# ELEMENTARY STUDY OF SUBMERGED ARC WELDING FOR HARDFACING AND SURFACE ENGINEERING

**[1] Sagar Kishor Waidande,[2]Dr. Kishor P. Kolhe**
[1]PG Student [2]Professor
[1,2]Department of Mechanical Engineering,
[1,2]JSPM's Imperial College of Engineering & Research, Pune, India

***Abstract— This paper presents the review of submerged arc welding process for different industrial application like fabrication, erection, repairs, surfacing and hardfacing, etc. The review of literature was carried out, studied by many researcher's for getting the better improvement in hardfacing and surface engineering characteristic, like mechanical properties, microstructures, resistance to wear and erosion of heavy duty welded structure under severe conditions joined by submerged arc welding. Most of the studies conclude the effect of welding variables, flux composition, power source, material composition etc, on the surface deposited by various welding processes like Shielded Metal Arc Welding (Covered Electrode), Flux Cored Arc Welding, Submerged Arc Welding, Gas hardfacing, Powder Spraying, Electric Arc Spraying, Plasma Transferred Arc (PTA), High Velocity Oxy-Fuel Process (HVOF). Hard surfacing is the deposition of a special alloy material on a metallic base part, by various welding processes, to obtain more desirable wear properties and/or dimensions. This paper gives the brief introduction to the process of submerged arc welding for hardfacing and surface engineering. The various consumables used in the SAW process i.e electrode and flux are described. The various base metals and hard facing alloys are also mentioned.***

***Index Terms— Submerged Arc Welding, Hardfacing, Consumables, Alloys In Hardfacing, Mechanical Properties, Macro-Structure.***

## I. INTRODUCTION

In industrial manufacturing, maintenance, etc processes welding operations are essential tool. There are various welding methods like Shielded Metal Arc Welding (Covered Electrode), Flux Cored Arc Welding, Submerged Arc Welding, Gas Hardfacing, Powder Spraying, Electric Arc Spraying, Plasma Transferred Arc (PTA), High Velocity Oxy-Fuel Process (HVOF) These various welding methods are applicable for different applications like joining two parts, fabrication, repairs, surface engineering, hardfacing, etc, depending on the various resultant parameters like wear resistance, corrosion resistance, hardness, tensile strength etc. Out of all these various welding method and operation we focus on the submerged arc welding method for the operation of Hardfacing and Surface engineering.

### *Submerged arc welding (SAW) –*

In 1930 era, various problems faced in the welding operation have set a need of improved welding technology. The idea of placing thick layer of dry granular flux on the joint covering the welding arc, electrode was evolved & successfully developed in USA and later applied to the welding of penstocks and water conduits in California. The next advancement was the Submerged Arc Welding & the SAW process developed its importance in commercial sections all over the world. The modern Submerged Arc Welding is an arc welding process in which one or more bare wire electrodes & the work piece provides the heat for joint. The arc developed during the welding process is completely submerged under the flux, these flux shields the arc from atmospheric contamination. The process can be fully automatic or semi-automatic. Submerged arc welding (SAW) is a Semi-automatic or fully automatic consumable electrode arc process in which the arc is protected by a granular, fusible flux which covers the weld section and surrounds the base metal to protect it from the atmosphere. Powder alloys can be added with the flux to utilize the existing heat produced by SAW to melt powders and thereby increase deposition rates. The flux stabilizes the arc, provides slag coverage, and also controls the properties of the deposit. Consumables are in the form of wire (electrode) and flux. High deposition rates using current up to 1800 Amps in DC mode allows, deep penetration, easy slag removal, smooth and excellent quality welds can be obtained using this process. Fully automatic systems are used for heavy depositions in various areas such as Surfacing continuous casting rolls, Blast furnace bells, forging die block, inside of ball mill shell, Welding of pressure / chemical vessels

### *Principle of Working of SAW –*

Important principles of submerged arc welding are shown in the diagram below. The bare uncoated wire electrode is continuously fed in the direction of the joint of weld component the arc produced by the wire is covered by supplying fine-granular flux through the flux hopper. The electrical resistance of the electrode is as low as possible so that it supports the welding at high current. A power source of designed capacity is used to supply current to the welding system and the power source supplies current to the work piece and electrode simultaneously with opposite poles. As the electrode is placed close to the workpiece the circuit is completed producing a spark called as arc. These arc melts the wire and fills into the cavity. The arc also tends to melt the constitutes contained by the flux these molten flux sets on the top of the weld layer. A part of the total flux is solidified and the remaining excess flux is removed and recirculated by using appropriate mechanism.

