INFLUENCE OF PROCESS PARAMETERS IN MULTIPASS SUBMERGED ARC WELDING

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Abstract— Welding processes that employ an electric arc are the most prevalent in industry are Shielded Metal Arc Welding, Gas Metal Arc Welding, Flux Cored Arc Welding, Submerged Arc Welding and Gas Tungsten Arc Welding. These processes are associated with molten metal. Molten metal reacts with the atmosphere so that oxides and nitrides are formed. All arc welding processes employ some means of shielding the molten weld pool from the air. The Submerged Arc Welding process is often preferred because it offers high production rate, high melting efficiency, ease of automation and low operator skill requirement. The quality of weld depends on bead geometry of the weld which in turn depends on the process variables. Submerged Arc Welding (SAW) is one of the major metal fabrication techniques in industry due to its reliability and capability of producing good quality weld. The ability to join thick plates (as thick as 1.5 inch) in a single pass, with high metal deposition rate has made this process useful in large structural applications. It is one of the most widely used processes for fabrication of pipes, thick plates, pressure vessels, marine vessels, rail tanks, ships, heat exchangers, offshore structure etc. This process is commercially used for welding of low carbon steel, high strength low alloy steel, nickel base alloys and stainless steel. It is possible to weld thin sheet of steels at over 5 m/min with minimum emission of welding fume. Selection of process parameters has great influence on the quality of a welded connection. In this paper the overall review on influence of Process Parameters in submerged arc welding during the multipass phase is presented. It is necessary to study on Process Parameters of submerged arc welding for getting quality and effective welding. Generally, all welding processes are used with the aim of obtaining welded joint with the desired weld-bead parameters, excellent mechanical properties with minimum distortion.

Index Terms— Multipass submerged welding, Heat Affected Zone (HAZ), Process Parameters

I. INTRODUCTION

Submerged arc welding is a versatile production welding process capable of making welds with currents up to 2000 amperes, alternate current (AC) or direct current (DC), using single or multiple (2 to 5) wires or strips of filler metal. Although currents ranging from 300 to 2000 amperes are commonly utilized, currents up to 5000 amperes have also been reported used with multiple arcs. Constant Voltage welding power supplies are most commonly used, however constant current systems in combination with a voltage sensing wire-feeder are also available. The submerged arc welding process is widely used because of its many advantages. It is readily adaptable to the use of automatic equipment and can be carried out at speeds significantly higher than those of other known most of the welding processes. SAW is normally operated in the automatic or mechanized mode, however, semi-automatic (hand-held) SAW guns with pressurized or gravity flux feed delivery are also available. The process is normally limited to the Flat or Horizontal-Fillet welding positions (although Horizontal Groove position welds have been done with a special arrangement to support the flux). (Ref.24)

Generally, submerged arc welding (SAW) requires a continuously fed consumable solid electrode. The molten weld and the arc zone are protected from atmospheric contamination by being "submerged" under a blanket of granular fusible flux. The flux for submerged arc welding also cleans the molten metal pool, it favourably modifies the chemical composition of the weld metal and it favourably influences the shape of the weld bead and its mechanical properties. It also forms a readily removable or free peeling fused slag to facilitate cleaning after use. In molten state, the flux becomes conductive, and provides a current path between the electrode and the work. This thick layer of flux completely covers the molten metal, thus preventing spatter and sparks as well as suppressing the intense ultraviolet radiation and fumes.

According to British Institute of Welding, "A flux is a material used during welding, brazing or braze welding to clean the surfaces of the joint chemically, to prevent atmospheric oxidation and to reduce impurities or float them on the surface" A flux has several complex functions to perform. For obtaining a sound welds, it is necessary that flux performs its function effectively.

The main functions of a good flux are as follows:

- **I.** Protects the weld pool from atmospheric contamination by providing a suitable cover on the weld bead.
- **II.** Stabilizes the arc.
- **III.** Provides desired weld metal composition.
- **IV.** Improves the mechanical and metallurgical properties by adding desirable alloying elements and removing deleterious elements from the weld metal.
- **V.** Deoxidizes the weld metal.
- **VI.** Provides the optimum thermodynamic properties for the desirable elements transfer
- **VII.** Improves weld bead geometry parameters.
- **VIII.** Improves the efficiency of metal deposition.

