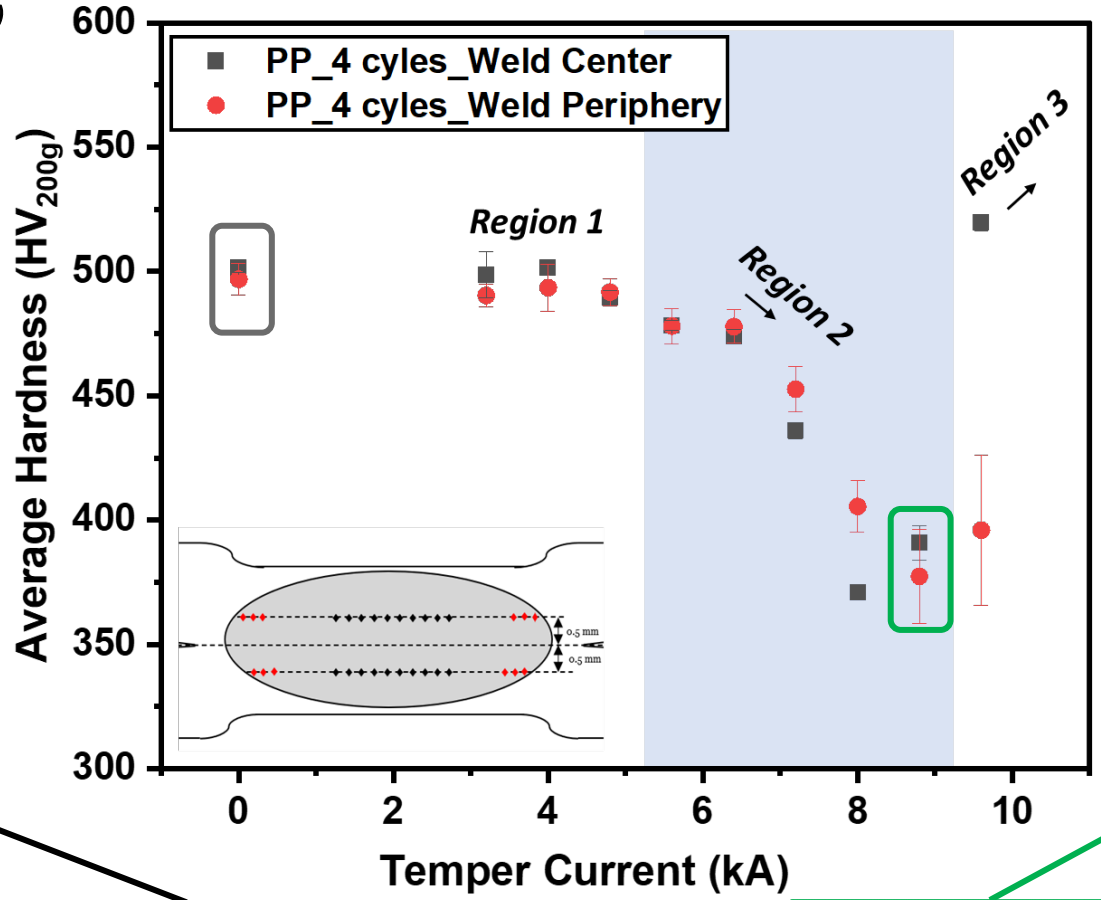
*Modified American Welding Standard (MAWS)

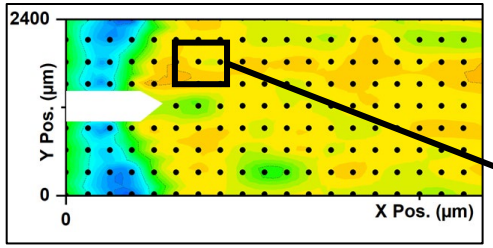
*Temper Pulse Schedule (TPS)

IN SITU TEMPERING

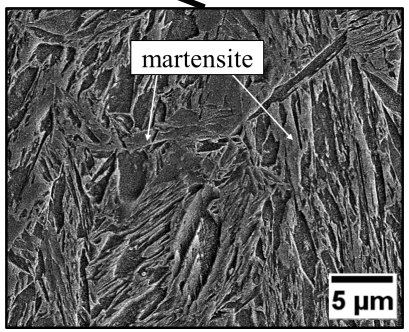
- *Modified American Welding Schedule (MAWS)*
- *Temper pulse schedule (TPS)*

