An Evaluative Characterization of Various Welding Indices on Bead characteristics in Submerged Arc Welding (SAW)

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***Abstract*—Welding is one of the important materials joining process that has drawn attention of many researchers. From time-to-time researches are being done in order to estimate and improve the quality of weld obtained in the joining process. Submerged-arc welding process is main focus of research for couple of years owing to its high productivity coupled with satisfactory penetration, simple joint design and easy weld control. All these indices are the functions of welding parameters. In the present work an attempt has been made to investigate some basic aspects like the bead geometry, the mode of metal transfer, the variations in microstructures during welding process. The effects of welding variables such as current, voltage, wire feed rate, carriage speed and number of passes on the above aspects of SAW are characterized and evaluated accordingly.**

***Index Terms*— Bead, current, electrode, flux, submerged arc welding (SAW), wire feed rate.**

I. Introduction

Submerged Arc Welding (SAW) is a joining process that involves the formation of an electric arc between a continuously fed electrode and the workpiece to be welded. A blanket of powdered flux surrounds and covers the arc and in molten form, provides electrical conduction between the metal to be joined and the electrode. It also generates a protective gas shield and a slag which protects the weld zone as shown in figure 1.

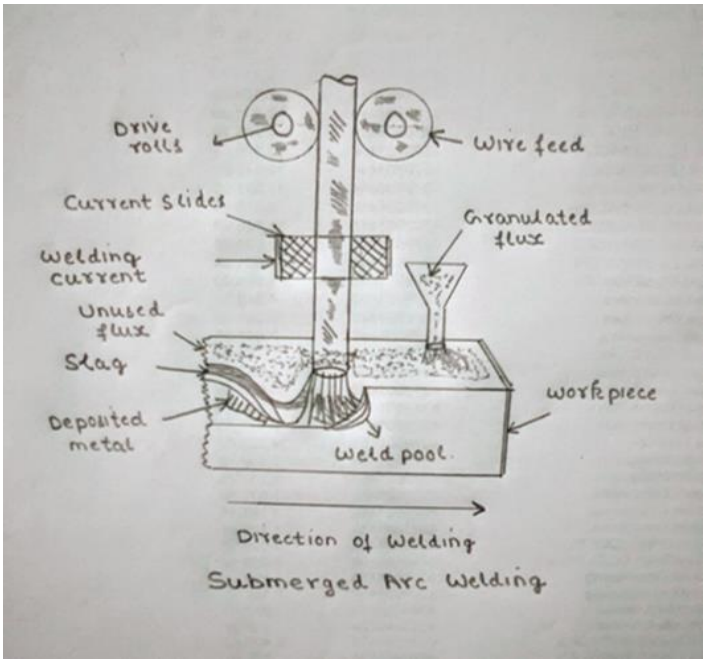

Fig.1. The Submerged Arc Welding Process

There are two welding consumables involved in the process, the electrode and the flux. The electrode can be a solid wire, a cored wire, or a strip. The flux, made from a variety of minerals and compounds, can be rather complex and can be produced in a number of forms.

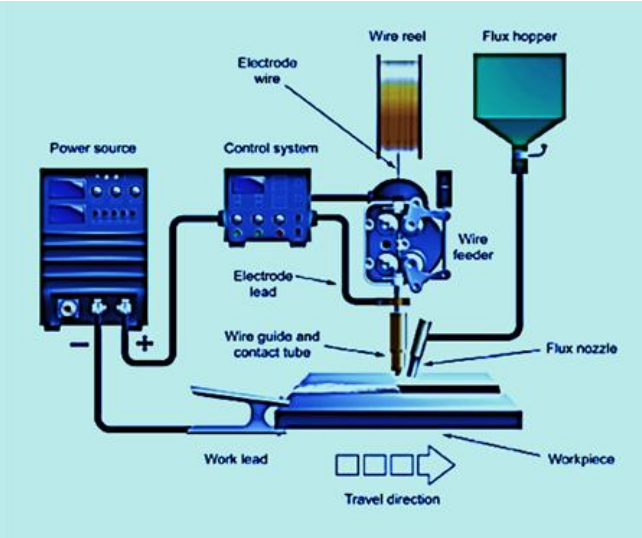

Fig 2. The general arrangement of the power source and controls, wire feed and flux.

