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Study of Metallurgical and Mechanical Properties of Multipass Butt Weld Joint on Pressure Vessel Steel Plates With Different Welding Processes

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Abstract— This study is conducted for the investigations of two different welding processes on mechanical as well as metallurgical properties of 63 mm thick high carbon butt welded steel. Two different types of techniques namely Submerged and Flux Cored Arc Welding which are widely used for their high quality deposition rate utilized for join thick plates for pressure vessels. These techniques provide high volume of weldment as compared to other traditional welding technique. In this study SA 516 Gr 70 steel plates with plate thickness of 63mm is utilized to investigate the properties like mechanical and metallurgical on butt weld joint with different welding process such as flux cored and submerged arc welding process. After the specimens were welded with submerged arc welding and flux cored arc welding process all samples were subjected to radiography testing, stress reliving and destructive testing; which states that the results found to be best when submerged arc welding process was used.

Keyword- Macrostructure, Micro hardness of weld metal and HAZ, Microstructure, SAW(Submerged arc welding), FCAW(Flux cored arc welding

INTRODUCTION

The carbon steel categorized as high, medium and low carbon steel, high carbon steel SA-516 Gr 70 are extremely used to making pressure vessel, boiler, towers, bridges, boats, wind turbine, oil and gas pipelines. With high strength and toughness of boiler plate material its joining process must be reialable in industry. Welding process is extensively utilized in industries for joining the plates with higher thickness in nuclear power plants, aerospace industries and automobile etc [1,2]. SAW and FCAW are the welding process which produce high quality, deposition rate. As per the national prespective this technology has huge social and economical implications. Refined microstructure was observed at heat affected zone imparts largely the intended properties of the welded joints [1, 3]. Parameters under consideration in FCAW and SAW process are voltage, speed, current and distance between workpiece and nozzle. These all parameters have consequence on mechanical properties and microstructure of the weld bead. In the case of multipass welding of heavy thickness material as well as welding process also affects the metallurgical-mechanical properties of welded joints such as microhardness, tensile strength, toughness, macrostructure, and microstructure. Preheating of metal at a initial stage diminishes the mechanical properties with the increased temperature in HAZ, as the microstructure have different grain size and structure before preheating and non preheated specimen. It was observed in the previous studies that the preheating phenomena increases the ferrite phases and decreases the graphitic phases and as a result the ferrite structure arises. The influence of SAW parameter on the macrostructure, microstructure and microhardness of high carbon steel of butt welded joints is more effective then the FCAW. The microhardness value found more in the case of FCAW as compare to the SAW as result shows the more ductility. Improvement in hardness and ductility of the final layer depends upon the different heat input in weld layers re-crystallization of weld metal and the time interval between the successive deposition [7]. To accomplish the above goal, design of experiment based structure is followed to evaluate the best welding process to decrease the hardness value and refine the grain structure of heavy thickness carbon steel plates with butt weld joint. Also, the aim of reducing the time and cost as well as to evaluate the mechanical microstructure properties due to the impact of heat effected zone produced in multipass of welding with FCAW and SAW process. This paper intend to present the effect of welding process on hardness, microstructure and macrostructure properties.

EXPERIMENTATION

After having thorough survey of industries the material for pressure vessel have been selected for the present study is SA516 Gr70, which is utilized for the manufacturing of boiler and pressure vessels. The chemical composition of selected material is shown in table-1 and mechanical properties in table-2.

Table 1-Chemical Compositions for Base Metal

Material	Chemical Composition by weight percentage					
Carbon Steel	C	Mn.	P	S	Si	Fe
	0.30	0.79-1.30	0.035	0.035	0.13-0.45	Balance

Table 2 Mechanical Properties for Base Metal

Material	Yield Strength (MPa)	Ultimate tensile Strength (MPa)	Elongation (%)
Carbon Steel	38 [260]	70-90 [485-620]	17

Specimen specification: Four plates of size 500mm x 150mm x 63mm were used for two test pieces with double vee groove joint on each test specimen, prepared with the help of shaper machine as shown in figure-1.

Figure 1: Double V-Butt joint in specimen

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Before performing the welding process, preheat of both test specimens with heating burner up to 100ºc and measured by thermal chalk to reduce the temperature difference as result to avoid cracks and distortion in butt welded joints. The first run was performed by SMAW process using the electrode E-7018-1. Subsequently, the second run was performed by SAW machine utilizing EH-14 wire with 4mm diameter and flux grade F7A4. The chemical composition shown in table 3 and mechanical properties of the flux is shown in table 4.