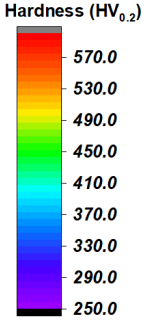


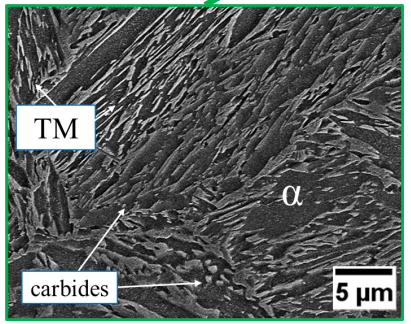


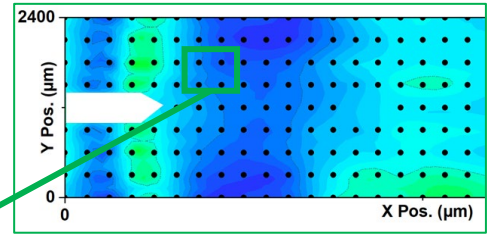


MAWS







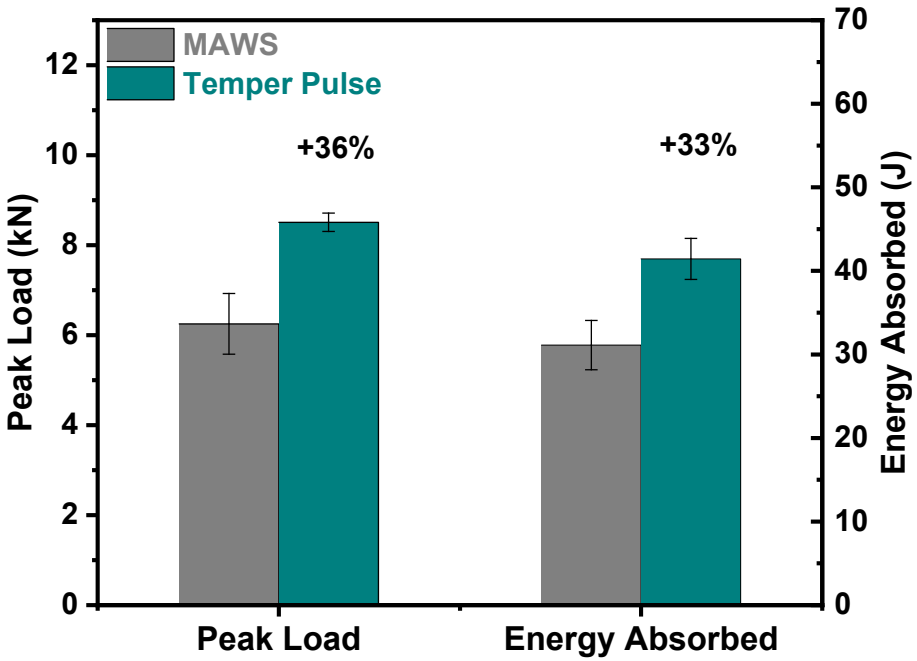


TPS

O.T Betiku et al, welding in the world, 2022.

IN-SITU TEMPERING

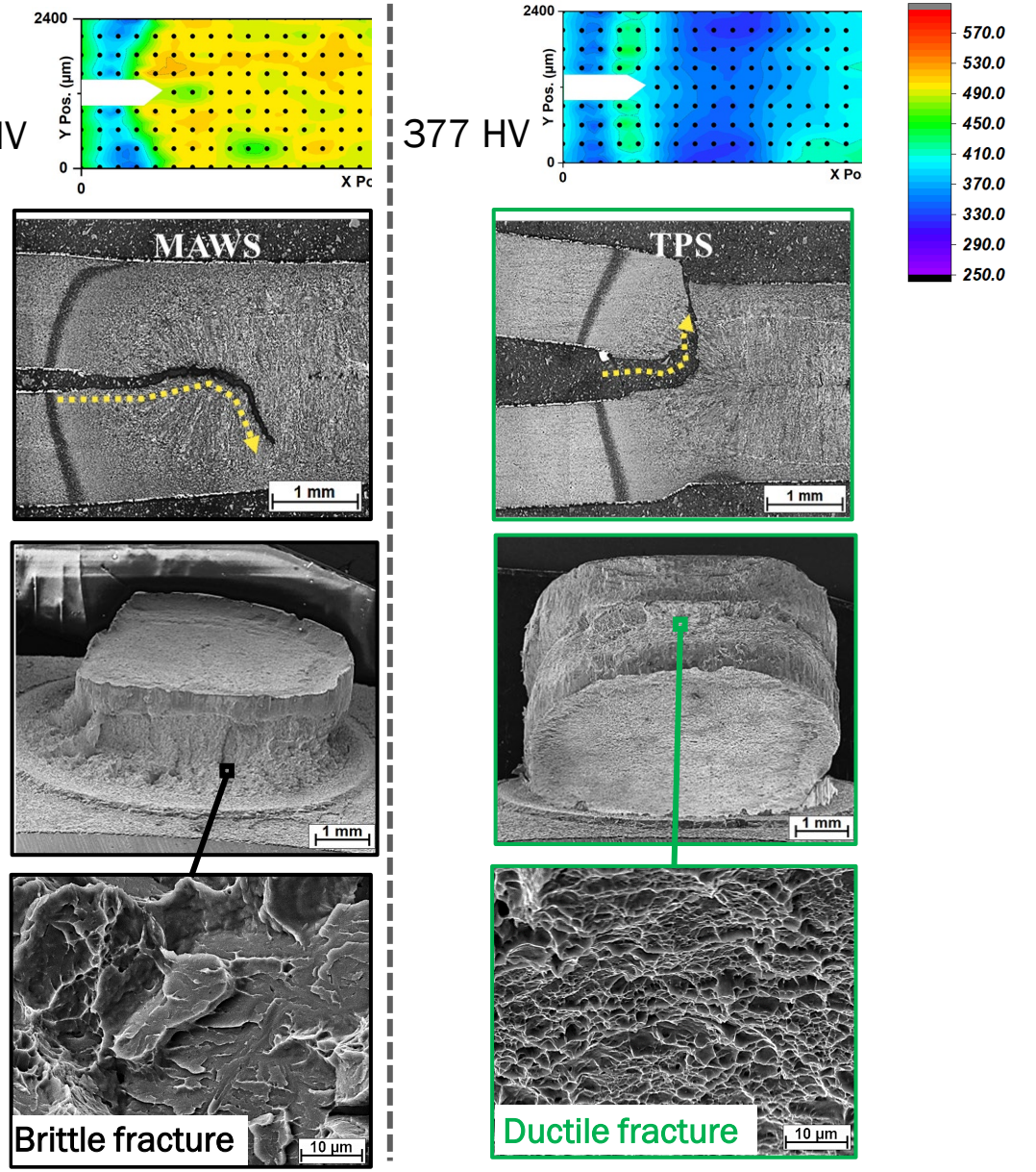
Mechanical Properties



Modified American Welding Schedule (MAWS)

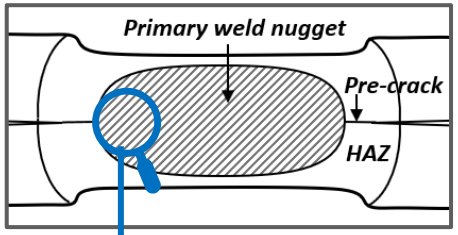
Temper Pulse Schedule (TPS)

	MAWS	Temper Pulse
Hardness	496 HV	377 HV
Crack propagation path		
Failure mode		
Fractography	Brittle fracture	Ductile fracture



