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Study of Hardness of Weldment Formed by Submerged Arc Welding (SAW) at different Plate Temperature

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Abstract—*Present investigation is selected to observe one of the mechanical properties of weldment formed by Submerged Arc Welding (SAW) without preheating the work metal in search of quality of weld done in such a place where ambient temperature is zero degree Celsius. Sixteen such cold specimens are welded by varying the most influencing parameters viz. Voltage, wire feed rate, travel speed and electrode stick-out at four different levels. Another set of sixteen specimens at normal room temperature of about 30 degrees Celsius are similarly welded by applying same combination of parameters. Number of specimen so experimented are decided based on the design of experiment of Taguchi's L16 orthogonal array. Different attributes of bead geometry of the entire sample for both the situations are identified and compared by visual inspection. It is established that submerged arc welding is feasible at zero degree Celsius without preheating on mild steel plate of designation IS 2062 grade B. Micro hardness is measured in different zones of weld bead geometry appeared in the cross section of all specimen. Slight difference in hardness is found in the reinforcement region due to change of plate temperature.*

Keywords: *Submerged Arc Welding, Taguchi's Design of Experiment, Zero degree Celsius, Hardness.*

Introduction

Submerged Arc Welding is a versatile metal joining process used in industries. It finds wide industrial application due to easy applicability, high current density and ability to deposit a large amount of weld metal at a time. And due to this it is used extensively in industry to fabricate pressure vessels, pipelines, marine vessels, wind turbine towers, girders of modern bridges etc. SAW is a multivariable, multi objective metal fabrication process, characterized by the use of granulated fusible flux which covers the molten weld pool during operation preventing atmospheric contamination and improving both mechanical properties and metallurgical characteristics of the weld bead as well as heat affected zone (HAZ).

In the past several efforts have been carried out to explore SAW in different ways. Some interesting literature overview can be found in the paper by Ajay Biswas and Abhijit Bhowmik [1] investigate the effect of heat generation during submerged arc welding at different plate temperature and noticed that submerged arc welding feasible at zero degree Celsius plate temperature. M.R. Forouzan et al. [2] experimented the residual stress prediction of saw spiral pipes. This method is based on the "unfurl mapping" that maps the pipe to a new flat space. This process contains two simulation processes applying the ANSYS software welding test and hydrostatic test simulation. Aniruddha Ghosh et al. [3] describe a paper for derive the analytical solution of transient three dimensional heat conduction equation of submerged arc welded plates. Some forces applied energy on the plate which is taken from the volume of heat lost. This heat conduction equation will be helpful for HAZ width calculation. P. Kanjilal et al. [4] developed the combined effect of flux mixture and welding parameters on submerged arc weld metal chemical composition and mechanical properties. The results show that flux mixture related variables based on individual flux ingredients and welding parameters have individual as well as interaction effects on responses, viz. weld metal chemical composition and mechanical properties. D.V. Kiran et al. [5] experimentally found that Two-wire tandem submerged arc welding process involves simultaneous depositions from two electrode wires with the leading wire usually connected to a DC power source and the trailing wire connected to a pulsed AC power source. In was observed the quantitative effects of the trailing wire current pulses and negative current pulse duration, leading wire current, and welding speed on the weld bead dimensions and mechanical properties are studied at fifty different sets of welding conditions that are designed following the principle of two-level, five factor central composite rotatable design. Kishor P. Kolhea et al. [6] experimentally investigated the various parameters like mechanical properties, microstructure of multipass SAW and study on the microstructure, phase analysis, mechanical properties, HAZ width of multipass joint. Keshav Prasad et al. [7] investigated the influence of the submerged arc welding (SAW) process parameters on the microstructure, hardness, and toughness of HSLA steel weld joints. Results showed that the increase in heat input coarsens the grain structure both in the weld metal and heat affected zone (HAZ). The hardness has been found to vary from the weld centre line to base metal and peak hardness was found in the HAZ. M. Ramakrishnan et al. [8] studied on the increase in productivity in NGSAW (narrow gap submerged arc welding). It was proposed to increase the quality and productivity in NGSAW through cold wire addition without addition of heat input. Further toughness at sub-zero temperature is also enhanced. R. Venkata Rao et al. [9] experimental analysis is presented in the present work for submerged arc welding of Cr–Mo–V steel. Various important responses like weld bead width, weld reinforcement, weld penetration, weld tensile strength and weld hardness are measured in each experiment using sophisticated instruments and the results are analyzed to study the effect of each input variable on the output responses. S. Shen et al. [10] carried out an experiment to determine how variation in heat input achieved on specimens of submerged arc welded plates of ASTM A709 Grade 50 steel. Cooling time related from 800 to 500 ◦C. It was found that increase in heat input the bead reinforcement, bead width, penetration depth, HAZ size, deposition area and penetration area increased.

