GREAT DESIGNS IN STEEL

EVALUATION OF IN-SITU MONITORING METHOD FOR LME CRACK OBSERVATION IN HALF-SECTIONED RESISTANCE SPOT WELDING

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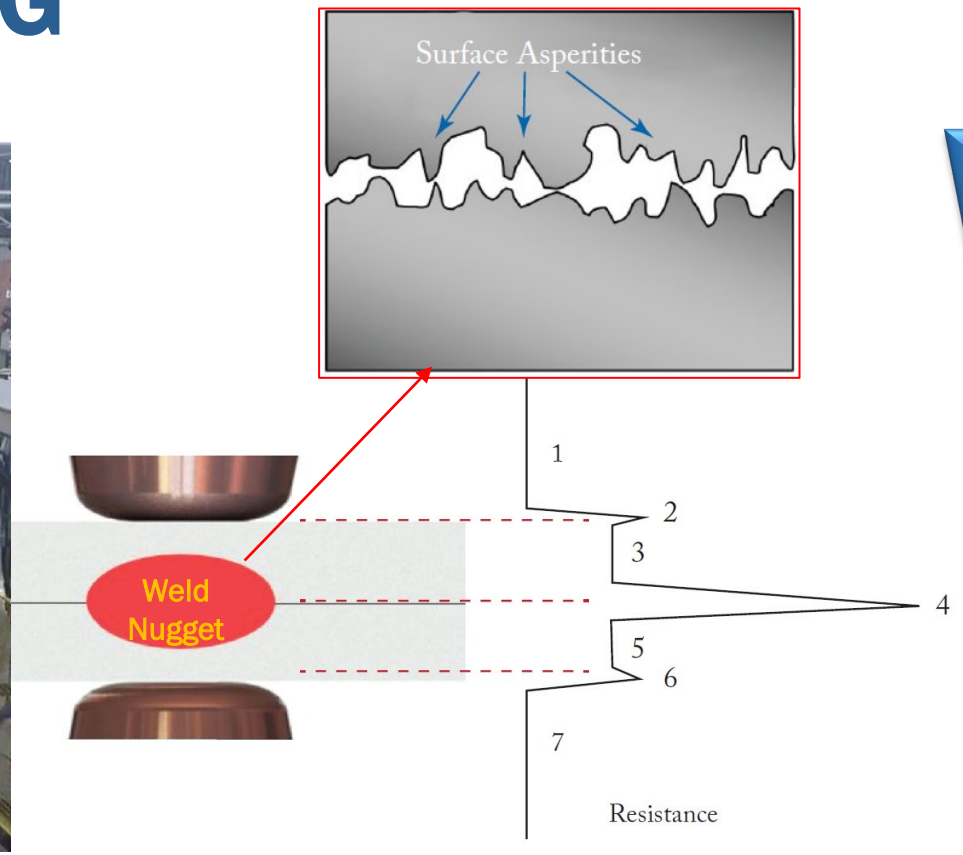
CONTENTS

RESISTANCE SPOT WELDING

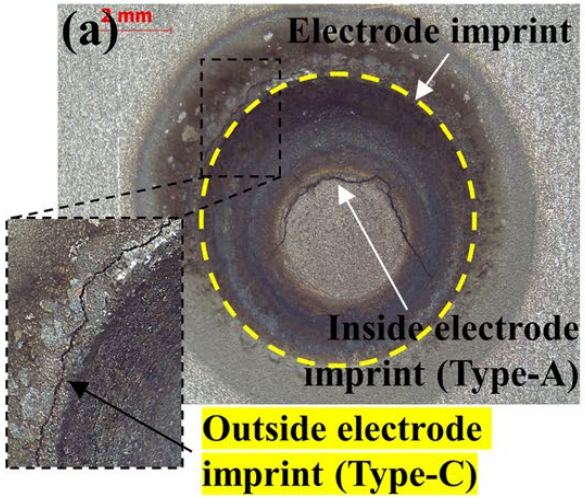
- Resistance spot welding in the automotive industry [1]



- Relative resistance across a resistance spot weld [2]

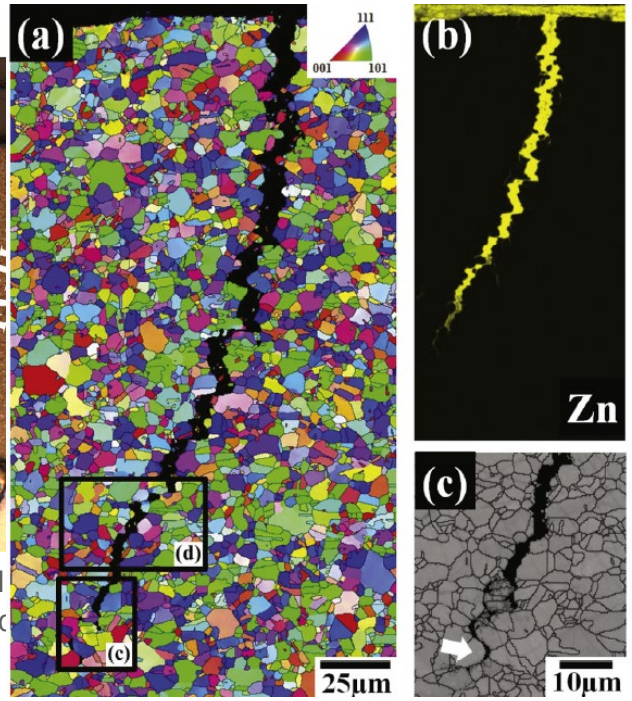
$$Q\ (\text{heat}) = \int_0^t I^2 RT$$

LIQUID METAL EMBRITTLEMENT

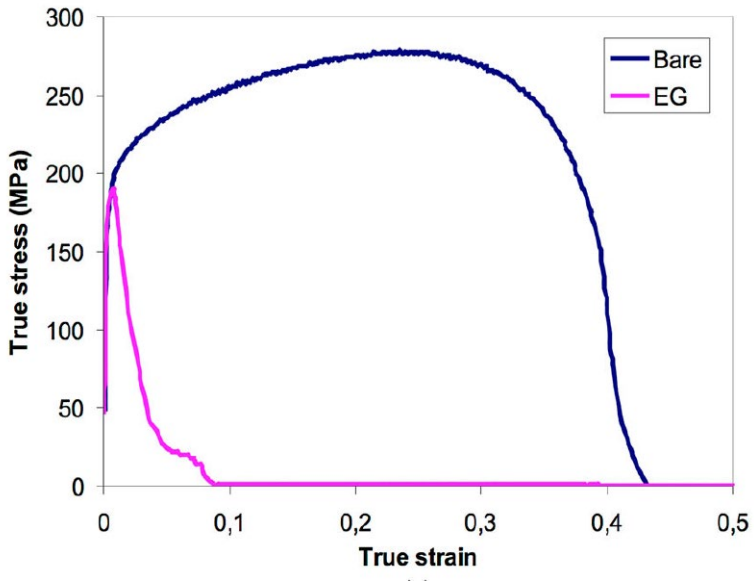


- LME cracks image on the top view (a) and cross-section image [3]

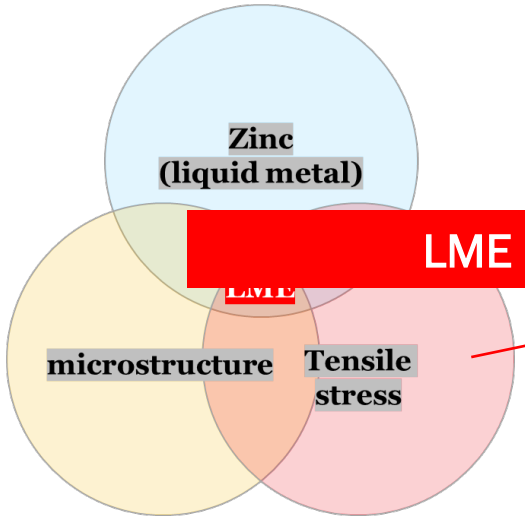
- LM
  and



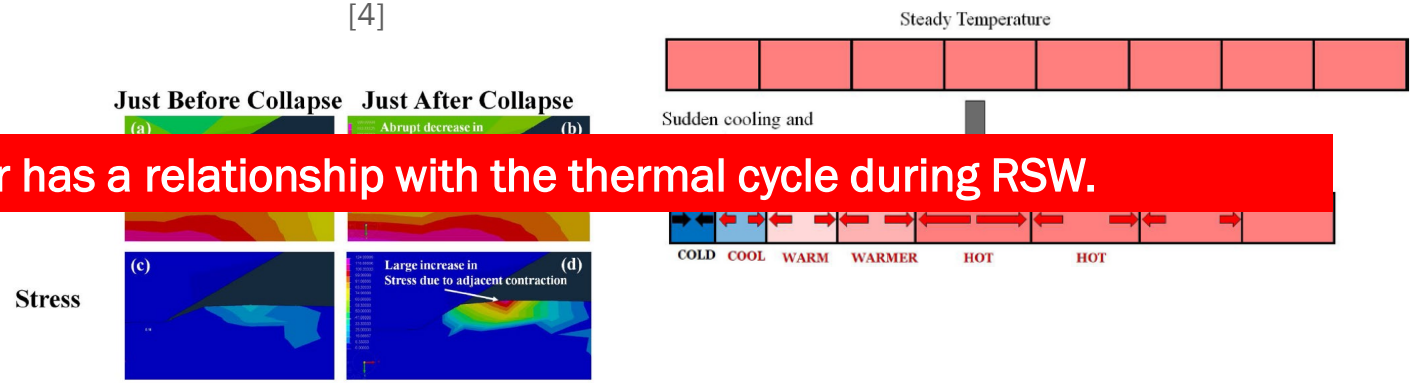
- EBSD image of LME cracks, Zn penetration along the grain boundaries [4]