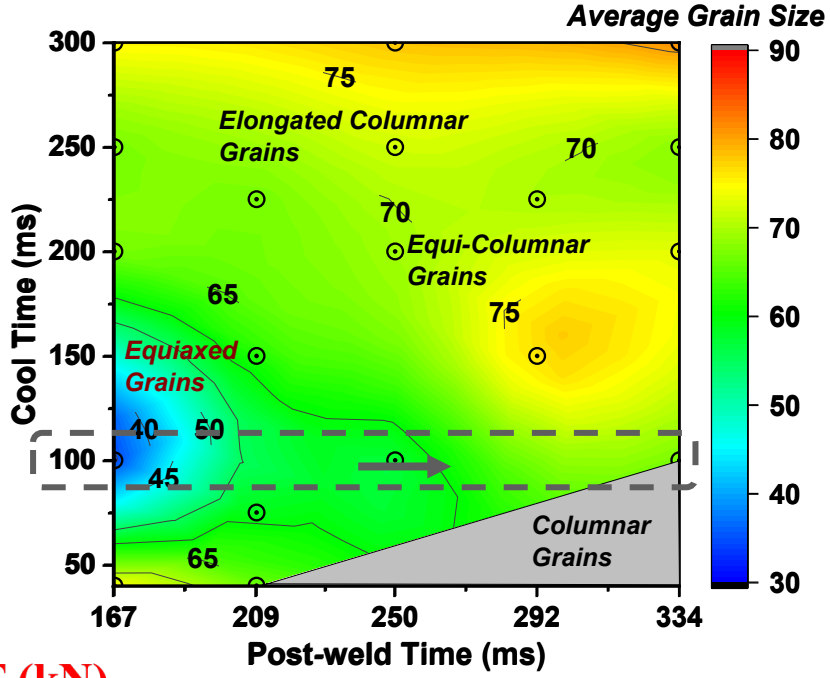
O.T Betiku et al, welding in the world, 2022.

