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The Auto/Steel Partnership would like to acknowledge the contributions of the Gas Metal Arc Welding of Advanced High Strength Steels Team in support of this project.

- Ted Coon, Ford
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- Mark Guegel, GM
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- Robert Geisler, GM
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- AK Khosrovaneh, GM
- Yekta Oenguen, GM
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- Shawn Kruczyk, Martinrea
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- Michael White, Auto/Steel Partnership
The purpose of this project is to evaluate the effects of gas metal arc welding (GMAW) on AHSS and to identify the impact of filler metal type on joint strength. The results of this investigation may be used as a basis to further develop appropriate welding parameters and processes for AHSS to meet design requirements and may allow for the development of a common test procedure for OEMs, Suppliers and the Steel Company members to establish gas metal arc weldability.
## PROJECT APPROACH - TEST MATRIX

<table>
<thead>
<tr>
<th>Grade</th>
<th>Thickness (mm)</th>
<th>Coating</th>
<th>Filler Metal</th>
<th>ASTM E-8 Tensile</th>
<th>X-ray Inspection</th>
<th>Quasi-static Shear Tension</th>
<th>Cross-section</th>
<th>Microhardness Traverse</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR700Y750T-LA-UC</td>
<td>2.5</td>
<td>uncoated</td>
<td>ER80S-D2</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ER100S-G</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>CR600Y980T-RA-HE-UC</td>
<td>1.4</td>
<td>uncoated</td>
<td>ER70S-6</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>CR600Y980T-RA-HE-GI</td>
<td>1.4</td>
<td>GI</td>
<td>ER70S-6</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>CR600Y980T-RA-HE-UC</td>
<td>2.0</td>
<td>uncoated</td>
<td>ER70S-6</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>CR1000Y1200T-RA-SE-GI</td>
<td>1.6</td>
<td>GI</td>
<td>ER70S-6</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>
Welds were made in the 1F position
0.1 mm shims were used to produce controlled sheet gaps for zinc coated materials
0.035” wire was used
90% Argon 10% CO₂ shielding gas was used
Targeted weld sizes are shown

<table>
<thead>
<tr>
<th>Minimum Tensile Strength (MPa)</th>
<th>%C</th>
<th>%Mn</th>
<th>%Si</th>
<th>%Cr</th>
<th>%Ni</th>
<th>%Mo</th>
<th>%S</th>
<th>%P</th>
<th>%Cu</th>
<th>%Al</th>
<th>%V</th>
</tr>
</thead>
<tbody>
<tr>
<td>ER70S-6</td>
<td>485</td>
<td>0.06-0.15</td>
<td>1.40-1.85</td>
<td>0.80-1.15</td>
<td>0.15 (max)</td>
<td>-</td>
<td>0.15 (max)</td>
<td>0.035 (max)</td>
<td>0.025 (max)</td>
<td>0.50 (max)</td>
<td>-</td>
</tr>
<tr>
<td>ER80S-D2</td>
<td>550</td>
<td>0.07-0.12</td>
<td>1.60-2.10</td>
<td>0.50-0.80</td>
<td>-</td>
<td>-</td>
<td>0.40 (max)</td>
<td>0.025 (max)</td>
<td>0.025 (max)</td>
<td>0.50 (max)</td>
<td>-</td>
</tr>
<tr>
<td>ER100S-G*</td>
<td>690</td>
<td>0.10</td>
<td>1.55</td>
<td>0.57</td>
<td>0.27</td>
<td>0.88</td>
<td>0.48</td>
<td>&lt;0.005</td>
<td>0.01</td>
<td>0.09</td>
<td>0.00</td>
</tr>
</tbody>
</table>

*typical composition shown
Source: www.lincolnelectric.com
Test specimens were taken from the center of the welded plates to avoid the weld starts and stops.

X-ray images correspond to the locations of the shear tension (ST) specimens.

Metallurgical (MET) specimens were taken from the locations shown.
APPROACH - BASE METAL TENSILE TEST SPECIMEN DIMENSIONS

Sheet-Type, 12.5 mm [0.500 in.] Wide

<table>
<thead>
<tr>
<th>mm [in.]</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>G—Gage length</td>
<td>50.0 ± 0.1</td>
</tr>
<tr>
<td>W—Width</td>
<td>12.5 ± 0.2</td>
</tr>
<tr>
<td>T—Thickness</td>
<td>12.5 [0.500]</td>
</tr>
<tr>
<td>R—Radius of fillet, min</td>
<td>200 [8]</td>
</tr>
<tr>
<td>L—Overall length, min</td>
<td>57 [2.25]</td>
</tr>
<tr>
<td>A—Length of reduced section, min</td>
<td>50 [2]</td>
</tr>
<tr>
<td>B—Length of grip section, min</td>
<td>20 [0.750]</td>
</tr>
<tr>
<td>C—Width of grip section, approximate</td>
<td></td>
</tr>
</tbody>
</table>
BASE METAL TENSILE TEST

