Welding Processes

Submerged Arc Welding (SAW)
SAW: Process Fundamentals

- In SAW the welding heat source is an arc maintained between a consumable electrode and the workpiece.
- The arc and molten metal are "submerged" in a blanket of granular fusible flux.
- The electrode is continuously fed into the arc and additional flux is distributed in front as the weld head moves along the joint.
Submerged Arc Welding
SAW Weld Pool

- Electrode
- Granular Flux
- Solidified Weld Metal
- Molten Flux
- Arc Cavity
- Weld Pool
SAW Electrodes

- Functions of the electrode:
  - Conducts electrical current to the arc
  - Supplies joint filler material

- Electrodes may consist of
  - solid rod or wire
  - composite electrode (a metallic sheath encasing metal powders)
SAW Fluxes

- Functions of the flux
  - Establish the electrical characteristics of the electrode and arc stability
  - Control the composition and metallurgy of the weld deposit
  - Supply additional filler material
  - Control weld bead shape

- Flux constituents
  - The flux consists of granular minerals and metals in the form of fused and crushed or bonded agglomerated particles
SAW Flux Types for Steels

- Various formulations in use
  - Calcium silicate
  - Manganese silicate
  - Aluminate rutile or basic
  - Basic fluorides

- Fluxes termed "neutral" or "active" according to their potency in modifying weld composition

- Also categorized as "basic" or "acid" based on various indices e.g.:

  \[
  B = \frac{CaO + CaF_2 + MgO + K_2 O + Na_2 O + \frac{1}{2}(MnO + FeO)}{SiO_2 + \frac{1}{2}(Al_2 O_3 + TiO_2 + ZrO_2)}
  \]
SAW Fluxes

- "Acid" silicate fluxes are active types
- Active fluxes and/or electrodes deoxidized with silicon and manganese are useful when making single pass welds on scaled or rusty steel plate.
  - However, Si and Mn build up may give poor toughness and soundness in multi-pass welds
- Basic fluxes give optimum strength and toughness in steel welds
Classification of SAW Electrodes and Fluxes for Carbon Steel

- AWS/ASME A5.17 specification
- Solid electrodes are classified on the basis of their chemical composition
- Composite electrodes and fluxes are classified according to the composition of the weld metal deposited with a particular electrode
- FXXX-EXXX designates a flux/wire combination
  - e.g., F7A6-EM12K
SAW Welding Procedures

- Operating Variables (in approximate order of importance for weld quality)
  - welding current
  - flux type and particle size distribution
  - welding voltage
  - welding speed
  - electrode size
  - electrode stick-out
  - type of electrode
  - width and depth of flux layer
SAW Welding Procedures

Single-electrode single pass welding of steel plate with backing strip

Steel backing strip

<table>
<thead>
<tr>
<th>T</th>
<th>R</th>
<th>Current (A)</th>
<th>DCEP (V)</th>
<th>Travel Speed (mm/min)</th>
<th>electrode diameter (mm)</th>
<th>Electrode consumption (kg/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>3</td>
<td>900</td>
<td>33</td>
<td>11</td>
<td>4.8</td>
<td>246</td>
</tr>
<tr>
<td>13</td>
<td>5</td>
<td>1100</td>
<td>34</td>
<td>8</td>
<td>5.6</td>
<td>665</td>
</tr>
</tbody>
</table>
SAW Welding Procedures

Flux backing technique for single sided welding, e.g. ship panel manufacturing lines

[Diagram showing flux backing technique with labels: Flux Backing, Flexible Sheet Material, Inflated Hose, Paper Insert (Optional), Plate, Trough]
SAW Welding Procedures

Single-electrode two-pass welding of steel plate

<table>
<thead>
<tr>
<th>T Pass</th>
<th>Current A</th>
<th>DCEP V</th>
<th>Travel Speed mm/s</th>
<th>Electrode dia mm</th>
<th>Electrode consumption kg/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 Root</td>
<td>500</td>
<td>33</td>
<td>14</td>
<td>4</td>
<td>343</td>
</tr>
<tr>
<td>10 Second</td>
<td>850</td>
<td>35</td>
<td>14</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>15 Root</td>
<td>900</td>
<td>36</td>
<td>9</td>
<td>4.8</td>
<td>745</td>
</tr>
<tr>
<td>15 Second</td>
<td>950</td>
<td>36</td>
<td>9</td>
<td>4.8</td>
<td></td>
</tr>
</tbody>
</table>
SAW Welding Procedures

