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Effect of Heat input on Micro Hardness and Metallurgical Properties of Shield Metal ARC Welded Duplex Stainless Steel

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Abstract - **The work was carried out to the effect of heat input on the hardness and metallurgical properties of shield metal arc welded of duplex stainless steel. Three specimen A, B and C with heat input combinations designated as low heat A (0.675 KJ/mm), medium heat B (0.860 KJ/mm) and high heat C (1.094 KJ/mm) and the weld joints made using these three combinations were subjected to observe the changes in thermal condition caused by variation of heat input can affect the metallurgical properties and the hardness of the welded joint. The result achieved from this research shows that the joints made using low heat input exhibited having more hardness than those welded with medium and high heat input. Heat affected zone of welded joint made with medium heat input has austenitic ferritic grain structure with some patchy austenite provide higher harness of the welded joint. Significant grain coarsening was observed in the heat affected zone (HAZ) of medium and high heat input welded joints, whereas low heat input welded joint shows the fine grain structure in the heat affected zone with small amount of dendritic formation and equiaxed grain structure where inner zone indicates slowly cooled grains in the direction of heat dissipation.**

I.INTRODUCTION

Austenitic stainless steels are used extensively in corrosive environments. A major drawback of these steels is their susceptibility to chloride-induced stress-corrosion cracking. Although ferritic stainless steels are far more resistant to this type of corrosion damage, they do not have quite the ductility and weldability of the austenitic. Duplex stainless steels offer higher yield strengths and resistance to stress-corrosion cracking. Duplex stainless steels UNS NO.S-31803 have been used for pipelines for gas and oil, heat exchangers, pressure vessels, pulp and paper production equipments and Pharmaceutical and biotechnology industries. Attarha and Sattari [2] studied the welding temperature distributions in the HAZ were measured using K-type thermocouples in similar and dissimilar thin welded joints (St 37 carbon steel and stainless steel type S 304) which experienced one-pass GTAW process. Three dimensional finite element simulations were also implemented to predict the temperature distribution throughout the plates using ABAQUS software. Peak temperature vs. Distance in the weld pieces shows that the temperature decreasing behavior has a non-linear nature. Caparison between the finite element and experimental results revealed that the developed model had good capability for predicting the temperature cycles throughout welding. Comparing of peak temperatures of dissimilar joint showed that the S304 peak temperature near the weld melt line is higher than St37. The difference between thermal conductivity coefficients can justify this behavior.The pitting resistance test performed by Ciofu et al. [4] on laser and gat tungsten arc welded LDX 2101. This shows thatthe corrosion performance of the lean duplex steel LDX 2101 higher than that of 304. Effect of the addition of filler metal, nitrogen in the shielding gas & effect of heat input on corrosion resistance is also analyzed. The work reported by Fourie and Robinson [5] on the difference in solidification mode and transformation characteristics of these two types of alloys (Austenitic stainless steel and duplex stainless steel). Its conclusion shows that Duplex stainless steels solidify in the single-phase ferrite mode, whereas austenitic stainless steels solidify in the austenitic or austenitic-ferities mode and the austenite phase in weldments of duplex stainless steel is formed by a solid-state transformation that is strongly affected by cooling rate. In duplex weldments, low heat inputs result in high volume fractions of ferrite and severe precipitation of chromium nitrides, adversely affecting mechanical and corrosion properties and it should be welded by the use of high heat inputs to allow sufficient time at high temperature for austenite to reform. Kordatos et al. [6] correlate the impact strength and corrosion resistance of duplex stainless steel weldments to the cooling rate and to explain their independence through micro structural observations. The DSS in the form of 4 mm plate is welded by GTAW process using 2.4 mm electrode: 110 A DCEN and parameters i.e. pure argon 99.99% shielding and backing gas, gas flow rate-12 1/min shielding gas, 6 1/min backing gas and interpass temp is 150 °C. It is found that fast cooling rates in DSS welds results in decrease of the width of the ferritisation zone to 500 μm compared to 600 μm in the case of air-cooling. Although the austenite volume fraction of the weld zone decreases in water-cooled welds, this fraction of 43% is high enough to provide sound corrosion and mechanical properties for the weld. Hardness also affected by cooling rates, water-cooling gives harder weld metal than air cooling due to higher volume fraction of the harder ferrite. Fast water cooled welds show better resistance to pitting and inter-granular corrosion than air cooled ones. Ferrite is more susceptible to pitting corrosion and corrodes preferentially, while austenite is more sensitive to inter-granular corrosion.Kumar and Shahi [8] studied the influence of heat input on the microstructure and mechanical properties of gas tungsten arc welded 304 stainless steel joints. Three heat input combinations designated as low heat (2.563kJ/mm), medium heat input (2.784kJ/mm) and high heat input(3.017kJ/mm) were selected. The result indicates that as the dendrite size in the fusion zone is smaller in low heat input joints then the dendrites in medium and high heat input joints, it is found that maximum tensile strength and ductility is possessed by the weld joints made using low heat input.Muruganet al. [11] studied that thermal cycles and transverse residual stresses due to each pass of welding have been measured in the weld pads of AISI type 304 stainless steel and low carbon steel with 6, 8 and 12mm thickness used Manual metal arc welding. X-ray diffraction method was used for residual stress measurements. It is observed that in spite of lower heat input, the peak temperatures in stainless steel weld pads(closer to weld line) are higher than those in low carbon steel weld pads due to the lower thermal conductivity of stainless steel. With the number of passes, the peak tensile residual stresses gradually reduce in magnitude on the root side, and gradually increase in magnitude on the top side of the weld pads.The work studied by Muthupandi et al. [13] on the effect of weld chemistry and heat input on the structure and properties of duplex stainless steel welds using autogenous TIG and electron beam welding process shows that chemical composition exerts a greater influence on the ferrite–austenite ratio than the cooling rate. Study on the influence of welding heat input on submerged arc welding (SAW) welded duplex steel joints imperfections has been reported by Nowacki et al. [14] where heat input from 2.5 to 4.0 kJ/mm was used for plate thickness of 10–23 mm and it was concluded that usage of larger welding heat input provided the best joints qualityFrom the paper review, it is found that there is short experimental data regarding the influence of heat input on the micro hardness and macrostructure details correlation with microstructure of duplex stainless steel. In this paper, the influence of heat input on microstructure, micro hardness and macrostructure of Shield metal arc welded duplex stainless steel is presented.