Flux plays an important role in deciding the weld metal quality. Fluxes should provide the appropriate weld metal composition and exhibit good welding behavior. These two requirements can be achieved by maintaining the flux ingredients within the optimum range. It influences the weld metal physically, chemically and metallurgically. Physically, it influences the bead geometry and shape relationships, which in turn affect the load carrying capacity of the weldment. Chemically, it affects the chemistry of the weld metal, which in turn influences the mechanical properties of the weld metal. (Ref.20)

Mechanical and metallurgical properties of the weld metal mainly depend upon the content of manganese, silicon carbon, sulphur, phosphorous, chromium and other alloying elements in the weld metal. Manganese content in the weld metal depends on the manganese content of the electrode wire, manganese oxide, and presence of the basic elements like calcium, magnesium and basicity of the flux. Apart from the chemical composition of the weld metal, the characteristics of the welds are also governed by the weld bead geometry which is further influenced by welding parameters viz. open circuit voltage, welding wire feed rate and welding speed. A variation in these parameters changes the heat input and consequently affects the bead geometry.

The microstructure of the weld metal depends upon chemical composition and heat-input and it is directly related to flux composition and welding parameters respectively. Grain boundary ferrite, acicular ferrite, polygonal ferrite, side plate ferrite, pearlite and bainite are the constituents of the microstructure of steel weld metal. Micro-hardness and mechanical properties are governed by the proportion and size of these micro-constituents. Submerged arc welding can be employed for an extremely wide range of workpieces. The method is suitable for butt welding and fillet welding of such applications as structural members in ships, manufacture of pressure vessels, bridge beams, massive water pipes, thin sheet shells and so on. In addition, the process is particularly effective for cladding applications, e.g. when surfacing mild carbon steel with stainless steel materials, or when depositing hard materials on a softer substrate. Submerged arc welding is generally performed indoors in fabrication shops. Working outdoors always carries the risk of undesirable levels of moisture finding their way into the joint or flux and resulting in porosity of the weld. If submerged arc welding must be carried out outdoors, special precautions should be taken, such as the construction of a roof over the work area. Submerged arc welding is most efficient if the joint can be filled with as few passes as possible. If, when working in mild steel, the workpiece can be turned over, and if the material is not too thick, a bead is often applied from each side of the joint. If the basic material is alloyed steel, a multi-pass procedure is normally necessary. Admittedly, this results in an increase in process costs, but for many workpieces the economics of the process are still sufficiently attractive for submerged arc welding to be more cost effective than, say, manual welding using coated electrodes. In addition, there will be fewer weld defects with automatic welding. (Ref.4)

II. LITERARTURE REVIEW

R. S. Chandel [1] has been evaluated Arc voltage, wire diameter, electrode extension (EE), electrode polarity, power source type and flux classification on melting rates (MR) for the submerged arc welding process. The results show that for a given heat input, greater melting rates are obtained when higher current, longer electrode extension, smaller diameter electrodes and electrode negative polarity are used. Arc voltage, power source type and flux classification do not have any significant influence on melting rates. Mathematical models to correlate process variables and melting rates have been computed from the data. V.

Gunrajj and N. Muruhan [2] has used five-level factorial technique to relate the important process-control variables - welding voltage, wire feed rate, welding speed and nozzle-to-plate distance - to a few important bead-quality parameters - penetration, reinforcement, bead width, total volume of the weld bead and dilution. The models developed were checked for their adequacy with the F test. Using the models, the main and interaction effects of the process-control variables on important bead geometry parameters determined in this quantitatively and presented graphically.

S Kumanan et. al [3] This paper details the application of Taguchi technique and regression analysis to determine the optimal process parameters for submerged arc welding (SAW). The planned experiments are conducted in the semiautomatic submerged arc welding machine and the signal-to-noise ratios are computed to determine the optimum parameters. The percentage contribution of each factor is validated by analysis of variance (ANOVA) technique. Multiple regression analysis (MRA) is conducted using statistical package for social science (SPSS) software and the mathematical model is build to predict the bead geometry for any given welding conditions.

K. P. Kolhe and C. K. Datta [4] were studied microstructure, phase analysis; mechanical properties and HAZ width of submerge arc welded specimens for different passes with different heat inputs. They investigated the microstructure of 16mm thick mild steel plate was carried out using metallurgical microscopy with image analysis software. The hardness, impact energy and micro hardness of multipass welded joint were tested by using Rockwell hardness testing machine and charpy V- notch testing machine. The proportionate value of micro hardness was observed for low heat input whereas for increased heat input variations in hardness value was observed. They concluded welding parameters of SAW used to control the microstructure, phases and mechanical properties of welded joint and help to get the robust welded structure of mild steel.