Electrode alignment in two-pass welds

Correct

Lack of fusion

Incorrect

Exception—unequal thicknesses
SAW Welding Procedures

Electrode position effects in circumferential welding

- Correct Displacement
- Too little Slag runs ahead
- Too much

Rotation

Slag spills
SAW Variants

Twin-wire dc/ac system:
1-dc power source, 2-ac power source, 3-trail arc, 4-lead arc

[Diagram showing the twin-wire dc/ac system with numbered components]
SAW Variants

Strip Cladding

- Strip Electrode
- Power Supply
- Welding Direction
- Flux

E.g. cladding the internal surfaces of pressure vessels
SAW Equipment

- Power Supply
  - Constant current or constant voltage type 100% duty cycle
    1000 A output

- Wire Feeder
  - Constant speed (for constant voltage power supplies) or
    voltage sensing (for constant current power supplies)

- Travel & Positioning Device
  - e.g. weld head crawler or rotary positioner

- Flux delivery/recovery system

- Process Controls
  - welding current, travel/workpiece positioning, wire feed sequencing
SAW Applications
SAW Applications

- Joining heavy sections in steel, stainless steels
  - pressure vessel & piping circumferential & longitudinal seams
  - plate girder fabrication
  - ship panel subassembly

- Surfacing
  - multi-wire & strip cladding variants
# SAW Capabilities & Limitations

| + High deposition rates and productivity | - Flat or horizontal position only |
| + Tolerant to variations in joint edge preparation and fit up | - Mostly limited to steels, stainless steel and nickel alloys |
| + Good weld mechanical properties (with appropriate choice of welding procedure) | - Flux and slag residues |
Welding Processes

Electro-Slag Welding (ESW)
ESW Process Fundamentals

- In ESW, electrical current passes from a continuous electrode to the workpiece through a conductive molten slag
- Resistance heating of the slag supplies the welding heat source. The slag also shields the weld pool from contamination
- The weld is formed by melting and resolidification of the joint edges and filler
ESW: Process Fundamentals

- MOLTEN SLAG BATH
- ELECTRODE GUIDE TUBE
- MOLTEN WELD POOL
- ELECTRODE
- SOLIDIFIED WELD METAL
- WATER-COOLED SHOE
- WELD DIRECTION
- COMPLETED WELD
- WORKPIECE
ESW Consumable Guide Method

POWER SOURCE

CONTROL PANEL

ELECTRODE WIRE FEEDER

Consumable Guide Tube

WORKPIECE

Feed Rolls

Cooling Water
ESW Welding Procedures

- Process Variables
  - Joint Preparation & Fit-up
  - Welding Current
  - Welding Voltage
  - Electrode Extension
  - "Form Factor"
  - Electrode Oscillation
  - No of Electrodes & Spacing
ESW: Joint Types

- Butt Joint
- Corner Joint
- T-Joint
- Flame cut typically
- T-Joint
- Transition Joint
- Fillet Weld
- Cross Joint
- Overlay
- Buildup

Lecture 3
ESW: Joint Fit Up and Alignment

- Run-off Tabs
- Temporary Strongbacks Welded to Plate
- Outboard shoe side
- 40 mm min.
- Starting Sump
- Root Opening

\[ W = \text{Width of Moving Shoe} + 50\text{mm} \]
**ESW Welding Procedures**

**Typical ESW Welding Conditions**
Single electrode, non-oscillating, carbon steel

<table>
<thead>
<tr>
<th>Plate Thickness (mm)</th>
<th>Joint Opening (mm)</th>
<th>Welding Current (A)</th>
<th>Welding Voltage (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>25</td>
<td>600</td>
<td>38</td>
</tr>
<tr>
<td>50</td>
<td>25</td>
<td>700</td>
<td>39</td>
</tr>
<tr>
<td>75</td>
<td>25</td>
<td>700</td>
<td>52</td>
</tr>
</tbody>
</table>
ESW: Weld Metal Grain Structure

