CHAPTER 2

SUBMERGED ARC WELDING (SAW)

2.1 Introduction

Welding is a fabrication process that joins materials, usually metals or thermoplastics by causing coalescence. This is often done by melting the work pieces and adding a filler material to form a pool of molten material that cools to become a strong joint, the process is carried out with pressure sometimes used in conjunction with heat or only with heat, to produce the weld. Many different energy sources can be used for welding, including a gas flame, an electric arc, a laser beam, an electron beam, friction and ultrasonic frequency. While often an industrial process, welding can be done in many different environments, including open air, under water and in outer space. Submerged arc welding is an ‘Arc Welding’ process in which the arc is concealed by a blanket of granular and fusible flux [166, 37]. Heat for SAW is generated by an arc between a bare, solid metal (or cored) consumable-wire or strip electrode and the work-piece. The arc is maintained in a cavity of molten flux or slag which refines the weld metal and also protects it from atmospheric contamination. Flux is a fundamental ingredient on which the stability of the arc depends. The mechanical, chemical properties, crack resistance and other qualities of the final weld deposit can be controlled by the flux. Alloy ingredients are being mixed with the flux to enhance the mechanical properties and crack resistance of the weld deposit. SAW is usually carried out fully mechanised (or automatically). However, in semi-
automatic (hand held) SAW process the operator does not see the weld pool and also does not have a direct interface with the welding process. As the ‘Automation’ in the SAW Process increases, the direct influence of the operator decreases and the precise setting of the parameters becomes much more important as compared to the manual welding process. Currents ranging from 300A to 3000A are commonly used. Currents upto 5000A can also be used in multiple arc welding. DC or AC powers as well as a combination of both are common sources of power on multiple electrode systems. Constant voltage power supply is a most commonly used source. However, constant current system in combination with a voltage sensing wire-feeder is also utilized in semiautomatic systems. Many attempts have been made to mechanise the arc welding process as there are many advantages of mechanised welding.

A continuous coated electrode in manual Metal Arc Welding has been ruled out, because of the following reasons.

- The coating is non-conducting, so getting electrical contact with electrode is not practicable.
- The coating gets peeled off when the electrode is coiled.
- The coating gets crushed when fed through the feed rolls.

Procedural variation in SAW process parameters will affect the weld shape and quality as well as the integrity of the weld deposit. There has been a continuing interest since 1930 in the increment of productivity without deterioration in weld quality. In Submerged Arc Welding, the qualities of weld deposits are determined by the following parameters.

- Welding Current
- Welding Arc Voltage
- Electrode stick out
- Grade of wire
- Travel speed
- Type of flux
- Size of electrode
- Flux layer depth

To get optimum results, it is most important to know the effect of the above parameters on weld bead geometry and how to select them and control their effects on the deposited bead shape.

(a) Sectioned view of weld deposit (source AWS: Welding Hand Book)

(b) Set-up in operation

Fig. 2.1 (a) Schematic views of key components of Automatic SAW
(b) Set-up (source RDSO, Welding Research Laboratory)
2.2 Principle of operation

A typical set up of an automatic SAW is shown in Fig.2.1 (b). A continuous (wire) electrode is being mechanically fed into the joint by powered drive rolls. A layer of granular flux, deep enough to prevent the flash through, is being deposited in front of the Arc. Electrical current which produces the Arc, is supplied to the electrode through the contact tube. The current can be DC current up to 2000A, using single or multiple wires or strip of various alloys with electrode positive (reverse polarity) or with electrode negative (straight polarity) or alternating current (AC). Figure2.2 shows the melting and solidification sequence of SAW. The un-fused flux and slag are removed from weld metal after solidification and may be used after screening. The solidified slag may be collected, crushed, resized, and blended back into the new flux.

