

## **Submerged Arc Welding**

This chapter presents the principle of submerged arc welding process besides methods of manufacturing and characteristics of different types of fluxes used in this process. Role of important welding parameters of SAW has also been discussed. Further, the advantages and limitations of this process have been described.

Keywords: Submerged arc welding, SAW flux, weld bead geometry, type of fluxes, limitation, advantages and application of SAW.

### **13.1 Introduction**

Submerged arc welding (SAW) process uses heat generated by an electric arc established between a bare consumable electrode wire and the work piece. Since in this process, welding arc and the weld pool are completely submerged under cover of granular fusible and molten flux therefore it is called so. During welding, granular flux is melted using heat generated by arc and forms cover of molten flux layer which in turn avoids spatter tendency and prevents accessibility of atmospheric gases to the arc zone and the weld pool. The molten flux reacts with the impurities in the molten weld metal to form slag which floats over the surface of the weld metal. Layer of slag over the molten weld metal results:

- Increased protection of weld metal from atmospheric gas contamination and so improved properties of weld joint
- Reduced cooling rate of weld metal and HAZ owing to shielding of the weld pool by molten flux and solidified slag in turn leads to a) smoother weld bead and b) reduced the cracking tendency of hardenable steel

### **13.2 Components of SAW System**

SAW is known to be a high current (sometimes even greater 1000A) welding process that is mostly used for joining of heavy sections and thick plates as it offers deep penetration with high deposition rate and so high welding speed. High welding current can be applied in this process owing to three reason a) absence of spatter, b) reduced possibility of air entrainment in arc zone as

molten flux and slag form shield the weld metal a.d c) large diameter electrode. Continuous feeding of granular flux around the weld arc from flux hopper provides shielding to the weld pool from atmospheric gases and control of weld metal composition through presence of alloying element in flux. Complete cover of the molten flux around electrode tip and the welding pool during the actual welding operation produces weld joint without spatter and smoke. In following sections, important components of SAW system and their role have been presented (Fig. 13.1).

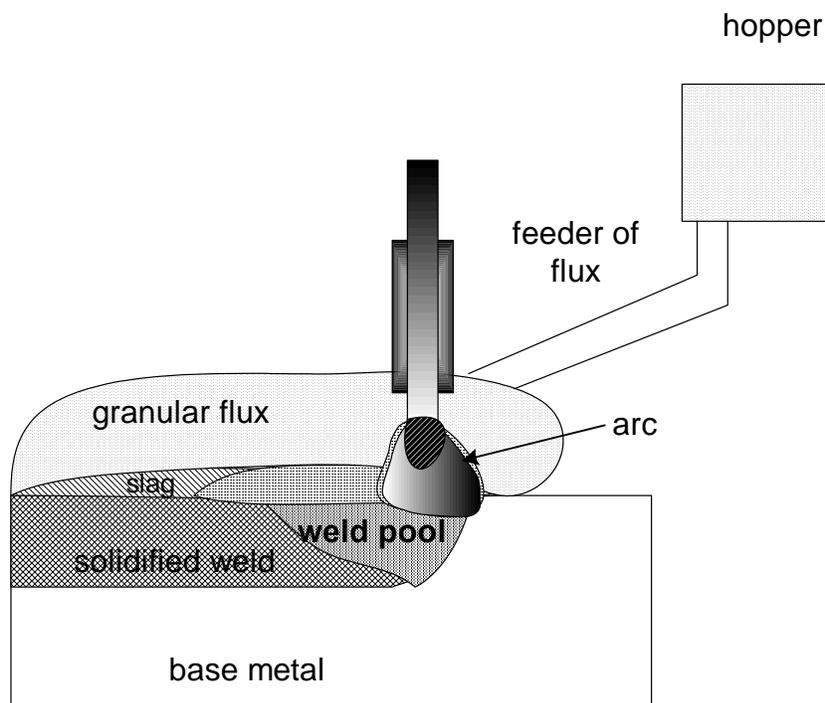


Fig. 13.1 Schematic of submerged arc welding system

### 13.2.1 Power source

Generally, submerged arc welding process uses power source at 100 % duty cycle; which means that the welding is done continuously for minimum 5 min without a break or more. Depending upon the electrode diameter, type of flux and electrical resistivity submerged arc welding can work with both AC and DC. Alternating current and DCEN polarity are generally used with large diameter

electrode (>4mm). DC with constant voltage power source provides good control over bead shape, penetration, and welding speed. However, DC can cause arc blow under some welding conditions. Polarity affects weld bead geometry, penetration and deposition rate. DCEP offers advantage of self regulating arc in case of small diameter electrodes (< 2.4mm) and high deposition rate while DCEN produces shallow penetration.