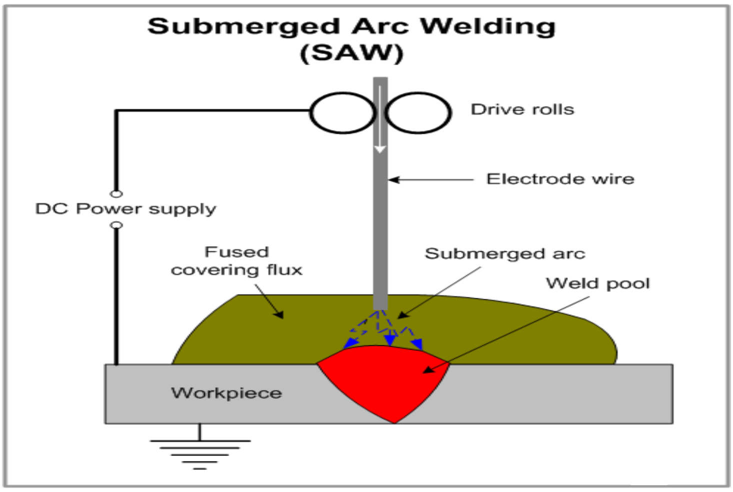



Figure 1 Submerged Arc Welding.

The electrode is continuously fed with the help of the feeder mechanism. Higher deposition rate can be achieved by increasing the electrode diameter (up to 6 mm ), and increased current ( up to 1800Amp). The flux also acts as a thermal insulator, and reduces the heat losses from the arc. Resulting in the complete usage of the available heat energy for the welding process.. The thermal efficiency is greater and the rate of welding is faster. It has been find submerged arc welding has a thermal efficiency of about 90 %, as against an approximate value of about 75 % for MMA welding. Submerged arc welding can be performed using either DC or AC. [16]. Submerged arc welding is a process which fond useful for the fabrication of structural steel, the metals can be joined using single as well as multipass. [1] The Submerged arc welding finds a very useful process in the heavy duty fabrication of farm machineries like Tractor Mounted Hydraulic Elevator, Farm equipments, etc [7-12]

***Submerged Arc Welding Consumable –***

Continuous bare wires in the form of coils & dry granular fluxes are used in combination as consumables for the Submerged Arc Welding of the base metal like mild steel. The welding current is directly proportional to the melting rate of electrode and flux, weld width, penetration, and reinforcement height.

***Electrode wires*** –

The electrode diameter varies from 1.2mm to 6.4mm and current capacity of 200 to 1500Amp basically the electrode types are single wire, twin wire. Generally the American welding society specification AWS A5.17 and AWS A5.23 are referred for the selection of the electrodes in submerged arc welding process. Let us consider an electrode EL12 from the table – 1 in this E indicates the electrode L, M & H represent low, Medium and high 8, 12 etc indicates in point the nominal carbon content of the electrode the letter indicated electrode is made from a heat of silicon killed steel. Here EL12 is a carbon steel wire containing 0.1% carbon, 1.0% manganese and 0.03% silicon is classified as EM-12. When this wire is used with a flux F72 then the combination will be designated as F72-EL12. [14]. The following is the reference for the selection of electrode.

**1)** AWS A5.17-1997. "specification for carbon steel electrodes & fluxes for SAW"
**2)** AWS A5.23-1980. "Specification for low alloy steel electrode & fluxes for submerged arc welding".
**3)** BS 4165: 1971 "Specification for electrode wires & fluxes for the SAW of carbon steel & medium tensile stress.
**4)** DOC IIS/IIW – 545-78. "Classification & symbolization of base steel wire electrode & fluxes for SAW of structural steel".
**5)** IS: 7280 – 1974. "specification for bare wire electrodes for SAW of structural steel".[1]

***Submerged Arc Welding Fluxes*** –

Welding flux constitutes nearly half of the cost in SAW process this have lead to the continuous development with the welding flux. Over the years, development of better welding flux compositions in terms of mechanical properties and productivity, which are economically cost effective too, has caught the eye of many researchers. [3]. Fluxes may be categorized in two ways, by the method of manufacturing (fused or agglomerated) or by its activity (neutral, active or alloying). Within these broad groupings the fluxes may be classified further by their constituents, silica, manganese oxide, calcium fluoride etc. Perhaps the most convenient method of classifying, however, is by reference to the 'basicity index' (BI) of the flux. The index is calculated by dividing the sum of the percentages of the basic constituents by the sum of the acid constituents. Calcium, magnesium, sodium, potassium and manganese oxides, calcium carbonate and calcium fluoride are the basic constituents of a flux, silica and alumina the acid constituents.

