Identification and assessment of the HAZ softening and hardening phenomena for Submerged Arc Welding Process for structural steel plates

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ABSTRACT

Submerged Arc Welding (SAW) process has lot of social and economical implication. Critical set of variables are involved in this process, and they are needed to be controlled. An attempt has been made in this paper to find out- the influence of the heat input on HAZ hardness (change of hardness & microstructure) for Submerged Arc Welding Process of Mild steel plates. Mild steel plates are welded by changing input variables (current, voltage, trolley speed, i.e. heat input) and Rockwell hardness No. on different grid points (points are taken horizontally & vertically 2 mm apart) of welded surface and at the zone adjacent to the welded portion has been observed. A detailed analysis of the microstructure changes is carried out to understand the HAZ softening phenomenon.

Keywords: SAW, HAZ hardness, Rockwell Hardness No., Microstructure, Grain growth.

INTRODUCTION

Submerged arc welding (SAW) is a high quality, high deposition rate welding process commonly used to join plates of higher thickness in load bearing components. This joining process important critically for fabricating structures, bridges, ships, boilers, etc. This method of arc welding provides a purer and cleaner high volume weldment that has relatively a higher material deposition rate compared to the traditional welding methods. In a country like India, in the context of infrastructural development, the SAW process has much more useful applications in welding of critical components and equipment. Use of this technology has huge economic and social implications in the national perspective. A common issue in the application of SAW process raises a concern about the uncertainties involved with the heat affected zone (HAZ) in and around the weldment. The most concerned query is about HAZ softening that imparts some uncertainties in the welded quality. It increases the probability of fatigue failures at the weakest zones caused by the heating and cooling cycle of the weld zone. It is observed that a refine microstructure of the HAZ, imparts largely the intended properties of the welded joint [1]. In order to bring out an appropriate combination of SAW parameters and a methodology to control such parameters an in depth investigations and characterizations of HAZ softening zone are necessary to enrich this submerged arc welding technology.

In Submerged Arc Welding process, major process control parameters are current, arc voltage and travel speed. They all affect the bead shape, depth of penetration and chemical composition of the deposited weld metal. Another very critical issue in the understanding of the joint performance obtained from SAW process rests on the analysis of heat affected zone. It is difficult for the operator to observe the weld pool during the process. So, better control comes from SAW process parameter settings than dependence on the operator□fs expertise. It is shown by the researchers [1] that the HAZ has various regions those influence the ability of the joint to provide crack resistance and uniform strength in both the direction of the weld. An estimation of bead width and depth of penetration obtained from infrared thermal imaging technique (IRTI technique) is also found to influence the quality of SAW process [2]. Very little information is available in the literature on the aspects of HAZ softening during SAW process. A three dimensional analysis to predict the zones of microstructure of SAW process is indicated in [3]. A model to predict HAZ in case of SAW is addressed by [1] attempts to predict HAZ in case of SAW.

A combined effect of chemical composition of flux and welding parameters on the mechanical properties of SAW process is shown to be of utmost significance [4-5]. It is apparent from these references [1-5] that SAW process has drawn much of attention, in recent time, for characterization of its various aspects. It is also very clear that a systematic study to bring out a correlation based performance characterization through identification of control parameters in conjunction with quality assessment is missing. An identification of the contribution of each of its process control parameters on the quality or performance of a SAW joint, possess a challenge to the researchers in this area and demands a very systematic study of the problem.

EXPERIMENTAL PROCEDURE

The experiment was conducted with the MEMCO semiautomatic welding equipment with constant voltage rectifier. Flux used is ADOR Auto melt Gr. II AWS/SFA 5.17(Granular flux), Electrode selected is ADOR 3.15 diameter copper coated wire, Test Piece is 400 x 75 x 16 mm square butt joint, weld position is flat with electrode positive and positioned perpendicular to the plate.

Appreciably high than that of base metal which indicates uniformity of properties in the welding. This is also a very desirable quality.

The experiments were conducted as per the design matrix at random to avoid errors due to noise factors. The job 400x25x16 mm (3 pieces) was firmly fixed to a base plate by means of tack welding and then the welding was carried. The slag was removed and the job was allowed to cool down. The job was cut at three sections. Rockwell hardness number taken on the grid points (points are taken horizontally & vertically 2 mm apart) of welded surface and at the zone adjacent to the welded portion has been observed (shown in fig No. 7).