II.EXPERIMENTAL DETAILS

Base material and Electrode used

The base material used in the present work was a duplex stainless steel UNS No. S-31803 plates of size of 100mm × 150 mm × 10 mm for the experiment and the electrode was E2209 solid electrode of 3.2 mm diameter conforming to AWS A 5.4.

Specimen Preparation

The specimens for the testing of micro hardness and macro-structural studies were taken from the welded specimen with three different heat input.

Hardness Testing

Hardness testing of welds was performed on ground, polished and [20] etched with international standards, cross-section of the joint area. Microvickers hardness test were performed on the various distances from the weld centre line. Total 11 readings have been taken at a distance of 1mm each from the weld centre line with HV-0.5. Micro hardness test was carried out using a microvicker harness tester (Make Akashi, Model: MVK-H2, Japan).

Microstructure and Macro-structural testing

Microstructure testing of welds was performed on ground, polished and etched cross-section of the welded joint area. Microstructure test of the welded samples was carried out on the optical microscope at 100X. For the macro-structural testing, Bead profile (Bead width, reinforcement area, penetration, Area of penetration, Bead area and dilution) was carried out on scanned pieces of welded job pieces.

III.RESULTS AND DISCUSSION

Micro Hardness analysis

Hardness is usually defined as a resistance to material. Hardness values of the welds were determined using a micro-hardness tester which uses a diamond indenter. Three characteristic zones from the fusion boundary to the base metal of a shielded metal arc welded joints were differentiated and checked by means of hardness test. Hardness profiles of welding specimens were made to show the variation of hardness with the distances from the weld centre line. Hardness measurement can provide information about the metallurgical changes caused by welding.