Submerged-arc welding process possesses high productivity coupled with satisfactory penetration, simple joint design and easy weld control. It has wide applications in the areas of fabrication of pressure vessels [7], locomotives, ships [6,8], etc. and in surfacing work. The strength and fracture toughness of SAW joints are, however, not always satisfactory band dependent on the proper selection of the various welding parameters [2-5],[9-12].

The parameters in SAW are welding current, voltage, speed of welding electrode (filler wire) diameter, number of passes, type of flux used, width and depth of layer of flux, etc. These parameters influence the mode of metal transfer, the bead geometry, the nature of protection offered by the flux covering, the microstructures and hardness characteristics especially micro hardness across the welded joint. influence the mechanical properties like the fracture toughness of the welded Joint, which is of considerable importance.

Two modes of metal transfer in this process are globular mode and projection mode, the latter mode normally leads in a more uniform deposit [1]. Although some work has been reported in the literature, yet it was proposed to study the effect on a common structural steel with respect to the above-mentioned properties.

II.LITERATURE REVIEW

Various researchers have worked in the field of submerged arc welding of various steels. Their contribution is given below:

Grong et al, (1986) studied the factors which affects the development of low carbon steel and mild steel microstructure. They confirmed that the behaviour of transformation takes place in the welded metal for a given heat cycle depends upon complex collaborations between a few significant factors which includes the aggregate sum of alloying components, chemical concentrations, size appropriation of non-metallic inclusions, the cementing microstructure and the earlier austenite grain size.

Mattes et al, (1990) examined the impact on the properties and microstructure of tempered and as-quenched HSLA 100 by using transmission, light and scanning electron microscopy. The result shows that the toughness depends on the grain size of austenite, copper precipitation and also on carbides and bainite dislocation. Yang et.al.,(1992) determined the process parameters and their effect on bead height in SAW of ASTM A36 steel plates. The results stated that it is influenced by electrode polarity, welding current, electrode-diameter, welding voltage, electrode- extension and speed. A big height of bead is obtained by a large extension of electrode, negative electrode polarity, a high speed or current, a small electrode diameter and voltage in many cases. Regression equations were used for calculation of bead height by using process parameters. Murugan et al., (1993) studied input process parameters namely voltage, nozzle to tip distance and speed in SAW and their effect after weld surfacing, Using technique five level factorial, Mathematical model was developed to predict geometry of welding bead to deposit (316 L) Stainless steel on (IS 2062) structural steel. Investigation of output responses such as reinforcement, width, dilution and penetration was done by taking inputs namely voltage, nozzle-to-plate distance, wire feed rate and weld speed. Trang et al., (2002) performed optimization of the SAW process using Taguchi technique (grey-based) for hard facing and also considered various welding qualities. For solving the submerged arc welding process having various weld qualities the grey analysis was adopted. A grey relational grade was used for performance characteristics and optimal parameters are taken using Taguchi method. Bhole et al, (2006) investigated the hardness and micro-structure of API HSLA-70 pipeline steel after addition of alloying element nickel (Ni), molybdenum (Mo) using SAW welding. It shows the increment in impact toughness and decrement in fracture appearance transition temperature when Mo is added in range of 0.817-0.881 wt.%. Mo shows a beneficial effect. Vedrtnam et al, (2018) studied following parameters namely voltage, current, plate distance and speed on Stainless steel using SAW process. The report stated that bead width increased width voltage increase, while the bead height is directly proportional to current. The bead height and width increase with rise in the weld speed. The hardness of the bead shows growth as the welding input current increases. Response Surface Methodology (RSM) was used for development of the mathematical model. to creation of granular bainite and acicular ferrite. The combined micro-structure of the welded specimen involving approx. AF (77%) and GB (20%) shows better toughness at temperature around -45°C. Bose Filho et al., (2007) studied combined effect of the alloying elements like nickel (Ni), molybdenum (Mo), titanium (Ti) and chromium (Cr) on development of microstructure of HSLA and also studied the number density, inclusion size distribution, chemical composition and volume fraction. No major effect is shown on micro-structural development when titanium content was added in a range of 50-