1.4 mm CR600Y980T-RA-HE-UC (Lot 115)
BASE METAL TENSILE TEST

1.4 mm CR600Y980T-RA-HE-GI (Lot 116)
BASE METAL TENSILE TEST

2.0 mm CR600Y980T-RA-HE-UC (Lot 124)
BASE METAL TENSILE TEST

1.6 mm CR1000Y1200T-RA-SE-GI (Lot 107)

Engineering Stress (MPa)

Engineering Strain (mm/mm)
## WELDING PARAMETERS

<table>
<thead>
<tr>
<th>Grade</th>
<th>Thickness (mm)</th>
<th>Coating</th>
<th>Process</th>
<th>Filler Metal</th>
<th>Current (A)</th>
<th>Voltage (V)</th>
<th>Travel Speed (in/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR700Y750T-LA-UC</td>
<td>2.5</td>
<td>uncoated</td>
<td>GMAW</td>
<td>ER80S-D2</td>
<td>150</td>
<td>19.0</td>
<td>40</td>
</tr>
<tr>
<td>CR600Y980T-RA-HE-UC</td>
<td>1.4</td>
<td>uncoated</td>
<td>GMAW</td>
<td>ER100S-G</td>
<td>150</td>
<td>20.0</td>
<td>40</td>
</tr>
<tr>
<td>CR600Y980T-RA-HE-GI</td>
<td>1.4</td>
<td>GI</td>
<td>GMAW</td>
<td>ER70S-6</td>
<td>105</td>
<td>15.0</td>
<td>50</td>
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<tr>
<td>CR600Y980T-RA-HE-UC</td>
<td>2.0</td>
<td>uncoated</td>
<td>GMAW</td>
<td>ER70S-6</td>
<td>120</td>
<td>20.0</td>
<td>50</td>
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<tr>
<td>CR1000Y1200T-RA-SE-GI</td>
<td>1.6</td>
<td>GI</td>
<td>GMAW</td>
<td>ER70S-6</td>
<td>85</td>
<td>18.5</td>
<td>20</td>
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</table>
# WELD SIZE

<table>
<thead>
<tr>
<th>Grade</th>
<th>Thickness (mm)</th>
<th>Coating</th>
<th>Process</th>
<th>Filler Metal</th>
<th>Leg Length L1 (mm)</th>
<th>Leg Length L2 (mm)</th>
<th>Penetration (mm)</th>
<th>Theoretical Throat (mm)</th>
<th>Convexity (mm)</th>
<th>Toe Angle (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR700Y750T-LA-UC</td>
<td>2.5</td>
<td>uncoated</td>
<td>GMAW</td>
<td>ER80S-D2</td>
<td>2.5</td>
<td>3.8</td>
<td>0.7</td>
<td>2.1</td>
<td>0.5</td>
<td>142</td>
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<tr>
<td></td>
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<td></td>
<td>GMAW</td>
<td>ER100S-G</td>
<td>2.5</td>
<td>3.9</td>
<td>0.9</td>
<td>2.1</td>
<td>0.9</td>
<td>150</td>
</tr>
<tr>
<td>CR600Y980T-RA-HE-UC</td>
<td>1.4</td>
<td>uncoated</td>
<td>GMAW</td>
<td>ER70S-6</td>
<td>1.4</td>
<td>3.2</td>
<td>0.6</td>
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<td>0.4</td>
<td>166</td>
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<tr>
<td>CR600Y980T-RA-HE-GI</td>
<td>1.4</td>
<td>Gi</td>
<td>GMAW</td>
<td>ER70S-6</td>
<td>2.1</td>
<td>3.9</td>
<td>0.6</td>
<td>1.5</td>
<td>0.7</td>
<td>148</td>
</tr>
<tr>
<td>CR600Y980T-RA-HE-UC</td>
<td>2.0</td>
<td>uncoated</td>
<td>GMAW</td>
<td>ER70S-6</td>
<td>1.9</td>
<td>3.5</td>
<td>0.5</td>
<td>1.7</td>
<td>0.5</td>
<td>162</td>
</tr>
<tr>
<td>CR1000Y1200T-RA-SE-GI</td>
<td>1.6</td>
<td>Gi</td>
<td>GMAW</td>
<td>ER70S-6</td>
<td>2.1</td>
<td>4.3</td>
<td>0.7</td>
<td>1.6</td>
<td>0.7</td>
<td>157</td>
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</tbody>
</table>
RESULTS - 2.5 MM HR700Y750T-LA-UC ER80S-D2 FILLER METAL
RESULTS - 2.5 MM HR700Y750T-LA-UC ER100S-G FILLER METAL
RESULTS - 1.4 MM CR600Y980T-RA-HE-UC ER70S-6 FILLER METAL
RESULTS - 1.4 MM CR600Y980T-RA-HE-GI ER70S-6 FILLER METAL
RESULTS – X-RAY IMAGES
1.4 MM CR600Y980T-RA-HE-GI, ER70S-6 FILLER METAL
RESULTS - 2.0 MM CR600Y980T-RA-HE-UC ER70S-6 FILLER METAL
RESULTS - 1.6 MM CR1000Y1200T-RA-SE-GI ER70S-6 FILLER METAL
RESULTS – X-RAY IMAGES
1.6 MM CR1000Y1200T-RA-SE-GI, ER70S-6 FILLER METAL
PROJECT RESULTS - SUMMARY