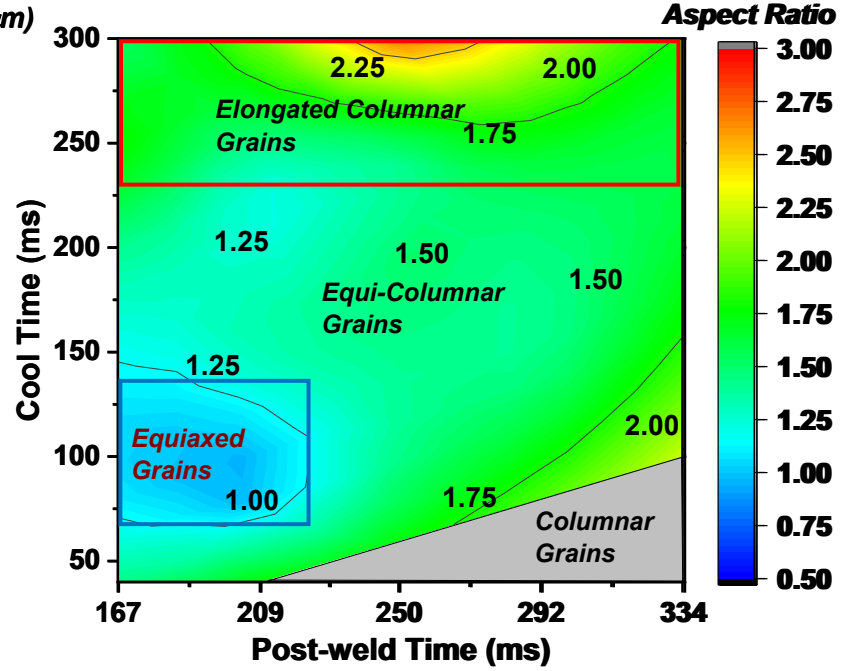
IN-SITU GRAIN REFINEMENT

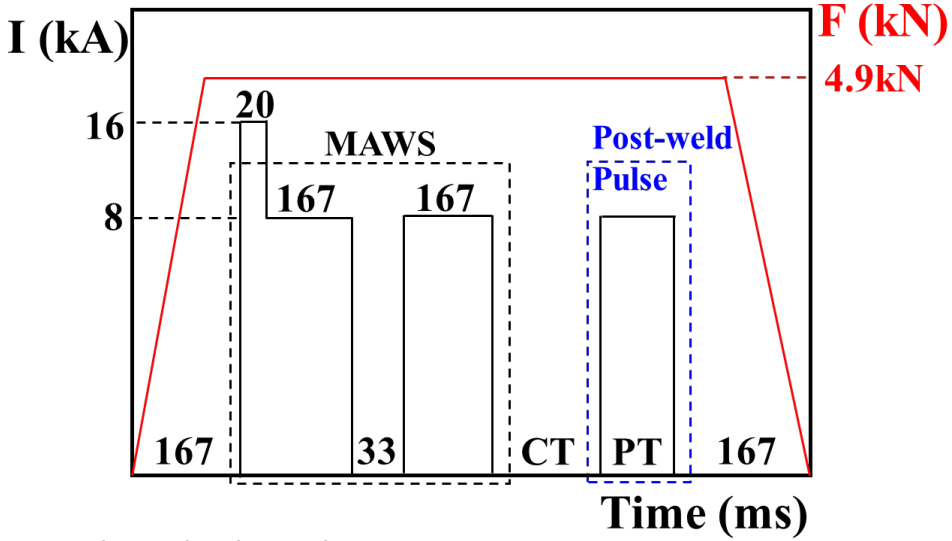


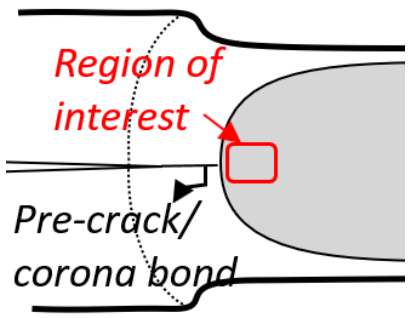
Refine grain structure

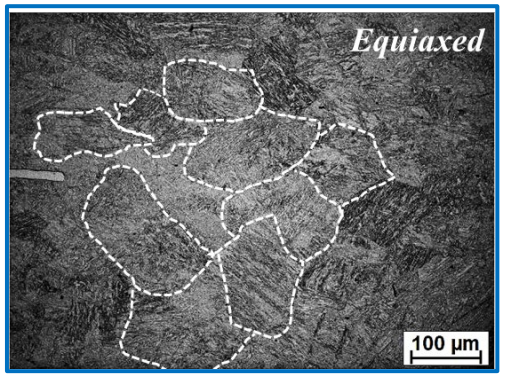
Develop process parameters

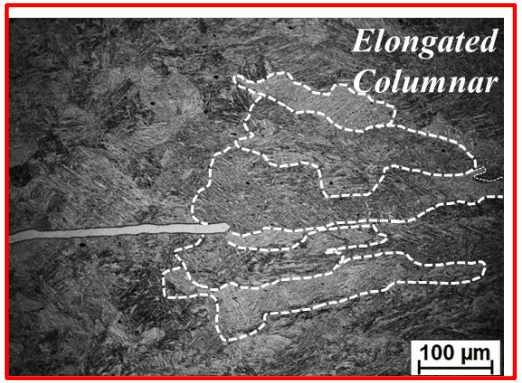








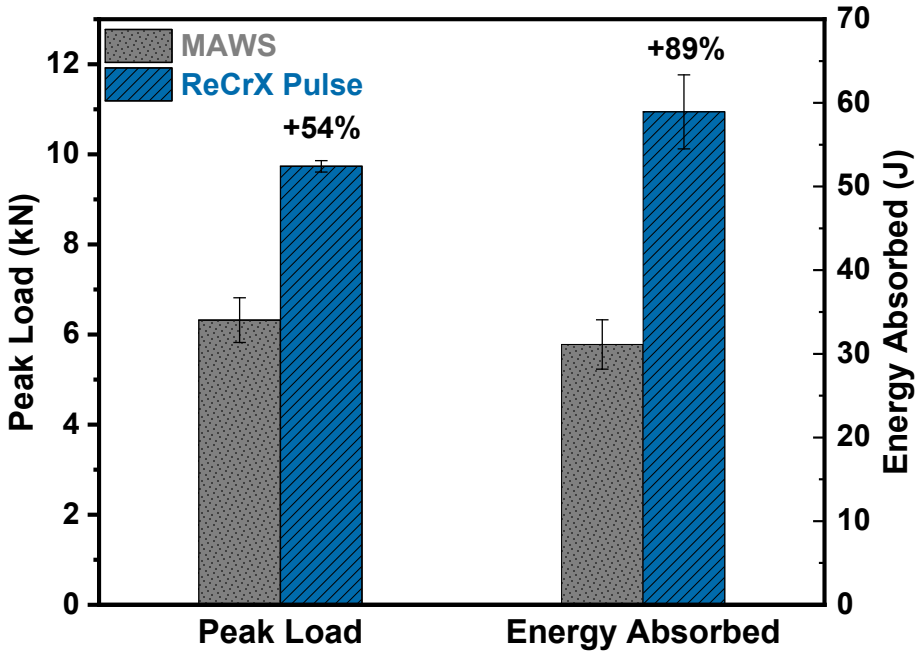




O.T Betiku et al, submitted manuscript, 2022.

IN-SITU GRAIN REFINEMENT

Mechanical Properties

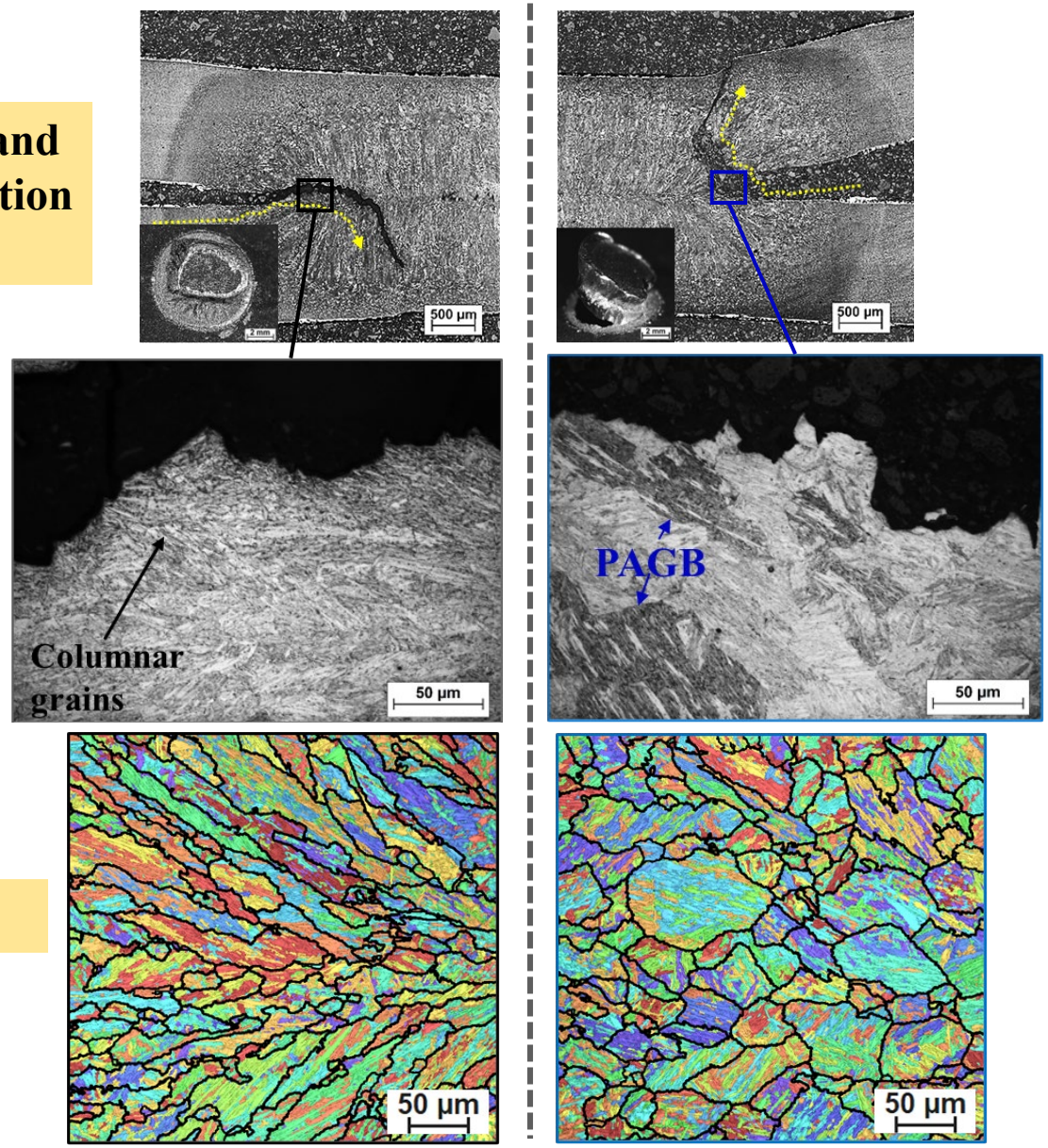


Weld Schedule	Squeeze time (ms)	Weld Pulse 1 (ms)	Cool time (ms)	Weld Pulse 2 (ms)	Cool time 2 (ms)	Post-Pulse time (ms)	Hold time (ms)	Weld and post pulse (kA)
MAWS	167	167	33	167	-	-	-	8
ReCrX	167	167	33	167	100	167	167	8