- Mechanical property degradation after LME [5]

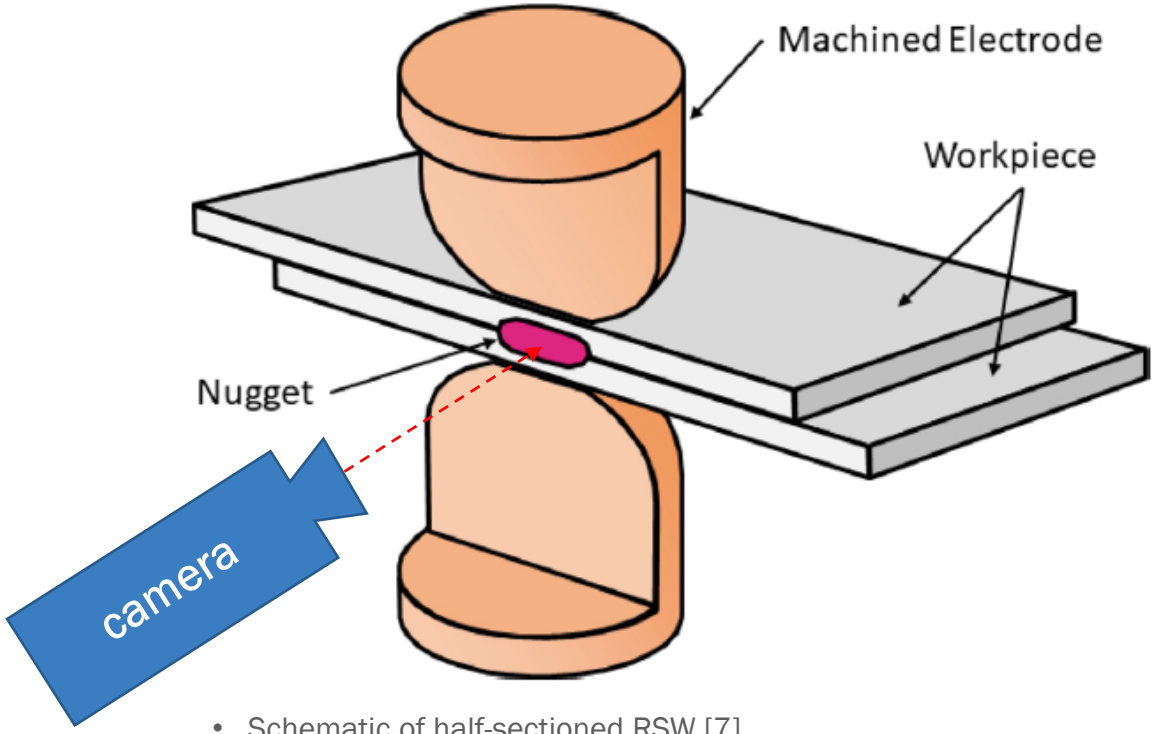


LME behavior has a relationship with the thermal cycle during RSW.

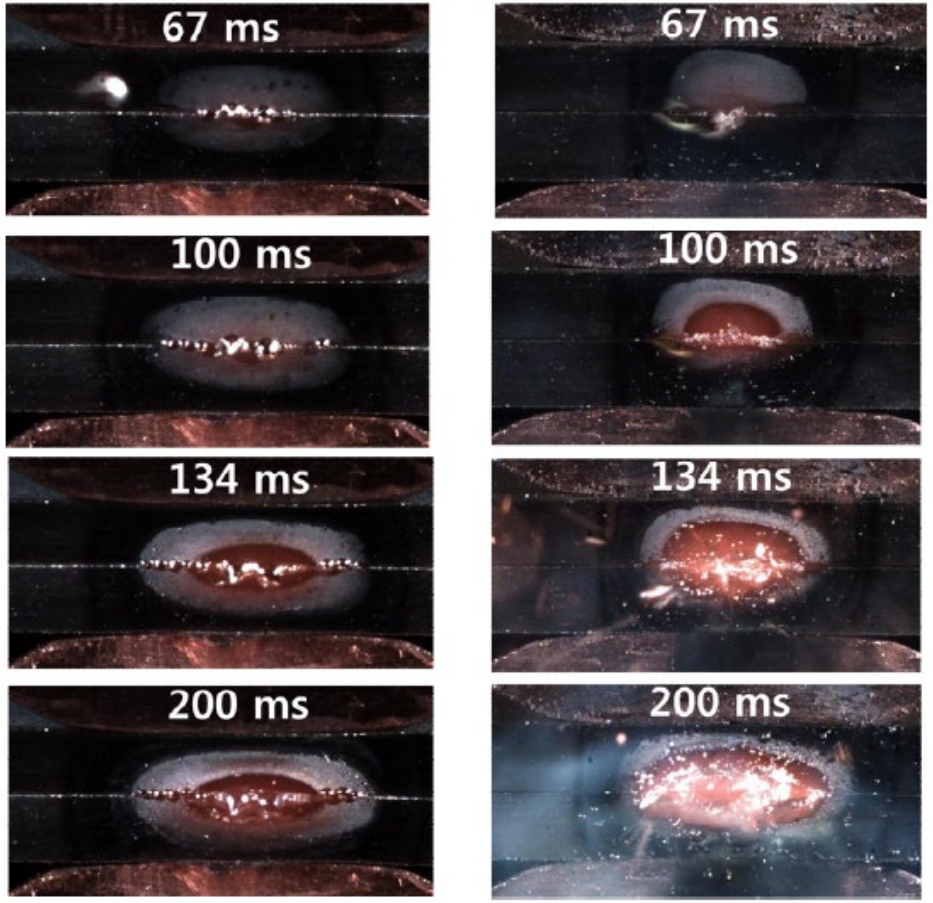


- Relationship between sudden temperature drop and tensile stress [6]

HALF-SECTIONED RESISTANCE SPOT WELDING



- Schematic of half-sectioned RSW [7].



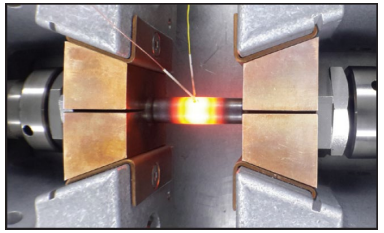
- Nugget growth behavior on (a) Al-Si coated steel and (b) Zinc-coated steel [8]

- Half-sectioned RSW was developed by Upthegorve et al. in 1972 [11].

MOTIVATION

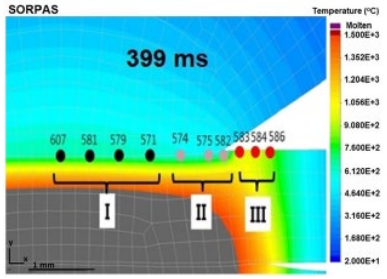
❖ Why half-sectioned welding is needed?

- **Limitation** of Gleeble test and Computed simulation



Gleeble simulator image [9]

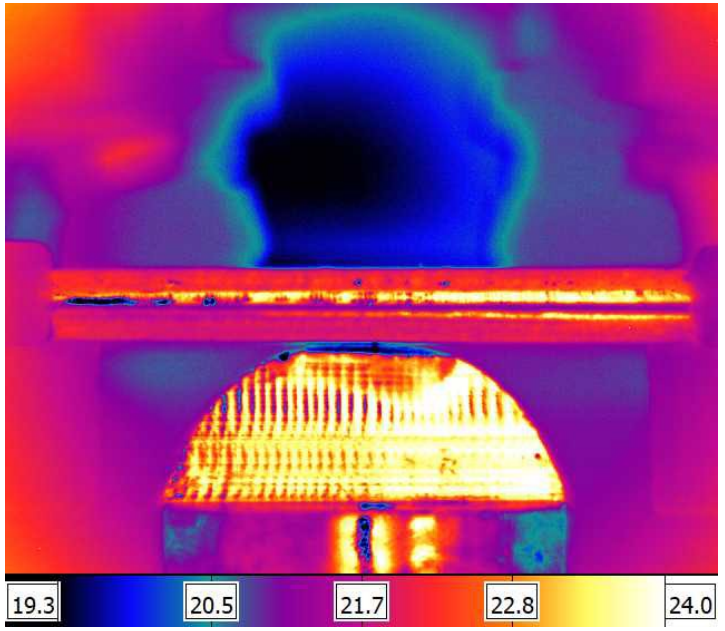
➢ Not able to analyze **how welding parameters affect the LME cracking behavior** in Gleeble simulation.



Example of computed simulation [10]

➢ Not able to **analyze the location of LME cracking formation** and **when the LME cracking is formed.**

- Half-sectioned method

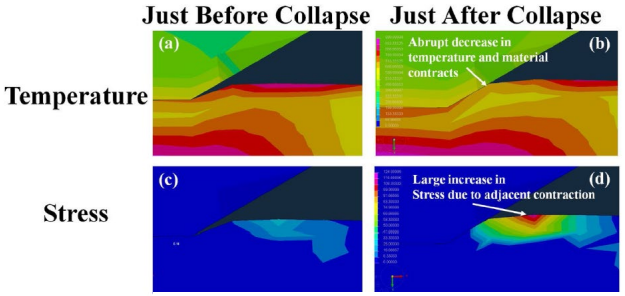


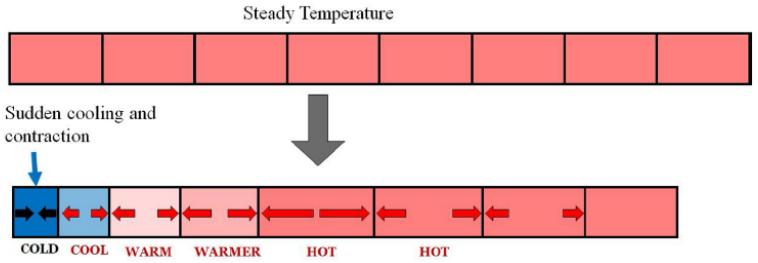
- For **quantitative analysis** of LME cracking behavior using **IR** and **high-speed camera** during real RSW.