### **13.2.2 Welding Electrode**

The diameter of electrodes used in submerged arc welding generally ranges from 1–5 mm. The electrode wire is fed from the spool through a contact tube connected to the power source. Electrode wire of steel is generally copper coated for two reasons a) to protect it from atmospheric corrosion and b) to increase their current carrying capacity. However, stainless steel wires are not coated with copper.

### **13.2.3 SAW Flux**

Role of fluxes in SAW is largely similar that of coating in stick electrodes of SMAW i.e. protection of weld pool from inactive shielding gases generated by thermal decomposition of coating material. SAW fluxes can influence the weld metal composition appreciably in the form of addition or loss of alloying elements through gas metal and slag metal reactions. Few hygroscopic fluxes are baked (at 250–300° C for 1-2 hours) to remove the moisture. There are four types of common SAW fluxes namely fused flux, agglomerated flux, bonded flux and mechanical fluxes. Manufacturing steps of these fluxes are given below.

- Fused fluxes: raw constituents-mixed-melted-quenched-crushed-screened-graded
- Bonded fluxes: raw constituents-powdered-dry mixed-bonded using K/Na silicates-wet mixed-pelletized-crushed-screened
- Agglomerated fluxes: made in similar way to bonded fluxes but ceramic binder replaces silicate binder
- Mechanically mixed fluxes: mix any two or three type of above fluxes in desired ratios

### **Specific characteristics of each type of flux**

## **Fused fluxes**

- Positives
  - Uniformity of chemical composition
  - No effect of removal of fine particles on flux composition
  - Non-hygroscopic: easy handling and storage
  - Easy recycling without much change in particle size and composition
- Limitation is related with difficulty in
  - incorporating deoxidizers and ferro alloys
  - melting due to need of high temperature

## **Bonded fluxes**

- Positives
  - Easy to add deoxidizers and alloying elements
  - Allows thicker layer of flux during welding
- Limitation
  - Hygroscopic
  - Gas evolution tendency
  - Possibility of change in flux composition due to removal of fine particles

## **Agglomerated fluxes**

These are similar to that of bonded fluxes except that these use ceramic binders

## **Mechanical fluxes**

- Positives
  - Several commercial fluxes can be easily mixed & made to suit critical application to get desired results
- Limitations
  - Segregation of various fluxes
    - during storage / handling
    - in feeder and recovery system
    - inconsistency in flux from mix to mix

## **13.3 Composition of the SAW fluxes**

The fused and agglomerated types of fluxes usually consist of different types of halides and oxides such as MnO, SiO<sub>2</sub>, CaO, MgO, Al<sub>2</sub>O<sub>3</sub>, TiO<sub>2</sub>, FeO, and CaF<sub>2</sub> and sodium/potassium silicate. Halide fluxes are used for high quality weld joints of high strength steel to be used for critical applications while oxide fluxes are used for developing weld joints of non-critical applications. Some of oxides such as CaO, MgO, BaO, CaF<sub>2</sub>, Na<sub>2</sub>O, K<sub>2</sub>O, MnO etc. are basic in nature (donors of oxygen) and few others such as SiO<sub>2</sub>, TiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub> are acidic (acceptors of oxygen). Depending upon relative amount of these acidic and basic fluxes, the basicity index of flux is decided. The basicity index of flux is ratio of sum of (wt. %) all basic oxides to all non-basic oxides. Basicity of flux affects the slag detachability, bead geometry, mechanical properties and current carrying capacity as welding with low basicity fluxes results in high current carrying capacity, good slag detachability, good bead appearance and poor mechanical properties and poor crack resistance of the weld metal while high basicity fluxes produce opposite effects on above characteristics of the weld.

#### **13.4 Fluxes for SAW and Recycling of slag**

The protection to the weld pool in submerged arc welding process is provided by molten layer of flux covering to the weld pool. Neutral fluxes are found mostly free from de-oxidizers (like Si, Mn) therefore loss of alloying elements from weld metal becomes negligible and hence chemical composition of the weld metal is not appreciably affected by the application of neutral fluxes. However, base metal having affinity with oxygen exhibits tendency of porosity and cracking along the weld centerline. Active fluxes contain small amount of de-oxidizer such as manganese, silicon singly or in combination. The deoxidizers enhance resistance to porosity and weld cracking tendency.