Table 3 Chemical Compositions for solid SAW wire

AWS Class	Chemical Composition by weight				
EH-14	C	Mn	Si	S	P
	0.10-0.20	1.70-2.20	0.10	0.030	0.030

Table 4 Mechanical Properties for solid SAW wire & Flux

AWS Class	Tensile Strength (psi)	Min.Yield Strength (psi)	Elongation (%)	Min. Average Energy Level
EH-14+ F7A4	70000-95000	58000	22	20 ft-lbf

The temperature of interpass considered for present experimental study was 150° C as per ASME section IX 5.17. After completion of one side of welding the shielded metal arc welding (SMAW) deposited metal is gouged and removed from the joint and then subsequently filled by SAW. Second specimen is made by using multipass FCAW welding using Ador Champ multi 400 with filler wire E71T-1. During making of this specimen the interpass temperature is again considered 150 °C as per ASME section IX 5.17. mechanical properties and chemical composition of the filler wire and saw flux is shown in table 3 and table 4. The second side of the plate is welded and vee groove is filled completely. The time consumed for welding of each pass was noted. After welding both test specimen, they are subject to stress relieving process up to 620ºc to remove the internal stress and fine the grains of weld metal and heat affected zone. After stress reliving both test coupons were tested with radiography to check the internal defect of weldment and no defect was found. Tensile and impact tests were performed to evaluate the tensile and toughness properties of the joint made with FCAW and SAW process. The chemical composition & mechanical properties of the FCAW wire is given in table 5 & 6 respectively.

Table 5 Chemical Compositions for FCAW Electrode

AWS Class	Chemical Composition by weight				
E-71T-1	C	Mn	Si	S	P
	0.12	1.75	0.90	0.03	0.03

Table 6 Mechanical Properties for FCAW Electrode

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AWS Class	Tensile Strength (ksi)	Min. Yield Strength (ksi)	Min. Elongation (%)	Min. Impact Energy
E71T-1	70- 95	58	22	20 ft-lbf at 0°C

During welding of these specimens the interpass temperature is again considered 150 °C. Before the second side welded, vee groove is gouged and removed the weld metal to clear the root then joint subsequently filled by FCAW. The specimen for are machined by using bend saw machine and machined by facing machine for hardness test, macro test and microstructure test were performed to evaluate the hardness and macrostructure properties of the joint welded with both FCAW and SAW.

METHODLOGY

The preceeding procedure for conducting the study was adopted: -

- The selected material utilized for the study was 63 mm thick carbon-steel plates.
- Specimen size was (500 x150 x 63 mm) which was prepared base material of pressure vessel by utilizing power hack saw.
- For preparation of v-groove, angle cutter was utilized and grinder used for removing burs of edges.
- Angular distortion was controlled by placing the welded joint on a flat surface.
- The root gap was 3mm and the inclined angle was 75°.
- Applying the weld bead by utilizing SMAW and FCAW machine for the subsequent layers of weld metal by varying the welding parameters in the first test run and second test run.
- Three welding parameters were varied during the application of weld joint are electrode polarity, voltage and current.
- Final test samples are prepared with grit paper shaping, grinding and finishing.
- Testing of specimens for microhardness and microstructure analysis was performed.
- The results obtained via tests were analyzed by using graphical plots.

WELDING PROCESS PARAMETERS

The process parameters selected for the present stud was current, voltage, speed of weld run and distance between nozzle and the workpiece. Welding was started as per the selection of welding parameters depending on the diameter of the wire and the maximum and minimum range was selected by observing the weld bead for even emergence with no visible defects. The upper limit and lower limit of the current, voltage and nozzle to plate distance with their units and notations are given in table 7 & 8 respectively.

Table 7 welding process parameter for FCAW

Parameter	Units	Lower limits	Higher limits
Welding Current	Amp	170	250
Arc Voltage	Volts	20	27

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Nozzle to Plate Distance	Mm	15	20

Table 8 Welding process parameter for SAW

Parameter	Units	Lower limits	Higher limits
Welding Current	Amp	590	610
Arc Voltage	Volts	31	35
Nozzle to plate distance	mm	20	25

RESULTS AND DISCUSSION

Macrostructure Examination

Macrostructure examination was performed on the welded specimen as shown in figure. Several test like passivation, corrosion resistance, salt spray and case depth measurement was performed on test specimens. The most frequent test which is utilized to analyze the welded joint is the cross section of the welded joint. To understand the variables like internal discontinuities, weld pass, internal discontinuities, penetration and quality of weld the cross section of welded joint is analyzed carefully.