SAW is adaptable to both semi-automatic and fully automatic operation. Fully automatic operation is more popular. In semi-automatic welding, the welder controls the travel speed, direction and placement of the weld. Semi-automatic electrode is usually less than 2.4mm to provide sufficient flexibility and feedability in the gun assembly. In fully Automatic SAW, travel speed and direction are controlled mechanically; flux is automatically fed in front of the arc, while the un-fused flux may be picked by a vacuum recovery system behind the arc.

SAW is a high quality welding process with a very high deposition rate. It is commonly used to join thick sections in the flat position. The wire is fed continuously to the arc by a feed mechanism using motor-driven rollers. The flux is fed from a hopper fixed to the welding head and a tube from hopper spreads the flux in a continuous manner in front of the Arc. When molten, the flux becomes conductive, and provides a current conducting path between the electrode and the work.
Fig. 2.2 (a), (b) & (c) Schematic view of typical Solidification zone, weld pool dynamics and nomenclature of a SAW.

### 2.3 Equipment and Supplies

The power supplied to the contact tip may be DC or AC. In the United States, DC power is most common for welding applications that require less than 1000A. In Europe and the Far East, however, AC is used extensively, even in applications requiring less than 1000A. Currents over 1000A DC tends to
create arc blow problems. AC is most commonly used for high-current applications. AC power sources are most commonly transformers based.

2.4 Process Applications

The Submerged Arc Welding Process creates an Arc Column between the wire electrode and the work piece. The electrode stick-out, the Arc Column and the weld pool are all submerged in a blanket of finely divided granulated powder which contains appropriate deoxidisers, cleansers and other fluxing ingredients. The flux is fed from a hopper which is an integral part of the welding head. The flux flows through a tube and spreads along the joint edges ahead of the electrode in the form of a heap of desired height which is controlled by the tube to plate distance. The flux layer is of sufficient depth to avoid spatter, smoke and protect the weld pool from the ill effects of atmospheric gases. The flux melts and provides a protective layer of slag on top of the weld bead. The un-melted flux acts as an insulator and reclaimed for reuse. The slag from the weld bead normally peels off on its own or removed with the help of a chipping hammer.

The main limitations of SAW are plate thickness and position, because SAW is a high heat input and high deposition rate process. It is generally used to weld thicker section of steel over 6.4 mm, although welding of 1.6mm is also possible.

2.4.1 Process Features

SAW involves formation of an Arc between a continuously fed bare wire electrode and the work piece similar to MIG welding. The process uses a granular flux to generate protective gas, slag and adding alloying elements to the weld pool. A shielding gas is not required prior of welding instead, a thin layer of flux powder is spread on the work piece surface. Heat loss is
extremely low as arc is completely covered with flux layer; this produces a thermal efficiency as high as 60% (for Manual Metal Arc welding it is 25%). There is no visible arc light and fume extraction is also not required. Nomenclature of SAW is shown in Fig.2.2 (c). It is most important to select and study the stability of welding parameters as per engineering facts to achieve high quality of welding. The mechanical properties of the welded joints greatly depend on weld bead geometry which is influenced by welding parameters like arc current, arc voltage, and arc travel speed. The bead geometry is specified by weld bead width, reinforcement height, reinforcement area, penetration depth, penetration area and contact angle of weld bead etc. Weld bead width is the maximum width of the weld metal deposit which increases with arc current, arc voltage, electrode weaving and decreases with increase in arc travel speed.

Fig.2.3 Weld bead geometry

Penetration depth or penetration is a distance from top of base plate surface to the maximum extent of the weld nugget, penetration determines the load carrying capacity of a welded structure, penetration area is covered by the fusion line below the base metal level; penetration area affects the weld strength. Reinforcement height is the maximum distance between the base metal level and the top point of the deposited metal, reinforcement area is between the contour line of the deposited metal above the base metal level.
2.5 Electrode Feed Wire Control

The rate of melting and deposition of electrode depends on the welding current. The wire electrode is to be fed at a controlled rate to maintain constant arc length and rate of melt-off. Melt-off rate or deposition rate are expressed in kg/hour. Wire feed system shown in Fig.2.4 (a, b).

