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

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RESISTANCE SPOT WELDING

• Resistance spot welding in the automotive industry [1]

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

• Relative resistance across a resistance spot weld [2]
LIQUID METAL EMBRITTLEMENT

Introduction

Experimental procedure

Result

Conclusion

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

• LME cracks image on the top view (a) and cross-section image [3]
• LME cracks image on the top view (a) and cross-section image [3]
• EBSD image of LME cracks, Zn penetration along the grain boundaries [4]
• Mechanical property degradation after LME [5]

• Relationship between sudden temperature drop and tensile stress [6]
• Schematic of half-sectioned RSW [7].

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

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

Why half-sectioned welding is needed?

- Limitation of Gleeble test and Computed simulation
  - Not able to analyze how welding parameters affect the LME cracking behavior in Gleeble simulation.
  - 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

<table>
<thead>
<tr>
<th>50% welding current and Force.</th>
<th>60% of welding current and 70% of Force.</th>
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<tbody>
<tr>
<td>Cho, Y. et al [12]</td>
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- the optimized half-sectioned welding parameter is not widely recognized.

- This study aims to validate the half-sectioned welding for analysis of LME crack.

- Existing study considered only power density and contact area.
**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

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Half-sectioned RSW setup

Half-sectioned 6R50 electrode

Electrode force (%5.4 kN) vs. Welding current (% I_{max})

Welding condition
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]
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.

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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.

\[
\text{Crack index} = \frac{nL}{t}
\]

“Number of cracks per weld”
“Lognormal median crack length”
“Sheet thickness”

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LME CI INDEX

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

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

- Nugget Diameter: 7.20 ± 0.63 mm
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LME cracking behavior of Full-sectioned and Half-sectioned welding

Full-sectioned

MCL (maximum crack length): 88.1 ± 8.6 μm

Half-sectioned

MCL (maximum crack length): 464.4 ± 82.05 μm
Ascertaining 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

\[ \text{Thermal Gradient}(\Delta T) = \frac{dT}{dx} \]

\[ T_{\text{melting}} - T_{\text{ICHAZ}} \]

**Introduction**

**Experimental procedure**

**Result**

**Conclusion**
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.
REFERENCE


Thank you for your attention!
FOR MORE INFORMATION

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