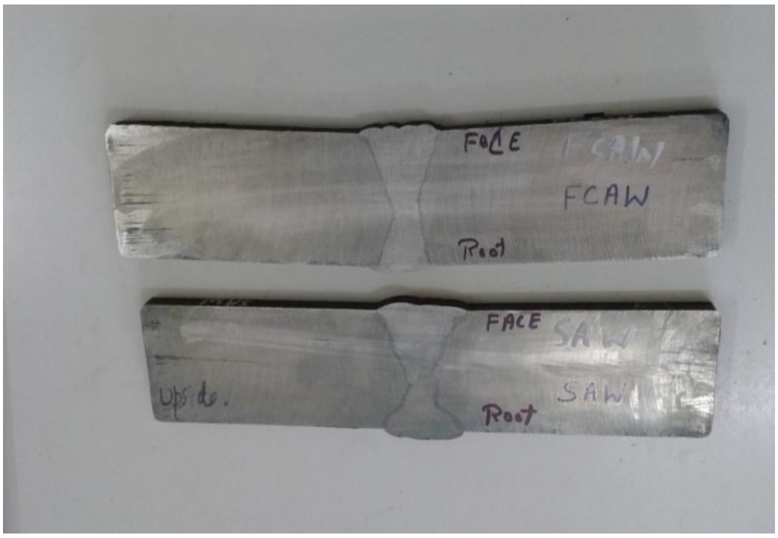

Figure 2 Macro Examinations of FCAW and SAW

It has been observed from the macro test that the penetration of the SAW test coupon was observed wide and as compare to FCAW test coupon on other hand the penetration of FCAW test coupon appears narrow as shown in figure 2.

MICROSTRUCTURE

Microstructure of the welded joint was analyzed and it was observed that there was an increase in grain size in preheated portion due to multipass of welding. In multilayers of weld, the upper layer has a tendency to normalize the thermal effect as compared to the previously applied layers. This leads to the variation of hardness value due to refinement of the grain structure. As the number of multipass increases the larger the grain size and refined grains at HAZ due to the preheating of the previous layer having medium and low heat input. The formation of larger columnar grains

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compared to medium and low heat inputs is due to high heat input. Microstructure observed at heat affected zone due to low heat input was the coarse grains of ferrite and pearlite as well as columnar grains at the weld bead. It was also observed that the coarseness of the grains increases and the orientation was different when heat input was increased. Primarily two phases i.e. pearlite (dark etched) and ferrite (light etched) was observed which was replaced by the heat affected zone over the multipass fusion zone. At low magnification some fine carbon particles were observed.
At high magnification acicular tempered martensite was observed at the fusion boundary which results in the grain coarsening.