Failure mode and Crack propagation path

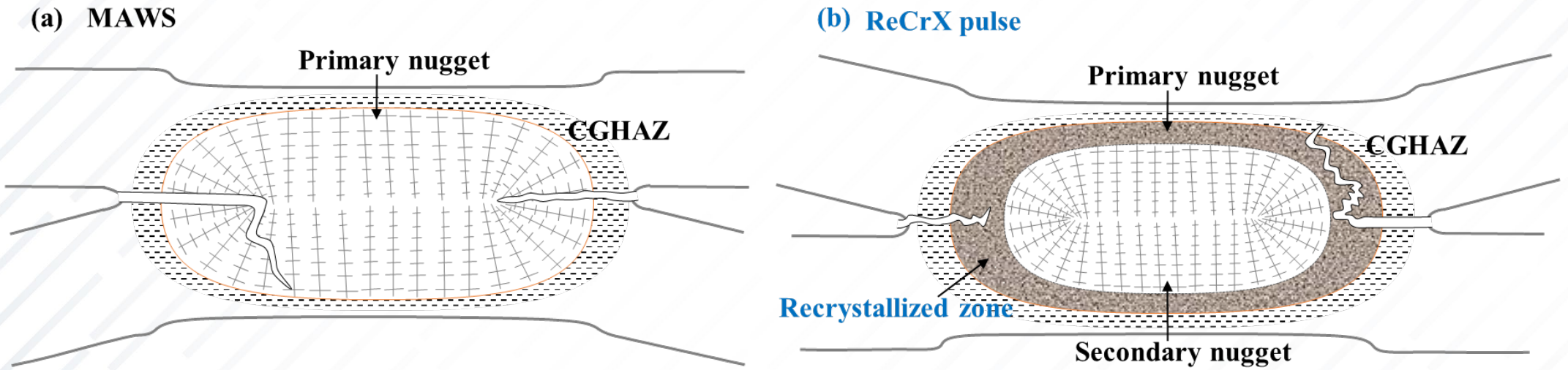
Optical Microscopy

EBSD



O.T Betiku et al, submitted manuscript, 2022.

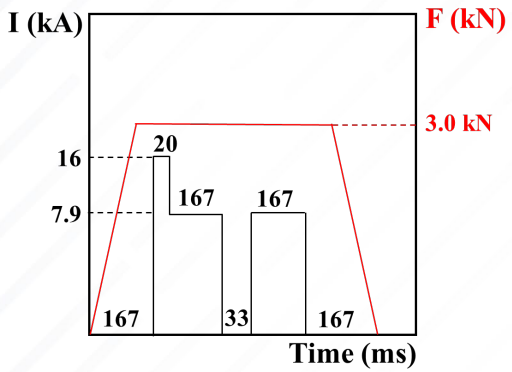
SCHEMATIC OF CRACK PATH



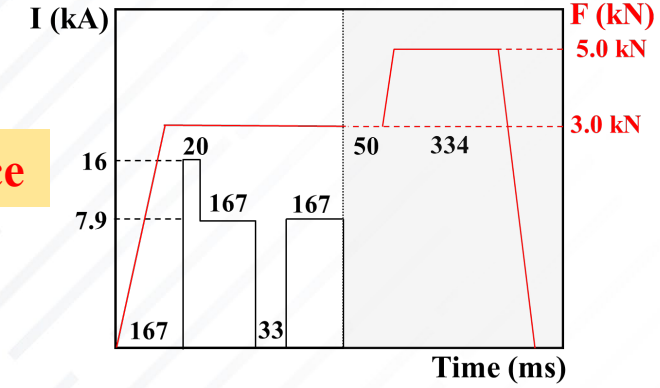
O.T Betiku et al, submitted manuscript, 2022.

