Submerged Arc Welding:

A discussion of the welding process and how welding parameters affect the chemistry of Corrosion Resistant Overlays (CRO)
Submerged Arc Welding (SAW)

• Part 1
  – The SAW welding process

• Part 2
  – Effects of welding parameters on weld metal chemistry of corrosion resistant overlays (CRO)
Process Characteristics

• High deposition rates – compared to other welding processes
• Faster travel speeds – compared to other welding processes
• Economical - High deposition rates and high travel speeds reduce overall costs
SAW Process Advantages

• Simple - mechanized process, easy to train machine operators
• Clean environment - minimal smoke or fumes
• Operator friendly - no visible arc, no spatter
Process Limitations

- Welding is done in the flat position
  - Can your part be positioned to weld in the flat position?
  - Can circumferential welds be rotated?
SAW Process

- Heat of the arc melts the wire, flux and plate.
- Fused flux shapes and protects weld metal.
- Flux covers weld zone in front of wire.
- Weld metal.

Diagram showing the welding process with labels for each component.
Welding Power Supply

• Supplies electrical power to the electrode - The heat of the arc melts the electrode and base plate to form the weld bead.

• Electrical current can be:
  – AC or DC
  – CV (constant voltage) or CC (constant current)
Influence of Polarity

- **DCEP** - Deep penetration
- **DCEN** - Shallow penetration
- **AC** - Penetration is in between DCEP and DCEN
Function of the Wire

• Carries the welding current for the welding arc
• Weld filler metal
• Weld metal chemistry
• Weld metal mechanical properties
Function of the Flux

- Molten flux shields the weld pool
- Affects weld metal chemistry
- Affects weld metal mechanical properties
- Affects weld performance/characteristics
- Fluxes have variable burn-off rates
Types of Fluxes

• Neutral
  – Multi-pass, unlimited thickness, high toughness

• Active
  – High in deoxidizers, high speed, weld over rust, limited thickness

• Alloyed
  – Addition of Cr, Ni ..., enhanced mechanical properties
Welding Variables

• Welding current
• Arc voltage
• Travel speed
• Wire size
• Wire extension
Welding Current

- Controls – Penetration and deposition rate

\[
\begin{align*}
current &= \uparrow \quad \text{penetration} \\
current &= \uparrow \quad \text{burn-off rate} \\
current &= \uparrow \quad \text{deposition rate}
\end{align*}
\]
Welding Current

500 amps @ 35 V
0.651”

600 amps @ 35 V
0.780”

20 ipm
Arc Voltage

• Arc voltage is a measure of arc length
  
  $\text{voltage} = \text{bead width}$
  
  $\text{voltage} = \text{penetration}$
Welding Voltage

500 amps @ 35 V

500 amps @ 30 V

20 ipm
Welding Voltage

600 amps @ 35 V

0.772”

0.336”

600 amps @ 28 V

0.503”

0.427”

20 ipm
Travel Speed

- Controls - penetration and volume of metal per unit length

  \[ \text{speed} = \downarrow \text{penetration} \]
  \[ \text{speed} = \downarrow \text{weld size, width, reinforcement} \]
Travel Speed

All welds made at 500 amps and 35 volts
Wire Size / Burn-off Rates

- Wire Burn-off rates (ipm) vs. Amps

Electrode Stick-out = 8X wire diameter

DCEP - 10-15% Less

DCEN - 10-15% More
Wire Stick-out

• Wire stick-out should be about 8 times the wire diameter - (1/8” wire = 1”)

• Electrical Stick-Out (ESO) - Tip-to-work distance

![Diagram showing wire stick-out](image-url)
Effects of ESO

- Longer stick-out – At the same wire feed speed, decreases welding current and penetration

- Longer stick-out – At the same current, increases deposition due to the higher burn-off rate
  - As stick-out increases, the wire feed speed must be increased to maintain the same welding current.
Effects of ESO on Deposition Rate

- 3/32” ERNiCrMo-3 wire at 250 amps

![Graph showing the effects of Electrode Stick-out (ESO) on Deposition Rate, lbs./hr.]
PART II

Effects of welding parameters on weld metal chemistry of CRO
Everyone is looking for:

- Increased production
- Increased welding speeds
- Increased deposition rates
- Reduced base metal dilution
Deposition rates for CRO

Deposition - lbs./hr.