RESULT AND DISCUSSION

It is evident from the table no.[3.2.1] that for the most of the portions of the fusion zone, the hardness is well above the base metal hardness. Therefore it could be suggested that the portion of cross-section lying in fusion zone has become brittle. So this weld joint may be susceptible to brittle fracture. Hence set of process parameters used for this welding is not recommended. This may have occurred due to the fact that heat input per unit length is less and heat has been rapidly removed by the base metal, thereby causing quenching of weld metal in fusion zone. Some patches of HAZ (Heat Affected Zone) has also occurred below the fusion zone as evident by low hardness values obtained.(indicated in bold letter) which is not desirable.

It is revealed from the table no.[3.2.2] that Many patches of HAZ softening have been found (as indicated in bold letter). This indicates appreciable grain growth in the welded piece which is not a desirable phenomenon in lieu of decrease in strength in HAZ. Hence set of process parameters used for this weld is not recommended.

From the table no. [3.2.3] its clear that few HAZ patches are obtained (one on each side of the weld) .It is also evident that there is some increase in hardness of weld metal near the boundary of fusion zone. On the basis of above analysis, it could be said that this is a weld of average quality free from both excessive HAZ softening and excessive weld bead hardening.

From the above table no.[3.2.4] No appreciable HAZ softening has occurred which is desirable. It is suggested that for high and concentrated heat input, no or very less HAZ develops. In this welding heat input is high and concentrated heat input is a characteristic of SAW. Hence both the above criteria are fulfilled, which leads to prediction of no or less HAZ as confirmed by experimental data. Hardness of weld metal in fusion zone is not appreciably high than that of base metal which indicates uniformity of properties in the welding. This is also a very desirable quality. Hence it is a very good weld w.r.t. HAZ and weld hardening and the set of process parameters used may be recommended.

As evident from table no.[3.2.5] at only one grid point the hardness value is below 18 RB, hence presence of HAZ cannot be confirmed. Weld hardening has also not occurred. Above qualities are desirable, still the set of process parameters could not be recommended, since the weld obtained is very narrow (weld width small) and the joint may not have enough strength to take the required load.

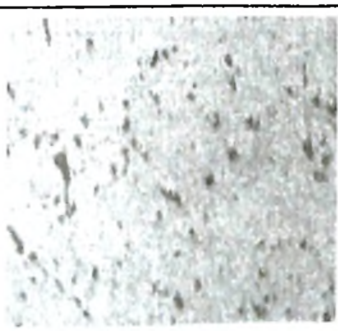
From table no. [3.2.6], no pattern for weld hardening is found; hence no conclusion could be drawn based on weld hardening. Appreciable and contagious HAZ softening is apparent at just below the fusion zone, which suggest grain growth and hence decrease in strength. Hence the set of process parameters used in the weld is not recommended.

A pattern of weld hardening is obtained at the boundary of fusion zone which is clear from table no. [3.2.7]. But at the rest of fusion zone the hardness is not appreciably high which suggests that the material is still sufficiently ductile. No HAZ softening is apparent which is desirable. Therefore the set of process parameters used in the weld may be recommended.

A very good pattern of weld hardening is obtained at the boundary of fusion zone which is apparent in table no. [3.2.8]. But at the rest of fusion zone the hardness is not appreciably high which suggests that the material is still sufficiently ductile. Some spots of HAZ softening is also evident but number of these spots are less and also not contagious. So, they can be considered as not significantly influencing the mechanical properties of weld joint. Therefore, the set of process parameters of this weld could be recommended.

Fig-1 Microstructure at the welded zone of 100 Magnification for 2.21 kJ/mm Heat Input

Few points are prominent in this microstructure, these are caused due to grain growth and these are the softening portion of welded zone.



10μm

Fig-2 Microstructure at the nonwelded zone of 100 Magnification for 2.21kJ/mm

Here more softening portions have been found.

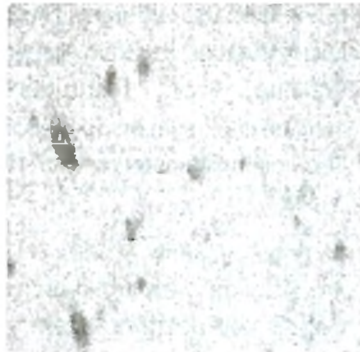
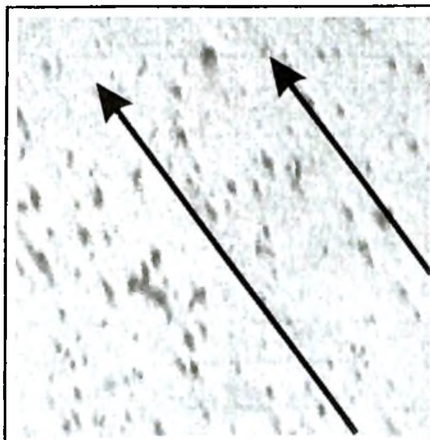