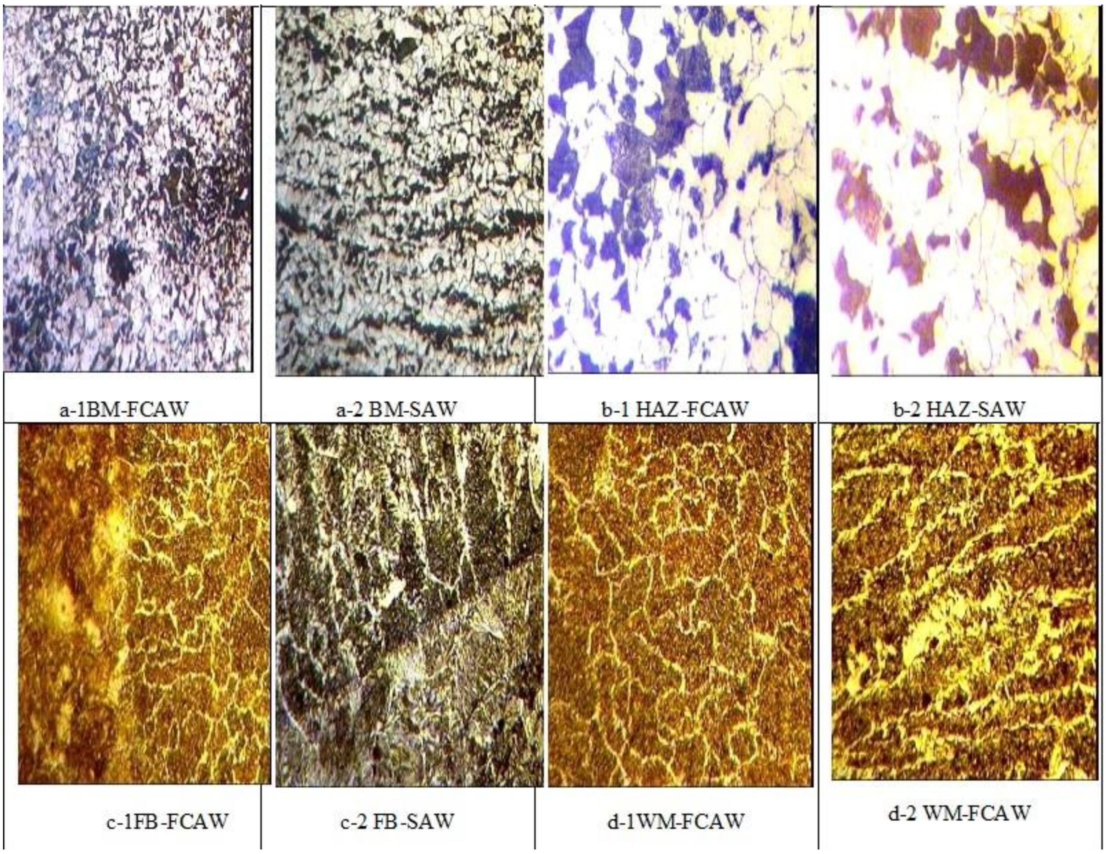

Figure 3: Different Microstructure of FCAW and SAW welding at different zones (a-1) Base metal at 100X of FCAW test specimen (a-2) Base metal at 100X of SAW test specimen (b-1) HAZ at 100X of FCAW test specimen (b-2) HAZ at 100X of SAW test specimen (c-1) FB at 100X of FCAW test specimen (c-2) FB at 100X of SAW test specimen (d-1) WM at 100X of FCAW test specimen (d-2) WM at 100X of FCAW test specimen.

Figure 3 represents the micrographs of different specimens at the weld metal zone. It indicates the presence of different morphological forms of ferrite mainly acicular ferrite (ACF). There is a noticeable difference found in the microstructure of the different samples such as base metal, Heat Affected Zone, fusion boundary & weld metal for FCAW & SAW processes respectively, which consists of grain boundaries and austenitic structure in this ferrite (white) and pearlite (dark) The grains are fine in size and shape clearly shows the microstructure of FB –fusion boundary in this grain boundary ferrite and polygon ferrite fusion boundary.

MICROHARDNES

Vertical hardness flows down the center of the welds and horizontal hardness flows along different weld passes (root and main weld passes) for different groove weld forms are performed to determine differences in hardness around various joints locations. The microhardness values along weld centre line are shown by M–M axis and across the weld cross section are represented by X–X, Y–Y and Z–Z respectively and in root side U-U,T-T, and S-S respectively for both test pieces, N-N axix is the centre line of the weldment shown in figure 4. Sufficient measurements were taken for vertical as well as horizontal traverses at a regular interval of 4 mm along the respective axis and the values are presented in graphical form for each type of joint as shown in Figure 5 to figure 12. Hardness is the property of a material which, usually through penetration, allows it to resist plastic deformation. The word hardness can also apply to bending, scraping, abrasion or cutting resistance. in this research work total eight axis was taken from each test coupon shown in figure 4 , along the weld metal and across the weld metal ,which include all weld metal along m- m section and transverse to welding with different section such as X,Y,Z.N,S,T,U,V respectively all the reading was taken in BHN-Brinell hardness number, total fourteen reading was taken from each axis and section and shown in different figures i.e. from figure 5 to 12 respectively

