Stainless Steel
Corrosion Resistant Overlay Study
Submerged Arc Welding (SAW)
Project 50107-I Final Report

A Technical Bulletin from
ARC Specialties Engineering & Consulting Services
December 12, 2012 Houston, TX
Objectives

• Compare four (4) commercially-available stainless steel SAW fluxes in terms of:
  – Performance
    • Wetting of weld bead
    • Slag peeling or release from weld bead
  – Properties of corrosion resistant overlay (CRO)
    • Chemistry
    • Ferrite Number (FN)
Objectives

• Determination of the need for 309L butter layer on carbon steel before applying 316L
  – Comparing chemistry and FN of first layer
• Determination of the effect of welding parameters on FN for stainless steel overlays
  – Key variables
    • Amperage
    • Weld travel speed
    • Weld pass step-over or bead overlap
Study conditions - fluxes

• Stainless steel fluxes evaluated
  – Neutral:
    • RECORD IND 24 and ESAB OK 10.93
      – Both provided same weld bead appearance and performance, so RECORD IND 24 used (another ESAB flux was evaluated)
  – Chromium-compensated
    • Sandvik 34WF and RECORD IN
      – Both provided same weld bead appearance and performance, so Sandvik 34WF used (another RECORD flux was evaluated)
    • Lincoln ST-100
    • ESAB OK 10.94
• Welds were made on 1 in [25mm] carbon steel test coupons
• Minimum preheat and interpass 500°F
  Maximum interpass 650°F
• Electrodes: 0.094 in [2.5mm] 309L and 316L
• Contact tip-to-work (CTTW) distance = 3/4 - 7/8 in [19 - 22mm]
• Fluxes were heated overnight at 300°F
Study conditions – welding parameter selection

• Initial welding parameters selected based on:
  – Minimizing dilution in first layer to
    • Meet minimum chemistry requirements (8% Ni & 16% Cr)
    • Have sufficient ferrite present to prevent cracking
      – Minimum FN of 3.5
  – First layer thickness about 1/8 in [3mm]
    • Chemistry for WPS measured on a surface 0.125in [3mm] above original base metal surface, so greater assurance that the chemistry will be taken in the second layer
Effect of first layer thickness on chemistry

0.125” chemistry is in first layer

0.125” chemistry is in second layer
Weld bead thickness can be achieved through adjustments in travel speed, step-over and welding amperage

- In first two series the amperage was reduced from 300A to 200A for the 1st layer to minimize thickness
  - To flatten bead and improve wetting, the ST-100 was run at 225A
- In third series of tests, 1st layer amperage maintained at 300A
  - In two (2) of the four (4) test welds, travel speed was increased from 16 to 20 in/min to reduce weld height
Testing procedures

- Weld metal chemistry
  - Chemistry was checked with the Thermo PMI (Positive Material Identification) gun

- Ferrite Number
  - Ferrite levels checked using the Fischer Feritscope

- Prior to testing, test surface prepared with sanding disk (used only on stainless steel) to produce a clean, flat test surface
  - For some of the test surfaces, the specimen was first milled to thickness and then sanded
Test series #1 – 07-S1

- 309L 1\textsuperscript{st} layer - beads 6 in [150mm] long
- 316L 2\textsuperscript{nd} layer - beads 4 in [100mm] long so some of first layer still exposed for testing
- Fluxes for test welds:
  - 07-S1-A: Soudokay RECORD IND 24 (neutral)
  - 07-S1-B: ESAB OK 10.94 (chromium-compensated)
  - 07-S1-C: Lincoln ST-100 (chromium-compensated)
  - 07-S1-D: Sandvik 34WF (chromium-compensated)
07-S1 - Weld appearance

07-S1-A – Record IND 24

07-S1-B – ESAB OK 10.94

07-S1-C – Lincoln ST 100

07-S1-D – Sandvik 34WF
Weld series #1 – 07-S1

- Weld chemistry and FN readings were taken at four (4) locations
  - Surface of first layer
  - Surface of second layer
  - 0.250 in [6mm] above original surface
  - 0.125 in [3mm] above original surface

- Transverse side bends were used to verify fusion and detect presence of micro fissuring
  - All side bends were bent around 1½ in [38mm] diameter to subject them to ~20% elongation
  - All were acceptable
Typical test coupon & side bends

Chemistry:

First Layer
Second layer
0.250”
0.125”
### 07-S1 - Test results

1\textsuperscript{st} layer was 309L  
2\textsuperscript{nd} layer was 316L

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Manuf.</th>
<th>Designation</th>
<th>Type</th>
<th>Flux</th>
<th>Layer 1 - Surface</th>
<th>Layer 2 - Surface</th>
<th>0.250&quot; above BM</th>
<th>0.125&quot; above BM</th>
</tr>
</thead>
<tbody>
<tr>
<td>07-S1-A</td>
<td>Soudokay</td>
<td>IND 24</td>
<td>Neutral</td>
<td>0.6</td>
<td>13.1 / 21.4 / 0.1</td>
<td>12.3 / 18.8 / 2.0</td>
<td>11.6 / 18.7 / 2.0</td>
<td>12.4 / 19.1 / 1.9</td>
</tr>
<tr>
<td>07-S1-B</td>
<td>ESAB</td>
<td>10.94</td>
<td>Cr+</td>
<td>6.0</td>
<td>12.1 / 22.1 / 0.1</td>
<td>11.5 / 20.2 / 1.9</td>
<td>11.9 / 20.2 / 1.9</td>
<td>11.7 / 20.2 / 1.9</td>
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<tr>
<td>07-S1-C</td>
<td>Lincoln</td>
<td>ST-100</td>
<td>Cr+</td>
<td>4.0</td>
<td>11.2 / 21.2 / 0.1</td>
<td>11.5 / 19.7 / 1.7</td>
<td>11.4 / 19.6 / 1.8</td>
<td>11.4 / 19.5 / 1.7</td>
</tr>
<tr>
<td>07-S1-D</td>
<td>Sandvik</td>
<td>34WF</td>
<td>Cr+</td>
<td>3.5</td>
<td>12.5 / 21.3 / 0.1</td>
<td>11.9 / 19.9 / 1.8</td>
<td>12.1 / 20.0 / 1.7</td>
<td>11.8 / 19.7 / 1.7</td>
</tr>
</tbody>
</table>