K.P.Kolhe and Rajesh Dharaskar focused [5] on the advance of arc welding technology in this paper e.g. electric arc welding, gas metal arc welding, tungsten arc welding, submerged arc welding etc, to improve the mechanical properties such as strength, ductility hardness etc., Microstructure, Heat-affected zone and welded structure of farm machines. From this study, they concluded that arc welding has huge effect on the farm machines as the total productivity, cost quality and overall mechanical properties of farm machines design are closely related to the type of welding process selected and the various parameters like striking voltage, arc voltage, current, choice of material, flux material used etc.

Dhas et al. (6) elaborates the study of welding procedures generation for the submerged arc welding process. Several research works have already been carried out in the field of submerged arc welding for parametric optimization.

Biswas et al. (7) studied the effect of process parameters on output features of submerged arc weld by using Taguchi method.

III. PRINCIPLE OF SUBMERGED ARC WELDING

The below diagram indicates, the main principles of submerged arc welding. The filler material is an uncoated, continuous wire electrode, applied to the joint together with a flow of fine-grained flux, which is supplied from a flux hopper via a tube. The electrical resistance of the electrode should be as low as possible to facilitate welding at a high current, and so the welding current is supplied to the electrode through contacts very close to the arc and immediately above it. The arc burns in a cavity which, apart from the arc itself, is filled with gas and metal vapour. The size of the cavity in front of the arc is delineated by unmelted basic material, and behind it by the molten weld.

The top of the cavity is formed by molten flux. The diagram also shows the solidified weld and the solidified flux, which covers the weld in a thin layer and which must subsequently be removed. Not all of the flux supplied is used up: the excess flux can be sucked up and used again.

The filler metal is a continuously-fed wire electrode like GMAW and FCAW. However, higher deposition rates can be achieved using SAW by using larger diameter electrodes (up to 1/4") and higher currents (650-1500 Amperes). Since the process is almost fully mechanized, several variants of the process can be utilized such as multiple torches and narrow gap welding. The flux also has a thermal insulating effect, and thus reduces heat losses from the arc. As a result, more of the input energy is available for the actual welding process itself than is the case with processes involving an exposed arc. The thermal efficiency is greater and the rate of welding is faster. It has been found that 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. (Ref.24)

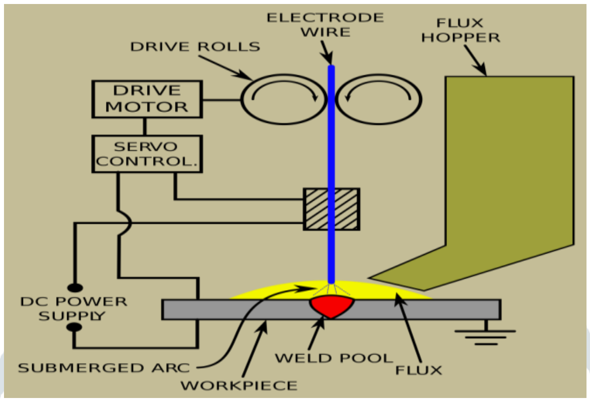

Fig. 1. Schematic of Submerged Arc Welding (SAW)

IV. IMPORTANT PARAMETERS IN SUBMERGED ARC WELDING

1. Arc voltage

The arc voltage is decisive in determining the shape and width of the arc and, to some degree, also in determining its penetration. Too high an arc voltage in an I-joint in flat sheet will produce a wider weld, while in a V-joint, X-joint and fillet radii it will result in a concave weld, with a risk of undercutting and slag that is difficult to remove. On the other hand, too low an arc voltage will result in a high, round weld in I-joints and V-joints, while in X-joints and fillet radii it will result in a convex weld, and which is also hard to de-slag.

2. Welding current

Welding current is the parameter that is of greatest importance for penetration. The current setting depends on the thickness of the metal and the type of joint. The current has no effect on the width of the bead, but too high a current can result in burn through, while too low a current can result in insufficient penetration with resulting root defects. (Ref.8)

3. Welding speed

The welding speed (the linear speed along the line of the weld) also affects the penetration. If the speed is increased relative to the original value, penetration will be decreased and the weld will be narrower. Reducing the speed increases penetration and results in a wider weld. However, reducing the welding speed to about 20–25 cm/min (depending on the actual value of the current) can have the opposite effect, i.e. a reduction in penetration, as the arc is prevented from transferring thermal energy to the parent metal by the excessive size of the weld pool. If the welding speed is to be changed while penetration is kept constant, it is necessary to compensate by adjustment of the welding current, i.e. to increase or decrease it. (Ref.8,24)

4. Wire diameter

For a given current, a change in wire size will result in a change in current density. Greater wire diameter results in a reduction in penetration and, to some extent, also the risk of burning through at the bottom of the weld. In addition, the arc will become more difficult to strike and arc stability will be adverse.