<table>
<thead>
<tr>
<th>PROCESS</th>
<th>Deposition</th>
</tr>
</thead>
<tbody>
<tr>
<td>GTAW-HW</td>
<td>5</td>
</tr>
<tr>
<td>SAW Wire</td>
<td>15</td>
</tr>
<tr>
<td>SAW 30 mm Strip</td>
<td>25</td>
</tr>
<tr>
<td>ESW 60 mm Strip</td>
<td>50</td>
</tr>
</tbody>
</table>
Flux selection

- Good slag peeling on SS and Ni alloy
- Good edge wetting
- Cr compensating (SS)
- Cr or Ni additive (SS & Ni)
Flux selection

Slag sticking to weld bead with flux - A

After slag removal some small spots remain

Flux – B was self-peeling but still has tiger stripes
Flux selection

Free peeling slag with flux - C

Smooth surface with excellent wetting along edges of weld bead
CRO requirements for ERNiCrMo-3

- Two-layer deposit
- Thickness – 1/8” per layer, 1/4” total
- Chemistry – Fe-5 or Fe-10 at 1/8” above original surface
• Dilution – the percentage of base metal in the weld bead.

\[
\% \text{ Dilution} = \left[ \frac{B}{A+B} \right] (100)
\]
Objectives

• Determine what welding parameters control weld metal chemistry.
• Achieving Fe-10 or Fe-5 in two layers
• First layer needs to be close to 0.125” thick so second layer fusion line is below 0.125”.

• The chemistry at 1/8” needs to come out of the second layer and not the first.
Second Layer fusion line needs to be below the 1/8” above original surface. Too much penetration will cause too much dilution in the second layer chemistry.

Second layer fusion line is below the 1/8” above original surface.

There are thee small areas visible from the second layer, but it won’t pass chemistry.
Factors Affecting Chemistry

- Amperage
- Voltage
- Travel speed
- Electrical stick-out (ESO), Tip-To-Work distance
- Step-over distance
Amperage

• Effects of Amperage on chemistry and deposition rate.
• 3/32” wire, 1” ESO, 32 volts, 20 ipm

<table>
<thead>
<tr>
<th>Amps / Sample</th>
<th>250 / A</th>
<th>300 / B</th>
<th>350 / C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deposition, lbs./Hr.</td>
<td>10.7</td>
<td>13.0</td>
<td>15.5</td>
</tr>
<tr>
<td>Chemistry, % Fe</td>
<td>41.14</td>
<td>40.84</td>
<td>44.78</td>
</tr>
</tbody>
</table>

• Amperage has little effect on chemistry
Effect of Amperage on Weld Dimensions

- Bead Height
- Bead Width
- Depth of Fusion

Accuracy: 37
Voltage

- Effects of Voltage on chemistry
- 3/32” wire, 1” ESO, 250 amps, 20 ipm

<table>
<thead>
<tr>
<th>Voltage / Sample</th>
<th>28 / D</th>
<th>30 / E</th>
<th>32 / F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemistry, % Fe</td>
<td>41.07</td>
<td>40.23</td>
<td>41.55</td>
</tr>
</tbody>
</table>

- Voltage has no significant effect on chemistry
Effect of Voltage on Weld Dimensions

- **Bead Height**
- **Bead Width**
- **Depth of Fusion**

Voltage

Weld Dimensions, in
Travel Speed

- Effects of travel speed on chemistry
- 3/32” wire, 1” ESO, 250 amps, 32 volts

<table>
<thead>
<tr>
<th>Travel Speed (ipm)</th>
<th>16 / G</th>
<th>20 / H</th>
<th>24 / I</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemistry, % Fe</td>
<td>40.76</td>
<td>41.55</td>
<td>42.50</td>
</tr>
</tbody>
</table>

