Influence of Electrode and Welding Parameters During Resistance Spot Welding of Hot-Stamped Ultra-High Strength Steel Sheets

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Introduction

Ref. ArcelorMittal
Properties of Hot-Stamped Steels

No spring-back
Complex geometries
Very high Strength (1500 MPa)

Hot-stamped “Boron steels”

Properties in-use
TS = 1400-1600 MPa
YS = 1000-1200 MPa
E% = 5 %
During the heat-treatment (900 to 950°C – 5 to 10 min) the coating is transformed into an alloyed intermetallic layer (Al, Fe, Si)
→ High Adhesion
→ High Roughness
→ No scale!

Ref. Autosteel.org
Motivations

• Narrow acceptable current range.
• Large alloying elements such as Mn and Cr make the welding condition difficult compared to conventional high-strength steel.
• Effect of Al-Si coating on weld properties.
• Poor electrode service life due to presence of Al-Si coating (25-30 µm).
• Most of the cases failure occurs as interfacial mode due to higher base metal strength.
Objectives

✓ To assess the contribution of a TiC/Ni multilayered coating on the life of copper electrodes (Paracap™) during resistance spot welding.

✓ To enhance the reliability of the welds by using modified electrodes.

✓ To investigate the effect of high current with short pulse times on the joint strength and microstructure.
Standard electrode (RWMA FB25-6mm)  
Modified electrode (Paracap™)  
Coated Paracap™ with internal cooling fins

- USIBOR® 1500P (1.5 mm)
- Al-Si Coated (25-30 µm)
- Heated to 930°C for 5 to 10 minutes, and cooled at a rate of >50°C/s
- Hardness 480-500 HV
## Welding Parameters

### Conditions examined using SORPAS

<table>
<thead>
<tr>
<th>Condition Number</th>
<th>Number of Pulses</th>
<th>Current (kA)</th>
<th>Impulse time (Cycles)</th>
<th>Force (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4</td>
<td>12-7-7-7</td>
<td>4-8-8-8</td>
<td>900</td>
</tr>
<tr>
<td>B</td>
<td>4</td>
<td>12-7-7-7</td>
<td>2-8-8-8</td>
<td>900</td>
</tr>
<tr>
<td>C</td>
<td>4</td>
<td>12-7-7-7</td>
<td>4-10-10-10</td>
<td>900</td>
</tr>
<tr>
<td>D</td>
<td>4</td>
<td>12-8-8-8</td>
<td>2-10-10-10</td>
<td>900</td>
</tr>
<tr>
<td>E</td>
<td>5</td>
<td>12-7-7-7-7</td>
<td>2-10-10-10-10</td>
<td>900</td>
</tr>
</tbody>
</table>
Preliminary SORPAS® Outputs

<table>
<thead>
<tr>
<th>Condition Number</th>
<th>Nugget Diameter (mm)</th>
<th>Nugget Height (mm)</th>
<th>Expulsion Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>6.312</td>
<td>2.720</td>
<td>Electrode Interface</td>
</tr>
<tr>
<td>B</td>
<td>6.244</td>
<td>2.672</td>
<td>None</td>
</tr>
<tr>
<td>C</td>
<td>6.481</td>
<td>2.766</td>
<td>Electrode Interface</td>
</tr>
<tr>
<td>D</td>
<td>6.956</td>
<td>2.662</td>
<td>Faying Interface</td>
</tr>
<tr>
<td>E</td>
<td>6.463</td>
<td>2.670</td>
<td>Faying Interface</td>
</tr>
</tbody>
</table>

Selected for further experimental comparison
## Experimental Comparison

### Parameters Studied

<table>
<thead>
<tr>
<th>Schedule Number</th>
<th>Number of pulses</th>
<th>Current per pulse (kA)</th>
<th>Pulse time (Cycles)</th>
<th>Electrode Force (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>12-7-7-7-7</td>
<td>2-10-10-10-10</td>
<td>4.0</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>12-8-8-8</td>
<td>2-10-10-10</td>
<td>4.0</td>
</tr>
</tbody>
</table>