Fig-3 Microstructure at the welded zone of 400 Magnification for 2.21 kJ/mm Heat Input

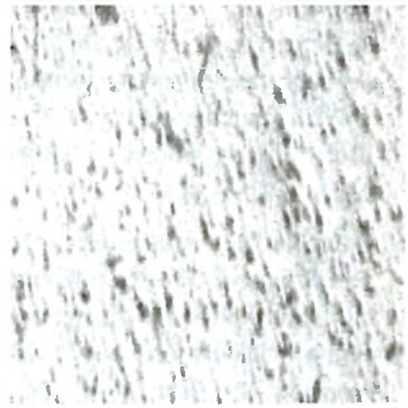
Fig-4 Microstructure at the non-welded zone of 400 Magnification for 2.21 kJ/mm Heat Input



10μm

Fig-5 Microstructure at the welded zone of 50 Magnification for 2.21 kJ/mm Heat Input.

The alignment of the grain formation confirms the directional component of the grain growth for the sub merged arc welding process of 2.21 kJ/mm heat input.



10μm

Fig-6Microstructure at the non-welded zone of 50 Magnification for 2.21 kJ/mm Heat Input

Here more softening portions have been found w.r.t welded portion.

CONCLUSION

Existence of prominent grain growth provides the confirmatory evidence of the HAZ softening phenomenon. In the welded portion, grain refinement occurs in most of the region due to the heating and cooling cycle of SAW method. Predominant direction of the grain growth is clearly observed from the photograph of the microstructure. This grain formation is distinctly revealed in the magnification (50,100) for the heat input of 2.21 kj/mm. Hall Petch equation states the strength of the metal is to vary reciprocally with size of subgrain.The similar phenomenon is also revealed in case of hardness. In context of this equation one can say that hardness of the grain growth portion will also manifest lower values related to higher grain sizes. In the grain growth portion of the welded region longer grains have been found depicting the chances of dislocation, slip, low yield strength and low hardness values measured in Rockwell scale B.

REFERENCES

1. Murugan,N., and Gunaraj,V., Prediction and Control of Weld Bead Geometry and Shape Relationships in submerged arc welding of Pipes; J. of Materials Processing Technology, V.168, N.3, 2005.
2. Menaka,M., Vasudevan,M., Venkatraman,B., Raj,B., Estimating bead width and depth of penetration during welding by infrared thermal imaging;, Non-Destructive Testing and Condition Monitoring , V.47, N. 9, 2005 ,564-568.
3. Pathak,A.K., Dutta,G.L., Three dimensional Finite Element Analysis to predict the different zones of Microstructure in Submerged Arc Welding; Proc., Institution of Mechanical Engineers, part B, J. of Engineering Manufacture, V.218, N. 3, 2004.
4. Kanjilal,P., Majumdar,S.K., Pal,T.K., Prediction of submerged arc weld-metal composition from flux ingredients with the help of statistical design of mixture experiment; Scandinavian J. of Metallurgy, V. 33, N. 3, 2004, 146-159.
5. Kanjilal,P., Pal,T.K., Majumdar,S.K., Combined Effect of Flux and welding Parameters on Chemical Composition and Mechanical Properties of submerged arc Weld Metal; J. of Materials Processing Technology V.171, N.2,2006.

Annexure

3.2 Tables on Values of hardness of welded portion and it adjacent zone

Assumption :

The average hardness of the base metal is found to be 19 R_B .

1. The occurrence of detrimental HAZ softening has been considered if hardness at a grid point is less than 18 R_B(Shown in bold letter).
2. Occurrence of excessive weld hardening has been considered if hardness at a grid point is greater than 22 R_B (shown in italic letter).
3. The centroid of each cell in the table shown below represents the grid points on which hardness data is taken.

Table-3.2.1
Job No. A1

Voltage: 25V, Current: 350A, Trolley Speed: 17 cm/min, Wire stick out: 13 mm, Heat Input: 2.78 kJ/mm [heat input (kj/mm) = {Arc voltage (volt) x Arc current (Amp.) x efficiency}/ {Trolley speed (mm/min) x 1000}]. Efficiency taken for SAW process =0.9.