- Travel speed has little effect on chemistry
Travel Speed

Effect of Travel Speed on Weld Dimensions

- Bead Height
- Bead Width
- Depth of Fusion

Weld Dimensions, in

Travel Speed, in/min

[Graph showing the effect of travel speed on weld dimensions with specific data points and trend lines for each dimension]
Weld Study Constants

- All the welds for this study were made using 3/32” diameter ERNiCrMo-3 wire.
- All the remaining welds were made at 32 volts.
- All the remaining welds were made at 24 ipm travel speed.
Electrical stick-out (ESO)

• If amperage is held constant:
  • Wire feed speed must increase as ESO increases
• What happens to dilution?
• \( \% \text{ Dilution} = \left[ \frac{B}{A+B} \right] \times 100 \)
Electrical Stick-out

- Effects of electrical Stick-out on deposition rate and chemistry
- \(\frac{3}{4}”, 1\frac{3}{4}”, 1\frac{7}{8}”\) ESO at 250 amps

<table>
<thead>
<tr>
<th>ESO / Sample</th>
<th>(\frac{3}{4}” / O)</th>
<th>(1\frac{3}{4}” / P)</th>
<th>(1\frac{7}{8}” / Q)</th>
<th>(\Delta)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deposition, lbs./Hr.</td>
<td>10.7</td>
<td>11.9</td>
<td>13.0</td>
<td>21.5% &gt;</td>
</tr>
<tr>
<td>Chemistry, % Fe</td>
<td>40.90</td>
<td>38.08</td>
<td>32.68</td>
<td>20.1% &lt;</td>
</tr>
</tbody>
</table>

- Increased ESO has positive effect on deposition rate and weld chemistry.
Effects of ESO on Chemistry

Effect of Electrode Extension on Weld Chemistry

Percent Iron, Fe

ESO, in

- 40.90
- 38.08
- 32.68
Step-over, 1” ESO, 250A

- Effects of step-over on chemistry
- **3.5, 6.0, 8.0 mm step-over at 1” ESO** and 250 amps

<table>
<thead>
<tr>
<th>Step-over, mm</th>
<th>3.5 / J</th>
<th>6.0 / K</th>
<th>8.0 / L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemistry, % Fe</td>
<td>9.73</td>
<td>28.97</td>
<td>37.85</td>
</tr>
</tbody>
</table>

- Step-over has a very significant effect on weld chemistry
Step-over, 1¾” ESO, 250A

- 4.0, 5.0, 6.0 mm at 1¾” ESO and 250 amps (105 ipm)

<table>
<thead>
<tr>
<th>Step-over / Sample</th>
<th>4mm / R</th>
<th>5mm / S</th>
<th>6mm / T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemistry, % Fe</td>
<td>7.65</td>
<td>12.48</td>
<td>16.65</td>
</tr>
</tbody>
</table>
4.0, 5.0, 6.0, 8.0 mm step-over at 1” ESO and 300 amps (105 ipm)

<table>
<thead>
<tr>
<th>Step-over, mm / Sample</th>
<th>4.0 / Y</th>
<th>5.0 / Y</th>
<th>6.0 / M</th>
<th>8.0 / N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemistry, % Fe</td>
<td>9.20</td>
<td>19.71</td>
<td>27.34</td>
<td>35.87</td>
</tr>
</tbody>
</table>
Effects of Step-over

Effect of Step-over on Weld Chemistry

20% line

- 250A, 1 in ESO
- 300A, 1 in ESO
- 250A, 1 3/4 in ESO

Percent Iron (Fe)

Step-over (mm)
Two Layers, 1” ESO, 250A/300A

- 1” ESO, 250 amps (86 ipm) 1<sup>st</sup> layer
- 1” ESO, 300 amps (105 ipm) 2<sup>nd</sup> layer
- Wire feed changed for amperage
- 4.0 mm/5.0 mm step – good chemistry
- 4.0 mm/6.0 mm step – good chemistry