The submerged arc welding fluxes produce a lot of slag which is generally disposed off away as a waste. The disposal of slag however imposes many issues related with storage, and environmental pollution. The recycling of the used flux can reduce production cost appreciably without any compromise on the

quality of the weld. However, recycling needs extensive experimentation to optimize the composition of recycled flux so as to achieve the desired operational characteristics and the performance of the weld joints. The recycling of flux basically involves the use of slag with fresh flux. The slag developed from SAW process is crushed and mixed with new flux. This process is different from recycling of un-fused flux which is collected from the clean surface and reused without crushing. Slag produced during submerged arc welding while using a specific kind/brand of the flux is crushed and then used as flux or used after mixing with original unused flux to ensure better control over the weld properties. Building of slag with unused flux modifies the characteristics of original unused flux therefore the blending ratio must be optimized for achieving the quality weld joints.

### **13.5 Welding parameters**

Welding parameters namely electrode wire size, welding voltage, welding current and welding speed are four most important parameters (apart from flux) that play a major role on soundness and performance of the weld therefore these must be selected carefully before welding.

#### **13.5.1 Welding Current**

Welding current is the most influential process parameter for SAW because it determines the melting rate of electrode, penetration depth and weld bead geometry. However, too high current may lead to burn through owing to deep penetration, excessive reinforcement, increased residual stresses and high heat input related problems like weld distortion. On the other hand, selection of very low current is known to cause lack of penetration & lack of fusion and unstable arc. Selection of welding current is primarily determined by thickness of plates to be welded and accordingly electrode of proper diameter is selected so that it can withstand under the current setting required for developing sound weld with requisite deposition rate and penetration (Fig. 2).

Diameter (mm)	Welding Current (A)
1.6	150-300

2.0	200-400
2.5	250-600
3.15	300-700
4.0	400-800
6.0	700-1200

### **13.5.2 Welding Voltage**

Welding voltage has marginal affect on the melting rate of the electrode. Welding voltage commonly used in SAW ranges from 20-35 V. Selection of too high welding voltage (more arc length) leads to flatter and wider weld bead, higher flux consumption, and increased gap bridging capability under poor fit-up conditions while low welding voltage produces narrow & peaked bead and poor slag detachability (Fig. 2).

### **13.5.3 Welding speed**

Required bead geometry and penetration in a weld joint are obtained only with an optimum speed of welding arc during SAW. Selection of a speed higher than optimum one reduces heat input per unit length which in turn results in low deposition rate of weld metal, decreased weld reinforcement and shallow penetration (Fig. 13.2). Further, too high welding speed increases tendency for a) undercut in weld owing to reduced heat input, b) arc blow due to higher relative movement of arc with respect to ambient gases and c) porosity as air pocket are entrapped due to rapid solidification of the weld metal. On other hand low welding speed increases heat input per unit length which in turn may lead to increased tendency of melt through and reduction in tendency for development of porosity and slag inclusion.

