Analysing the Effect of Parameters in Multipass Submerged arc Welding Process

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***Abstract* – 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 process provide a purer and cleaner high volume weldment that has a relatively a higher material deposition rate compared to the traditional welding welding methods. The effect of controllable process variables on the heat input and the microhardness of weld metal and heat affected zone (HAZ) for bead on joint welding were calculated and analysed using design of experiment software and fractional factorial technique developed for the multipass SAW of boiler and pressure vessel plates. The main purpose of present work is to investigate and correlated the relationship between various parameters and microhardness and microhardness of single "V" butt joint and predicting weld bead qualities before applying to the actual joining of metal by welding. It is found that the microhardness of weld metal and heat affected zone decreased when the number of passes increases that is total heat input increased.**

Keywords – Design expert tool, microhardness of weld metal and HAZ, microstructure, *Submerged arc welding*

I. INTRODUCTION

Boiler and pressure vessel plate SA- 516 grade 70 have been widely used in Boilers and pressure vessels, boats, bridges, wind turbine towers, oil and gas pipelines. Boiler and pressure vessel plate are the most important structural materials for construction because of their high strength and toughness and relatively low cost. Welding is the most reliable, efficient and practical metal joining process which is widely used in industries such as nuclear, aerospace, automobile, transportation, and off-shore[1, 2]. Submerged arc welding (SAW) is a high quality; high deposition rate provided a purer and high volume weldment. Use of this technology has huge economic and social implications in the national perspective. It is observed that a refined microstructure of HAZ imparts largely the intended properties of the welded joints [1, 3] . In submerged arc welding process, parameters are current, arc voltage, travel speed and nozzle to plate distance. They all affect the microstructure and mechanical property of the welded joints. A Mechanical properties of hardness, tensile strength and toughness in arc welded mild steel plates were found to be higher in the heat affected zone and reduce to the base metal value under all the welding conditions. Impact of initial metal preheat on mechanical properties diminishes with increased temperature in the heat affected zone. Microstructures of preheated specimens differ from the no preheat specimen, showing traces of precipitation of bainite [4]. Studied that increased in heat input the percentage of graphitic phase was slightly decreased whereas the percentage of ferrite sharply increased and finally the ferrite structures were observed. The proportionate value of microhardness was observed for low heat input where as for increased heat input variations in hardness value was observed. [5]. The influence of the submerged arc welding (SAW) process parameter on the microstructure, hardness, and toughness of HSLA steel weld joints. The average hardness of both weld metal and HAZ decreased with increased in heat input. HAZ showed higher hardness than the weld metal. Toughness was found higher at low welding speed compared to that at high speed for a given welding current [6]. In multilayer welds partial or complete re-crystallization of weld metal occurs depending upon the heat input, bead dimensions and time interval between successive deposition with the exception of final layer the structure is refined with corresponding improvement in ductility and toughness [7,8]. This paper presents the experimental results of micohardness and effect of various process parameters on microhardness at different heat input. With a view to achieving the above mentioned aim design of experiment based on fractional factorial were used to reduce the cost and time as well as to obtain the required information about the main and interaction effects of the process parameters on microhardness of weld metal and heat affected zone in multipass submerged arc welding process.

II. EXPERIMENTAL WORK

The material of plate selected for the present work is SA-516 grade 70 i.e. boiler and pressure vessel plate. Typical chemical composition of the plates used in the experiments work is given in the table 1. Two plate of size 300*75*12 which would form a single V- groove joint with the help of shaper machine. The two plates are tacked with root pass in TIG welding before commencing welding with a uniform gap 2.4 mm between the plates as is ASME SECTION IX-guide QW 402.1.10 in industrial practice [9]. The welding process selected for present experimental work was submerged arc welding (SAW). Thermocouples (K-type) were used to measure the transient temperature distribution during welding. The thermocouples were fixed in the equal distance from the weld center line. The dimensional details of plates and position of thermocouple were fixed are shown in Fig. 1. The temperature distributions during experimentation were recorded by temperature meter. Multipass welding was carried out at 'KERC' Submerged Arc Welding equipment, type ASA-I, has been used with a power source WR-1200-H. The electrode wire used for the welding was Auto melt Grade - A of 3.15 mm diameter conforming to AWS SFA 5.17, EL-08. An agglomerate flux and crushed slag is used in this investigation. The specification of flux used for welding is AWS 5.17 OK FLUX 10.71 L, F7AZ - EL 8 [7]. The interpass temperature was considered for experimental work is the 150^0C from ASME-IX 5.17. During multipass welding, temperature is measured as a function of time, by thermocouple for different points. These readings of temperature are useful to draw temperature distribution. Temperature distribution plays important role for finding the distortions and total heat input effect on microhardness and microstructure. The temperatures measured at 3 minute at welding started. Care was taken to ensure thermocouple connections were not disturbed during flux removal. The duration of welding was noted down for each passes.

