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Study of mechanical properties of SS-304 steel for different heat input using hardfacing of submerged arc welding

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Abstract

This paper presents the study of submerged arc welding process for different heat input to find out strength and heat transfer after hardfacing on stainless steel material. The literature review was carried out, studied by many researcher's for getting the better improvement in hardfacing characteristic, like mechanical properties, microstructures, resistance to wear and erosion of heavy duty welded structure under severe conditions joined by submerged arc welding. Number of studies conclude the effect of welding variables, flux composition, power source, material composition etc, on the surface deposited by various welding processes like Submerged Arc Welding, Shielded Metal Arc Welding, Gas hardfacing, Flux Cored Arc Welding, Powder Spraying Plasma Transferred Arc (PTA),Electric Arc Spraying, and High Velocity Oxy-Fuel Process (HVOF). In HardFacing a special alloy material is deposited on the base metal, using 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. In that, study is carried out for getting result of mechanical properties like hardness, toughness after SAW hardfacing on SS-304 steel.

Keywords: Submerged arc welding (SAW), hardfacing, stainless steel, heat transfer, hardness etc.

1. Introduction

In industrial manufacturing, maintenance, etc processes welding operations are essential tool. The various welding methods used in hardfacing are 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. In SAW process an arc is generated between one or more bare wire electrodes & the work piece to provide the heat for joining. The arc developed during the welding process is completely covered by the flux, these flux shields the arc from atmospheric contamination. The process can be fully automatic or semi-automatic. In SAW the electrode is consumed and the arc is protected by a fusible flux which covers the weld section and surrounds the base metal to protect it from the atmosphere. In order to utilize the complete heat generate and also increase the deposition rate powder alloy is added to the flux. 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. In case of 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 fully automatic systems are used.

***Principle of Working of SAW* –**Refer the below Fig 1 for the working principle of SAW. 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 fine-granular flux supplied through the flux hopper. The electrical resistance of the electrode is maintained 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 work piece the circuit is completed producing a spark called as arc. This 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.

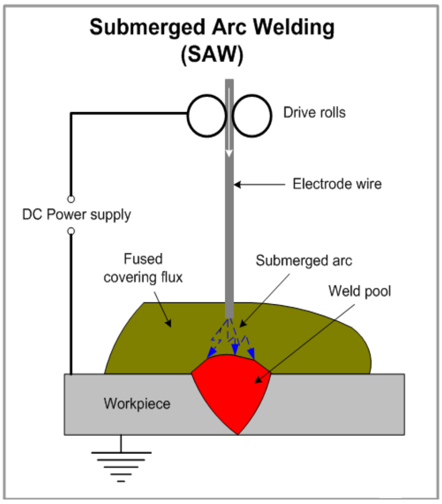

Fig.1 Submerged Arc Welding.

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 6mm), and increased current (up to 1800Amp). The flux covering the welding area acts as a thermal insulator, resulting in the reduction of heat losses from the arc and complete usage of the available heat energy. From the studies it has been observed that submerged arc welding shows a thermal efficiency near about 90 %, as against an approximate value of about 75 % for MMA welding. Either AC or DC current can be used in submerged ARC welding [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]

***Hardfacing* –** In Hard Facing a special alloy material is deposited on the base metal, using various welding processes to obtain more desirable wear properties and/or dimensions. The important properties considered 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). Hardfacing is basically used for recondition worn parts and protection of the metal component against wears corrosion.

2. Literature Survey

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]

Kolhe and Datta, have carried an experimental study on the test specimen of 16 mm 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 Onix Vision 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 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]

Kolhe, et al carried out an experimental study to effects in pulsed gas tungsten arc welding (pulsed GTAW) for aluminium alloy (AA7039) using various Argon-Helium mixtures as a shielding gas with sinusoidal AC wave layout, to analyze 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 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. Due to low density, high specific strength and excellent corrosion resistance AA7039 is employed in aircraft, automobiles, high-speed trains and high-speed ships.