Micro hardness test of test samples A, B and C across cross section from weld centre line towards the base metal was performed. Micro hardness result across cross section of sample A,B, C showed that of hardness value of heat affected zone (HAZ) is decreases as the heat input increases. Weld sample C has alternatively increase and decreases in hardness values. High value of hardness measured in the weld zone of low heat input as shown in figure 1. This may be due to the equiaxed grains where as inner zone indicates slowly cooled grains in the direction of heat dissipation

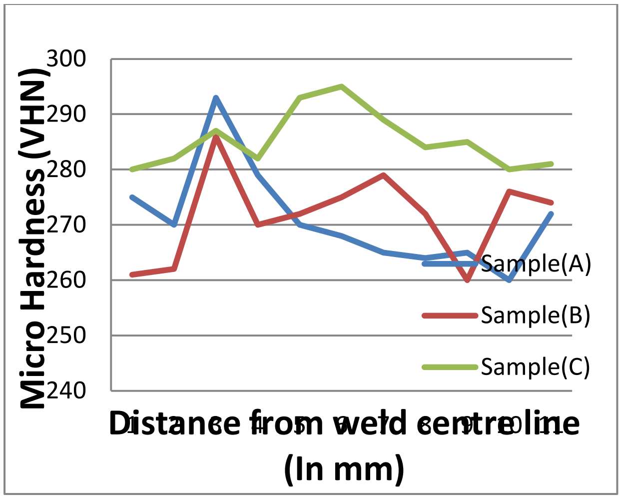

Fig.1 Micro hardness graph of weld samples across Weld cross section

Micro hardness examination was carried in longitudinal direction i.e. parallel to the base plate surface. It is observed from the measurements that joint made with low heat input exhibit higher harness value. This is due to the fine grain structure observed in the HAZ of low heat input welded specimen. The steep rise in the micro hardness with value of 293 VHN, 286 VHN and 282 VHN respectively for low, medium and high heat input respectively. The reason for this is that from the optical micrographs, it is observed that at low heat input produced weld metal free from columnar grains and formation of fine grains structure with small amount of dendrites in the HAZ (heat affected zone).

Macro-structural details of the weld joints

Bead profile (Bead width, reinforcement area, penetration, Area of penetration, Bead area and dilution) was carried out on scanned pieces of welded joints made by using three heat input combinations as shown in table 1.

TABLE I MACRO-STRUCTURAL DETAILS OF WELD JOINT

Heat input	**Bead width (mm)**	**Penetration (mm)**	**Reinforcement (mm)**	**Area of weld bead (mm^2)**	**Area of penetration (mm^2)**	**Dilution = <u>100×A.P</u> Total area (Total area=A.P+A.F)**
Low heat	14.73	9.39	2.032	83.87	51.61	61.53
Medium heat	15.24	9.39	2.032	70.967	58.06	81.81
High heat	17.27	10.668	2.54	90.322	64.516	71.42

Microstructure Examination

Optical micrographs showing the microstructure of weld zone and HAZ (heat affected zone) at 100 X for three different heat input combinations are shown in fig. 2-4. From these optical micrographs, it is observed that at low heat input produced weld metal free from columnar grains and formation of fine grains structure with small amount of dendrites in the HAZ (heat affected zone). As the heat input increases, mixed grains structure including equiaxed grains has been observed in the weld metal and austenitic ferritic structure with some patchy of austenite in the HAZ of medium heat input joint.

Partial dendritic formation has been observed in the HAZ and mixed grains structure showing unevenly cooled grains with partial dendritic formation observed in the weld metal of high heat input joint. As the heat input increases coarse graining has been observed. This is due to the fact that as the heat input increases, the cooling rate decreases. The dendrite formation can be attributed to the fact that at low heat input, cooling rate is relatively higher due to which steep thermal gradients are established in the weld metal, which in turn lesser time for the dendrites to grow, whereas at high heat input, cooling rate is slow which provides more time for the dendrites to grow