- Acid fluxes have a BI of 0.5 to 0.8
- Neutral fluxes have a BI of 0.8 to 1.2
- Basic fluxes have a BI of 1.2 to 2.5
- Highly basic fluxes have a BI of 2.5 to 4.0.

The basicity of a flux has a major effect on the weld metal properties, most importantly the notch toughness. As a general rule the higher the basicity the higher the notch toughness. The basicity index for the flux is given by

$$BI = \frac{\sum Basic\ Fluxes\ Wt\ \%}{\sum Acidic\ Fluxes\ Wt\ \%} \quad \ldots (1)$$

$$BI = \frac{CaF_2 + CaO + MgO + BaO + SrO + Na_2O + K_2O + Li_2O + 0.5(MnO + FeO)}{SiO_2 + 0.5(Al_2O_3 + TiO_2 + ZrO_2)}$$

….(2) [23]

Table 1 Some SAW Electrode classifications as per AWS A5.17. [2]

| AWS Classification | Composition, % | | | |
|---|---|---|---|---|
| | C | Mn | Si | Mo |
| EL12 | 0.07-0.15 | 0.35-0.60 | 0.05 | - |
| EM12K | 0.07-0.15 | 0.85-1.25 | 0.15-0.35 | - |
| EH14 | 0.10-0.18 | 1.75-2.25 | 0.05 | - |
| EA1 | 0.07-0.15 | 0.70-1.00 | 0.05 | 0.45-0.65 |
| EA2 | 0.07-0.15 | 1.00-1.30 | 0.05 | 0.45-0.65 |
| EA4 | 0.10-0.18 | 1.30-1.60 | 0.20 | 0.45-0.65 |
| EA3 | 0.10-0.18 | 1.70-2.40 | 0.05 | 0.45-0.65 |

***Effects of Process Parameter in SAW***

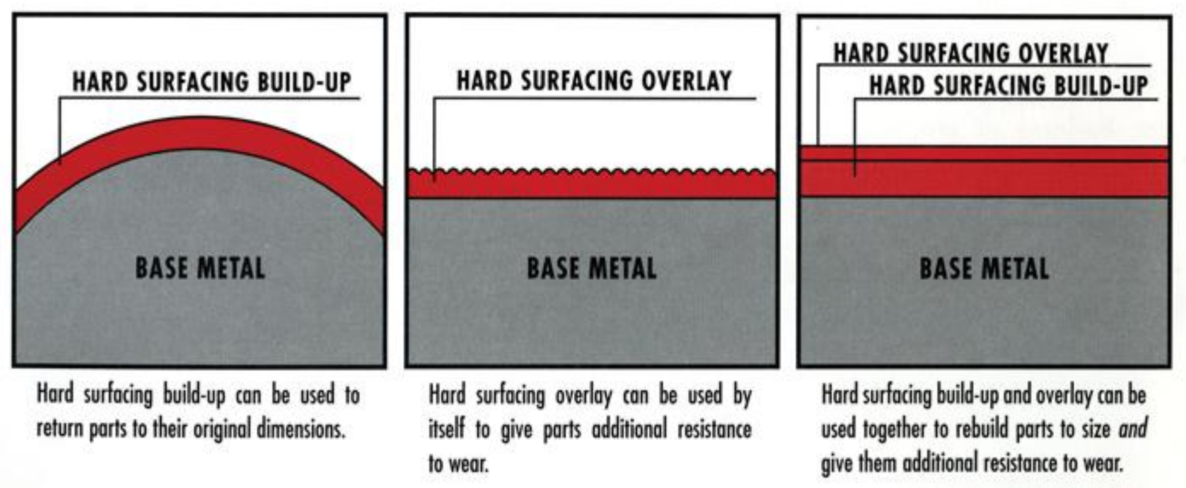
- Increase in welding current enhances the melting rate of the electrode and flux, weld width, penetration and reinforcement height. For a given welding current electrode melting rate and flux melting rate is the highest in DCEN, followed by AC and DCEP.
- Decrease in arc voltage has increased the electrode melting rate and reinforcement height but decreased the flux melting rate and the weld width while showed no effect on the weld penetration.
- For a given current, increase in the electrode diameter decrease the electrode melting rate, reinforcement height and weld penetration, while increase the weld width. On the other hand, increase in the electrode extension enhance the electrode melting rate and weld width with smaller penetration.
- The weld width, penetration and reinforcement height increased inversely with the welding speed.
- Higher electrode melting rate in the case of the twin-wire SAW process is observed in comparison to the single wire SAW process for a given welding current.
- Increase in either trailing wire current or the leading wire current results in higher weld bead dimensions in SAW-T process. At smaller welding current and shorter electrode extension length, increase in the inclination angle of the trailing electrode wire has decreased the weld penetration in SAW-T process.
- The final weld microstructure in submerged arc weldment depend on the cooling rate from 800 to 500 °C