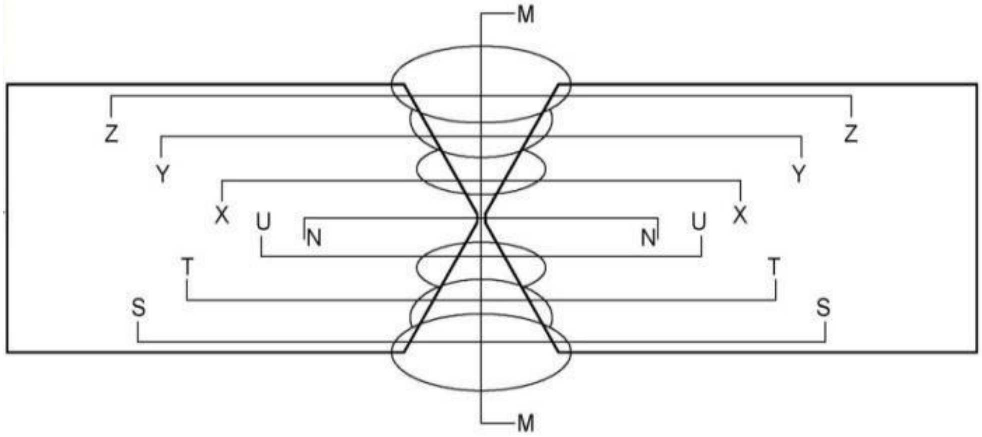

Figure 4 Hardness Testing Locations at different axis

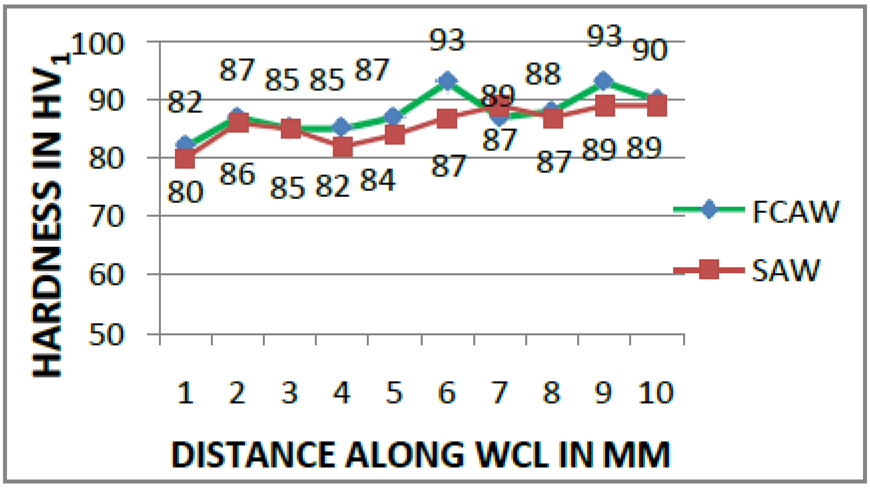

Figure 5 Hardness testing results along M-M

It was observed from figure 5 that the hardness value of FCAW was on higher side as compare to saw welding across the weldment at M-M axis, in case of FCAW the maximum value was observed 93 BHN and in SAW it was observed maximum 89 BHN

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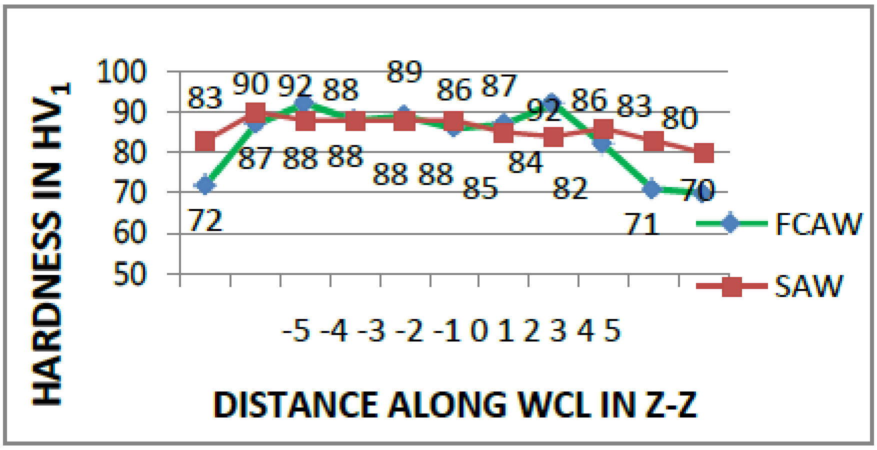

Figure6 Hardness Testing results along Z-Z

It was observed from figure 6 that the hardness value of FCAW was on higher side as compare to saw welding across the weldment at Z-Z axis, in case of FCAW the maximum value was observed 92 BHN and in SAW it was observed maximum 90 BHN