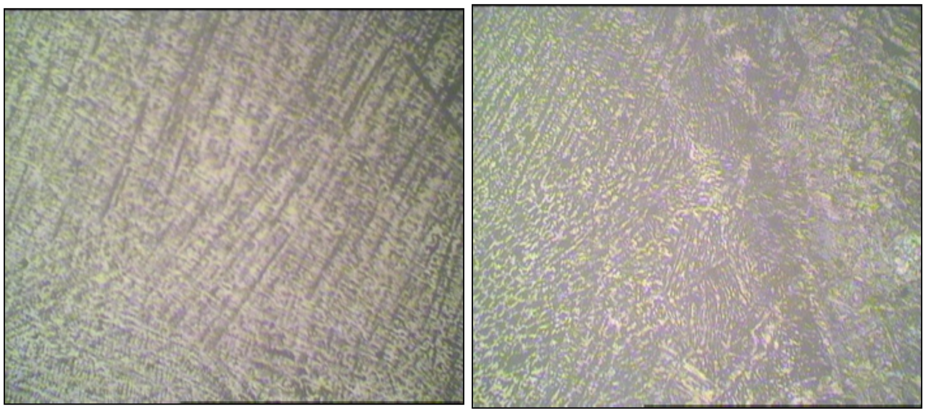

Fig.2 Optical micrograph showing the microstructure of (a) weld zone, (b) HAZ (Low heat, at 100X)

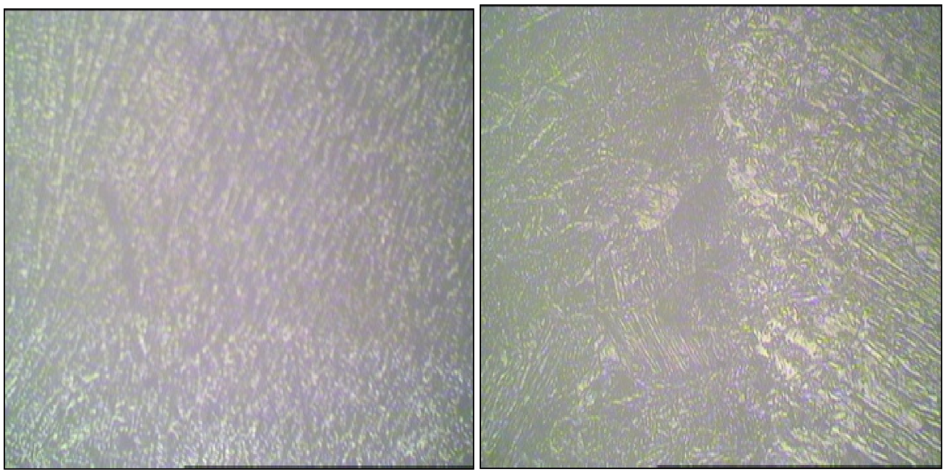

Fig.3Optical micrograph showing the microstructure of (a) weld zone, (b) HAZ (Medium heat, at 100X)

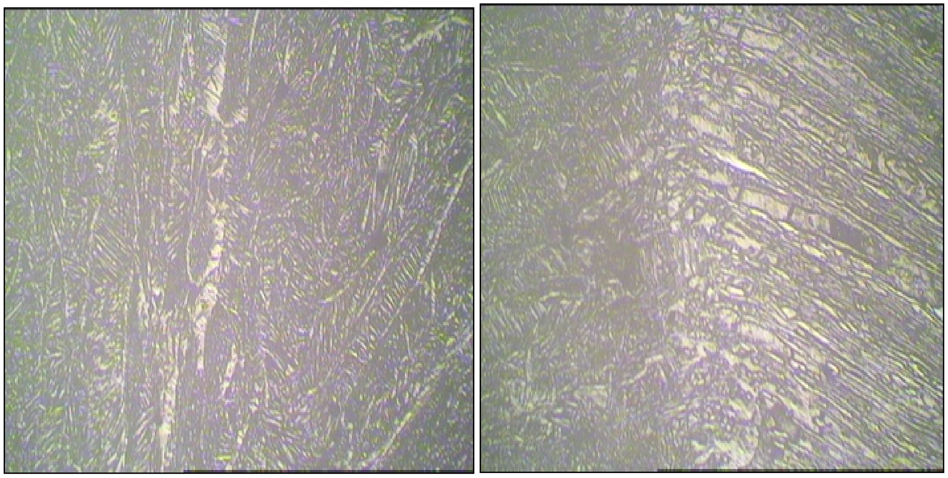

Fig.4Optical micrograph showing the microstructure of (a) weld zone, (b) HAZ (High heat, at 100X)

IV.CONCLUSION

It is found that weld joint made with low heat input (A) shows higher micro hardness in the weld zone rather than the joint made with medium and high heat input. The fine grain microstructure is observed in the HAZ of low heat input welded joint. As the heat input increases the weld bead width and the depth of penetration increases.

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