3. Aim and Objectives

The objectives of this paper is given below

1. To study the mechanical properties such as hardness and toughness of SS-304 for different heat input
2. To control heat input for enhancing Strength and Toughness.
3. To improve Quality of weld by varying different input parameters of welding like current, voltage and welding time.

3. Present Work

The present work is carried out for hardfacing of SAW on stainless steel 304 base material (200×100×10 mm) for various tests. SAW machine is used for welding at different heat input. Fig.1 shows the SAW machine which is used for hardfacing of ER-316L filler wire.
Here used five samples of base materials for welding and various testing.

Fig.1 SAW machine used for hardfacing.

The specification of base material and welding wire is given below:

Table 1 chemical composition of SS 304 (In % max)

C	Mn	P	S	Si	Cr	Ni
0.08	2.0	0.045	0.030	0.75	18-20	8-12

Table 2 chemical composition of ER-316L (In %)

C	Mn	Si	Cr	Ni	S	P	Cu
0.04-0.08	1.0-2.5	0.30-0.65	18-20	11-14	0.03	0.03	0.75

In this study hardfacing done on sample of dimension of 100×40 mm. samples are hardfaced at different current such as 100, 150, 200, 300 Amperes and voltages at 20, 23, 26 and 29 volts. Heat input is calculated by,

$$Heatinput = \frac{V \times I \times 60}{1000 \times S} \quad \text{... In KJ/min (1)}$$

Fig.2 Actual photo of a sample after SAW hard facing

After hardfacing the tests carried out on sample plate at different heat input are.

1. Brinell hardness test for Hardness measurement
2. Charpy Impact Test for Toughness measurement

3.1 Brinell Hardness Test

In this test, five points named as point1, point2, point3, point4, point5, point6 and poit7 have been taken along the thickness with distance of 2 mm between each other. The base metal having hardness of 229 BHN.

3.2 Charpy Impact Test

Charpy impact test is used for measurement of toughness of SS-304 Steel materials after SAW hardfacing. It is taken in single trials.
Standard specimen size dimensions = 55×10×10 mm
Centre V-notch measured 2 mm from top

4. Result and Discussion

4.1 Relation between Heat Input and Hardness along Thickness of Plate

The below table shows hardness at different point of plate along the thickness at different heat input.

Table 3 Relation between Heat Input and Hardness along Thickness of Plate

Heat Input	Top Point-1	Point-2	Point-3	Point-4	Point-5	Point-6	Point-7
0.3	229	228	230	229	285	363	361
0.517	362	284	255	285	254	95.5	228
0.69	228	187	226	229	156	187	283
0.975	477	228	229	284	186	285	229
1.305	285	228	229	254	96	229	285