### Chemical Compositions and Ferrite Numbers
• Same as Series #1, except that 316L used for both 1st and 2nd layers – to determine if 309L buttering layer required for acceptable results
  – 316L wire had a FN of 6.6 (per WRC 1992)
• Fluxes for test welds:
  – 07-S2-A: Soudokay RECORD IND 24 (neutral)
  – 07-S2-B: ESAB OK 10.94 (chromium-compensated)
  – 07-S2-C: Lincoln ST-100 (chromium-compensated)
  – 07-S2-D: Sandvik 34WF (chromium-compensated)
07-S2 - Weld appearance

07-S2-A – RECORD IND 24

07-S2-B – ESAB OK 10.94

07-S2-C – Lincoln ST-100

07-S2-D – Sandvik 34WF
### Chemical Compositions and Ferrite Numbers

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<th>Manuf.</th>
<th>Desig.</th>
<th>Type</th>
<th>Flux</th>
<th>Layer 1 - Surface</th>
<th>Layer 2 - Surface</th>
<th>0.25O&quot; above BM</th>
<th>0.125&quot; above BM</th>
</tr>
</thead>
<tbody>
<tr>
<td>07-S2-A</td>
<td>Soudokay</td>
<td>IND 24</td>
<td>Neutral</td>
<td>Neutral</td>
<td>11.7 / 16.8 / 2.4</td>
<td>12.5 / 18.0 / 2.6</td>
<td>12.3 / 17.8 / 2.5</td>
<td>11.8 / 17.8 / 2.5</td>
</tr>
<tr>
<td>07-S2-B</td>
<td>ESAB</td>
<td>10.94</td>
<td>Cr+</td>
<td>Neutral</td>
<td>11.0 / 18.2 / 2.3</td>
<td>11.7 / 19.8 / 2.4</td>
<td>12.1 / 19.6 / 2.5</td>
<td>12.1 / 19.3 / 2.5</td>
</tr>
<tr>
<td>07-S2-C</td>
<td>Lincoln</td>
<td>ST-100</td>
<td>Cr+</td>
<td>Neutral</td>
<td>10.0 / 18.1 / 2.2</td>
<td>11.1 / 19.5 / 2.3</td>
<td>11.6 / 13.6 / 2.3</td>
<td>11.0 / 18.9 / 2.4</td>
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<tr>
<td>07-S2-D</td>
<td>Sandvik</td>
<td>34WF</td>
<td>Cr+</td>
<td>Neutral</td>
<td>10.2 / 16.5 / 2.1</td>
<td>12.2 / 18.6 / 2.4</td>
<td>11.8 / 18.7 / 2.4</td>
<td>11.4 / 18.6 / 2.5</td>
</tr>
</tbody>
</table>

1\textsuperscript{st} layer was 316L  
2\textsuperscript{nd} layer was 316L
• Purpose: determine effect of process parameters on overlay chemistry and FN
  – All welds were made with ESAB OK 10.94 flux
  – One layer using 316L electrode, 6.6 FN WRC
  – All welds were made at 300A and 30V

• Travel speed (TS) and step-over (SO) process variables
  – 07-S4-A: TS = 16 in/min [6.7mm/sec]; SO = 1X
  – 07-S4-B: TS = 16 in/min [6.7mm/sec]; SO = 1.5X
  – 07-S4-C: TS = 20 in/min [8.4mm/sec]; SO = 1X
  – 07-S4-D: TS = 20 in/min [8.4mm/sec]; SO = 1.5X
07-S4 - Weld appearance

S4-A – 300A, 30V, 16 ipm, SO=1X
S4-B – 300A, 30V, 16 ipm, SO=1.5X
S4-C – 300A, 30V, 20 ipm, SO=1X
S4-D – 300A, 30V, 20 ipm, SO=1.5X
Process Parameters

300 amps, 30 volts, 16 ipm, Step-over 1X

1st layer - 300 amps, 30 volts, 16 ipm, Step-over 1X
2nd layer - 300 amps, 30 volts, 16 ipm, Step-over 1.5X
Process Parameters

300 amps, 30 volts, 20 ipm, Step-over 1X

300 amps, 30 volts, 20 ipm, Step-over 1.5X
## 07-S4 - Test results

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Welding Parameters</th>
<th>Chemical Analyses and FN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Amps / Volts</td>
<td>TS, in/min</td>
</tr>
<tr>
<td>07-S4-A</td>
<td>300A / 30V</td>
<td>16</td>
</tr>
<tr>
<td>07-S4-B</td>
<td>300A / 30V</td>
<td>16</td>
</tr>
<tr>
<td>07-S4-C</td>
<td>300A / 30V</td>
<td>20</td>
</tr>
<tr>
<td>07-S4-D</td>
<td>300A / 30V</td>
<td>20</td>
</tr>
</tbody>
</table>
Conclusions

• Flux type influences both chemistry and FN
  – Chromium-compensated types help replace Cr losses across arc, providing improved chemistry and FN

• Travel speed, amperage and step-over affect dilution which in turn controls chemistry and FN
  – Ferrite content determines cracking potential

• 316L can be used without a 309L butter layer with proper control of parameters to minimize dilution