400ppm. Addition of Mo, Ni and Cr increase the hardenability and the micro-structure of weld metal changes from a blend of bainite, acicular ferrite and carbon martensite to a blend of allotriomortic, wedmenstatten and acicular ferrite. silicon and manganese were the primary content of inclusion in welded metal having low Titanium content. Prasad et al, (2008) examined the effect on hardness, toughness and microstructure of HSLA type steel taking various input parameters in SAW. The welding was done by taking a higher value of heat input (3.0-6.3k]/mm) and fluctuate the input value of current in range of 500 to 700 A and simultaneously changing the speed of welding (200-300 mm/min). Grain structure and zone affected by heat found to be rough when there is an increment done in heat input. The hardness found to be uniform. The hardness showed an inverse relation with current and a direct relation to welding speed. Beidokhti et al., (2009) investigated the API 5L-X70 pipeline steel micro structure by adding titanium using SAW procedure. Tensile, HIC and Charpy-V notch test were used for transversely cut specimens to study the relationship between the toughness and microstructure of weld beads. When titanium was added in a range of 0.02-0.05%, shows the finest impact and impact micro-structural properties. The impact toughness was improved by acicular ferrite formation due to titanium-base inclusion. Kiran et.al.,(2012) investigated single pass two wire couple lowered circular segment welding cycle of an average HSLA steel plate having width of 12 mm.The mechanical properties of fifty different sets having different input parameters as leading wire current, negative current pulses duration, trailing current pulses and weld speed were studied. The trailing wire current affects the weld bead width and the reinforcement whereas penetration of final weld bead was affected by leading wire current.Lan.et.al(2012) performed a detailed micro-structural investigation of high strength low carbon bainite steel weld metal using transmission electron, optical and scanning electron microscope. Welded joint shows different microstructures as fine polygonal, coarse granular and acicular ferrite. The orientation of weld metal product phase and retained austenite shows close relationship to Kurdjumov-Sachs relationship. The weld metals toughness is higher than that of coarse grain region. Jindal et.al.,(2013) developed a prediction equation for form factor, dilution, diffusible H2 content and micro-structure taking welding parameters as current, weld speed and voltage. The developed prediction equation can be used to get desirable weld properties of HSLA steel during SAW process. The result stated that welding current is vital parameter which controls the output responses. Welding current significantly affect the diffusible hydrogen content, whereas there is little or no cause of arc voltage. Welding current has negative effect over micro-hardness whereas having positive effect on diffusible H2 content and dilution. The voltage shows incremental effect on the dilution, form factor and diffusible H2 content but shows decremented effect on micro-hardness. Holub et al,(2015) performed SAW welding (multi-layered) on W. Nr."1.6946" using dissimilar welding consumables (Thermanit MTS 616, Topcore 833B).Mechanical properties were evaluated for welding consumables. The resultant values of ductility and impact energy of the welded specimen were below the specific value when welded with Thermanit MTS 616.Lan et al.,(2016) performed multi-pass SAW process on HSLA with the help of multi micro-alloyed electrodes and micro- structural evolution was investigated using different heat inputs. Strength and hardness of welded joints decreases with increases in heat inputs. The titanium oxide inclusions of bigger size have better capacity to enhance the formation of the acicular ferrite. Choudhary et al, (2018) analyzed effect of various input welding parameters in performing SAW welding procedure for AISI 1023 steel and fractional factorial design was used for that purpose. The welding process was done by taking input parameters as voltage, welding speed, feed wire rate, condition on flux, nozzle to tip distance for output responses namely reinforcement height, bead height and penetration. Mathematical models were developed by using linear regression for the output variables. They used Java algorithm, desirability approach and genetic algorithm for the optimization process of the welding input variables. The optimization results provided by Jaya algorithm was better than that of genetic algorithm and desirability approach. Dirisu et al.,(2019) used CMT-WAAM for depositing steel component with the help of single pass deposition strategy. The micro-structural variation effects over the fracture resistance and direction of welding were done by using layer by layer deposition. Investigation of fracture mechanics was done for the deposited parts.Kolhe et al.,(2020) conducted a study which predicted the mechanical properties: heat affected zones and weld geometry of joints. The mathematical model was developed using the statistical methods. The regression equations were prepared for various important controls of welding current, travel speed and the arc voltage. Thus, the mathematical equations are useful during the actually fabrication. Thakur et al, (2020) studied effects of dissimilar parameters of drop geometry on EN31 grade steel plate using automated SAW process. Four welding parameters specifically input voltage, the speed of welding, welding current and nozzle-tip distance were taken. The results stated that width of the bead, penetration, reinforcement increased with the weld current. The bead width shows increment with voltage increase, but reinforcement and penetration decrease with voltage increases. Rajkumar et al, (2020) welded 6 mm plates of mild steel. Experiment was planned using three parameters at three different levels such as current, welding speed and voltage. Optimal parameters of process were recognized using Taguchi Lo orthogonal array and its effects on SAW parameters. Mechanical properties of welds were examined using Scanning Electron Microscopy and Energy Dispersive X-Ray Analysis. Sharma and Mohal, (2020) studied bead height and bead width on Stainless Steel (SS316) by performing experiment on SAW. RSM was used to optimize the input parameters. The results showed that width and height of bead are influenced by welding current while the voltage and welding speed has direct cause over bead height. Singh et al.,(2020) used nine weld joints for program test. Their work predicted various input parameters to get the finest value of hardness regarding known input parameters. Alishavandi et al, (2020) performed bead on plate on heat treatable low alloy steel by SAW machine using Cr-Mo granular flux with welding wire. Bonded-unfused method was used to prepare the Cr-Mo active flux. Recovery rate of alloying material and the amount of alloy transferred to the welded metal is calculated by generated equations. Various tests such as tensile, micro-hardness, Charpy-V notch (CVN) impact tests were done and investigated. Mician et al., (2021) focused the research on assessing the impact of cooling rate and heat input over width of the delicate zone, which essentially influences the mechanical properties of the welded specimens.