Table I: Chemical Composition Of Plate

Element	**C**	**Mn**	**S**	**P**	**Si**	**ferrous**
%	0.20	0.75	0.035	0.035	0.016	Rest.

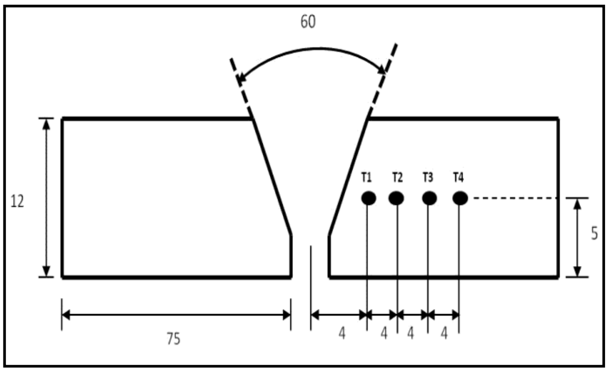


Fig. 1: Plate dimension and thermocouple position

III. PLAN OF INVESTIGATION

1. Identification of process parameters
2. Finding the limits of the process parameters
3. Developing the design matrix
4. Conducting the experiments
5. Developing the mathematical model
6. Recording the response i.e. microhardness
7. Checking the adequacy of the model
8. Optimization of the process parameters and responses

The research work was to be carried out in the following steps [1,12].

1. *Identification of process parameters and finding their limits*

The independently controllable process parameters affecting the microhardness were identified to enable the carrying out of experimental work and these are arc voltage (V), welding current (I), welding speed (S), and nozzle to plate distance (N). trial runs were carried out by varying one of the process parameters while keeping the rest constant values.[v murgan 8 reference]. The working range was decided upon by inspecting the bead for smooth appearance without any visible defects. The upper limits of factors was coded as + 1 and lower limit as – 1 or simply (+) and (-).

$$\mathrm{Xj} = \frac{\mathrm{Xjn} - \mathrm{Xjo}}{\mathrm{Jj}}$$

Where, X_j, X_{jn} and X_{jo} are coded, natural and basic value of the parameters respectively. Jj and j are the variation and number of parameters respectively.

TABLE 2 : WELDING PROCESS PARAMETERS

Parameters	Units	Notations	Lower limits	Higher limits
Welding current	Amp	I	300	350
Arc voltage	Volts	V	30	38
Welding speed	mm/min	S	256	550
Nozzle to plate distance	mm	N	18	22

2. *Developing the design matrix*

The selected design matrix, shown in Table, is a two-level, four-factor, 2^{4-1} fractional factorial design consisting of two sets of coded conditions. It comprises a full replication of 8 fractional factorial design points and eight star points. All welding variables at their combinations of each of the welding variables at either it's lowest (– 1) or highest (+1), with the other three variables. Thus the 16 experimental runs allowed estimation of the linear, and two-way interactive effects of the welding variables on the microhardness of weld bead and HAZ.

Table

S. No.	I	V	S	N	Heat input (HI/ pass) KJ/mm	No. of passes	Total heat input KJ/mm	Microhardness of weld metal (VHN)	Microhardness of HAZ (VHN)
1	+	+	+	+	2.281	2	4.576	201	240
2	-	+	+	-	2.669	2	5.338 **M**	206	232
3	+	-	+	-	2.891	2	5.696	202	226
4	-	-	+	+	3.381	1	3.381 **L**	227	235
5	+	+	-	-	0.981	6	5.886 **H**	163	180
6	-	+	-	+	1.145	5	5.725	159	175
7	+	-	-	+	1.243	4	4.972	184	209
8	-	-	-	-	1.412	4	5.648	193	217
9	+	+	+	+	2.281	2	4.576	207	236
10	-	+	+	-	2.669	2	5.338	209	234
11	+	-	+	-	2.891	2	5.696	200	228
12	-	-	+	+	3.381	1	3.381	232	242
13	+	+	-	-	0.981	6	5.886	170	186
14	-	+	-	+	1.145	5	5.725	160	177
15	+	-	-	+	1.243	4	4.972	182	207
16	-	-	-	-	1.412	4	5.648	194	215

3. *Conducting the experiments*

The experiments were conducted as per design matrix at random to avoid systematic errors in system. Weld beads were deposited on the 12 mm thick SA- 516 grade 70 boiler and pressure vessel plates explained previously.