***Hardfacing –***

Hard surfacing is the deposition of a special alloy material on a metallic base part, by various welding processes, to obtain more desirable wear properties and/or dimensions. The properties usually sought are greater resistance to wear from abrasion, impact, adhesion (metal-to-metal), heat, corrosion or any combination of these factors. The various processes used in Hardfacing are Shielded Metal Arc Welding (Covered Electrode), Flux Cored Arc Welding, Submerged Arc Welding, Gas Hardfacing, Powder Spraying, Electric Arc Spraying, Plasma Transferred Arc (PTA), High Velocity Oxy-Fuel Process (HVOF).

***Need of Hardfacing –***

1. **1.** Cost Reduction – In case of reconditioning a worn out part save up to 25 -75% of the cost which would be needed in case of replacement.
2. **2.** Increases Life – Hardfacing increase the life of the product by noticeable times, as per application as compared to that of non surfaced part.
3. **3.** Reduce downtime - Because parts last longer, the number of break downs are reduced.
4. **4.** Reduce inventory of spare parts - There is no need to keep numerous spare parts when worn parts can be rebuilt.



***Applications of Hardfacing –***

There are basically two main areas where hard surfacing is used:

1. To recondition worn parts - Since the wear of the metal are unavoidable and have no pre solution the solutions are applicable after complete wear out of the component. There are basically two solutions. Replacement of the part or to recondition the part. To replace the part he must have it in stock or try to obtain a new one these may lead to increase of cost and inventory. Even though the part is available for replacement it may require any machining and modification operation to fit as desired.
2. The protection of the metal component against wears corrosion etc - Hard surfacing overlay is used on both new and/or original equipment where the part is most porn to wear. The higher alloy overlay offers much better wear resistance than that of the original base material. This usually increases the work life of the component up to two or more times that of a part which is not surfaced. Although the added hard surfacing material may add to the price of the equipment, we can save it by using a less expensive base material may be used bymany researchers. In the present paper research work carried out by various researchers in the field of welding flux development has been reviewed. [3].

***Hardfacing Alloys –***

Many different hardfacing alloys are available, they fall into four categories.

1. Low alloy iron - base alloys: Materials containing up to 12% alloy components usually chromium, molybdenum and manganese.
2. High alloy iron – base alloys: Materials with 12-50% alloy content in addition to the chromium found in all iron – base hardfacing alloys some of these alloys might also contain Nickel or Cobalt.
3. The Cobalt – base and Nickel – base alloys: Alloys, which contain relatively small amount of iron (1.3 to 12.5%) of these the most costly, but also the most versatile are the Cobalt – Chromium tungsten alloys. All the Cobalt – base and Nickel – base alloys have high resistance to corrosion and oxidation, they processes low co efficient of friction making them especially suitable for applications involving metal to metal wear; and they are almost always selected for applications involving temperatures of 550 degrees or higher. The Cobalt – base alloys retain much of their original hardness at red-hot (800degrees).
4. Tungsten carbide materials: Tungsten carbide is one of the hardest materials available for industrial use. It cannot be melted by any flame, it is also rather brittle. For hardfacing purposes, it is crushed and applied in conjunction with a binding metal. The Tungsten carbide particles are usually enclosed in a steel tube rod. Recently a tube rod enclosing Tungsten and Vanadium carbides has been introduced. It is said to give more uniform surface coverage than the straight the straight tungsten carbide rod.