III.RESEARCH METHODOLOGY/SITE SELECTION FOR EXPERIMENT

The research mainly focused on investigating the effects of welding variables like voltage, current, number of peaks per second and impact energy variation with change of welding temperature of environment pertaining to SAW on Weld bead parameters. Experiment was conducted at Metal Fab High Tech. at Nagpur India on Twin wire Submerged Arc Welding Machine (SAW). It is a heavy-duty inverter DC power source ideal for Submerged Arc Welding and Electro Slag Welding. With exclusive high-power non-parallel inverter technology, the machine has simplified structure and reduced the potential failure points, with less current and voltage fluctuations issue among the modules caused by parallel method.

It has twin wire feeding system with constant wire feeding speed along with significant flux holding capacity with good testing plate area.

Figure 3: Twin wire Submerged Arc Welding Machine (SAW)

Figure 4: Submerged Arc Welding Machine in experiment

Table 1: Welding machine characteristics:

Feature	Details
Machine Name:	Twin wire Submerged Arc Welding Machine (SAW)
Model Name	KAIYUAN N10
Welding Position:	Keeping the electrode positive and perpendicular to the plate
Wire Feeding speed	266cm/min
Electrode Flux Capacity	8 liters
Diameter of Electrode:	4.00 mm
Wire Diameter	3.15+3.15 mm (twin)
Size of test plate (in mm):	20 X 300 X 500

IV. EXPERIMENTAL DETAILS

The research work was carried out on an automatic submerged arc welding machine having a constant voltage and a DC power supply under following steps:

- Machine has a rectifier/type with 1200A capacity was used to join the mild steel plates.
- Samples of 10 mm cut from test piece and were polished, etched and the bead parameters were studied.

- Mild steel filler wire of 4.0 mm diameter and silicate type fluxes (200 mesh) were used in the Welding.
- The current was varied in the range of 300 A to 900 A with voltage varying from 30 to 45 V and carriage speed 3.8 mm/s to 8.5 mm/s.
- For studying the effects of the welding variables such as current, voltage and carriage speed on the bead geometry single run beads were deposited on mild steel plates
- The bead parameters were measured with the help of height gauges and calipers.
- The samples were brought to various temperatures in the range of 40°C to-27°C and the tests were carried out. For checking any variations in microstructures during single and multi-run beads, metallographic studies were conducted.