[Calculated Nugget]

[Thermal Cycles]
Effect of Electrodes

Welds produced using Schedule 1
Mechanical Properties

First 3 tests showed only interfacial fracture

2 tests showed interfacial fracture, and 1 nugget pullout
Tensile Strength after 300 Welds

Required Minimum Strength = 14 kN
Electrode Face Growth

- Uncoated
- Coated ParaCap

Electrode Face Diameter (mm) vs. Number of Welds
Electrode Thermal Softening

Cooling fins increased thermal gradients and suppressed softening

Vicker's Hardness (HV)

Position from contact surface (mm)

- Coated electrode
- Uncoated electrode
Comparison of Weld Schedules using Paracap™ Electrodes

- The average cooling rate was 208°C/s calculated for Schedule 2, while for Schedule 1 the cooling rate was 462°C/s
- How does this influence nugget hardness and fracture strength?
Slightly higher hardness for Schedule 1 is consistent with higher cooling rate.
Schedule 1 is slightly more refined, consistent with smaller martensite packet size reported with cooling rates $>400^\circ$C/s.
• Multivariant carbides (leaf-like and needle-like) are observed in both cases; some film-like retained austenite
• Presence of carbides indicates autotempering occurred
Microstructures Analysis – HAZ – OM

(a) Schedule 1

BM  SCHAZ  ICHAZ  UCHAZ

(b) Schedule 2

BM  SCHAZ  ICHAZ  UCHAZ
• Microstructures composed of fine grained martensite, and no significant difference between welding conditions
## Results Summary – Tensile Tests

<table>
<thead>
<tr>
<th>Weld Parameters</th>
<th>Peak Load (kN)</th>
<th>Average Peak Load (kN)</th>
<th>Extension (mm)</th>
<th>Average Extension (mm)</th>
<th>Failure Mode</th>
<th>Nugget diameter (mm)</th>
<th>Average nugget diameter (mm)</th>
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</thead>
<tbody>
<tr>
<td>Schedule 1</td>
<td>10.86</td>
<td>16.43 ±4.7</td>
<td>2.6</td>
<td>2.75 ±0.19</td>
<td>IF</td>
<td>7.34</td>
<td>6.99 ±0.53</td>
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<tr>
<td></td>
<td>14.44</td>
<td></td>
<td>3</td>
<td></td>
<td>PO</td>
<td>7.24</td>
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<tr>
<td></td>
<td>18.76</td>
<td></td>
<td>2.6</td>
<td></td>
<td>IF</td>
<td>6.20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>21.64</td>
<td></td>
<td>2.8</td>
<td></td>
<td>IF</td>
<td>7.20</td>
<td></td>
</tr>
<tr>
<td>Schedule 2</td>
<td>20.63</td>
<td>21.13 ±2.7</td>
<td>3.32</td>
<td>3.11 ±0.36</td>
<td>IF</td>
<td>7.74</td>
<td>7.28 ±0.48</td>
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<tr>
<td></td>
<td>23.51</td>
<td></td>
<td>2.8</td>
<td></td>
<td>IF</td>
<td>7.11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>17.53</td>
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<td>3.5</td>
<td></td>
<td>PO</td>
<td>7.59</td>
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<tr>
<td></td>
<td>22.86</td>
<td></td>
<td>2.8</td>
<td></td>
<td>IF</td>
<td>6.68</td>
<td></td>
</tr>
</tbody>
</table>

IF: interfacial; PO: pull-out
Conclusions

• Modified ParaCap™ electrodes provided higher life due to coating and enhanced cooling from internal fins
• It was possible to produce at least 300 welds using modified coated electrode without compromising weld strength
• A 4-pulse welding schedule using 12-8-8-8 kA provided slightly improved mechanical properties, even though weld nugget hardness was slightly reduced due to a reduced cooling rate, compared to a 5 pulse 12-7-7-7-7 kA profile
Thank you

Acknowledgements:

Questions & Comments?