DUAL FORCE TECHNIQUE

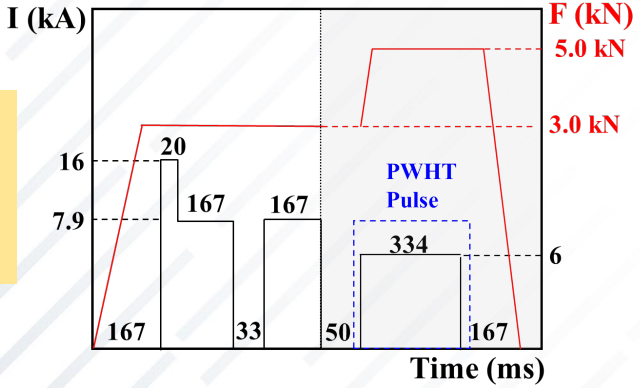
Baseline

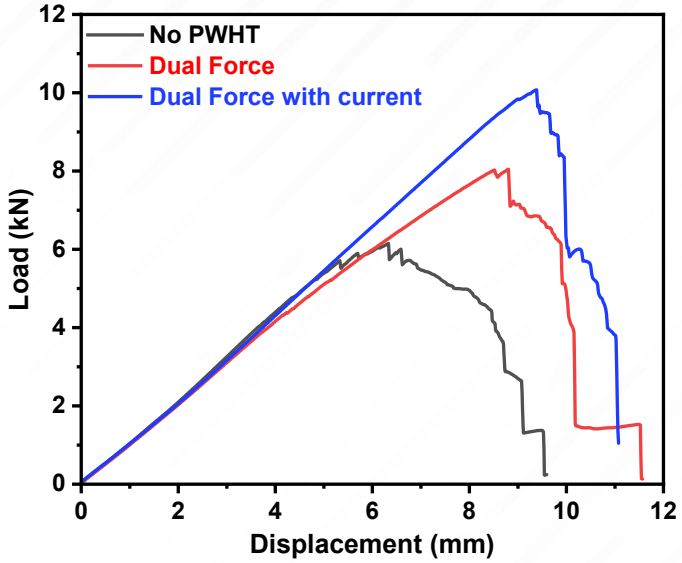


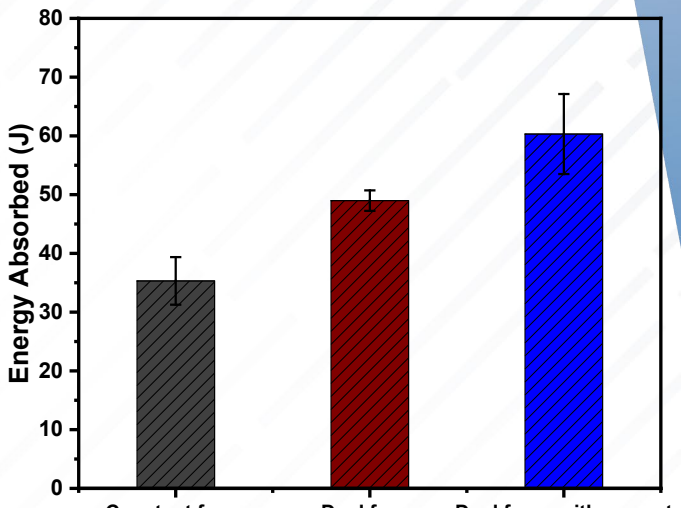
Dual Force

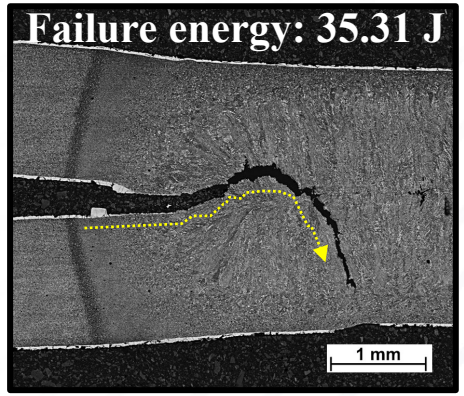


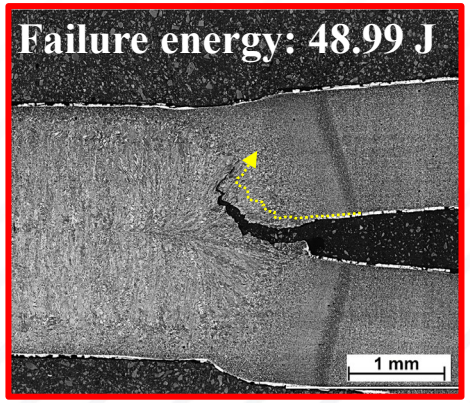
Dual Force + Current

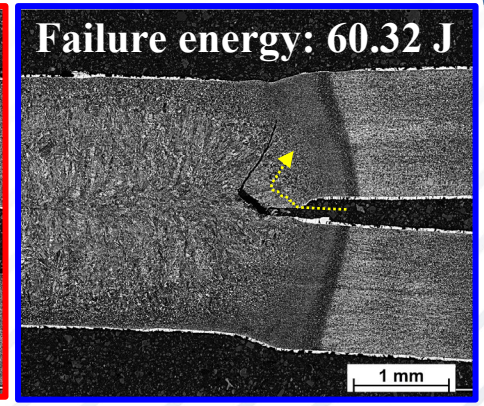




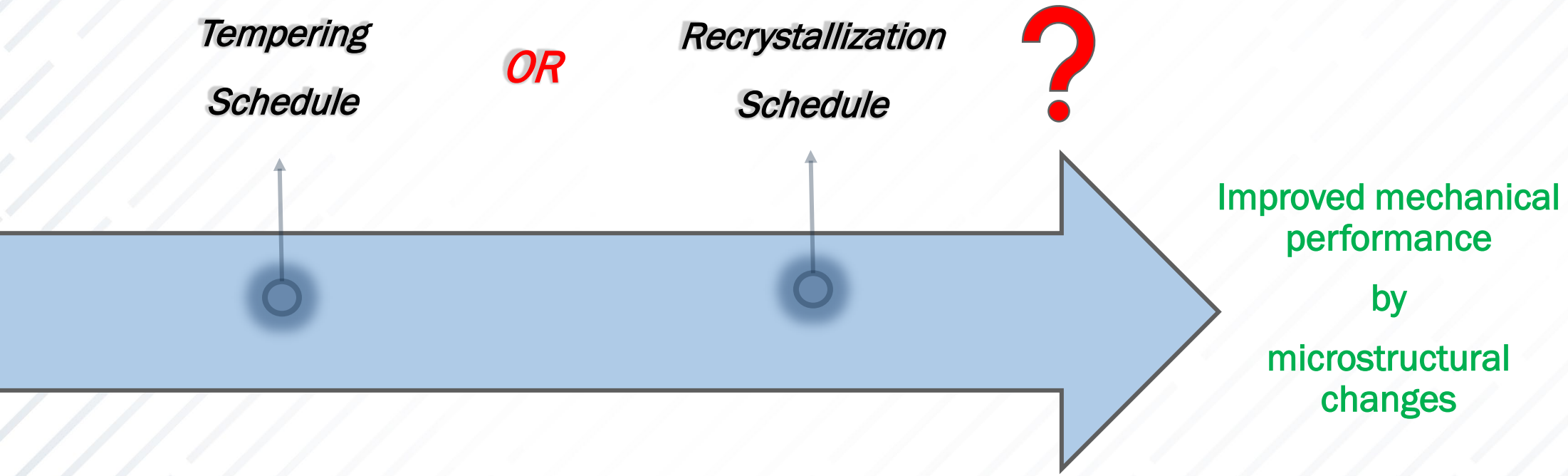








COMPARISON

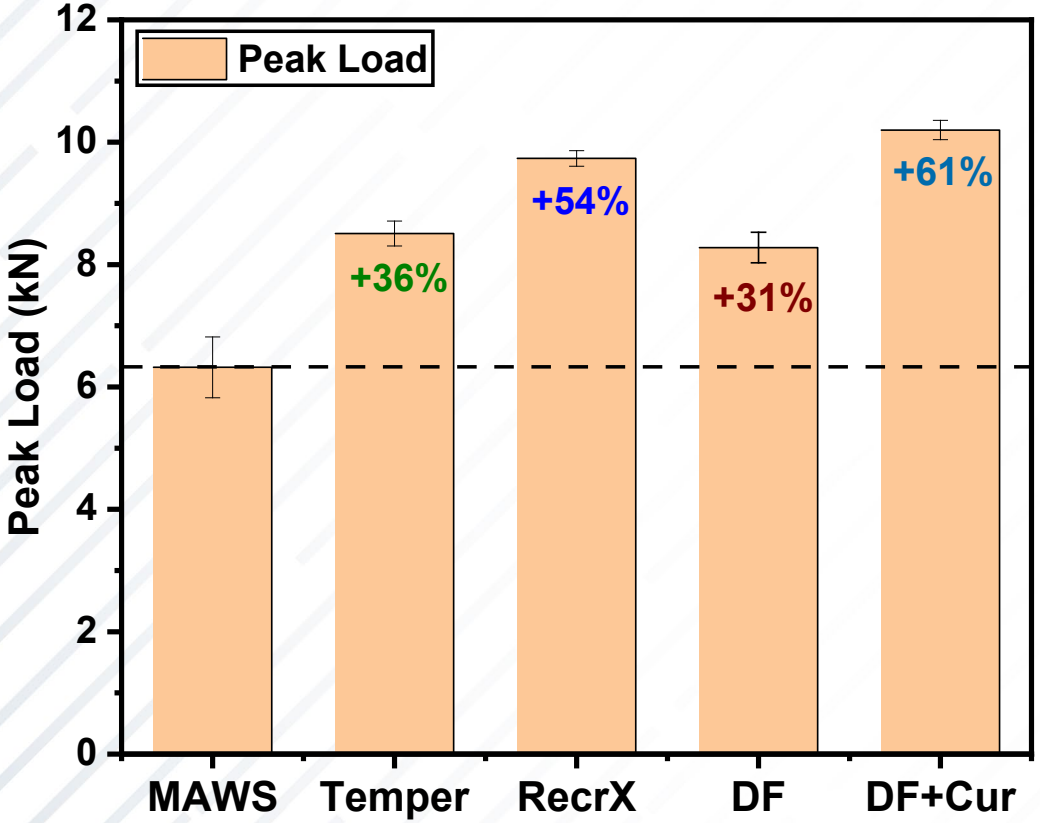