<table>
<thead>
<tr>
<th>Parameters / Z</th>
<th>1&lt;sup&gt;st&lt;/sup&gt; Layer</th>
<th>2&lt;sup&gt;nd&lt;/sup&gt; Layer</th>
<th>2&lt;sup&gt;nd&lt;/sup&gt; Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amps</td>
<td>250-260</td>
<td>300-310</td>
<td>300-310</td>
</tr>
<tr>
<td>Step Distance, in</td>
<td>4.0 mm</td>
<td>5.0 mm</td>
<td>6.0 mm</td>
</tr>
<tr>
<td>Chemistry, % Fe (1/8”)</td>
<td>13</td>
<td>3.22</td>
<td>4.20</td>
</tr>
<tr>
<td>Chemistry, % Fe (1/4”)</td>
<td>3.24</td>
<td>3.68</td>
<td></td>
</tr>
</tbody>
</table>
Two Layers, 1” ESO, 250A/300A

- 1” ESO, 250 amps (86 ipm) 1\textsuperscript{st} layer
- 1” ESO, 300 amps (105 ipm) 2\textsuperscript{nd} layer
- Wire feed changed for amperage
- 4.0 mm step 1\textsuperscript{st} layer
- 6.0 mm step 2\textsuperscript{nd} layer

<table>
<thead>
<tr>
<th>Parameters / DD</th>
<th>1\textsuperscript{st} Layer</th>
<th>2\textsuperscript{nd} Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amps</td>
<td>250-260</td>
<td>300-310</td>
</tr>
<tr>
<td>Step Distance, in</td>
<td>4.0 mm</td>
<td>6.0 mm</td>
</tr>
<tr>
<td>Chemistry, % Fe (1/8”)</td>
<td>13</td>
<td>4.20</td>
</tr>
<tr>
<td>Chemistry, % Fe (1/4”)</td>
<td>3.68</td>
<td></td>
</tr>
</tbody>
</table>
Two Layers, 1” ESO, 250A/300A

- 1” ESO, 250 amps (86 ipm) 1\textsuperscript{st} layer
- 1” ESO, 300 amps (105 ipm) 2\textsuperscript{nd} layer
- Wire feed changed for amperage
- 6 mm step 1\textsuperscript{st}, 6 mm step 2\textsuperscript{nd}
- Failed to meet Fe-5 at ¼”

<table>
<thead>
<tr>
<th>Parameters / CC</th>
<th>1\textsuperscript{st} Layer</th>
<th>2\textsuperscript{nd} Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amps</td>
<td>250-260</td>
<td>300-310</td>
</tr>
<tr>
<td>Step Distance, in</td>
<td>6.0 mm</td>
<td>6.0 mm</td>
</tr>
<tr>
<td>Chemistry, % Fe (1/8”)</td>
<td>22.66</td>
<td>4.98</td>
</tr>
<tr>
<td>Chemistry, % Fe (1/4”)</td>
<td></td>
<td>5.57</td>
</tr>
</tbody>
</table>
Two Layers, 1¾” ESO, 250A/300A

- 1¾” ESO, 250 amps (105 ipm), 1\textsuperscript{st} layer
- 1” ESO, 300 amps (105 ipm), 2\textsuperscript{nd} layer
- Change in ESO to change amperage
- 6 mm step 1\textsuperscript{st}, 6 mm step 2\textsuperscript{nd}
- Good weld

<table>
<thead>
<tr>
<th>Parameters / X</th>
<th>1\textsuperscript{st} Layer</th>
<th>2\textsuperscript{nd} Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amps</td>
<td>250-260</td>
<td>300-310</td>
</tr>
<tr>
<td>Step Distance, in</td>
<td>6 mm</td>
<td>6 mm</td>
</tr>
<tr>
<td>Chemistry, % Fe (1/8”)</td>
<td>17.0</td>
<td>4.62</td>
</tr>
<tr>
<td>Chemistry, % Fe (1/4”)</td>
<td></td>
<td>4.44</td>
</tr>
</tbody>
</table>
Two Layers, 1¾” ESO, 250A/300A

