Welding Processes

Flux Shielded Welding Processes
Flux Shielded Welding Processes

- Shielded Metal Arc Welding (SMAW)  Lecture 2
- Flux Cored Arc Welding (FCAW)
- Submerged Arc Welding (SAW)
- Electro Gas Welding (EGW)
- Electro Slag Welding (ESW)  Lecture 3
Lecture Scope

- Welding process fundamentals
- Applications
- Welding procedures
- Equipment
- Process capabilities and limitations
Shielded Metal Arc Welding (SMAW)
SMAW Process Fundamentals

- The heat source is an arc maintained between the tip of a covered electrode and the workpiece
- The tip of the electrode is moved along the joint, fusing the edges
- The electrode is consumed in the process
- The electrode supplies filler and materials that shield the weld and control weld metallurgy
SMAW

Process Fundamentals

- ELECTRODE COVERING
- CORE WIRE
- SHIELDING ATMOSPHERE
- WELD POOL
- SOLIDIFIED SLAG
- METAL AND SLAG DROPLETS
- WELD METAL
- BASE METAL
- PENETRATION DEPTH
- DIRECTION OF WELDING
SMAW Electrode Components

- The electrode consists of
  - the core
  - the covering
SMAW Electrode Core

- The functions of the core are:
  - conduct the electric current to the arc and
  - supply filler metal for the joint

- The core consists of:
  - a solid metal rod of drawn or cast material, or
  - a metallic sheath encasing metal powders
SMAW Electrode Covering

- The functions of the covering are:
  1. Provide gas and/or slag shielding
  2. Establish the electrical characteristics of the electrode
  3. Control the composition and metallurgy of the weld deposit
  4. Supply additional filler material
  5. Control weld bead shape

- The electrode covering consists of granular minerals, metals and binders extruded on the core rod
Electrode Covering Constituents

<table>
<thead>
<tr>
<th>Covering Constituent</th>
<th>Arc Stabiliser</th>
<th>Slag Former</th>
<th>Reducing agent</th>
<th>Binder</th>
<th>Coating strength</th>
<th>Oxidising Agent</th>
<th>Gas Shield</th>
<th>Alloying</th>
</tr>
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<tbody>
<tr>
<td>Gum/resin</td>
<td>B</td>
<td>A</td>
<td></td>
<td></td>
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<td>B</td>
<td>A</td>
<td></td>
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<tr>
<td>Feldspar CaF₂</td>
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<tr>
<td>Clay (Al Silicates)</td>
<td>B</td>
<td>A</td>
<td></td>
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<tr>
<td>Talc (Mg Silicates)</td>
<td>B</td>
<td>A</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Rutile (Titania)</td>
<td>A</td>
<td>B</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Iron Oxides</td>
<td>B</td>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>CaCO₃</td>
<td>A</td>
<td>B</td>
<td></td>
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<td></td>
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<td></td>
<td>A</td>
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<tr>
<td>Asbestos</td>
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<tr>
<td>Ferro Manganese</td>
<td>A</td>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>B</td>
</tr>
<tr>
<td>Potassium Silicate</td>
<td>A</td>
<td>A</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Sodium Silicates</td>
<td>B</td>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Powdered Alloys</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A</td>
</tr>
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</table>

A=principal function  B=minor function
# AWS Electrode Classification

<table>
<thead>
<tr>
<th>Covering</th>
<th>Positions</th>
<th>Polarity</th>
</tr>
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<tbody>
<tr>
<td>Exx10 Cellulosic</td>
<td>F,H,V,OH,</td>
<td>DCEP</td>
</tr>
<tr>
<td>Exx11 Cellulosic</td>
<td>F,H,V,OH,</td>
<td>AC, DCEP</td>
</tr>
<tr>
<td>Exx12 Rutile</td>
<td>F,H,V,OH,</td>
<td>AC, DCEN</td>
</tr>
<tr>
<td>Exx13 Rutile</td>
<td>F,H,V,OH,</td>
<td>AC or DC</td>
</tr>
<tr>
<td>Exx14 Rutile + iron powder</td>
<td>F,H,V,OH,</td>
<td>AC or DC</td>
</tr>
<tr>
<td>Exx15 Basic</td>
<td>F,H,V,OH,</td>
<td>DCEP</td>
</tr>
<tr>
<td>Exx16 Basic</td>
<td>F,H,V,OH,</td>
<td>AC, DCEP</td>
</tr>
<tr>
<td>Exx18 Basic + iron powder</td>
<td>F,H,V,OH,</td>
<td>AC or DC</td>
</tr>
<tr>
<td>Exx20 iron oxide/silicate</td>
<td>H-fillets</td>
<td>AC, DCEN</td>
</tr>
<tr>
<td>Exx24 Rutile + iron powder</td>
<td>H-fillets,</td>
<td>AC or DC</td>
</tr>
<tr>
<td>Exx27 iron oxide + iron powder</td>
<td>H-fillets,</td>
<td>AC, DCEN</td>
</tr>
<tr>
<td>Exx28 Basic + 50% iron powder</td>
<td>H-fillets,</td>
<td>AC, DCEP</td>
</tr>
<tr>
<td>Exx48 Similar to Exx20</td>
<td>F,H,OH,V-down</td>
<td>AC, DCEP</td>
</tr>
</tbody>
</table>