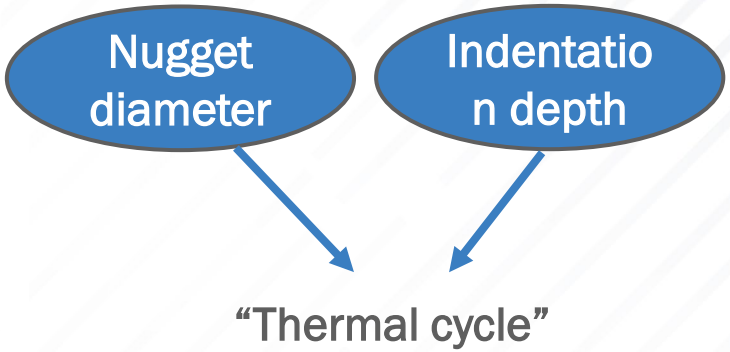
MOTIVATION

❖ Thermal cycle match between normal welding and half-sectioned welding

Thermal cycle can influence on LME cracking behavior







- Relationship between sudden temperature drop and tensile stress [6]

- Half-sectioned welding condition in the literature

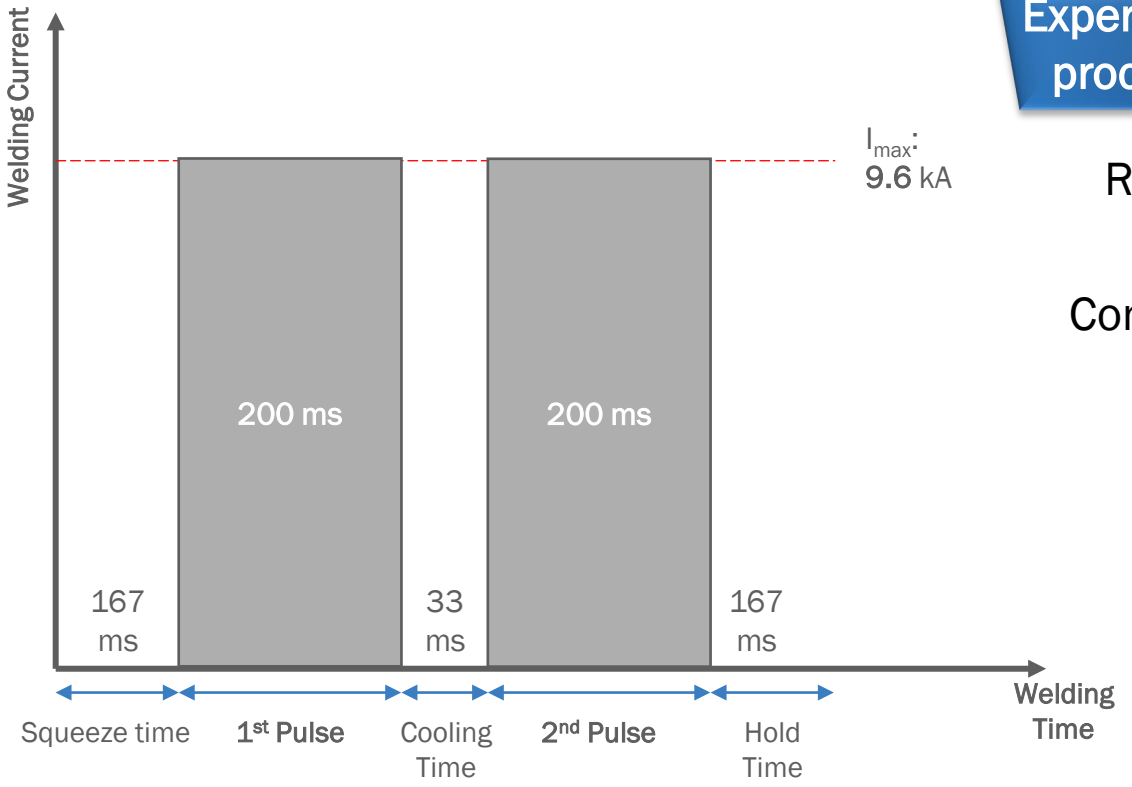
• 50% welding current and Force.	• 60% of welding current and 70% of Force.
• Lane, C.T. et al [7]	• Kim, J.W. et al [8]
• Cho, Y. et al [12]	-

- Existing study considered only power density and contact area.

- the optimized half-sectioned welding parameter is not widely recognized.
- This study aims to validate the half-sectioned welding for analysis of LME crack.

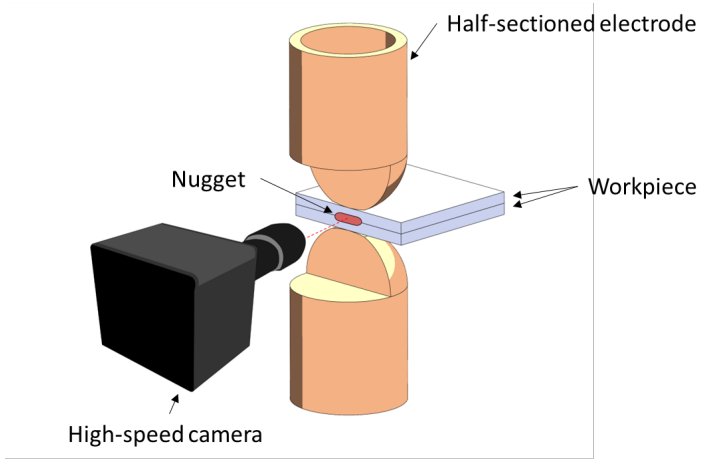
WELDING PARAMETER FOR FULL-SECTION WELDING

- **Material**: GI coated 3rd gen AHSS, 1.6 mm (Similar combination)
- **Electrode**: 6R50 (half-sectioned)
- **Welding schedule**
  - **Welding time**: 167 ms – 33 ms (cooling time) – 167 ms (AWS D 8.9)
  - **Electrode force**:
    - Full section welding: **5.4 kN**
  - **Welding current**:
    - Full section welding: **9.6 kA (I_{max})**