*Base Metals* –

Almost 85% of the metal produced and used is steel, the term steel encompasses many types of metals made principally of iron. The various types of steels used in the industry for making different components for different applications are grouped in to the mentioned types.

1. Low – carbon steels and low – alloy steels**:** These steels include those in the AISI series C - 1008 to C – 1020, carbon ranges from 0.10 to 0.25% manganese ranges from 0.25 to 1.5%, phosphorous is 0.4%maximum, and sulphur is 0.5% maximum. Steels in this range are most widely used for industrial fabrication and construction. These steels can be easily welded with any of the arc, gas and resistance welding processes. The low – alloy high – strength steels represent the bulk of the remaining steels in the AISI designation system. These steels in clued the low manganese steels, low-to-medium nickel steels, the low nickel-chromium steels, the molybdenum steels, the chromium – molybdenum steels, and the nickel chromium-molybdenum steels. In these alloys, carbon ranges from0.12 to 030%, manganese from 0.40 to 0.60%, silicon from 0.20% to 0.45% and nickel from 3.25 to 5.25%.
2. Medium – carbon steels: These steels include those in the AISI series C-1025 to C-1050 the composition is similar to low-carbon steels, except that the carbon ranges from 0.25 to 0.50% and manganese from 0.60 to 1.65% medium-carbon steels are readily weld able provided some precautions are observed. These steels can be welded with all of the processes mentioned above.
3. High – carbon steels: These steels include those in the AISI series from C-1050 to C-1095. The composition is similar to medium-carbon steels, except that carbon ranges from 0.30 to 1.00%. Special precautions must be taken when welding steels in these classes. High – carbon steels can be welded with the same processes mentioned previously.
4. Other steels are low-nickel chrome steels, low-manganese steels, low – alloy chromium steels and the electric furnace steels, which can be welded without special precautions when carbon is at low end of the range. [15]

***Hardness Tests Methods:***

Rockwell Hardness Test, Rockwell Superficial Hardness Test, Brinell Hardness Test, Vickers Hardness Test, Microhardness Test, Moh's Hardness Test, Scleroscope and other hardness test methods. [22].

## II. LITERATURE REVIEW

Ebert and Winsor presented a study on background information on the subject of tensile strength, yield strength, elongation, and reduction in area. The authors have conducted various tests to determine the effect of after weld heat treatment on the strength and hardness of various types of carbon steel. Weld samples were prepared using the joint geometry and welding variables by AWS-5.17 and A5.23. The consumables used in the experiment are EM12K and fluxes used EH14, EA-2 and EA-3. According to the test conducted using the above weld sample the tensile strength should not exceed 60000 psi (415Mpa). These weld sample is application where lower strength joints are acceptable. [2]

Rehal, has given the brief information about the fluxes used in the submerged arc welding. It consist the study of the composition of the flux. According to the research carried out the flux for welding can be designed by statistical and design of experiment methods. [3]

Kolhe and Datta, have carried an experimental study on the test specimen of 16mm thick mild steel plate to study the microstructure, phase analysis and mechanical properties, HAZ width of SA weld metal multipass joint and heat-affected zone. The experiment was carried out using trinacular metallurgical microscopy, with OnixVision Video Microscope Projection System including mega pixel camera and image analysis software. The hardness test was done using the Rockwell hardness test. The main purpose of present work is to investigate and correlate the relationship between the various parameters; mechanical properties and microstructure of single "V" butt joint of mild steel plate, and also to perform the phase analysis of the multi-pass welded joint to get defect free welded structures. [4]

Degala and Na, has given the brief review of the experimental studies on the single wire and multi-wire SAW process. The influence of various parameters like dimension, temperature, distribution, metallurgical phases and the mechanical properties are discussed. The author have studied and referred over the various experiment over the influence of process parameters like current, voltage, polarity, welding speed, wire electrode and the flux on weld quality. The author gives us a brief idea on the statistical predictive models based on multiple regression analysis to estimate several weld joint characteristics. [5]

Kolhe *et el* , have carried out the desing and development of the hydraulic eleveators in harvesting coconuts and mangoes. In these research and development work they have studied the problems faced by the farmers in the south eastern areas of Maharastra (Ratnagiri) and to over come these problems they have design and developed a new automised technique of harvesting the coconuts and mangoes. They have found a vast use of submerged arc welding during the manufacuring of the elevators. The lifitng capacity of the eleveator is arround 2000 Kg at a time. The researchers have carried out number of testing and modification form year 2008 till now to develop a advanced prototype. The elevator is mounted on the tractor and very much useful for the farms to nullify their various problems and increase the productive rate significantly. The Ministry of Agriculture have promoted this research and development work. [7-12].