The present investigation has been carried out to determine the changes of hardness by comparing the weldment formed by SAW on mild steel plate of designation IS 2062 grade B at the temperature of zero degrees Celsius and 30 degree Celsius. Bead on plate submerged arc welding is formed on the specimen plate fitted on the special fixture ensuring zero degree Celsius temperature to the specimen plate during welding.

Materials used for experiment

Material used for experimentation: Bead on plate welding by SAW process has been carried out on mild steel plate having size (200mm×50mm×16.5mm) as well as having designation as IS 2062 Grade B, manufactured by Steel Authority of India Limited (SAIL).

Electrode used: Copper coated electrode wire of diameter 3.15 mm namely AUTOMELT EL8 (AWS A 5.17/5.23 EL8, IS 7280: AS-1) of ADOR WELDING LIMITED, INDIA.

Flux used: AUTOMELT A55 flux [Make: ADOR WELDING LIMITED, INDIA] having the following compositions.

$SiO_2 + TiO_2$= 30%; CaO + MgO= 10%;

Al_2O_3 + MnO= 45%; CaF_2= 15%.

Design of Experiment (DOE)

Full factorial design consideration increases the number of experimental runs exponentially as the number of the factors or parameters as well as their level increases and involves huge experimental cost and considerable time. To compromise these two adverse factors and to search the desired observations through a limited number of experimental runs, the present study is carried out by varying four major process parameters viz. voltage, wire feed rate, travel speed and electrode stick-out at four different levels by incorporating Taguchi's L16 orthogonal array using MINITAB software and restricted experimental runs to16.

Table 1 Process parameters and their range

Parameters	Notation	Unit	Working range of process parameters
Open circuit voltage	V	Volt	35 to 63
Travel speed	S	m/min	0.1 to 1.5
Wire feed rate	F	m/min	0.5 to 4.0
Stick-out	N	mm	25 to 31

Table 2 Taguchi'S L16 Orthogonal Array (DESIGN OF EXPERIMENT)

SL NO.	V	S	F	N
1	31	0.45	0.85	25
2	31	0.60	1.10	27
3	31	0.75	1.45	29
4	31	0.90	1.80	31
5	32.5	0.45	1.10	29
6	32.5	0.60	0.85	31
7	32.5	0.75	1.80	25
8	32.5	0.90	1.45	27
9	35	0.45	1.45	31
10	35	0.60	1.80	29
11	35	0.75	0.85	27
12	35	0.90	1.10	25
13	37	0.45	1.80	27
14	37	0.60	1.45	25
15	37	0.75	1.10	31
16	37	0.90	0.85	29

Experimentation

A set of sixteen of specimens for each boundary condition such as zero degree Celsius and 30 degrees Celsius temperature are selected by varying major parameters based on the design of experiment of Taguchi's L16 orthogonal array. One set of Sixteen Weld beads are formed on those specimens by placing the work piece on special fixture duly cooled down the specimen along with fixture at the temperature not more than zero degrees Celsius in such a manner shows in Figure 1 and Figure 2 that the bottom side of the specimen is in contact with ice to ensure zero degree Celsius plate temperature. Weld beads are also formed on another set of sixteen of specimens by applying same process parameter at 300C ambient temperature.

During welding of the entire specimens heat inputs are recorded based on the following equation.

$$H = [(V \times I \times 60) / (1000 \times S)] \times \text{Efficiency}$$

Where,

H = Heat input (KJ/mm),

V = Arc voltage (volts),

I = Current (Amps),

S = Travel speed (mm/min).

The efficiency is dependent on the welding process used, for Submerged Arc Welding it is 0.9.