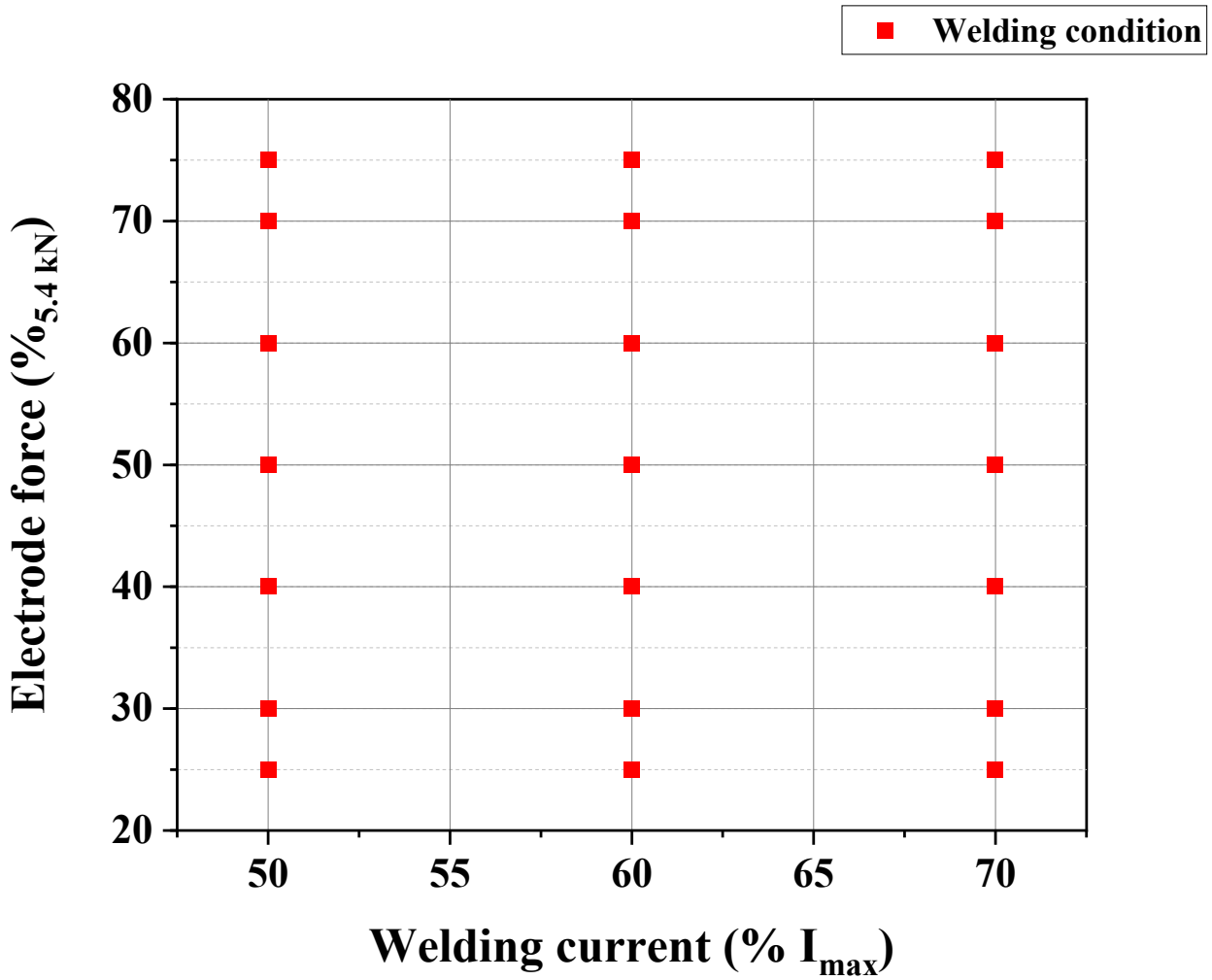


WELDING PARAMETER FOR HALF-SECTIONED WELDING

Half-sectioned RSW setup



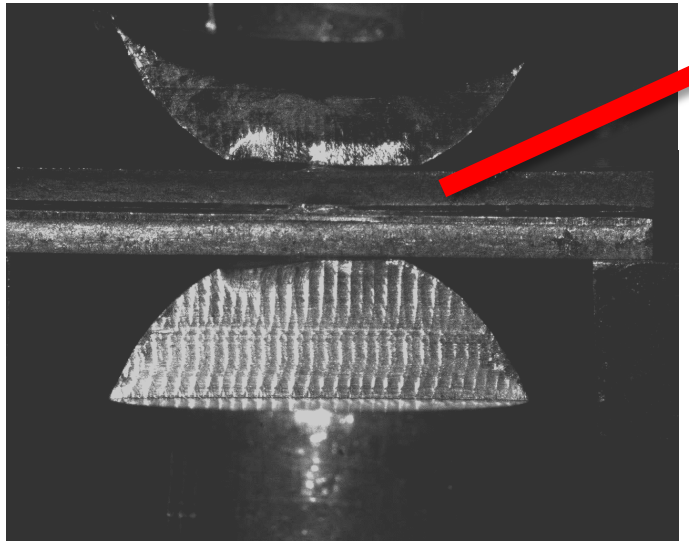
Half-sectioned 6R50 electrode



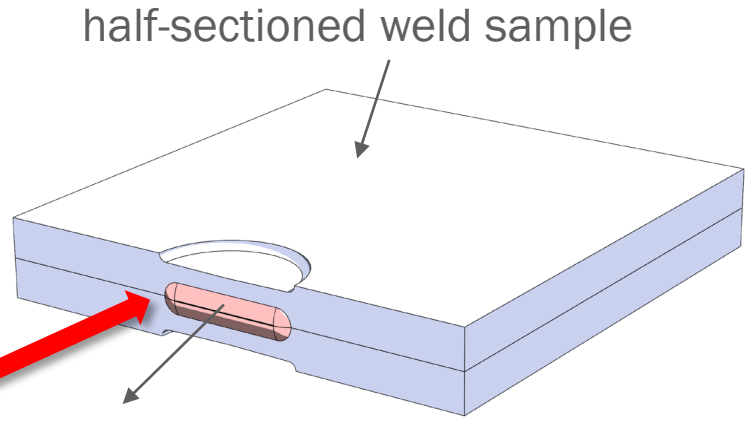
SAMPLE PREPARATION FOR HALF-SECTIONED WELDING

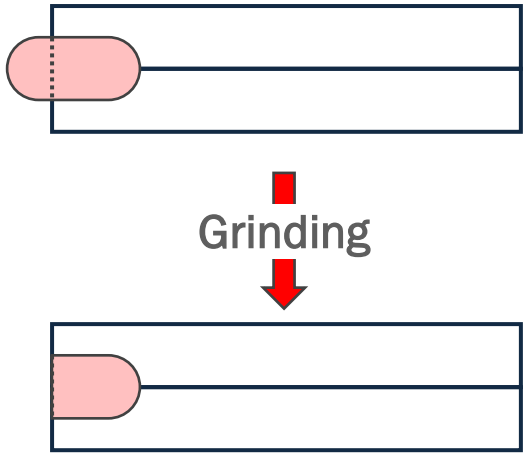
Objective: To observe the microstructural evolution during half-sectioned welding

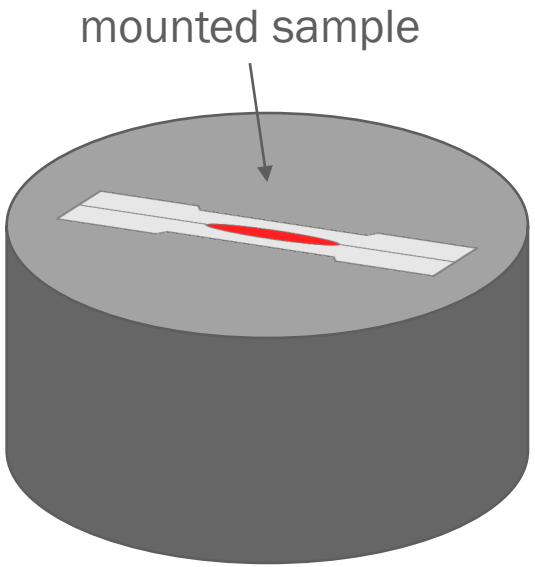
A unique property of Half-section welding

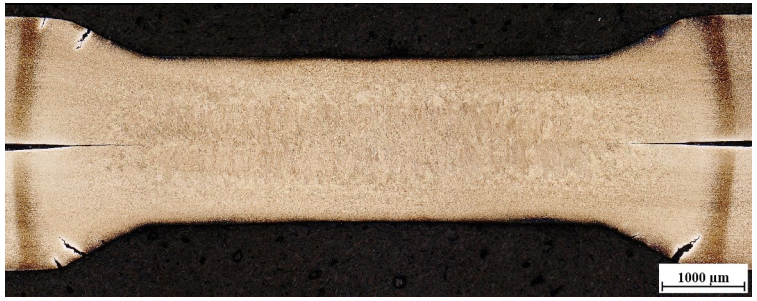


Extruded nugget is formed during half-section welding





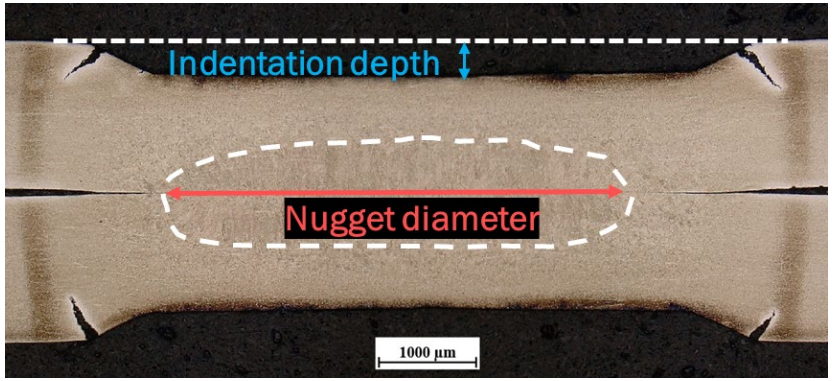


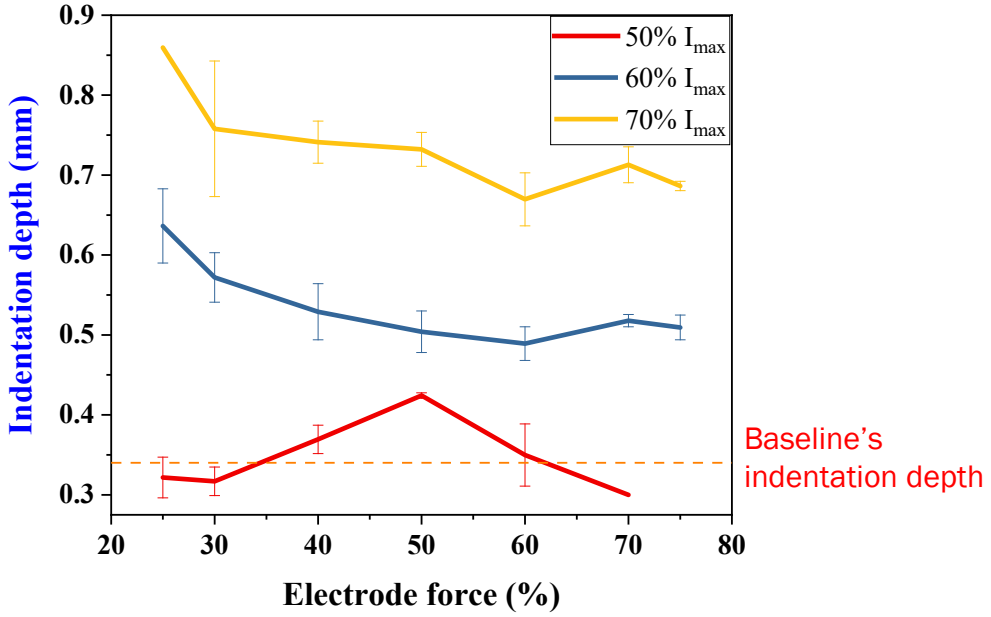


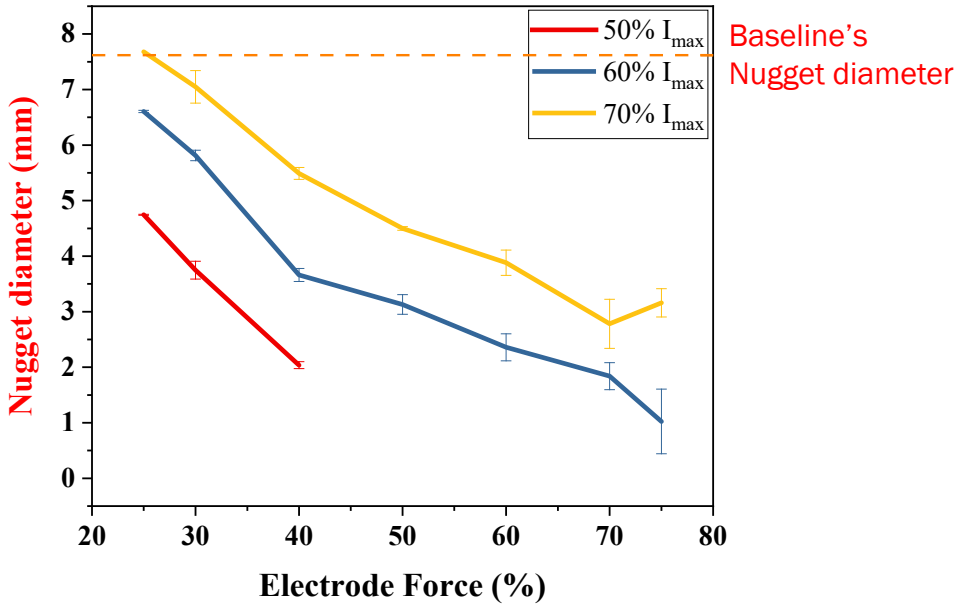
[cross-sectional micrograph for half-sectioned welding]