<table>
<thead>
<tr>
<th>Arc length</th>
<th>Too short</th>
<th>Correct</th>
<th>Too long</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wire feed speed</td>
<td>reduces until Arc length is correct</td>
<td>remains constant</td>
<td>increases until Arc length is correct</td>
</tr>
</tbody>
</table>

SAW is normally carried out with a single wire electrode on either AC or DC current but the other options are also in use:

- Twin wire
- Triple wire
- Single wire with hot wire addition
- Metal powder addition
  All contribute to improve the productivity through a marked increase in weld metal deposition rate or travel speed. Other factors includes
  - Flux depth/width
  - Flux and electrode classification and type
  - Electrode wire diameter
  - Multiple electrode configurations
Fluxes

Most metals in their molten state are oxidized by the atmospheric oxygen. Flux is a chemical compound used to prevent this oxidation and other unwanted chemical reactions. They help to make the welding process easier and ensure a sound weld. Fluxes for Submerged Arc Welding usually consist of metallic oxides such as CaO, MgO and FeO and fluorides such as CaF$_2$. It is specially formulated to be compatible with a given electrode wire so that the combination of flux and wire yields desired mechanical properties, all fluxes react with the weld pool to produce the weld metal chemical composition and mechanical properties. Like the manual electrode coating, the SAW Flux can incorporates alloying elements so that in combination with an unalloyed wire it yields suitably alloyed weld metal. The molten slag also provides favourable conditions for very high current densities which together with the insulating properties with the flux, concentrate heat into a relatively small welding zone. This results in a deep penetrating arc which makes narrower and shallower welding grooves practicable and reducing the amount of weld metal required to complete the joint as well as provides higher welding speeds. The properties of the flux enable Submerged Arc Welds to be
made over a wide range of welding currents, voltage and speeds, each can be controlled independently from other and welded joints of desired shapes, chemistry and mechanical properties can be obtained by using an appropriate welding procedure. The SAW flux is so formulated, not to emit appreciable amount of gases under intense heat of welding zone, it is in granular form and capable of flowing freely through the flux feeding tubes, valves and nozzles of standard welding equipment. The flux in its solid state is a non-conductor of electricity but in molten condition becomes a highly conducting medium. It is necessary to initiate the arc by special means. Once the arc is struck and the surrounding flux becomes molten, the welding current continues to flow across the arc while the Arc provides a conducting path of molten flux as it advances. The flux contains elements capable of assisting in the initial striking of Arc and stabilizing it later. It is common practice to refer fluxes as 'active' if it added manganese and silicon to the weld, the amount of addition of manganese and silicon is influenced by the Arc voltage and the welding current. Schematic view of flux feeding is shown in Fig.2.5 (a , b).
2.6.1 Mechanics of flux shielding:

Mechanised SAW units are usually equipped with a hopper with gravity feed of flux ahead or concentric with the electrode wire. It is commonly equipped with vacuum system to pick up the unused flux after welding for re-use.

2.6.2 Classification of SAW Fluxes:

SAW fluxes can be classified into two main groups:
- According to the method of manufacturing
- According to the chemical nature

2.6.2.1 According to the method of manufacturing:

There are mainly two methods of flux manufacturing.

- **Fused Fluxes**
  
The constituents such as quartz, limestone and manganese dioxide (MnO₂) with small quantities of fluorspar and aluminium oxide (Al₂O₃) are melted in an electric arc furnace where the manganese dioxide (MnO₂) is reduced to MnO. After melt attains the state of a glossy paste, it is cooled, crushed, ground to suitable grain size obtained by sieving. The grains are homogeneous and of size 0.2 to 1.6 mm thickness.