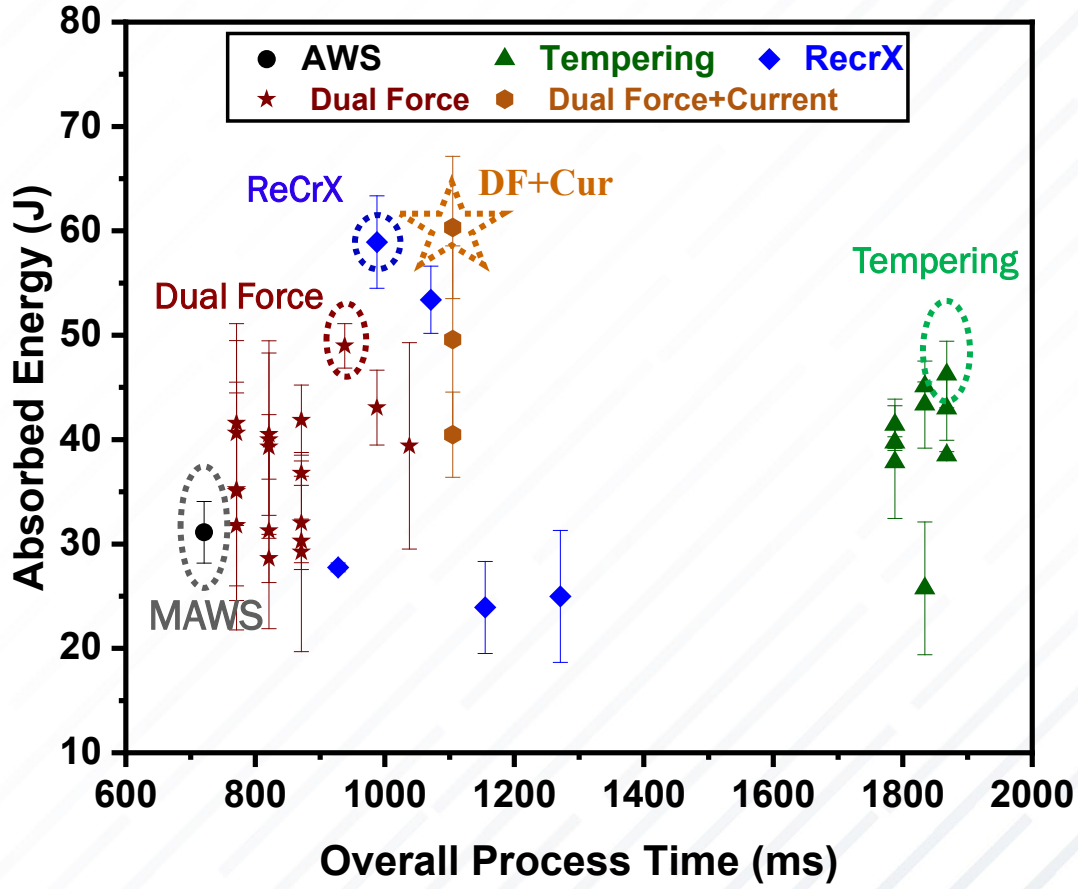
Improved mechanical performance

by

microstructural changes

COMPARISON OF MECHANICAL PROPERTIES WITH PROCESS TIME





* *Circles ◌ represents the **optimum condition** from each technique*

CONCLUSION

- With a temper pulse of **67 ms** and **8.8 kA** current, tempered martensite was observed in the FZ which led to **33% increase** in the weld energy absorption capability and crack deviation from the FZ.