NUGGET DIAMETER AND IDENTATION DEPTH

To analyze the effect of the welding parameters on weld geometry during half-sectioned welding



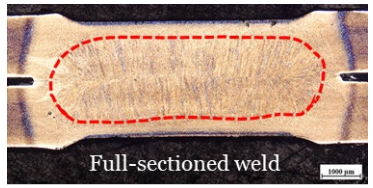




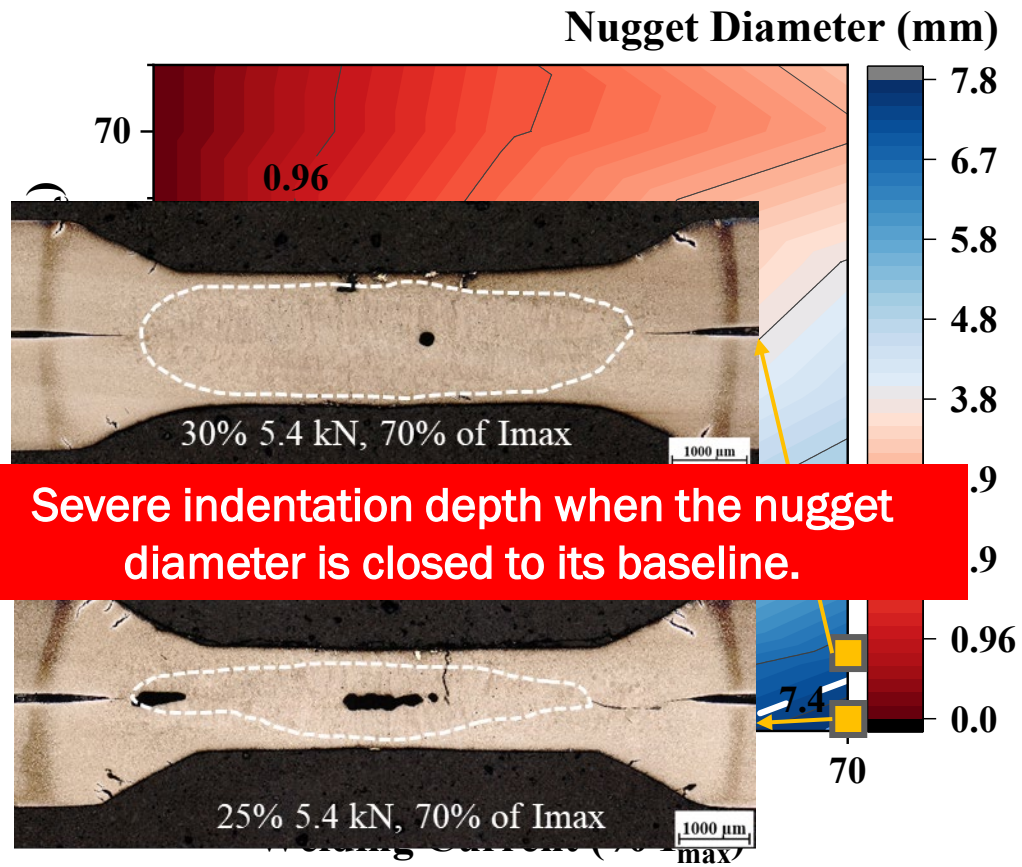
- Indentation depth is highly related to welding current rather than electrode force
- The nugget diameter decreased with increasing electrode force but increased with increasing weld current

HALF-SECTIONED WELDING PROCESS MAP

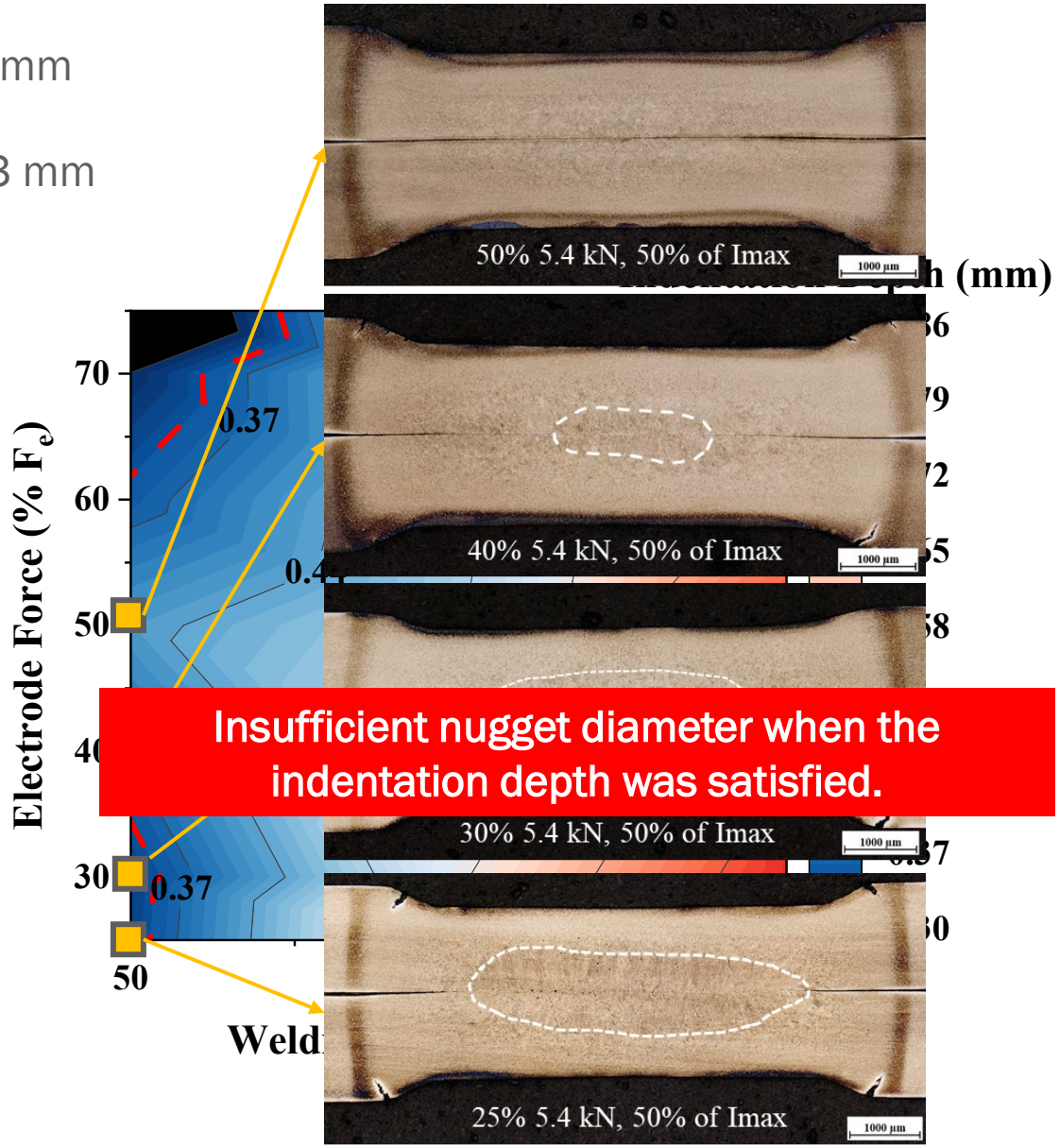
To develop the optimized welding parameters which have a similar thermal cycle to normal weld.



- Nugget Diameter: 7.20 ± 0.63 mm
- Indentation depth: 0.35 ± 0.03 mm



Severe indentation depth when the nugget diameter is closed to its baseline.



Insufficient nugget diameter when the indentation depth was satisfied.

CALCULATING LME CRACK INDEX

To identify the half-sectioned welding parameters that have similar LME cracking behavior with normal welding.

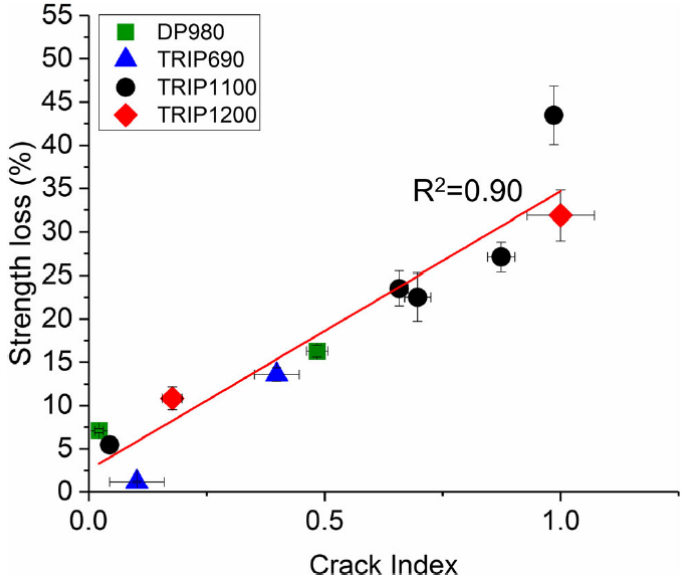
- The crack index developed by E. Wintjes [11] was used to quantify the LME cracks observed in each half-section welding condition.