To calculate **heat input** for submerged arc welding the following equation can be used.

$$q=(V*I*60)/(s*100)$$

Where, q = Heat Input (KJ/mm)
V = Voltage (V)
I = Current (A)
S= Welding Speed (mm/min.)

From the above equation we can find out the initial heat that is heat input required to the base metal.

To calculate the effect of **heat transfer rate on microstructure of metal plate** we can use the following equation. (Ref.24)

$$Q = -KA\ (T0-T1)/dx$$

Where, Q = Heat Transfer Rate.
K=Thermal Conductivity.

A=Area of plate.
T0=Initial Temperature.
T1=Final Temperature.
dx= Thickness of plate.
The above equation can be used to obtained the effect of heat transfer is different at different point

Lower and Higher limits of process parameters as below

Parameters	Units	Notations		Lower limits	Higher limits
Welding current	Amp	I		300	350
Arc voltage	Volts	V		30	38
Welding speed	mm/min	S		256	550
Nozzle to plate distance	Mm	N		18	22

V. EFFECT OF PROCESS PARAMETERS ON WELDMETAL AND HAZ:

Effect of Current

It is observed that when welding current is increased the microhardness is reduced. With an increase in welding current, there is a linear increase in heat input, due to increased heat input the reduction in average cooling rate in every pass. And reduction in heat input causes increase in microhardness value. Fig.2. describes the effect of welding current on the microhardness of weld and HAZ respectively when other parameters are constant. (Ref.9)

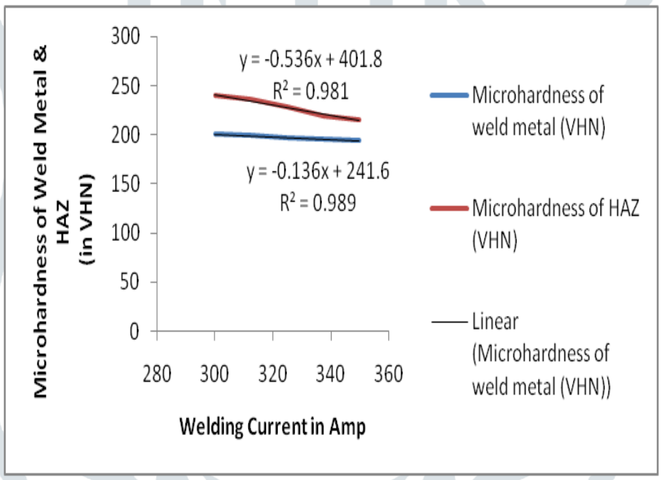

Fig.2. Effect of Welding Current of Weldmetal and HAZ (Ref.9)

Effect of Voltage

Figure indicates that effect of open circuit voltage on microhardness of weld metal and HAZ respectively. It can be observed that microhardness decreases linearly with an increase in arc voltage from 30 to 38 volt. This decrease in microhardness with increase in voltage is due to when open circuit voltage is increased the heat input in multipass also increased and reduction in average cooling rate and increases number of passes in multipass causes increase in grain size as a result microhardness decreases. (Ref.9)

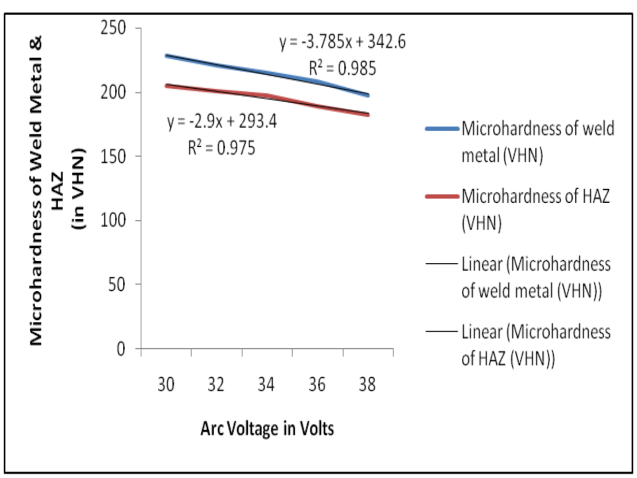

Fig.3. Effect of Arc Voltage of Weldmetal and HAZ (Ref.9)