Ali Moarrefzadeh, studied the existing mathematical simulation technique and used the SIMPLEC algorithm to generate a new mathematical model to simulate the effect of various parameters of SAW. A 3D mathematical model for the metal transfer process in SAW was formulated in this article. In this experiment the ANSYS software is used to simulate the heat flow during the SAW process. [17]

Kolhe, *et al*, have carried a detailed study on the various parameters of welding joint to get a defect free weld. In this article the authors have focused the detailed study of mechanical properties, heat affected zone and microstructure of single "V" butt joint of mild steel plate, and also to perform the phase analysis of the multipass welded joint to get defect free welded structure. The variation in hardness of weld metal, fractured surface and base metal were compared with the microstructure, to get a defect free weld, and also it was correlated with the microstructure of weld metal and heat-affected zone.[18]

Kasabe and Kolhe, have studied the heat transfer across the weld component in submerged arc welding process. the authors have studied the effects of heat input and preheating on microstructure of material, metal and mechanical properties of material, on current and welding speed.[19]

Deshmukh and Teli, carried out experiment to establish the relationship between process variables and optimization tools used to find an optimal solution, they have used Taguchi orthogonal array, the signal to noise (S/N) ratio and analysis of variance were used for the optimization of welding parameters. The authors developed a model which is a powerful tool in experimental welding optimization.[20]

Kolhe, *et al*, carried out an experimental study to effects in pulsed gas tungsten arc welding (pulsed GTAW) for aluminium alloy (AA7039) using various Ar + He (Argon + Helium) mixtures as a shielding gas with sinusoidal AC wave layout, to analyse the effect of each process parameter on the bead geometry, and to predict the optimum setting for each the Taguchi method is used welding process parameter. In this experiment the pulse current of 210 A, background current of 120 A, pulse frequency of 150 Hz, pulse duty cycle of 90 per cent and 30per cent of He in Ar + He gas mixture resulted the optimum values of bead geometry. The confirmation test conducted with predicted levels of factors proved to be worthy. It is observed that the micro hardness reduces in the particular area of the heat affected zone due to grain coarsening and precipitation hardening. Also, the drop in the micro hardness shifts away from weld centre towards the unaffected base metal due to the increase in heat input as current and frequency are increased.AA7039 is employed in aircraft, automobiles, high-speed trains and high-speed ships due to their low density, high specific strength and excellent corrosion resistance. [21]

Verdins, Kanaska, Kleinbergs, have given the detailed selection method for the hardness test method. They have studies various experiments done on the various test specimens have concluded, that for hardness test of small size flat samples the best methods are Rockwell, Brinell and Vickers methods, however, Mobil tester M-295 is more appropriated for scientific researches because the absolute value of the hardness figure has not relevant importance. [22]

## III. CONCLUSION

Submerged arc welding is a versatile welding process used in metal joining, surfacing and hard facing. This process is having tremendous scope in the allied industrial applications like ship building, pressure vessel, farm machineries, oil and gas pipes etc. For the process of Hardfacing the SAW method is suitable, there are various parameters to be considered while the selection of the electrode, flux, voltage, current, welding speed etc. These all parameters affect the microstructure and increase various mechanical properties like wear resistance, serviceability of the component, corrosion resistance etc. The effect of process parameter of SAW during hardfacing are -

- The microstructure using submerged arc welded component depends on the cooling rate from nearly 800 to 500 °C.
- The welding current is directly proportional to the melting rate of electrode and flux, weld width, penetration, and reinforcement height.
- The voltage is inversely proportional to the electrode melting rate and reinforcement. And the voltage is directly proportional to the flux melting rate and the weld width and is irrespective of the weld penetration
- At constant current the electrode diameter is inversely proportional to the electrode melting rate, reinforcement height, and weld penetration where as directly proportional to the weld width. And similarly, the electrode extension is directly proportional to the electrode melting rate and weld width and inverse with the weld penetration.
- The Welding speed is inversely proportional to the width, penetration and reinforcement height.
- Comparatively the twin-wire SAW have higher electrode melting rate than that of the single wire SAW process for same welding current.

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