4. *Recording the responses*

After welding, transverse section of the welded plates were cut at the centre of bead to obtain 12 mm wide test specimens. These specimens are prepared by standard metallurgical polishing methods. After applying the 1000 to 2500 grades of sand paper the micro hardness is carried out in metallurgy lab, SLIET Longowal. The etching procedure for steel was employed to identifying the microstructure and microhardness of weld metal and HAZ. For etching the electrolytic 3 % nital etch was used with the conditions. Electrolyte used nital solution is HNO_3 (3 ml) + ethanol (97 ml), cell voltage- 6V, etiching time - 1 min. The readings of microhardness of the pieces are studied by the Vicker hardness machine, under the load 500gm with a dwell time of the 20 seconds. There were 2 point in weld and HAZ where microhardness is tested and value given in the table.

5. *Development of mathematical model*

The response function representing any of the weld bead dimensions could be expressed as y=f(I,V,S,N).Assuming a linear relationship in the first instant and taking into account all the possible two factor interactions only, the above expression could be written as [12]

$$Y = b_0 + b_1 I + b_2 V + b_3 S + b_4 N + b_{12} IV + b_{13} IS + b_{14} IN + b_{23} VS + b_{24} VN + b_{34} SN \quad (1)$$

After confounding the model can be rewritten as

$$Y = b_0 + b_1 I + b_2 V + b_3 S + b_4 N + b_{12}(IV) + b_{13}(IS) + b_{14}(IN) \quad (2)$$

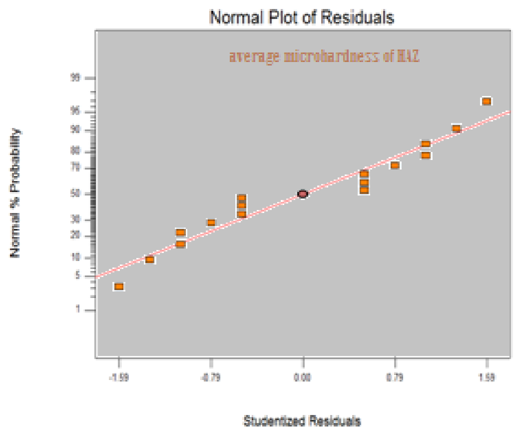
6. *Checking the adequacy of the models*

The adequacy of the model was then tested by the analysis of the variance technique (ANOVA) [1,3].

1- If the calculated value of the models F- ratio does not exceed its tabulated value for a desired level of confidence as 95%.

2- If the calculated value of the model's R- ratio exceeds its standard tabulated value for a desired level of confidence as 95%. Then the models are adequate.

It is evident that for all models the above conditions were satisfied, and hence adequate.



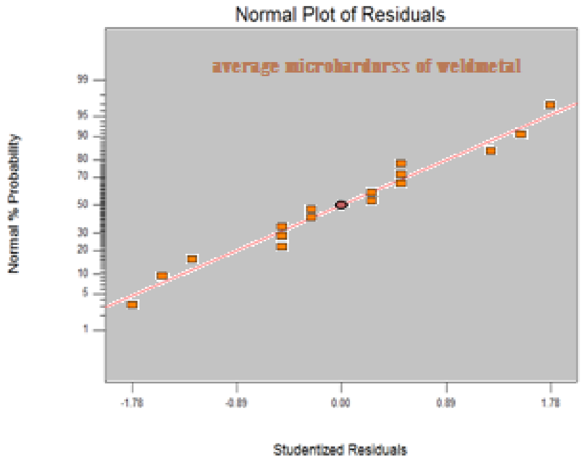


Fig. 2: Normal probability and residuals

7. *Testing the significance of the coefficients and development of final mathematical models*

The final mathematical models follow the process control variables are their coded and actual form. Significance of the coefficients was tested using the DEGINE EXPERT-6 software. The software used to eliminate insignificant coefficients and reduced models with significant coefficients were developed.