| E 60xx  | 60,000 psi |
| E 70xx  | 70,000 psi |
| E 80xx  | 80,000 psi |
| E 90xx  | 90,000 psi |
| E100xx  | 100,000 psi |

F: Rail  
H: Horizontal  
V: Vertical  
OH: Overhead  
H-Fillet: Horizontal Fillet
Electrode Types

Different electrode coatings suit different purposes. The four main types in use are:

1. Cellulosic
2. Rutile
3. Iron Oxide
4. Basic
Electrode Types

1. Cellulosic
   - Covering has high cellulose content e.g. wood flour
   - Provides large quantities of H₂ and CO₂ gas shielding
   - Small volume of slag
   - Operate on DC electrode positive (DCEP)
   - Forceful penetrating arc
   - All positions
Electrode Types

- Electrode Types
  1. Cellulosic
  2. Rutile (titania)
     - Main constituent of coating is titanium dioxide (rutile)
     - Voluminous viscous slag covering which covers and supports the molten weld metal
     - Good for all-positional welding
     - DC electrode positive or negative (DCEP/DCEN) or AC
     - Smooth arc and medium penetration
     - Iron powder may be added to increase deposition rate
Electrode Types

- Electrode Types
  1. Cellulosic
  2. Rutile (titania)
  3. Iron Oxide
     - Covering contains Fe, Mn oxides and silicates
     - Voluminous fluid slag giving smooth weld bead from which solidified slag is easily removed
     - Limited to flat "downhand" position
     - DCEP or alternating current (AC)
     - (AC is preferable from cost point of view)
Electrode Types

- Electrode Types
  1. Cellulotic
  2. Rutile (titania)
  3. Iron Oxide
  4. Basic
     - Coating contains CaCO3 and CaF2 with minerals having combined water kept to a minimum
     - Some iron powder may be added
     - Shielding by CO-CO2 (No H2) and a fluid "basic" slag
     - Produces weld metal of excellent ductility and toughness
     - All positions
     - DCEP/DECN (some types suitable for AC)
     - More difficult to use than rutile/cellulotic
SMAW Equipment

Typical Welding Circuit

AC OR DC POWER SOURCE AND CONTROLS

ELECTRODE HOLDER

ELECTRODE

ARC

WORKPIECE LEAD

ELECTRODE LEAD

WORK
SMAW Welding Procedures

Variables that influence SMAW weld quality and productivity are:
- Electrode type and size
- Welding current, voltage, travel speed, technique
- Size of weld beads
- Material composition, thickness & joint geometry
- Surface condition
- Pre and post weld heat treatment
- Welder skill
SMAW Effects of Welding Variables

a)-OK; Current (b) too low, (c) too high; Arc Length (d) too short, (e) too long; Travel Speed (f) too slow, (g) too fast
SMAW Deposition Rates

- Deposition rates depend mainly on electrode type and welding current
- Increased welding current increases deposition rate and speeds joint completion
- However, welding position, joint design and thickness, and metallurgy may limit the maximum useable current
- The highest deposition rates can be obtained in the flat position
SMAW Deposition Rates

Various Electrode types

[Graph showing deposition rates for different electrode types at various welding currents]
SMAW Electrode Orientation
SMAW Joint designs