Effect of welding speed

It is observed from the figure that welding speed is directly proportional to the microhardness. With the increasing in welding speed from 236 mm/min to 550 mm/min the microhardness is also gradually increased. Because increasing in welding speed the heat input per pass as well as total heat input is reduced in multipass welding and average cooling rate is increased and due to this the hardness is increased. (Ref.9)

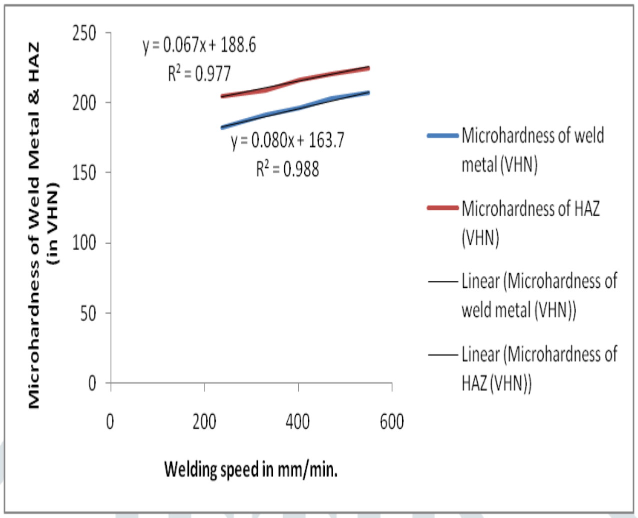

Fig.4. Effect of Welding Speed of Weldmetal and HAZ (Ref.9)

Effect of Current and Voltage

Reduction in microhardness is lower at arc voltage 38 volt for the current vary from 300 to 350 ampere. Micro hardness reduce from 216 VHN to 194 VHN in weld and from 240 VHN to 217 VHN in HAZ when welding current increase from lower to higher level and arc voltage at lower level. In the same way microhardness reduce from 184 VHN to 180 VHN in weld and from 209 VHN to 196 VHN in HAZ when current increase from lower to higher level and arc voltage is at higher level. Response surface due to interactive effect of welding current and voltage on hardness of weld and HAZ has been displayed in figure respectively. (Ref.9)

Effect of Current and Welding Speed

As increased in microhardness is higher at the welding speed 236 mm/min and decreased in microhardness is very low at welding speed 550 mm/min for the current vary from 300 to 350 ampere. Micro hardness increased from 207 VHN to 219 VHN in weld and decreased from 235 VHN to 224 VHN in AZ when welding current increase from lower to higher level and welding speed at lower level. In the same way microhardness increase from 174 VHN to 177 VHN in weld and decreased from 204 VHN to 195 VHN in HAZ when current increase from lower to higher level and welding speed is at higher level. Response surface due to interactive effect of welding Current and welding speed on hardness of weld and HAZ has been displayed in figures.

VI. RESULT AND DISCUSSION

Multipass submerged arc welding process parameters are to be directly affecting the number of passes on the joint of base metal. It also affects the total heat input given the parameter. The individual effect is higher to the current, voltage, speed on hardness of weld and heat affected zone. Hardness is less in the weld metal and hardness is higher in HAZ that is heat affected zone. When hardness is increases that time cooling rate also increases. During welding the temperature become increases in fusion zone and metal will be deposited from the electrode to join the weld surface. The reduction in the micro hardness is higher at the arc voltage lower and reduction in micro hardness is lower at arc voltage high. When voltage is increases the structure of micro hardness decreases. When the welding current is increased the micro hardness is reduced. Increase in to the welding current, there is a linear increase in heat input, due to that there is increased heat input the reduction in average cooling rate in every pass. And reduction in heat input causes increase in micro hardness value of the specimen.

VII. CONCLUSION

After doing this study on these process parameters it can be conclude that the variations in microstructures and mechanical properties are observed at each and every pass of SAW weld joint due to continuous changes in heat transfer rate in the welded metal. Welding parameter of the submerged arc welding can be used to control the mechanical properties of the materials. When the welding current is increased the micro hardness is reduced. When voltage is increases the structure of micro hardness decreases.

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