microhardness of weld metal

Final equation in term of coded factors

$$Y = 193.13 + 4.50\, I + 8.63\, V - 17.63\, S + 5.25\, IV - 3.75\, IS \quad (3)$$

Final equation in term of actual factors

$$Y = 1107.27 - 2.879\, I - 14.90\, V + 0.198\, S + 0.052\, IV - 9.55\, IS \quad (4)$$

Microhardness of HAZ

Final equation in term of coded factors

$$Y = 219 + 3.63\, I + 5.88\, V - 18.75\, S + 2.75\, IV + 1.62\, IS \quad (5)$$

Final equation in term of actual factors

$$Y = 1929.37 - 5.30\, I - 7.46\, V - 0.253\, S + 0.0275\, IV + 4.14\, IS \quad (6)$$

8. *Conducting the conformity test*

Validity of the developed models was further tested by drawing scatter diagrams that show the observed and predicted value of weldmetal and HAZ microhardness. A representative scatter diagram is shown in fig. Responses were measured and presented in table. The results show the models accuracy was above 97%.

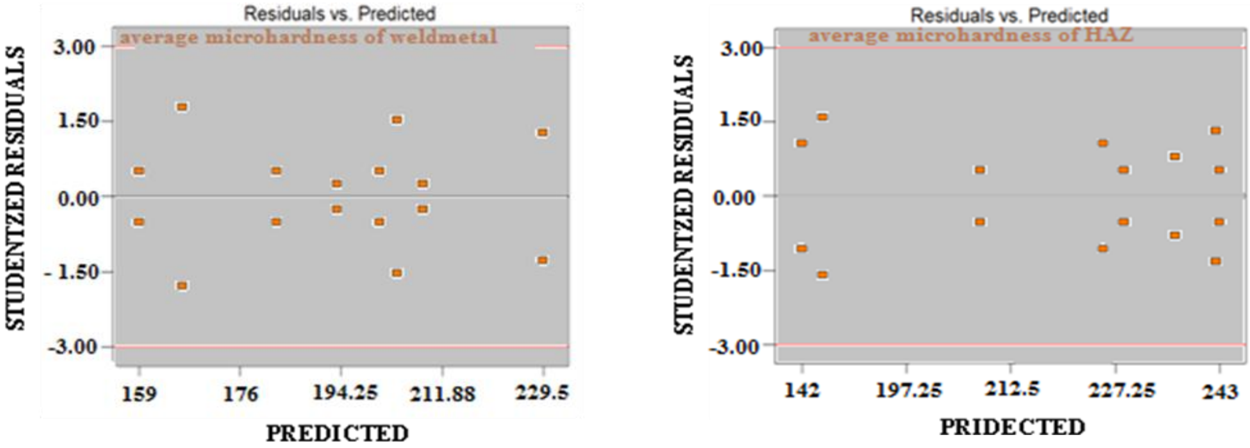


Fig. 3

ANOVA Table for Response 1 and Model summary statistics (microhardness of weld metal)

Source	S. S.	D.F. freedom (df)	M.S.	F-value	P-value Prob>F	Remarks	Std. Dev.	2.81
Model	7422.75	6	1237.13	156.82	< 0.0001	Significant	Mean	193.13
A-Current	324.00	1	324.00	41.07	< 0.0001	Significant	C.V. %	1.45
B-Voltage	1190.25	1	1190.25	150.88	< 0.0001	Significant	PRESS	224.40
C-Speed	4970.25	1	4970.25	630.03	< 0.0001	Significant	(R2)	0.9905
AB	441.00	1	441.00	55.90	< 0.0001	Significant	Adjusted (R2)	0.9842
AC	225.00	1	225.00	28.52	0.0005	Significant	Predicted	0.9701
AD	272.25	1	272.25	34.51	0.0002	Significant	Adequate	37.948
Residual	71.00	9	7.89					
Lack of Fit	9.00	1	9.00	1.16	0.3126	not significant		
Pure Error	62.00	8	7.75					
Cor Total	7493.75	15						

ANOVA Table for Response 2 and Model summary statistics for (microhardness of HAZ)