- **Agglomerated Fluxes**
  
These are more easily manufactured than the fused type, as these are made at a lower temperature and are heterogeneous in nature because they include compounds in powder form whose grains join together by the agglomeration process and make larger grains, each grain having the correct proportion of each component. The dry powder is fed onto a rotating disc with the addition of water glass (a concentrated and viscous solution of sodium and potassium silicate) as a binding agent. The grains are then furnace dried at about 700-800 °C and then sieved to obtain grain size of 0.2 to 1.6 mm.
2.6.2.2 According to the chemical nature

The chemical nature of a welding flux can be expressed as the basicity or Basicity index.

\[
\text{CaO} + \text{MgO} + \text{CaF}_2 + \text{Na}_2\text{O} + \text{N}_2\text{O} + \frac{1}{2}(\text{MnO} + \text{FeO})
\]

\[
\text{B (Basicity)} = \frac{\text{SiO}_2 + \frac{1}{2}(\text{Al}_2\text{O}_3 + \text{TiO}_2 + \text{ZrO}_2)}{\text{SiO}_2 + \frac{1}{2}(\text{Al}_2\text{O}_3 + \text{TiO}_2 + \text{ZrO}_2)}
\]

The formula for Basicity or Basicity index is based upon the ratio of basic oxides to acidic oxides. Welding fluxes can thus be divided as shown in Table 2.1.

Table 2.1 Classification of SAW fluxes

<table>
<thead>
<tr>
<th>Welding Flux</th>
<th>Basicity</th>
<th>Melting Point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acidic</td>
<td>0.9</td>
<td>1100-1300</td>
</tr>
<tr>
<td>Neutral</td>
<td>0.9 – 1.2</td>
<td>1300-1500</td>
</tr>
<tr>
<td>Basic</td>
<td>1.2 - 2.0</td>
<td>&gt;1500</td>
</tr>
<tr>
<td>High Basic</td>
<td>&gt;2.0</td>
<td>&gt;1500</td>
</tr>
</tbody>
</table>

2.7 SAW Procedural Variables

The variables which alter the weld size, shape, penetration, dilution, rate of the weld deposit material, bead geometry, etc., are mentioned below.
- Welding current
- Arc voltage
- Travel speed
- Size of electrode
- Electrode stick out
- Heat input rate

It is essential to set several variables in correct range before starting SAW for obtaining good quality welds.

![Figure 2.6](image)

**Fig. 2.6** (a) Effect of variation in welding current on weld bead profile
(b) Effect of variation in welding voltage at constant current on weld bead profile

### 2.7.1 Welding Current:
It controls the melting rate of the electrode, weld deposition rate as well as depth of penetration. Too high a current causes excessive weld reinforcement, burn of thinner plates and badly fitted joints, excessive current also produces narrow deep beads and undercut. Excessively low current gives an unstable
arc and overlapping. SAW control panel is usually provided with an ammeter to monitor and control the welding current.

Fig. 2.7 Effect of welding current on bead shape

2.7.2. Welding Voltage

The arc voltage varies in direct proportion to the arc length. With the increase in arc length the arc voltage increases and thus more heat is available to melt the metal and the flux. However, increase in Arc length means more spread of the Arc column; this leads to increase in weld width and volume of reinforcement while the depth of penetration decreases. The arc voltage varies with the welding current and wire diameter.

Fig. 2.8 Effect of welding arc voltage and arc length on bead shape
2.7.3 Travel Speed:
For a given combination of welding current and voltage, an increase in welding speed results in lesser penetration, lesser weld reinforcement and lower heat input rate. Excessively high travel speed, decreases fusion between the weld deposit and the parent metal, increases the tendencies for undercut, arc blow, porosity and irregular bead shape. As the welding speed decreases, penetration and reinforcement increase but too slow a speed results in poor penetration. Excessively high welding speed decreases the wetting action and increases the probability of undercutting, arc blow, weld porosity and uneven bead shapes. Excessively low speeds also produce a convex hat shaped beads that are subjected to cracking and cause excessive melt through and produces a large weld puddle that flows around the arc resulting in rough bead, spatter and slag inclusions.