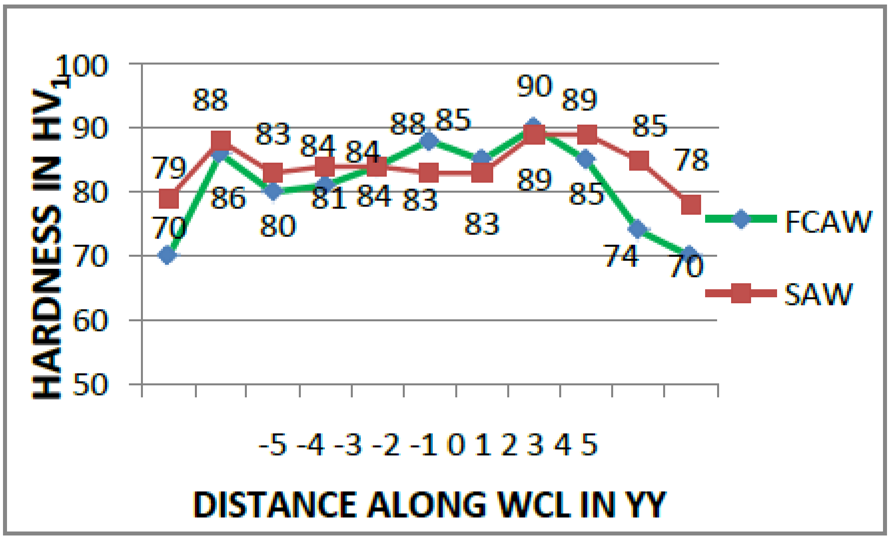

Figure 7 Hardness Testing results along Y-Y

It was observed from figure 7 that the hardness value of FCAW was on higher side as compare to saw welding across the weldment at Y-Y axis, in case of FCAW the maximum value was observed 90 BHN and in SAW it was observed maximum 89 BHN.

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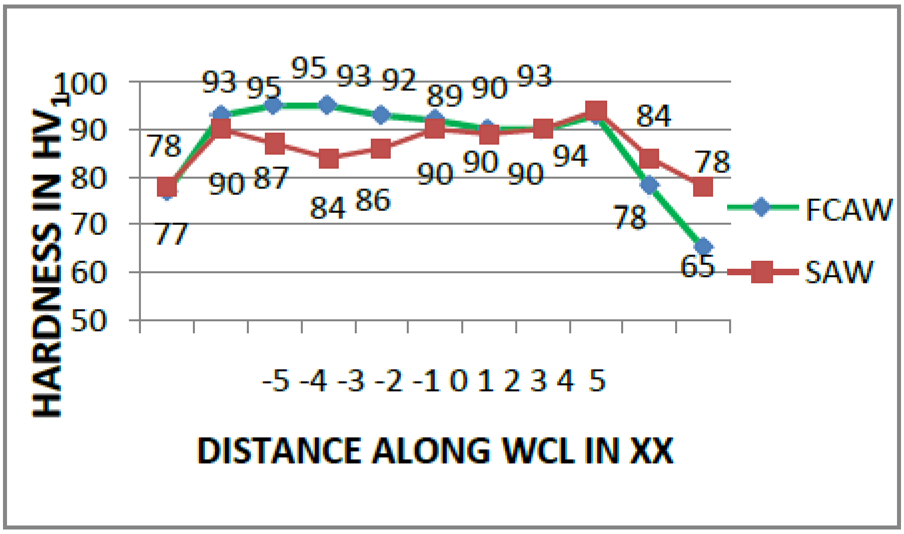

Figure 8 Hardness Testing results along X-X

It was observed from figure 8 that the hardness value of FCAW was on higher side as compare to saw welding across the weldment at X-X axis, in case of FCAW the maximum value was observed 95BHN and in SAW it was observed maximum 94BHN