<table>
<thead>
<tr>
<th>Joint Design</th>
<th>Dimension</th>
<th>Position</th>
<th>Recommended for</th>
</tr>
</thead>
<tbody>
<tr>
<td>Square groove, welded from one side</td>
<td>T = 1/16 max for all joints</td>
<td>1/8 to 1/4</td>
<td>Horizontal position</td>
</tr>
<tr>
<td>Square groove, welded from both sides</td>
<td>T = 3/16 max</td>
<td>1/8 to 1/4</td>
<td>Horizontal position</td>
</tr>
<tr>
<td>Single V-groove, welded from one side with backing</td>
<td>T = 3/16 max</td>
<td>1/8 to 1/4</td>
<td>Horizontal position</td>
</tr>
<tr>
<td>Single V-groove, welded from one or both sides</td>
<td>T = 3/16 max</td>
<td>1/8 to 1/4</td>
<td>Horizontal position</td>
</tr>
<tr>
<td>Single bevel-groove, welded from one or both sides</td>
<td>T = 3/16 max</td>
<td>1/8 to 1/4</td>
<td>Horizontal position</td>
</tr>
</tbody>
</table>

All dimensions in inches except angles.
SMAW Applications
SMAW Applications

- General steel construction
  - bridges, ships, plant and machinery

- High quality fabrication with requirements for
  strength, toughness and NDE quality
  - nuclear piping & pressure vessels

- Maintenance
  - hardfacing (e.g earthmover blades, materials handling equipment)
  - reclamation of defective or worn components

- All ferrous metals and nickel alloys, cast iron
## Summary: SMAW Capabilities and Limitations

| + Low-cost, portable equipment and consumables adaptable to shop or field | - Low productivity |
| + All welding positions | - Results depend on skill of manual operator |
| + High-quality welds with correct technique | - Limited mainly to joining cast iron, steels and nickel alloys |
| | - Slag removal |
Flux Cored Arc Welding (FCAW)
FCAW Process Fundamentals

- The heat source is an arc maintained between a consumable electrode and the workpiece.
- The electrode is continuously fed into the arc as the weld head moves along the joint
- The arc and molten metal are shielded by granular flux contained in the tubular electrode (self shielded process)
- Shielding may be supplemented by an inert gas stream (gas shielded process)
FCAW Process Fundamentals

Self-Shielded

TUBULAR ELECTRODE

ARC & METAL TRANSFER

ARC SHIELD COMPOSED
OF VAPORIZED AND
SLAG FORMING COMPOUNDS

POWDERED METAL, VAPOR
FORMING MATERIALS,
DEOXIDIZERS AND SCAVENGERS

WIRE GUIDE AND CONTACT TUBE

SOLIDIFIED SLAG

MOLTEN SLAG

WELD POOL

WELD METAL

DIRECTION OF WELDING
FCAW Process Fundamentals

Gas Shielded

- Gas Nozzle
- Wire Guide & Contact Tube
- Shielding Gas
- Tubular Electrode
- Powdered Metal, Flux, & Slag Forming Materials
- Direction of Welding
- Molten Slag
- Weld Pool
- Arc & Metal Transfer
- Solidified Weld Metal
- Solidified Slag
FCAW Electrodes

- The electrode consists of a metallic sheath which encases a mixture of granular flux and metal powders
- The functions of the electrode are
  - to supply electric current to the welding arc
  - to supply flux to the weld zone
FCAW Electrodes

Typical electrode cross-sections

Sheath
Flux

...
FCAW Electrodes

- The composition and functions of the flux in FCAW are similar to those of SMAW:
  - Provide gas and/or slag shielding of the weld zone and scavenge impurities
  - Establish the electrical characteristics of the electrode
  - Control the composition and metallurgy of the weld deposit
  - Supply additional filler material
  - Control weld bead shape
FCAW Electrode Classification

- AWS A5.20 classification for Mild Steel Tubular Electrodes:

  - Minimum tensile strength of deposited weld metal
  - Primary welding position
    - 0: F and H only
    - 1: All Positions
  - Indicates a flux cored electrode
  - Indicates performance characteristics