"Number of cracks per weld"

"Lognormal median crack length"

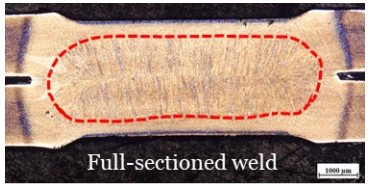
$$Crack\ index = \frac{nL}{t}$$

"Sheet thickness"



LME CI INDEX

To identify the half-sectioned welding parameters that have similar LME cracking behavior with normal welding.



- Nugget Diameter: **7.20** ± 0.63 mm
- Indentation depth: **0.35** ± 0.03 mm

Introduction

Experimental procedure

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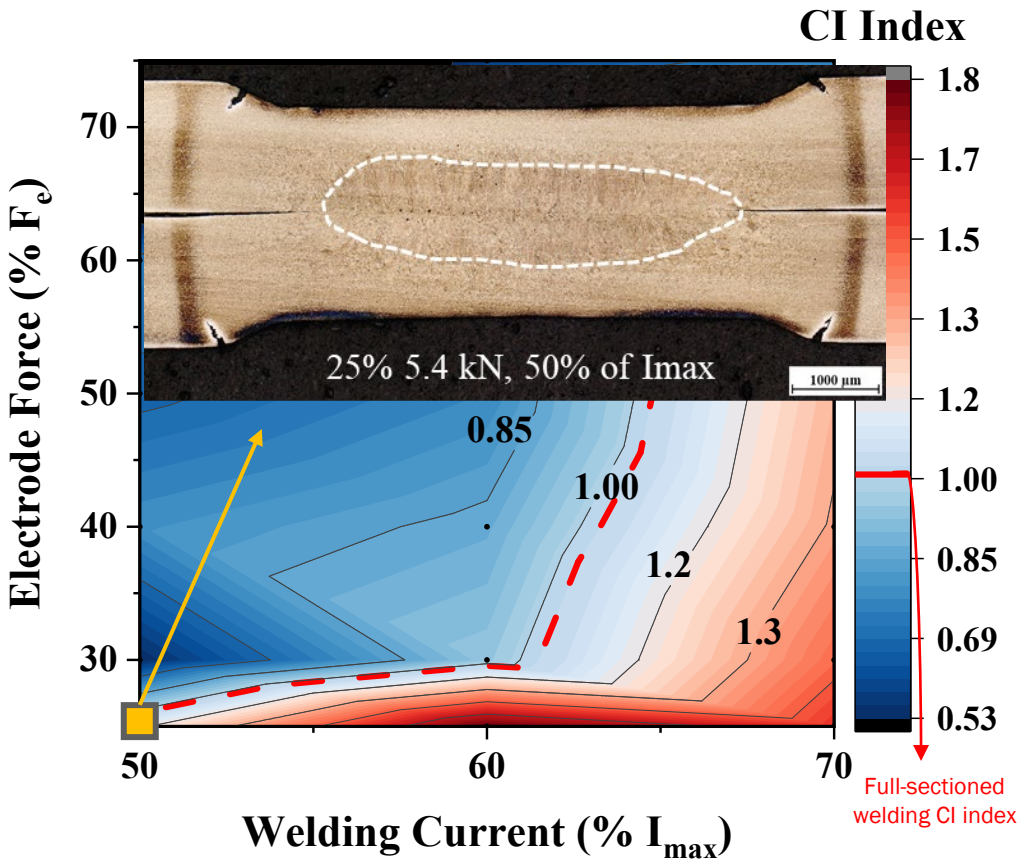
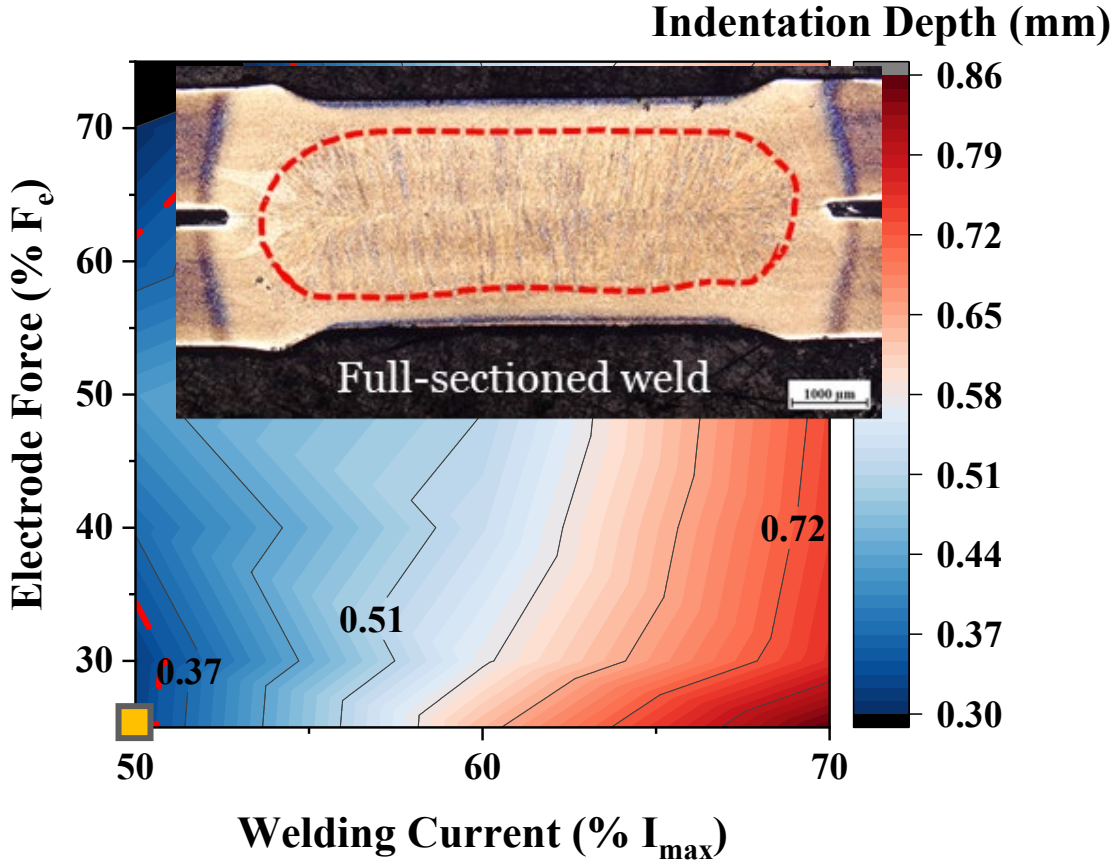
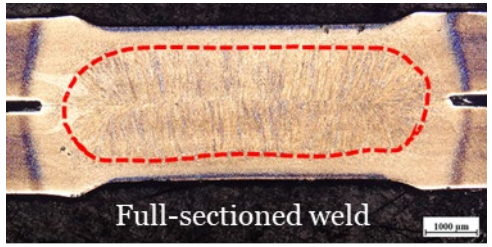




LME CRACKING BEHAVIOR

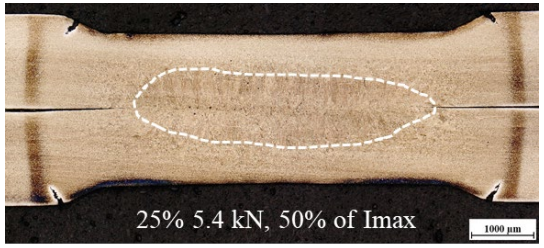
LME cracking behavior of Full-sectioned and Half-sectioned welding

Full-sectioned

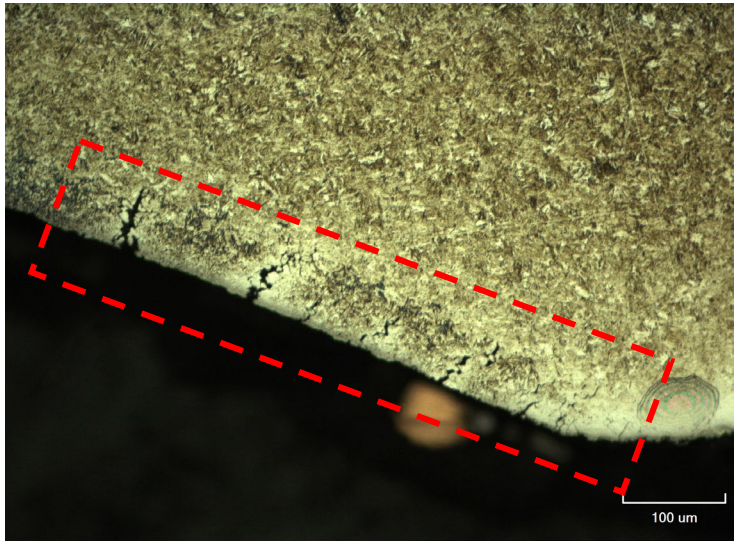


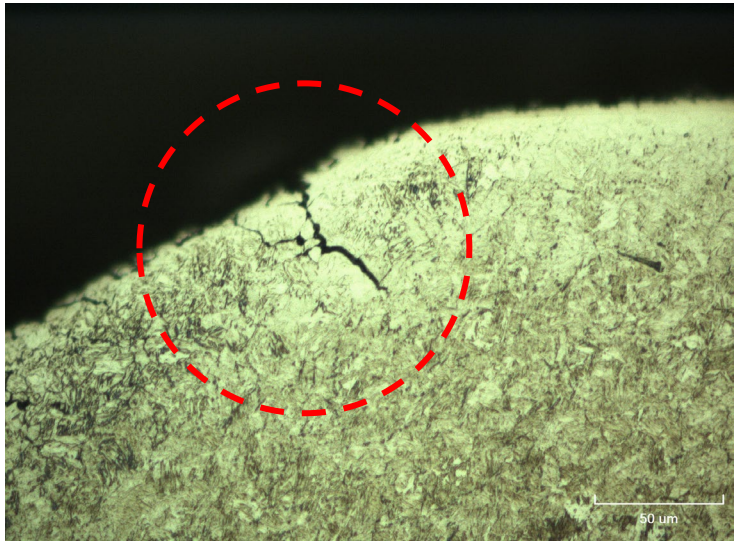
MCL (maximum crack length):
88.1 ± 8.6 um