![Effect of travel speed on bead shape](image)

Fig.2.9 Effect of travel speed on bead shape

2.7.4 Size of Electrode
For a given welding current, a decrease of wire diameter results in an increase in current density. This results in a weld with a deeper penetration and reduced width. The submerged arc welding process usually employs wires of 2 to 5 mm diameter. A wire diameter 2 to 3 mm is best suited for deeper penetration at low currents.
2.7.5 Electrode Stick out:
It is also termed as electrode extension. It refers to the length of electrode between the end of the contact tube and the arc column, which is subjected to resistance heating at the high current densities used in the process. The longer the stick out, the increase in deposition rate is accompanied by a decrease in penetration, Longer stick-out is avoided when deep penetration is desired.

2.7.6. Heat Input Rate:
The heat input rate is directly proportional to the current and voltage and inversely proportional to the travel speed, as the formula is given by:

\[
\text{HIR} = \frac{V \times A}{S}
\]
Where \( HIR \) = heat input rate in j/mm

\[ V = \text{Arc voltage (V)} \]

\[ A = \text{welding current (A)} \]

\[ S = \text{welding speed in mm/sec} \]

For a given joint thickness, the higher the heat input rate the lower is the cooling rate of the weld metal and heat affected zone of parent metal and vice versa. Heat input rate has an important bearing on the weld metal microstructure and the final microstructure of the HAZ.

2.8 Advantages of Submerged Arc Welding

- Cost per unit length of joint is relatively low
- The arc is under a blanket of flux, which virtually eliminates arc flash, spatter, and fume.
- Extremely high deposition rates and welding speeds are possible.
- Sound welds are readily made (with good process design and control).
- High current densities increase weld penetration and decrease the need for edge preparation.
- High speed welding of thin sheet steels at over 2.5 m/min is possible.
- Can be easily Automated
- Minimum welder training is required (relatively unskilled welders can be employed).
- Low hydrogen weld deposits can be produced.
- The flux acts as a scavenger and deoxidizer to remove contaminants such as oxygen, nitrogen, and sulphur from the molten weld pool. This helps to produce sound welds with excellent mechanical properties.
2.9 Limitations of Submerged Arc Welding

- Initial cost of wire feeder, power supply, controls, and flux-handling equipment is high.
- Limited to ferrous (steel or stainless steels) and some nickel based alloys. Because of the high heat input, SAW is most commonly used to join steels more than 6.4mm thick.
- Normally limited to the 1F, 1G, and 2F positions.
- Normally limited to long straight seams or rotating pipes or vessels.
- Requires relatively troublesome flux handling systems.
- Flux and slag residues can present a health & safety issue.
- Requires inter-pass and post weld slag removal.

2.10 Applications of SAW

It is generally used to weld thicker section steels for longitudinal and circumferential ‘Butt’ and ‘Fillet’ welds. However, because of high fluidity of the weld pool, molten slag and loose flux layer, welding is generally carried out on butt joints in the flat position and fillet joints in both the flat and horizontal-vertical positions. For circumferential joints, the work piece is rotated under a fixed welding head with welding taking place in the flat position. Depending on material thickness, either single-pass, two-pass or multi-pass weld procedures can be carried out. There is virtually no restriction on the material thickness, provided a suitable joint preparation is adopted. Most commonly welded materials are plain carbon steel, carbon manganese steels, low alloy steels and stainless steels, although the process is capable of welding some non-ferrous materials with judicious choice of electrode filler wire and flux combinations. Major application in industry
• Used to build up parts and overlays with stainless or wear resistant steels.
• Manufacturing of ships, heavy structural components of bridges.
• It is widely used for the repairing of machine parts by depositing cladding and hard-facing beads.
• Fabrication of pipes, penstocks, pressure vessels, boilers, railroad, structure of railway coaches and locomotives.
• Automobile, Aviation and Nuclear Industry.
• For welding mild steels, medium & high tensile low alloy steels it is most commonly used.