-	-	-	23	22.5	24	21	23	23.5	26	23	20	-	-
22	24	26	24.5	24	23	24.5	26.5	18.5	24.5	25	24	21.5	22.5
12	24	23	23.5	25	23	24	22	25	-	-	-	-	-
26	21.5	23	24	23	25	22	24	21.5	23	21.5	18.5	20	22
20.5	12	16	21	17	26.5	21.5	25	22	21.5	21	21.5	23	23

Table-3.2.2
Job No. A2

Voltage: 35V, Current: 350A, Trolley Speed: 17 cm/min, wire stick out: 13 mm,Heat Input: 3.89 kJ/mm

-	-	-	16	19	19	21	20	19	18	-	-
20	21	22	20.5	17	18	20	19	19	19	18.5	20.5
17.5	19	18	19	17	19	20	18.5	22	22.5	21.5	17
19	20	17.5	21	21	25	24.5	19.5	21.5	18.5	21	21
19.5	20	20.5	21.5	19.5	19	17	17	20.5	20	19	18.5

Table-3.2.3
Job No. A3
Voltage: 25 V, Current: 450A, Trolley Speed: 17 cm/min,
Wire stick out: 13mm, Heat Input: 3.57 kJ/mm

-	-	22	22.5	20.5	20.5	20	21	24	24	-	-
22	21.5	20.5	18	20.5	21.5	21	22	21	22	20	21.5
20	22	18	18	19.5	21	20	22	24	23.5	15.5	19
17.5	20	18.5	20	21	21	18.5	22	21.5	23	19	20
19	19	21	18	22	22	24	26	19	20.5	20.5	19

Table-3.2.4
Job No. A4
Voltage: 35 V, Current: 450 A, Trolley Speed: 17 cm/min Wire stick out: 13 mm, Heat Input: 5 kJ/mm

-	-	-	14.5	18	20	19	19	18	19	19	20	18	20	19	-	-	-
20.5	20	19	21	21	20	20	21	20	21	20	19.5	19	21	22.5	20.5	20	19.5
19.5	21	20.5	21.5	21.5	19.5	19	21	21	21	21	22.5	21.5	24	24	22.5	23	22
22	20.5	21.5	23	22	22	21.5	21	24.5	20	19	19	20	20	18.5	20	21.5	22
18	21	18	18.5	21	19.5	20	20	19	14.5	20.5	20	19	22	22	18.5	17.5	18

Table-3.2.5 Job No. B1
Voltage: 25 V, Current: 350 A, Trolley speed: 30 cm/min,
Wire stick out: 13 mm, Heat input: 1.58kJ/mm

-	-	21	17.5	21	-	-	-
21	18	20	21	19	18	19	21
19	20	23	19	20.5	22	19	19
19	19.5	21	15.5	18	21	20.5	22
22	21	19	18	21	21	21	21

Table-3.2.6 Job No. B2
Voltage: 35 V, Current: 350 A, Trolley speed: 30cm/min,
Wire stick out: 13 mm, Heat input: 2.21 KJ/mm

-	-	19	20.5	22.5	20	22	22	21	20	-
22	22	21	25	21	20	20.5	20.5	25	20.5	21.5
20	19.5	23.5	19.5	19.5	18	18.5	20	20.5	19.5	22
17.5	20.5	24	21	17.5	16.5	16	16	19	19	22

Table-3.2.7
Job No. B3
Voltage: 25V, Current: 450 A, Trolley speed: 30cm/min,
Wire stick out: 13 mm, Heat input: 2.03kJ/mm

-	18	21	19	20.5	21.5	21	19	-
20	24	20	20	23	25	24	24	21
21	21.5	23.5	20	18	18	20.5	20	20
22	21	21	23	21	21	23	23	21.5
20.5	20	22	22	22	21	25	21	22

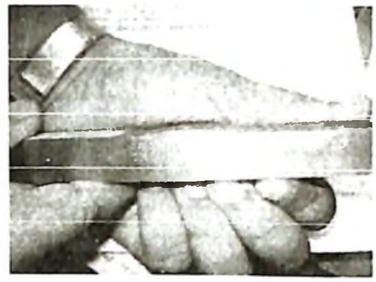


Fig 7
Grid points (points are taken horizontally & vertically 2 mm apart) of welded surface and at the zone adjacent to the welded portion

Table-3.2.8
Job No. B4
Voltage: 35 V, Current: 450 A, Trolley speed: 30cm/min, wire stick out: 13 mm,Heat input: 2.84 Kj/mm

-	-	-	10.5	16	21.5	19	18.5	20	19	16	18	19	19.5	19.5	21
20	18.5	19	23	18.5	19	23	18	23	21	20	19.5	21	22	20	18.5
17	20	22	22	23	22.5	19	20	19	22.5	20	23	22	21.5	21	21
19	21	21.5	21	20	22.5	21	20	18	22	20	22	20	21	21	21
17	24	21	20	21	23	24	21.5	19.5	23	20	23	22	21	20.5	22.5
21	25	22	23	21.5	23	22	15	14	21.5	21.5	20.5	24	19.5	19	14.5