ExxT-x
# FCAW Mild Steel Electrodes

<table>
<thead>
<tr>
<th>Type</th>
<th>Current</th>
<th>Shielding Gas</th>
<th>Position</th>
<th>Operating Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exxx-3</td>
<td>DCEP</td>
<td>Ar-C02</td>
<td>All</td>
<td>Single pass welds on rimmed or coiled steel</td>
</tr>
<tr>
<td>Exxx-4</td>
<td>DCEP</td>
<td>Ar-C02</td>
<td>F, HF</td>
<td>Single pass in sheet metal &lt; 5mm thick</td>
</tr>
<tr>
<td>Exxx-5</td>
<td>DCEP</td>
<td>self shield</td>
<td>F, HF</td>
<td>Single or multi pass welds, low penetration</td>
</tr>
<tr>
<td>Exxx-6</td>
<td>DCEP</td>
<td>self shield</td>
<td>F, HF</td>
<td>Single or multi pass welds with good notch toughness</td>
</tr>
<tr>
<td>Exxx-7</td>
<td>DCEN</td>
<td>self shield</td>
<td>All</td>
<td>Single or multi pass welds, deep penetration with good notch toughness</td>
</tr>
<tr>
<td>Exxx-8</td>
<td>DCEN</td>
<td>self shield</td>
<td>All</td>
<td>Single or multi pass welds with good notch toughness</td>
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<tr>
<td>Exxx-9</td>
<td>DCEN</td>
<td>self shield</td>
<td>F, HF</td>
<td>Single pass welds at high speed</td>
</tr>
<tr>
<td>Exxx-10</td>
<td>DCEN</td>
<td>self shield</td>
<td>All</td>
<td>Single and multi pass welds, general purpose</td>
</tr>
</tbody>
</table>

Ar-C02: Carbon dioxide or argon-C02 mixtures
F: flat position; HF: horizontal fillet
FCAW Equipment

Typical semi-automatic

Diagram:

NOTE: Gas shielding is used only with flux-cored electrodes that require it.
FCAW Equipment

Hand-held (semi automatic) gas-shielded welding gun
Process Variables

- The main variables that influence FCAW weld quality are:
  - Electrode type
  - Welding current
  - Arc voltage
  - Electrode extension ("stick-out")
  - Travel speed
  - Shielding gas flow
  - Electrode orientation
FCAW Deposition Rates

E70T-1 Electrodes with CO2 Shielding

![Graph showing deposition rates for E70T-1 electrodes with CO2 shielding. The graph plots welding current against deposition rate, with different lines for various electrode sizes and positions (flat, semi-automatic, automatic).]
**Typical FCAW Welding Procedures**

<table>
<thead>
<tr>
<th>Joint Design</th>
<th>Thickness T (mm)</th>
<th>Root Opening R (mm)</th>
<th>No. Passes</th>
<th>Electrode Dia. (mm)</th>
<th>Welding Voltage (V)</th>
<th>Welding Current (A)</th>
<th>Wire Feed (mm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>5 - 10</td>
<td>3 - 6</td>
<td>1-2</td>
<td>2</td>
<td>30</td>
<td>425</td>
<td>116</td>
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<tr>
<td>b</td>
<td>10 - 25</td>
<td>0</td>
<td>2-6</td>
<td>2.4</td>
<td>30-32</td>
<td>480</td>
<td>95</td>
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<tr>
<td>c</td>
<td>25-50</td>
<td>0</td>
<td>6-14</td>
<td>2.4</td>
<td>32</td>
<td>450</td>
<td>80</td>
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</tbody>
</table>

**Vertical Position**

<table>
<thead>
<tr>
<th>Joint Design</th>
<th>Thickness T (mm)</th>
<th>Root Opening R (mm)</th>
<th>No. Passes</th>
<th>Electrode Dia. (mm)</th>
<th>Welding Voltage (V)</th>
<th>Welding Current (A)</th>
<th>Wire Feed (mm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>b</td>
<td>10-15</td>
<td>0</td>
<td>2-3</td>
<td>1.6</td>
<td>30-32</td>
<td>480</td>
<td>70</td>
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</tbody>
</table>
FCAW Applications
<table>
<thead>
<tr>
<th>FCAW: Summary of Capabilities &amp; Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ High deposition rates</td>
</tr>
<tr>
<td>+ Continuous electrode eliminates stub losses and stop/starts</td>
</tr>
<tr>
<td>+ Good tolerance to joint fit-up variations</td>
</tr>
<tr>
<td>- More costly equipment</td>
</tr>
<tr>
<td>- Complexity in setup and control</td>
</tr>
<tr>
<td>- Restricted distance from wire feeder</td>
</tr>
<tr>
<td>- Fume generation</td>
</tr>
<tr>
<td>- Slag removal</td>
</tr>
</tbody>
</table>