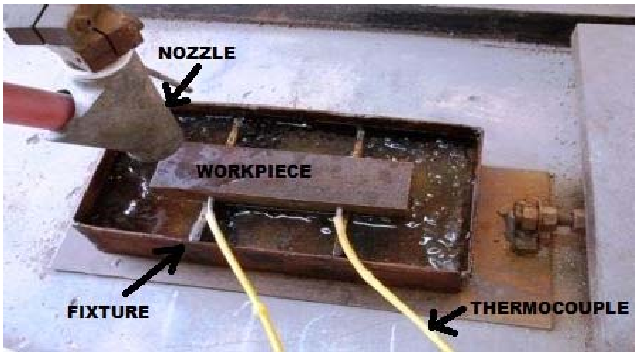

Figure 1: Fixture (full of ice below work piece) arrangement before welding.

Figure 2: Submerged Arc Welding machine setup.

Results and Discussions

All the selected weld samples have been cooled in the room atmospheric condition after removing the solidified slag, Faces of the cross sectioned specimens of about 5mm thickness have been machined by shaper to get parallel plane as well as semi-finished surface. Then samples have been filed with smooth flat file followed by finishing with the emery paper of different grade and got mirror finished surface. Thereafter the mirror finished surfaces have been etched with natal solution i.e. 10% nitric acid solution in distilled water in room atmospheric condition and clear view of weldment is appeared. The weld bead geometry descriptors such as reinforcement, weld zone, and heat affected zone (HAZ) are identified and subsequently micro hardness is measured in the entire region. In each region micro hardness is measured in three points and considered their average value.

From the graphical representation it can be explained that higher hardness in the reinforcement zone is formed when the plate temperature is zero degree Celsius due to fast cooling rate is shows in Figure 3.

Table 3: Micro hardness of reinforcement zone at different plate temperature

Sl no	Heat Input (J/mm)	Hardness of Reinforcement (welded at 30^0C plate temperature)	Hardness of Reinforcement (welded at 0^0C plate temperature)
1	929.7	165.2	158.7
2	837	143.7	175.8
3	948.6	108.8	147
4	744.3	149.7	152.4
5	1072.8	164.9	148.6
6	877.5	111.9	155.8
7	702	142.5	135.7
8	780	135.6	204.7
9	1784.7	134.9	152.5
10	1575	126.6	178.4
11	756	131.9	132.7
12	630	139.4	132.1
13	2220.3	144	139.6
14	1332	128.4	140.5
15	799.2	163.3	189.5
16	888.3	165.3	115.1

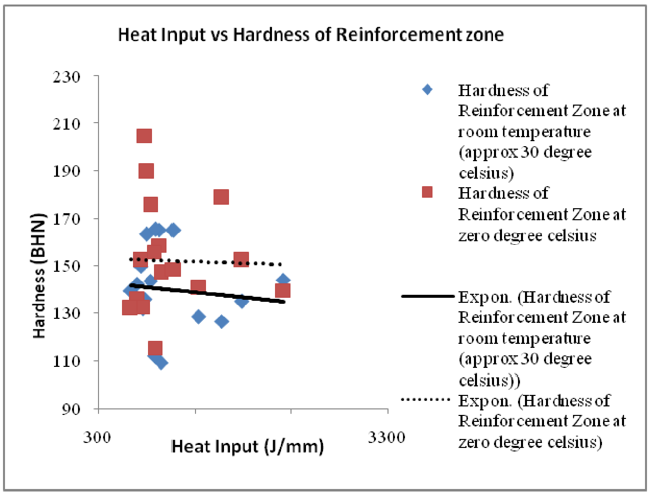

Figure 3 Graph shows the variation of micro hardness of reinforcement against heat input.

No significant change is found in hardness in the weld zone irrespective of the plate temperature as the weld zone is surrounded by reinforcement and base metal and influencing cooling rate are shows in Figure 4.

Table 4: Micro hardness of weld zone at different plate temperature

SL NO.	Heat Input (J/mm)	Hardness of weld zone (welded at 30^0C plate temperature)	Hardness of weld zone (welded at 0^0C plate temperature)
1	929.7	208.1	181.7
2	837	168.3	169.5
3	948.6	133.4	152.1
4	744.3	162.1	159.2
5	1072.8	143.6	149.9
6	877.5	109.1	196.2
7	702	156	179.9
8	780	228	182.4
9	1784.7	140.8	120.5
10	1575	128.2	143
11	756	183.3	178.6
12	630	173	161.7
13	2220.3	133.8	126.5
14	1332	149.5	130.6
15	799.2	162.9	177.8
16	888.3	183.3	148