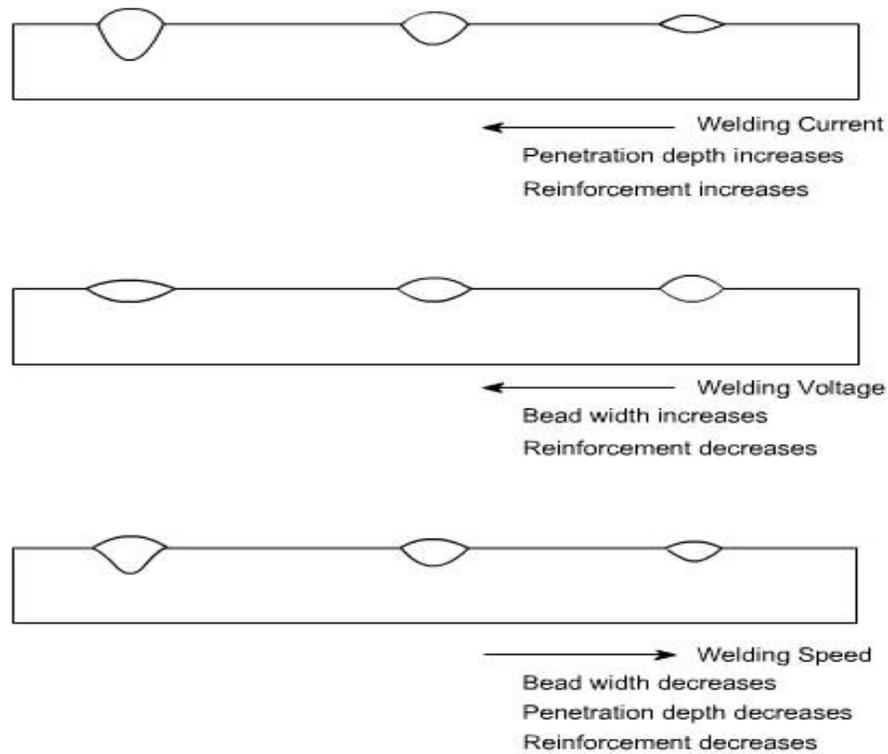


Fig. 13.2 Influence of welding parameters on weld bead geometry

### 13.6 Bead geometry and effect of welding parameters

Bead geometry and depth of penetration are two important characteristics of the weld bead that are influenced by size of the electrode for a given welding current setting. In general, an increase in size of the electrode decreases the depth of penetration and increases width of weld bead for a given welding current (Fig. 13.3). Large diameter electrodes are primarily selected to take two advantages a) higher deposition rate owing to their higher current carrying capacity and b) good gap bridging capability under poor fit-up conditions of the plates to be welded due to wider weld bead.

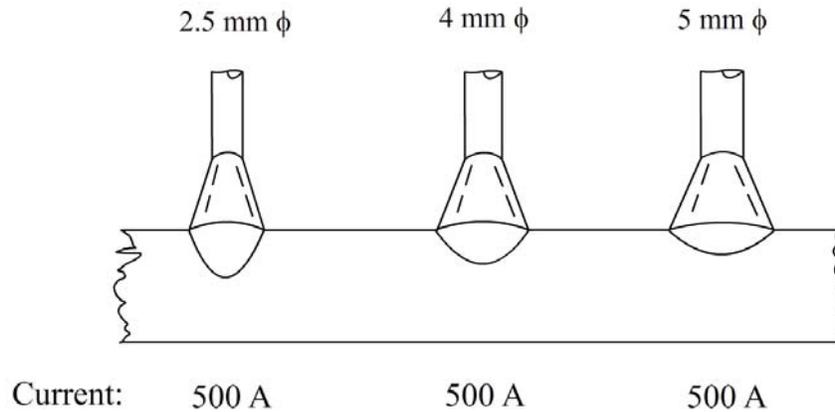


Fig. 13.3 Influence of electrode diameter on weld bead geometry

### 13.7 Advantage

Due to unique features like welding arc submerged under flux and use of high welding current associated with submerged arc welding processes compared with other welding process, it offers following important advantages:

- High productivity due to high deposition rate of the welding metal and capability weld continuously without interruptions as electrode is fed from spool, and the process works under 100% duty cycle.
- High depth of penetration allows welding of thick sections
- Smooth weld bead is produced without stresses raisers as SAW is carried out without sparks, smoke and spatter

### 13.8 Limitations

There are three main limitations of SAW a) invisibility of welding arc during welding, b) difficulty in maintaining mound of the flux cover around the arc in odd positions of welding and cylindrical components of small diameter and c) increased tendency of melt through when welding thin sheet. Invisibility of welding arc submerged under un-melted and melted flux cover in SAW makes it difficult to ensure the location where weld metal is being deposited during welding. Therefore, it becomes mandatory to use an automatic device (like welding tractors) for accurate and guided movement of the welding arc in line with weld groove so that weld metal is deposited correctly along weld line only.

Applications of SAW process are mainly limited to flat position only as developing a mound of flux in odd position to cover the welding arc becomes difficult which is a requisite for SAW. Similarly, circumferential welds are difficult to develop on small diameter components due to flux falling tendency away from weld zone. Plates of thickness less than 5 mm are generally not welded due to risk of burn through.

Further, SAW process is known as high heat input process. High heat input however is not considered good for welding of many steels as it leads to significant grain growth in weld and HAZ owing to low cooling rate experienced by them during welding. Low cooling rate increases the effective transformation temperature which in turn lowers nucleation rate and increases the growth rate during solid state transformation. A combination of low nucleation rate and high the growth rate results in coarse grain structure. Coarse grain structure in deteriorate the mechanical properties of the weld joint specifically toughness. Therefore, SAW weld joints are sometime normalized to refine the grain structure and enhanced the mechanical properties so as to reduce the adverse effect of high input of SAW process on mechanical properties of the weld joints.

### **13.9 Applications**

Submerged arc welding is used for welding of different grades of steels in many sectors such as shipbuilding, offshore, structural and pressure vessel industries fabrication of pipes, penstocks, LPG cylinders, and bridge girders. Apart from the welding, SAW is also used for surfacing of worn out parts of large surface area for different purposes such as reclamation, hard facing and cladding. The typical application of submerged arc welding for weld surfacing includes surfacing of roller barrels and wear plates. Submerged arc welding is widely used for cladding carbon and alloy steels with stainless steel and nickel alloy deposits

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