- A correlation between the welding parameter and grain refinement at the edge of the FZ has been investigated. Applying the PWHT pulse in the austenitic phase leads to a transition from **columnar to equiaxed grains** at the edge of the FZ.

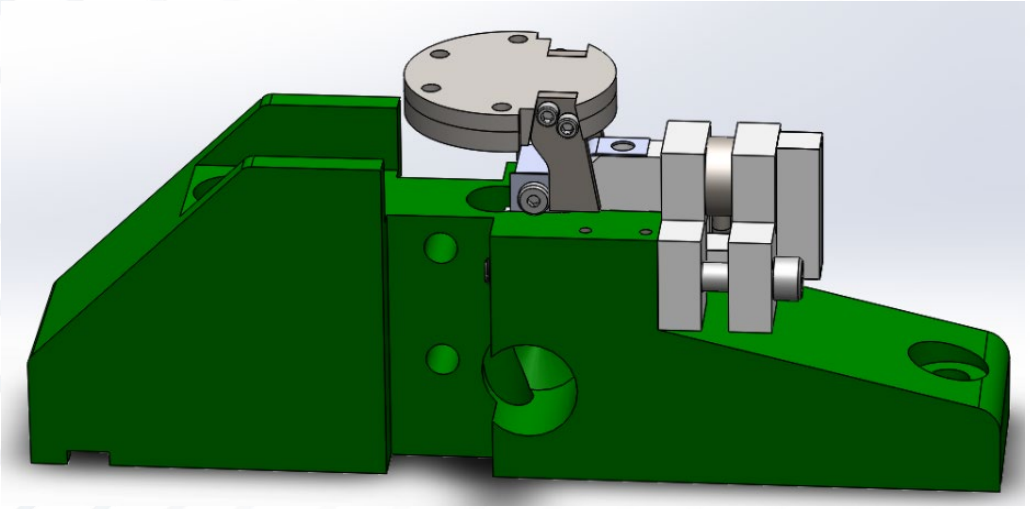
- The optimal condition of **100 ms cool time** and **167 ms post-weld time** at 8 kA resulted in **89%** improvement in energy absorption capability compared to the baseline condition.

- The **dual force method** improved the energy absorption capability **by 57%** while **dual force with current** leads to **94%** improvement in the energy absorption capability compared to the baseline condition.

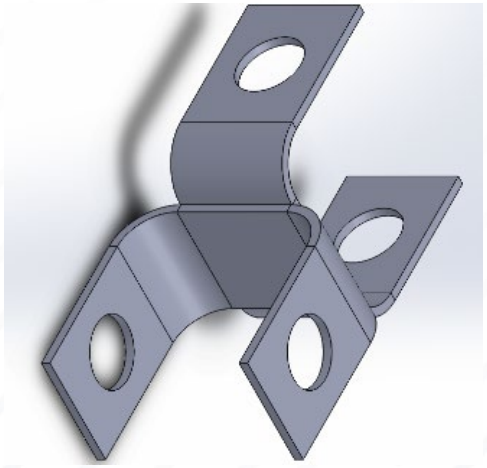
- Optimized **recrystallization pulse schedule** is preferred for improving PHS weld mechanical properties and can be achieved with reduced process time compared to tempering pulse schedule.

NEXT STEPS

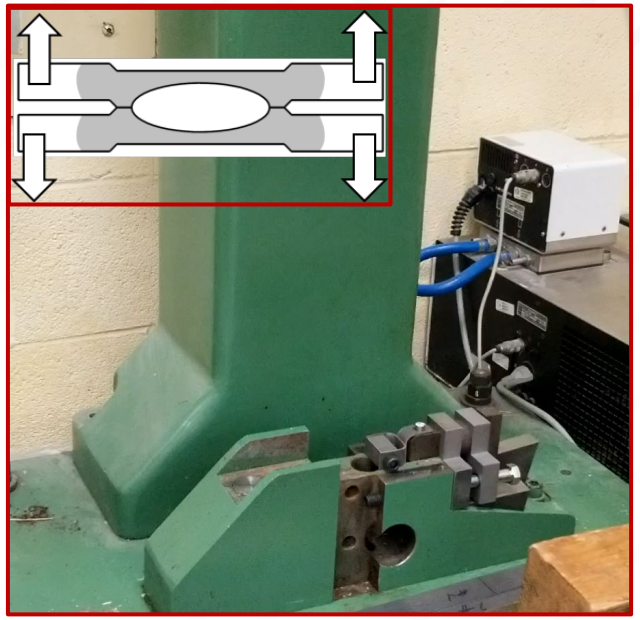
- Novel dynamic loading technique to obtain weld toughness in opening and shear modes



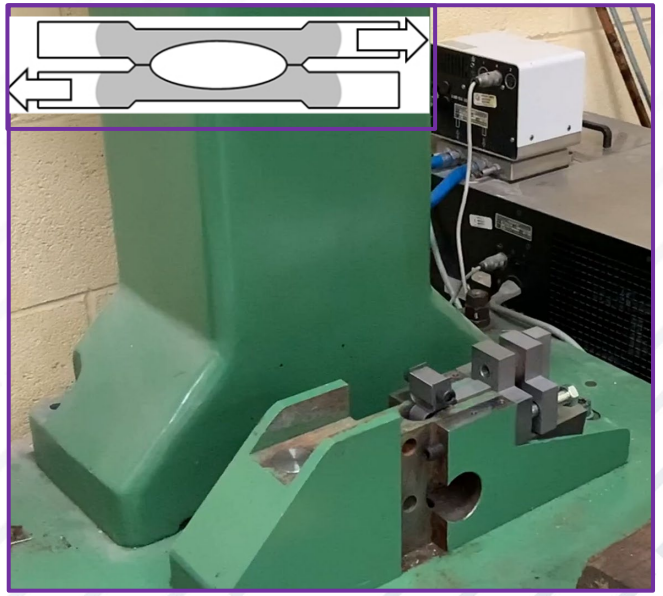
- *Schematic of experimental set-up*



- *Schematic of coupon (half KS-II geometry)*



- *Opening mode*



- *Shear mode*

ACKNOWLEDGEMENT

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More Questions? Meet the speaker(s) at the Auto/Steel Partnership booth.