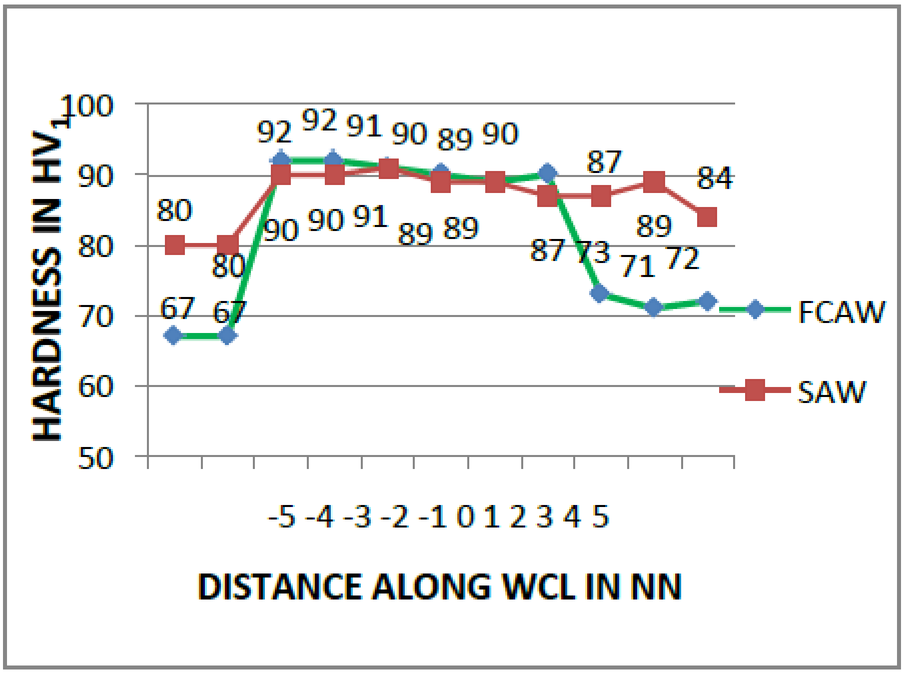

Figure 9 Hardness Testing results along N-N

It was observed from figure 9 that the hardness value of FCAW was on higher side as compare to saw welding across the weldment at N-N axis, in case of FCAW the maximum value was observed 92 BHN and in SAW it was observed maximum 91 BHN.

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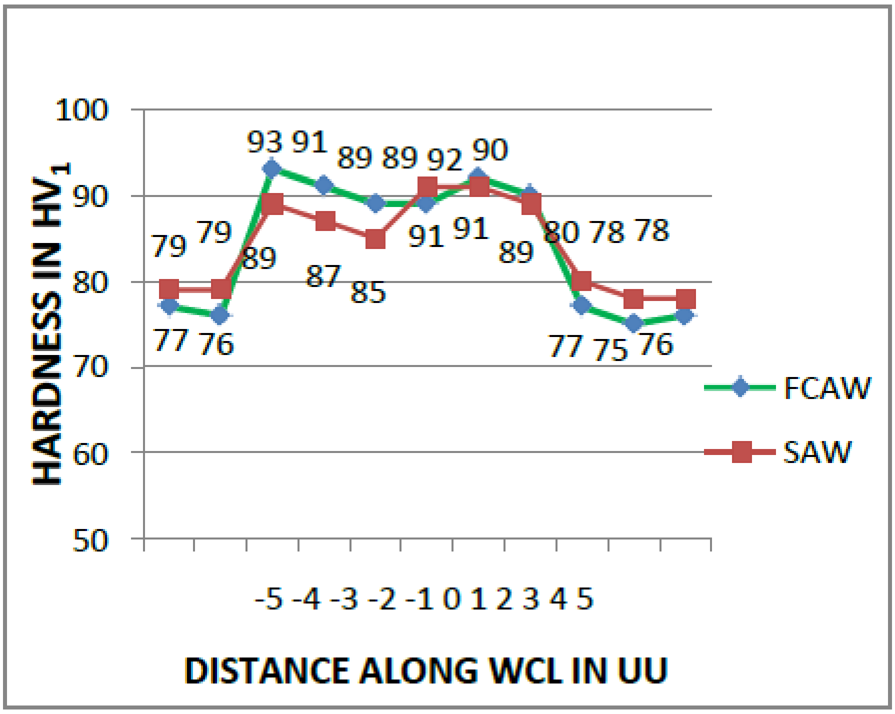

Figure 10 Hardness Testing results along U-U

It was observed from figure no 10 that the hardness value of FCAW was on higher side as compare to saw welding across the weldment at U-U axis, in case of FCAW the maximum value was observed 93 BHN and in SAW it was observed maximum 91 BHN