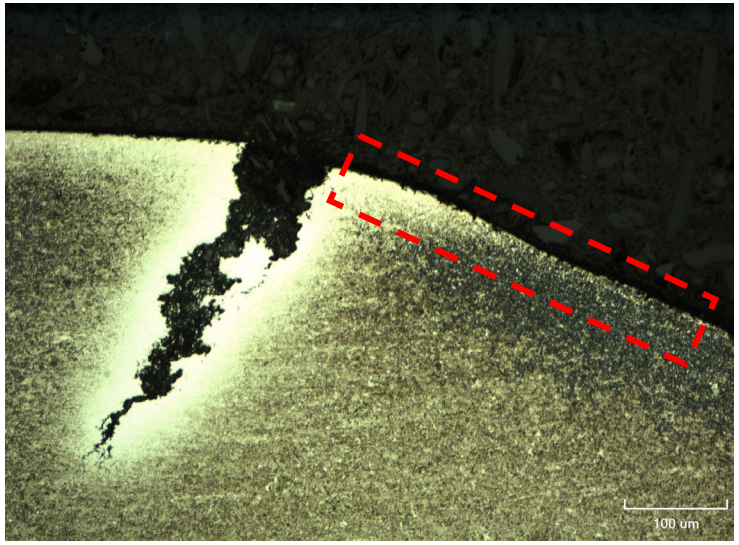
Half-sectioned

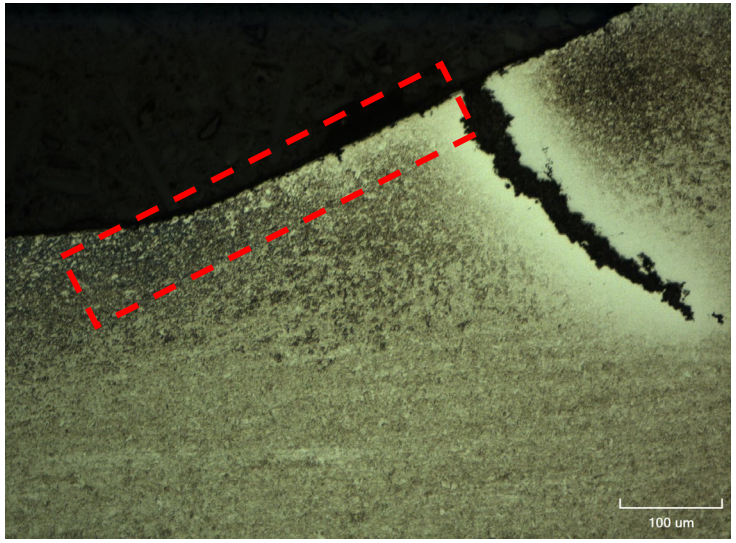


MCL (maximum crack length):
464.4 ± 82.05 um



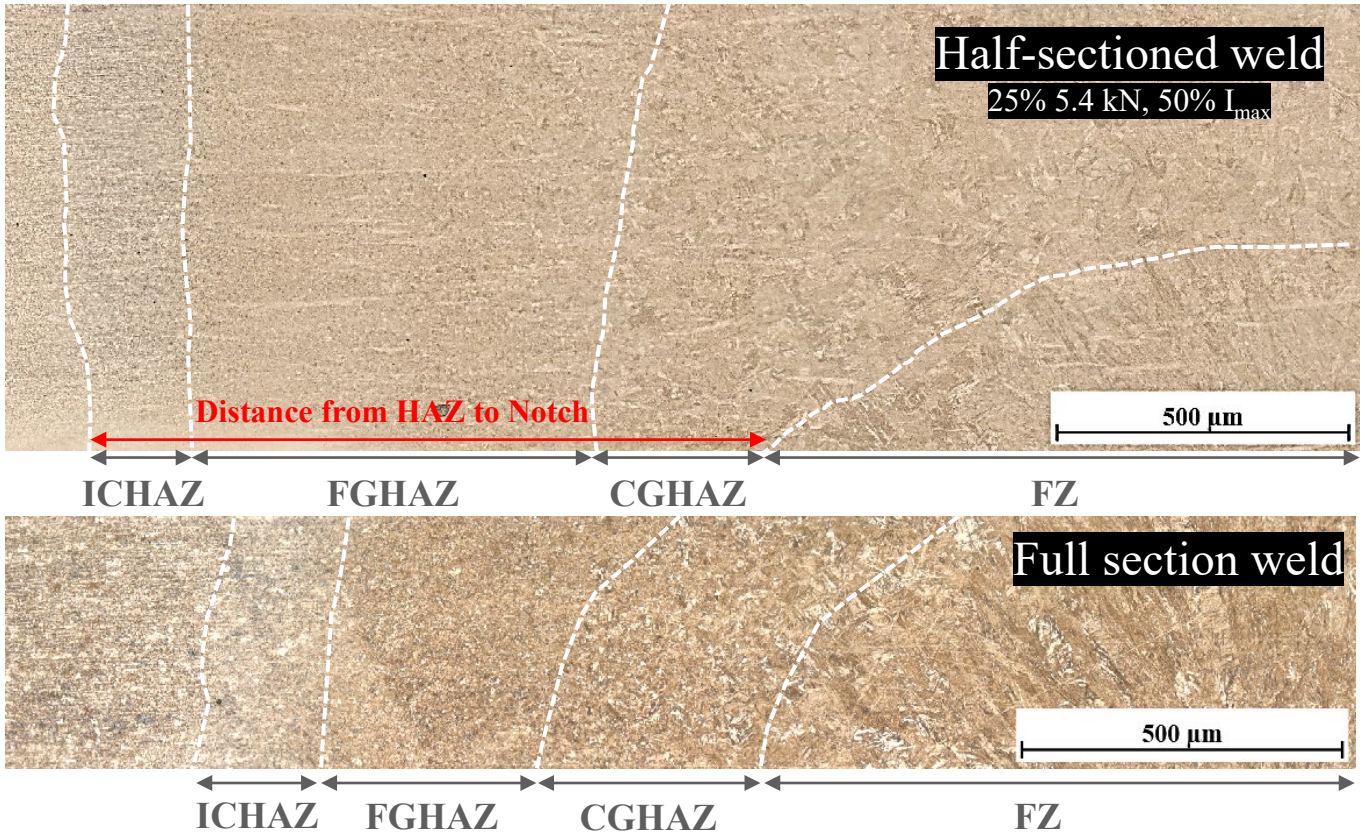


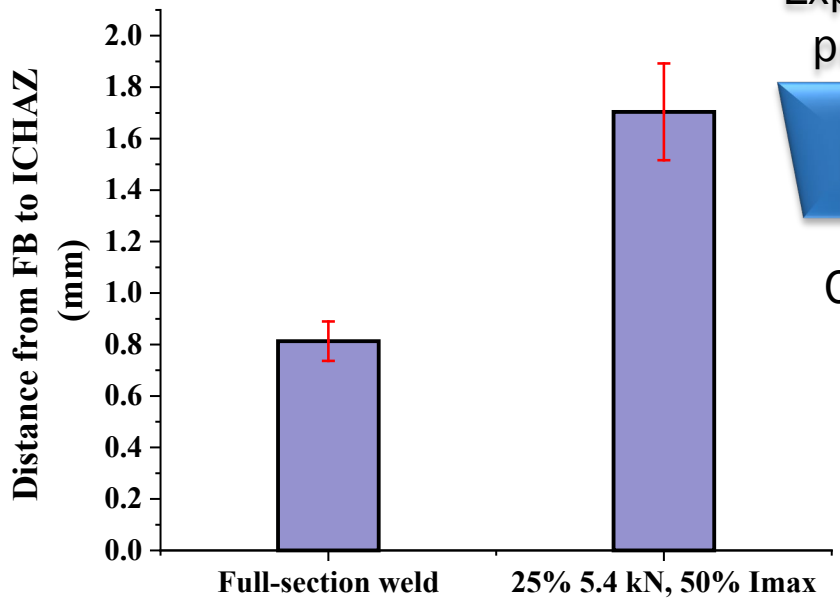




MICROSTRUCTURAL EVOLUTION IN H-RSW

Ascertain the reason for the discrepancy between the full-section and half-sectioned weld





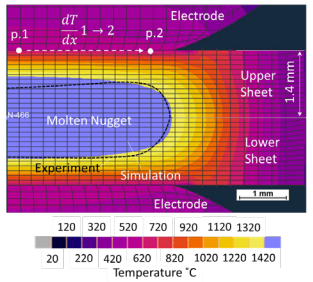
The discrepancy in LME cracking behavior is related to the distance between FB and ICHAZ.