- 1¾” ESO, 250 amps (105 ipm), 1st layer
- 1” ESO, 300 amps (105 ipm), 2nd layer
- Change in ESO to change amperage
- 6 mm step 1st, 5 mm step 2nd
- Chemistry at 1/8” didn’t meet Fe-5

<table>
<thead>
<tr>
<th>Parameters / BB</th>
<th>1st Layer</th>
<th>2nd Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amps</td>
<td>250-260</td>
<td>300-310</td>
</tr>
<tr>
<td>Step Distance, in</td>
<td>6.0 mm</td>
<td>5.0 mm</td>
</tr>
<tr>
<td>Chemistry, % Fe (1/8”)</td>
<td>17</td>
<td>7.59</td>
</tr>
<tr>
<td>Chemistry, % Fe (1/4”)</td>
<td></td>
<td>3.94</td>
</tr>
</tbody>
</table>
Two Layers, 1” ESO, 300A/300A

- 1” ESO, 300 amps (105 ipm), 1\textsuperscript{st} layer
- 1” ESO, 300 amps (105 ipm), 2\textsuperscript{nd} layer
- 4.5 mm step 1\textsuperscript{st} layer
- 4.5 mm step 2\textsuperscript{nd} layer
- Reinforcement too thick – 0.293”

<table>
<thead>
<tr>
<th>Parameters / AA</th>
<th>1\textsuperscript{st} Layer</th>
<th>2\textsuperscript{nd} Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amps</td>
<td>300-310</td>
<td>310-320</td>
</tr>
<tr>
<td>Step Distance, in</td>
<td>4.5 mm</td>
<td>4.5 mm</td>
</tr>
<tr>
<td>Chemistry, % Fe (1/8”)</td>
<td>10.5</td>
<td>3.03</td>
</tr>
<tr>
<td>Chemistry, % Fe (1/4”)</td>
<td></td>
<td>3.38</td>
</tr>
</tbody>
</table>
Two Layers, 1” ESO, 300A/300A

- 1” ESO, 300 amps (105 ipm), 1\textsuperscript{st} layer
- 1” ESO, 300 amps (105 ipm), 2\textsuperscript{nd} layer
- 5 mm step 1\textsuperscript{st} layer
- 5 mm step 2\textsuperscript{nd} layer
- Good weld

<table>
<thead>
<tr>
<th>Parameters / EE</th>
<th>1\textsuperscript{st} Layer</th>
<th>2\textsuperscript{nd} Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amps</td>
<td>300-310</td>
<td>300-310</td>
</tr>
<tr>
<td>Step Distance, in</td>
<td>5.0 mm</td>
<td>5.0 mm</td>
</tr>
<tr>
<td>Chemistry, % Fe (1/8”)</td>
<td>14.26</td>
<td>3.94</td>
</tr>
<tr>
<td>Chemistry, % Fe (1/4”)</td>
<td>4.49</td>
<td></td>
</tr>
</tbody>
</table>
Key Factors

- Keep first layer ≤ 1/8” thick
- Keep first layer chemistry less than 18%
- Second layer fusion line must be below 1/8”, but not too much
- Second layer dilution needs to be less than 20%
- Keep overall thickness close to ¼”; don’t over-weld
- Step-over distance is critical, need for precise control
Conclusion

• Traditional amps, volts and travel speed have minimal effect on weld metal chemistry.
• ESO increases deposition rate at a given current. This reduces iron content.
• Step-over has the greatest influence on weld metal chemistry.
• Check first and second layer chemistry and thickness.
• Check weld cross section if needed.
• Accurate step-over control is critical
Q & A

dave@arcspecialties.com