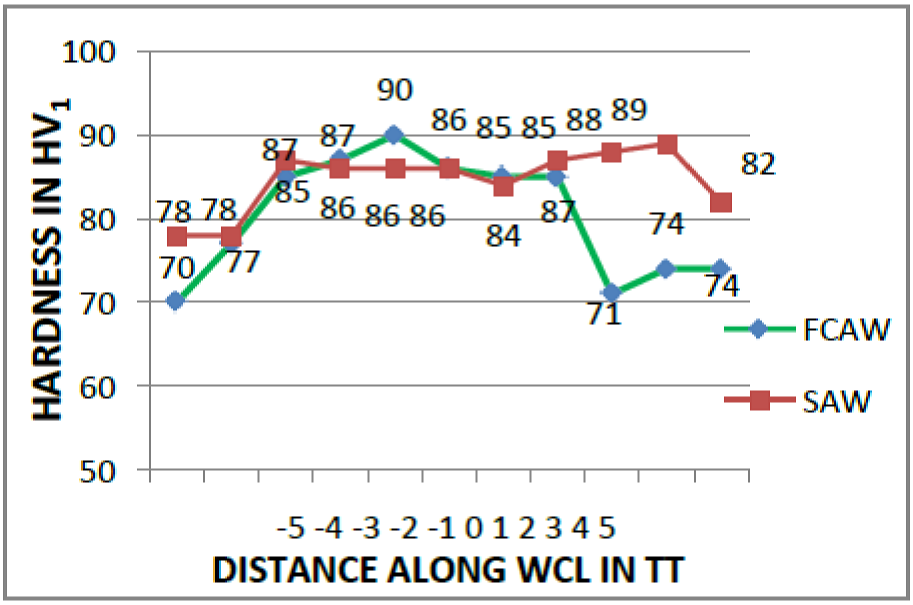

Figure 11 Hardness Testing results along T-T

It was observed from figure no 11 that the hardness value of FCAW was on higher side as compare to saw welding across the weldment at T-T axis, in case of FCAW the maximum value was observed 90 BHN and in SAW it was observed maximum 89 BHN.

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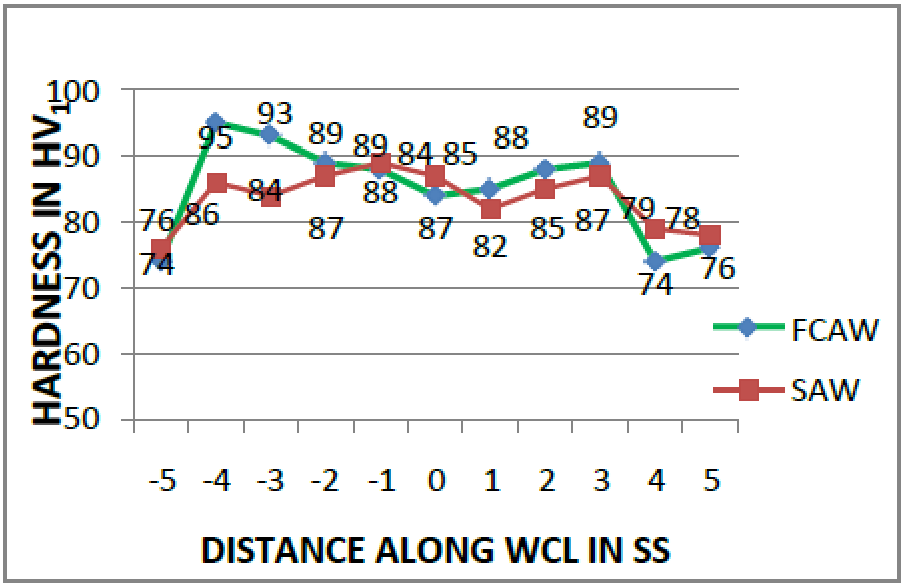

Figure 12 Hardness Testing results along S-S

It was observed from figure 12 that the hardness value of FCAW was on higher side as compare to saw welding across the weldment at S-S axis, in case of FCAW the maximum value was observed 95 BHN and in SAW it was observed maximum 89 BHN

As result from above observation it was clear that the hardness value flux cored arc welding is more as compare to submerged arc welding coupon, in all axis as a result submerged arc welding is more ductile as compare to flux cored arc welding.

CONCLUSION

In the present study following conclusions have been drawn:

- It is observed that In the case of multipass welding of heavy thickness carbon steel plate submerged arc welding show the lower value of hardness as compare to flux cored arc welding as result due to low hardness value the joint is more efficient rather than FCAW.
- In multipass welding it is observed that the distortion is high in the case of flux cored arc welding with 12 mm and 4mm distortion in the case of submerged arc welding
- It is observed from the Relatively study of macrostructure of flux cored are welding and submerged arc welding, SAW welded joint show deep penetration into the base metal
- Corresponding to different it was found that submerged arc welding is the best method to enhance the mechanical properties of the butt welded joints.

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