In the experiment, the nozzle was maintained vertical with respect to plate and the distance between the nozzle tip and the plate was kept at 2.9 ± 0.05 cm.

Table 2: Table showing bead height variation with change of welding current

Welding Current (in A)	**Bead Height (in mm)**
400	3.2
500	3.6
600	4.8
700	5.6
800	6.4
900	6.7

Table 3: Table showing bead width variation with change of welding current

Welding Current (in A)	**Bead Width (in mm)**
400	16
500	18
600	21
700	23
800	25
900	27

Table 4: Table showing variation of number of peaks obtained per second with change of welding current

Current (in A)	**No of peaks per second**
400	12
450	13
500	14
550	14
600	14
650	15

700	17
750	15
800	14
850	12
900	7

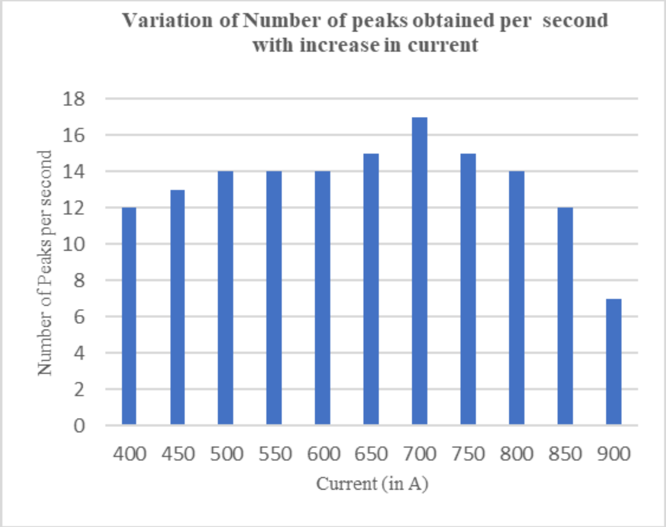

Fig 5: Graph showing variation of number of peaks obtained per second with current in amperes.

Table 5: Table showing impact energy variation with change of welding temperature of environment

Testing Temperatures (in ^{0}C)	Energy Absorbed (KJ-m)
-20	8.37
0	8.60
+27	5.50
+40	7.90

Table 6: Table showing variation of rate of wire feeding with change of welding current

Current (in A)	Wire feed rate (in mm/s)
400	4.88
450	5.64
500	6.63
550	8.71
600	11.29
700	12.20
800	13.36
850	15.37
900	17.42

Table 7: Table showing variation of welding voltage with change of welding current

Current (in A)	Welding Voltage (in V)
400	33
450	34
500	34
550	34
600	34
700	35
800	35
900	34

V.RESULTS AND DISCUSSIONS

From the graphs and tabular values, it can be inferred that out of all indices in SAW, welding current has significant effect on the bead geometry.

- It can be seen that bead height as well as bead width increases with the increase in amount of welding current
- The wire feed rate increases with the increase in current at constant voltage.
- In globular mode, instantaneous current showed significant variations while it remained constant during projection mode at maximum value of 800A
- With increase in welding voltage bead width increases but bead height decreases at constant wire feed rate and constant carriage speed rate.
- Carriage speed plays a significant role in determining the bead width but play no role in bead height estimation. Former decrease follows exponential distribution and latter is hardly influenced.
- When beads sectioned were electro micro graphed, it showed inclusions and carbides which is main reason for having low impact values.

VI.CONCLUSION

The research focused on investigating the effects of various indices pertaining to SAW on bead characteristics. The effect of carriage speed, wire feed rate, welding current and voltage on bead geometry was investigated and plotted by means of graphs and tables. Also, reason for having low impact energy values of welded metal was studied at various temperatures was investigated. Electromicroscopic image of single pass and multipass welding processes showed various inclusions and carbide particles validated the cause for having low impact values.

VII.ACKNOWLEDGMENT

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VIII.DISCLOSURE OF INTEREST

It is declared that there is no relevant or material financial interests of both authors pertaining to the research work. The data used in this research is proprietary in nature.

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