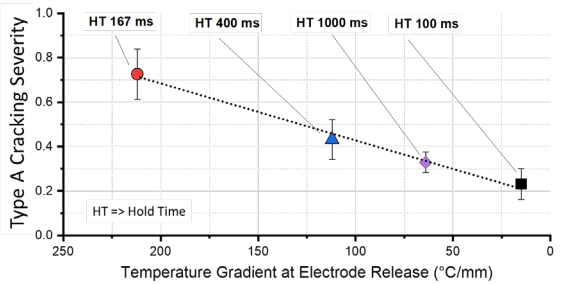
MICROSTRUCTURAL EVOLUTION IN H-RSW

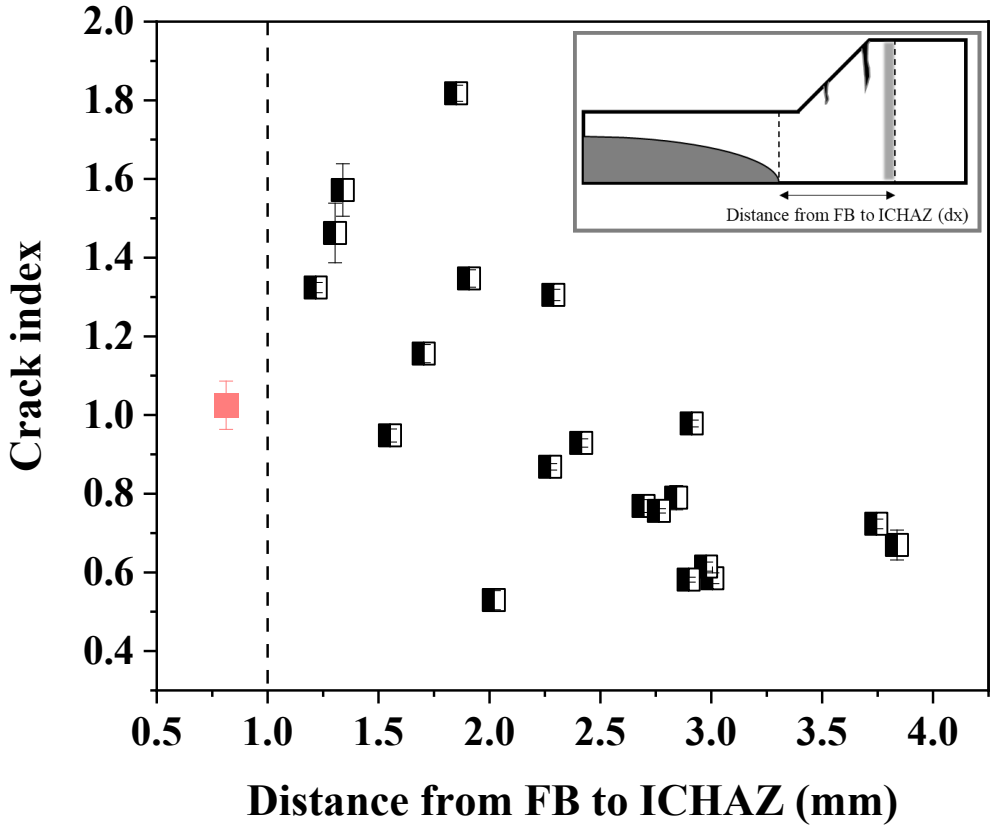
Correlate the temperature gradient, distance from FB to ICHAZ, and LME crack index

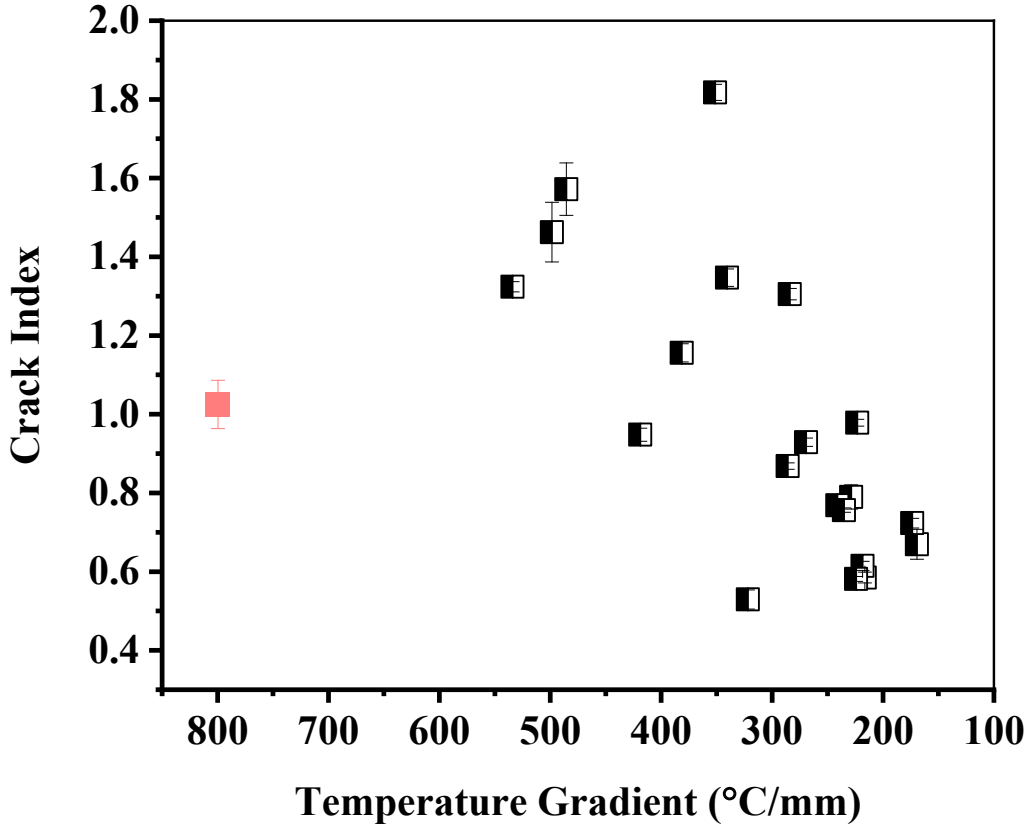
$$Thermal\ Gradient(\Delta T) = \frac{dT}{dx}$$

$T_{melting} - T_{ICHAZ}$









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CONCLUSION

- A process map was developed for the half-section geometry to match the full-section nugget diameter and the indentation depth
- It was challenging to reproduce the thermal cycle of a full-sectioned weld.
- It was possible to achieve a close CI in the shoulder area as a full-section weld
- Even though the CI index was similar between full and half-section welding, the cracking behavior exhibited disparity.
- The thermal cycle was correlated with the distance from FB to ICHAZ and its corresponding temperature gradient.
- The temperature gradient in the HAZ is highly related to the LME cracking behavior in half-sectioned welding.

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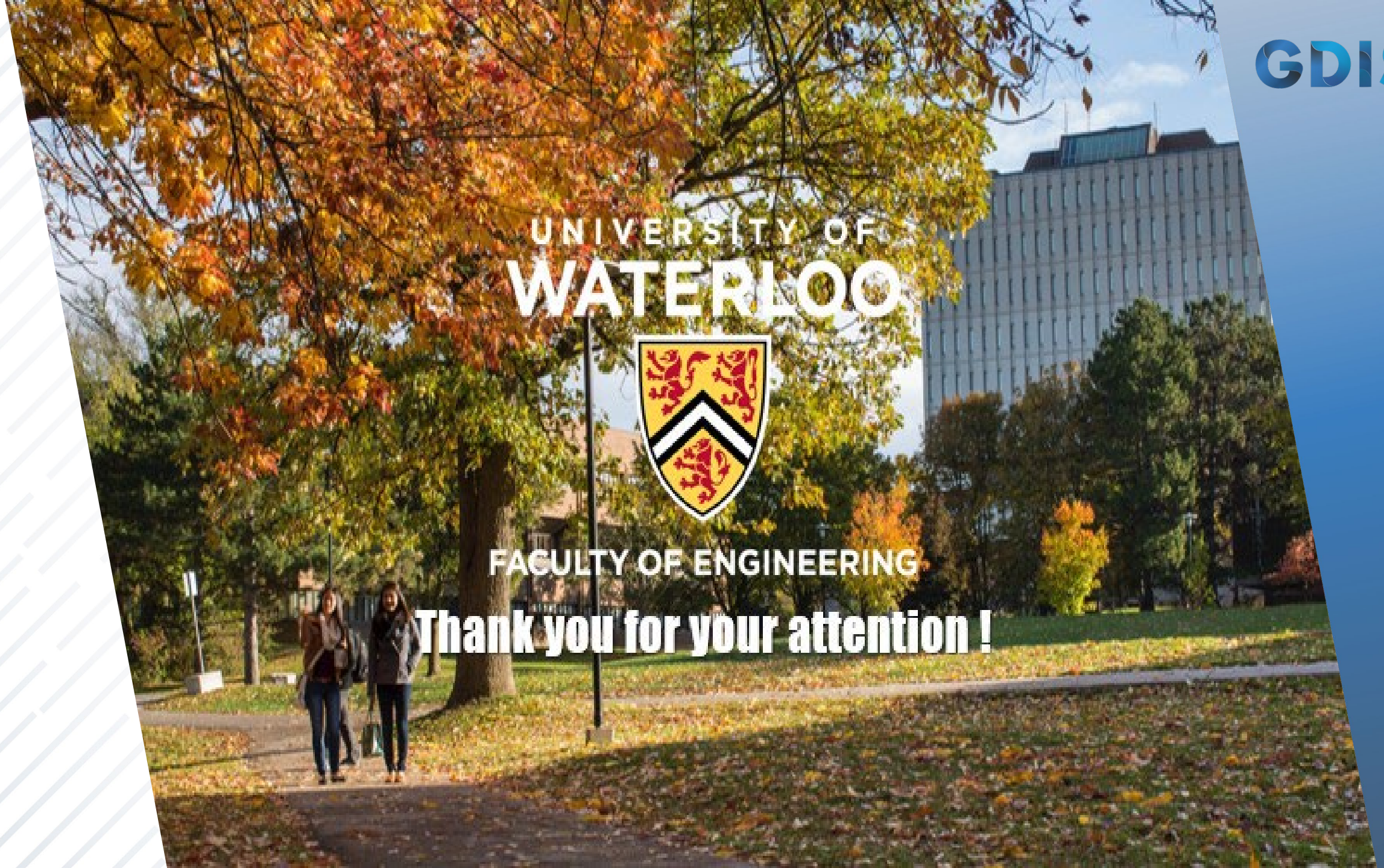
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Thank you for your attention !

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FOR MORE INFORMATION

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