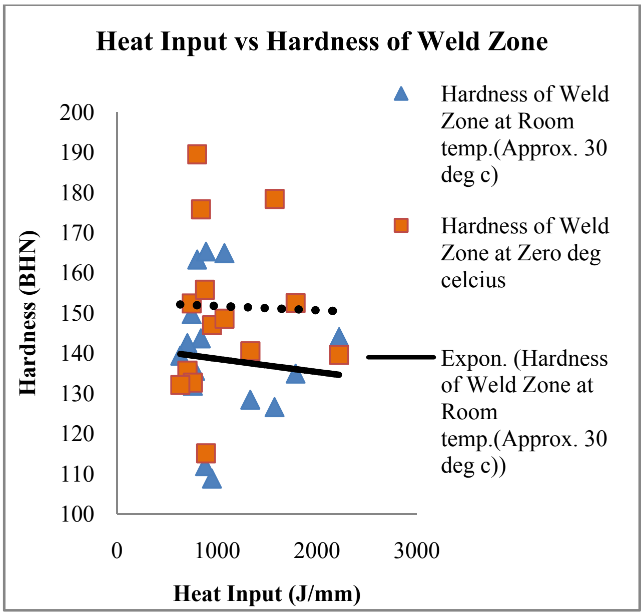

Figure 4 Graph shows the variation of micro hardness of weld zone against heat input.

In the heat affected zone (HAZ), rate of decreasing hardness due to an increase in heat input is higher when plate temperature is zero degrees Celsius than plate temperature is in room temperature of about thirty degrees Celsius. The reason is lesser rate of heat dissipation during higher rate of heat input is shows in Figure 5.

Table 5: Micro hardness of heat affected zone at different plate temperature

SL NO.	Heat Input (J/mm)	Hardness of heat affected zone (welded at 30^0C plate temperature)	Hardness of heat affected zone (welded at 0^0C plate temperature)
1	929.7	160.7	256.6
2	837	144.9	203.9
3	948.6	148.4	222.6
4	744.3	129.2	267.6
5	1072.8	154.6	131.9
6	877.5	133.8	305
7	702	168.4	262.2
8	780	149	279.1
9	1784.7	128	164.6
10	1575	149.3	149.6
11	756	155.7	312.2
12	630	156.5	227
13	2220.3	132.2	120.1
14	1332	162.2	131.6
15	799.2	166.4	153.9
16	888.3	208.3	140.6

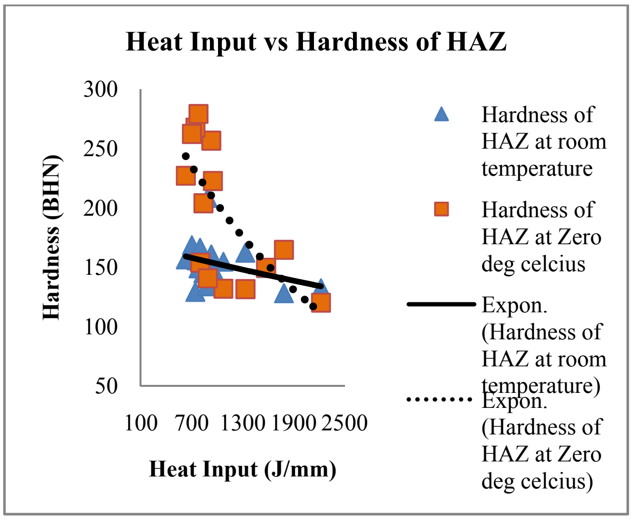

Figure 5 Graph shows the variation of micro hardness of heat affected zone (HAZ) against heat input.

Conclusions

From the present experimental investigation it is established that

(a) Without preheating submerged arc welding on mild steel plate of designation as IS 2062 Grade B, is feasible at zero degree Celsius plate temperature.

(b) There is a general tendency to form higher hardness in the major region of weldment such as reinforcement, weld zone, and HAZ when the plate temperature is zero degrees Celsius due to fast cooling of molten metal.

(c) Comparatively less hardness is formed in those major regions when the plate temperature is room temperature of about thirty degrees Celsius due to slow cooling rate of molten metal.

(d) Hardness of reinforcement zone enhanced at zero degree plate temperature due to rapid cooling.

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