Transverse Section

Plate Thickness

Solidification Front

Longitudinal Section at A-A

Welding Direction
ESW: Weld Grain Structure

Solidification Front
ESW: Weld Faults

(a) Porosity  (b) Centre-Line Cracking  (c) Centre-Line Cracking
(d) Incomplete Fusion  (e) Incomplete Fusion  (f) Incomplete Fusion
(g) Overlap  (h) Underfill  (i) Copper pickup & internal cracks

(j) Overlap caused by metal spillage
ESW Applications

- Most types of carbon steels, low alloy and stainless steels
- Pressure vessel longitudinal seams
- Heavy structural fabrications, machinery
ESW Capabilities and Limitations

+ Very high deposition rates
+ Ability to weld very thick materials
+ Minimum joint preparation requirements
+ Minimum materials handling

- Limited to carbon, low alloy and some stainless steels
- Joints must be vertically positioned
- Risk of stop/start defects
Welding Processes

Electro Gas Welding (EGW)
EGW Process Fundamentals

- In EGW the welding heat source is an arc maintained between a continuous electrode and the weld pool.
- The weld is formed by melting and resolidification of the joint edges and filler in the vertical position.
- The weld zone is shielded from contamination by shielding gas and/or flux supplied from flux-cored wire.
EGW Welding Procedures

- Operating Variables
  - Materials and consumables
  - Joint fit-up and alignment
  - Welding Voltage
  - Welding Current/Electrode Feed Speed
  - Electrode Extension
  - Electrode Oscillation
EGW Consumables

- Both flux cored and solid wires are used in EGW
- EGW flux cored wires contain less slag-forming compounds than FCAW electrodes
- Flux-cored and solid wires are available in various chemical compositions to achieve desired weld metal strength and notch toughness.
Classification of EGW Consumables

- AWS A5.26 Specification for Consumables Used for Electrogas Welding of Carbon and High Strength Low Alloy Steels

- Denotes an EGW electrode
- Indicates the min. weld metal strength in 10 ksi
- Indicates the minimum impact strength
- Designates a flux-cored electrode (The letter S designates a solid electrode
- Indicates the chemical composition of the deposited weld metal

Example: **EG 6 2 S-1**: Solid carbon-manganese EGW electrode with 60 ksi min strength and 20ft-lb impact energy at -40F
EGW Welding Procedures

Moving or Stationary Shoes for Consumable Guide Welding

(A) Butt Joint With Square Groove Weld

(B) Butt joint with Single V Groove Weld
EGW Welding Procedures

Typical Conditions for Electrogas Welds Using a 3 mm Diameter AWS Class EG72T1 Electrode with Moving Shoes

<table>
<thead>
<tr>
<th>Thickness mm</th>
<th>Joint Opening mm</th>
<th>Current A</th>
<th>Voltage V</th>
<th>Electrode Feed Speed mm/s</th>
<th>Electrode Extension mm</th>
<th>Travel Speed mm/s</th>
<th>Oscillation Distance mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>12</td>
<td>450-500</td>
<td>35-37</td>
<td>120</td>
<td>50</td>
<td>2.5</td>
<td>-</td>
</tr>
<tr>
<td>25</td>
<td>20</td>
<td>625-675</td>
<td>40-42</td>
<td>150</td>
<td>75</td>
<td>1.25</td>
<td>-</td>
</tr>
<tr>
<td>37</td>
<td>19</td>
<td>625-675</td>
<td>40-42</td>
<td>150</td>
<td>75</td>
<td>7</td>
<td>19</td>
</tr>
</tbody>
</table>
EGW Equipment

- Power supply
- Electrode feeder
- Electrode guide
- Electrode guide travel and oscillator
- Retaining shoes
- Controls
The principal applications of EGW include storage tanks, pressure vessels, structural members and ship hulls.
### EGW Capabilities and Limitations

| + High Deposition Rates          | - Limited to carbon, low alloy and some stainless steels |
| + Simple Joint Preparation       | - Joints must be vertically positioned                   |
| + Applicable to thinner materials than ESW | - Risk of stop/start defects |