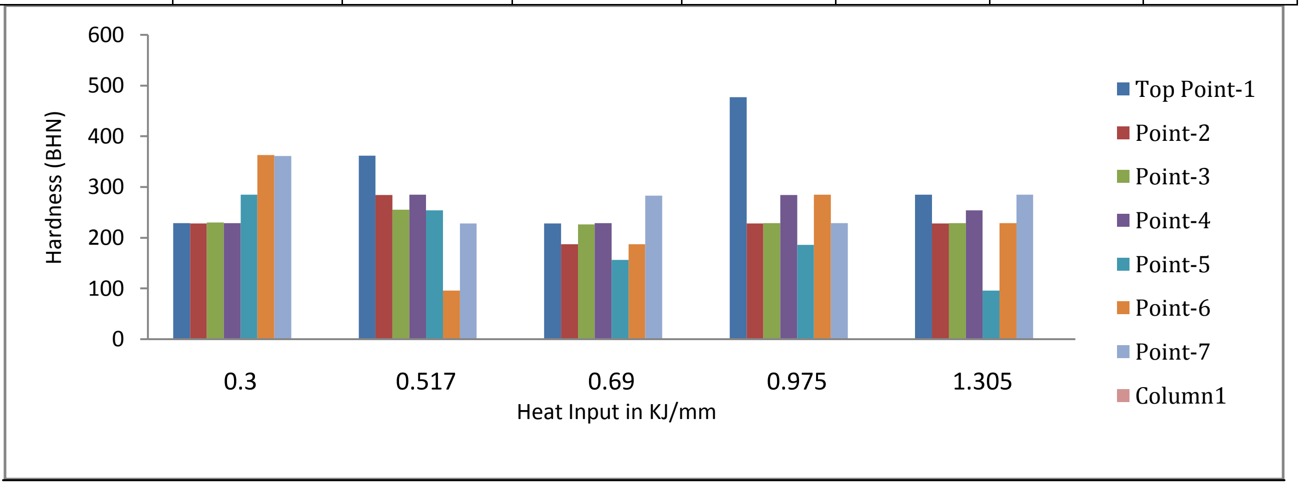

Fig 3 Effect on hardness at different point at different heat input

From fig 3, it is observed that the hardness of material after hardfacing is sometime increases and sometime decreases as per material structure reacts with heat.

4.2 Effect of heat input on toughness

Table 4 Effect of heat input on toughness

Heat Input in KJ/mm	Toughness in Joule
Base Metal	148
0.3	168
0.5175	281
0.69	155
0.975	158
1.305	134

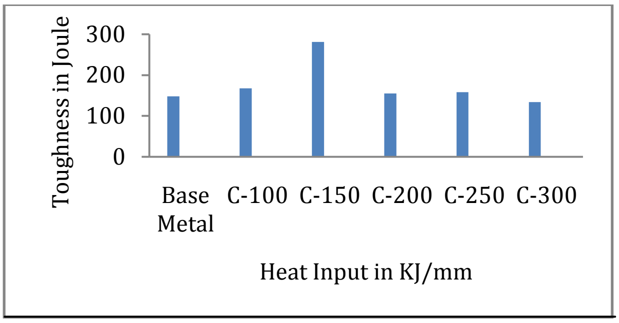

Fig 4 Graph of heat input Vs toughness

From fig 4, we get maximum toughness for C-150 i.e 281 joule at 0.5175 KJ/min heat input and minimum for C-300 at 1.305 KJ/min heat input. As heat input increases toughness also increases, but after that it going to be decreases.

4.3 Temperature distribution from weld surface to bottom surface of Plate

Table 5 Temperature Distribution

Sample No.	T-1	T-2	T-3	T-4	T-5	T-6
100A	360	294	140	130	127	117
150A	458	218	235	224	217	195
200A	524	133	138	122	110	96
250A	550	304	181	156	150	84
300A	650	519	304	244	183	158

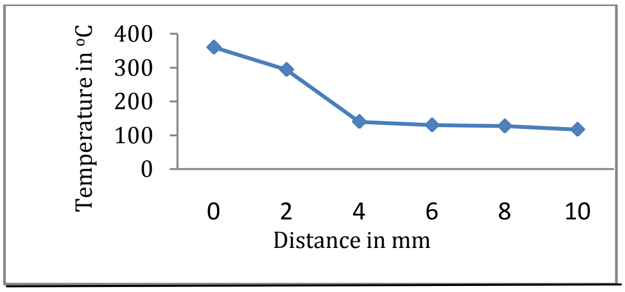

Fig 5 Temperature distribution from top to bottom of sample 100A

Table 5 shows the temperature at different point on the thickness of 10mm of each sample. The distance maintained in each point is 2 mm. It indicates temperature decreases as distance increases i.e heat transfer decreases through conduction. Fig 6 shows the decrement of temperature as distance of heat transfer increases for sample 100A and same happens for other samples too.

5. Conclusion

From this study of mechanical properties on SS-304 for different heat input by enhancing hardfacing of SAW, it is concluded that:

1) Submerged arc welding is a versatile welding process used in metal joining, surfacing and hard facing.
2) 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.
3) At minimium heat input, the hardness of SS-304 increased due to hardfacing. And if heat input is increases, the hardness will be decreased gradually.
4) After impact test, we get maximum toughness i.e. 281 joule at 0.5175 KJ/min heat input. And minimum at large heat input in our study.
5) Heat transfer is inversely proportional to distance from top to bottom surface of plate.

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