ER70S-6 minimum tensile strength: 485 MPa
ER80S-D2 minimum tensile strength: 550 MPa
ER100S-G minimum tensile strength: 690 MPa

Nominal joint strength was calculated using the steel sheet cross-section dimensions.
Joint efficiency was calculated as the nominal joint strength divided by parent metal tensile strength, expressed as a percentage.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Thickness (mm)</th>
<th>Coating</th>
<th>Process</th>
<th>Filler Metal</th>
<th>Base Metal Microhardness (HV500g)</th>
<th>Minimum Microhardness (HV500g)</th>
<th>Minimum Microhardness Location</th>
<th>Joint Peak Load (kN)</th>
<th>Nominal Joint Strength (MPa)</th>
<th>Joint Efficiency (%)</th>
<th>Porosity (X-ray) (%)</th>
<th>Fracture Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR700Y750T-LA-UC</td>
<td>2.5</td>
<td>uncoated</td>
<td>GMAW</td>
<td>ER80S-D2</td>
<td>278</td>
<td>238</td>
<td>heat-affected zone</td>
<td>89.0</td>
<td>685</td>
<td>0.83</td>
<td>n/a</td>
<td>heat-affected zone</td>
</tr>
<tr>
<td>CR600Y980T-RA-HE-UC</td>
<td>1.4</td>
<td>uncoated</td>
<td>GMAW</td>
<td>ER70S-6</td>
<td>273</td>
<td>270</td>
<td>base metal</td>
<td>53.6</td>
<td>750</td>
<td>0.73</td>
<td>n/a</td>
<td>weld metal</td>
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<tr>
<td>CR600Y980T-RA-HE-UC</td>
<td>1.4</td>
<td>GI</td>
<td>GMAW</td>
<td>ER70S-6</td>
<td>277</td>
<td>265</td>
<td>weld metal</td>
<td>60.3</td>
<td>846</td>
<td>0.80</td>
<td>0.53</td>
<td>weld metal</td>
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<tr>
<td>CR1000Y1200T-RA-SE-GI</td>
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<td>GI</td>
<td>GMAW</td>
<td>ER70S-6</td>
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<td>weld metal</td>
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<td>852</td>
<td>0.67</td>
<td>0.77</td>
<td>weld metal</td>
</tr>
</tbody>
</table>
PROJECT RESULTS - SUMMARY

• Quality welds were achieved with all test materials.
• Zinc coated steels were able to be welded with average area percent porosity less than 1% using appropriate welding schedules and the test conditions used.
• Fractures occurred in the heat affected zone, weld metal, or near the weld fusion line.
• Fracture location did not necessarily correspond to the areas with the lowest microhardness.
• Joint efficiency ranged from 67% (CR1000Y1200T-RA-SE-GI with ER70S-6 filler metal) to 84% (HR700Y750T-LA-UC with ER100S-G filler metal).
• Nominal joint strength ranged from 685 MPa (HR700Y750T-LA-UC with ER80S-D2 filler) to 852 MPa (CR1000Y1200T-RA-SE-GI with ER70S-6 filler metal).
• The data obtained using the test procedure defined in this project quantifies joint characteristics and could be used as a basis for developing a GMAW qualification procedure.
FOR MORE INFORMATION

Visit: www.a-sp.org

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Presentations will be available for download on SMDI’s website on Wednesday, May 22