Source	S.S.	D.F.	M.S.	F-value	P-value Prob>F	Remarks	Std. Dev.	2.46
Model	8087.38	6	1347.90	222.33	< 0.0001	Significant	Mean	214.44
A-Current	210..25	1	210.25	25.92	0.0007	significant	C.V. %	1.15
B-Voltage	517.56	1	517.56	85.37	< 0.0001	Significant	PRESS	172.44
C-Speed	5587.56	1	5587.56	921.66	< 0.0001	Significant	(R^2)	0.9933
AB	175.56	1	175.56	28.96	0.0007	Significant	Adjusted (R^2)	0.9888
AC	42.25	1	42.25	5.21	0.0484	significant	Predicted (R^2)	0.9788
AD	1785.06	1	1785.06	294.44	0.0009	Significant	Adequate	40.833
Residual	54.56	9	6.06					
Lack of Fit	3.06	1	3.06	0.48	0.5099	not significant		
Pure Error	51.50	8	6.44					
Cor. total	8141.94							

SS= sum of squarer, DF= degree of freedom, MS= mean square

➢ *Effect of Current*

It is observed that when welding current is increased the microhardness is reduced. With an increase in welding current, there is a linear increase in heat input, due to increased heat input the reduction in average cooling rate in every pass. And reduction in heat input causes increase in microhardness value. Fig. describes the effect of welding current on the microhardness of weld and HAZ respectively when other parameters are constant.

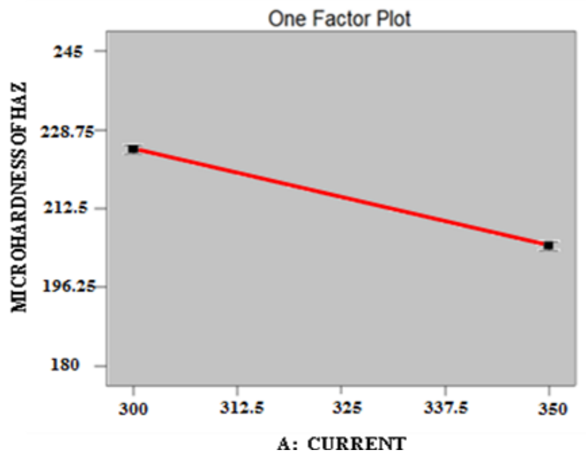
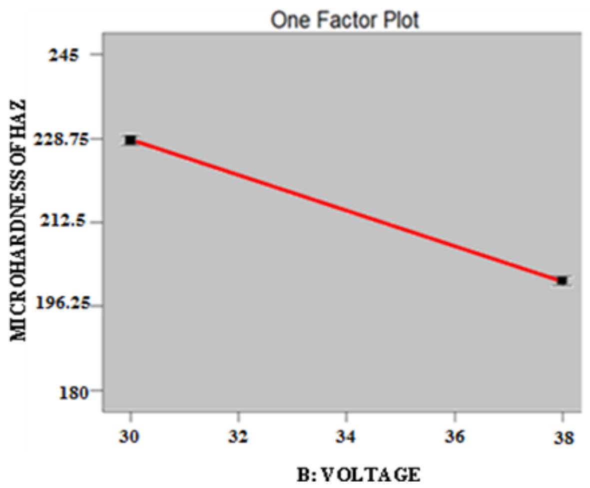


Fig. Effect of welding current on hardness of HAZ and weld metal (Voltage = 34V, welding speed = 393mm/min, NTPD = 20 mm)

➢ *Effect of Voltage*

Figure indicates that effect of open circuit voltage on microhardness of weld metal and HAZ respectively. It can be observed that microhardness decreases linearly with an increase in arc voltage from 30 to 38 volt. This decrease in microhardness with increase in voltage is due to when open circuit voltage is increased the heat input in multipass also increased and reduction in average cooling rate and increases number of passes in multipass causes increase in grain size as a result microhardness decreases.



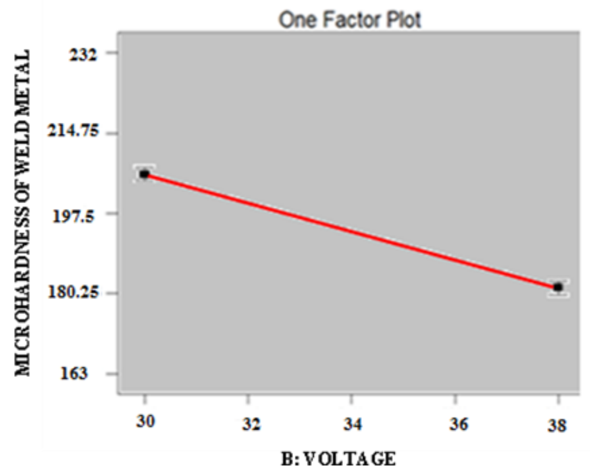
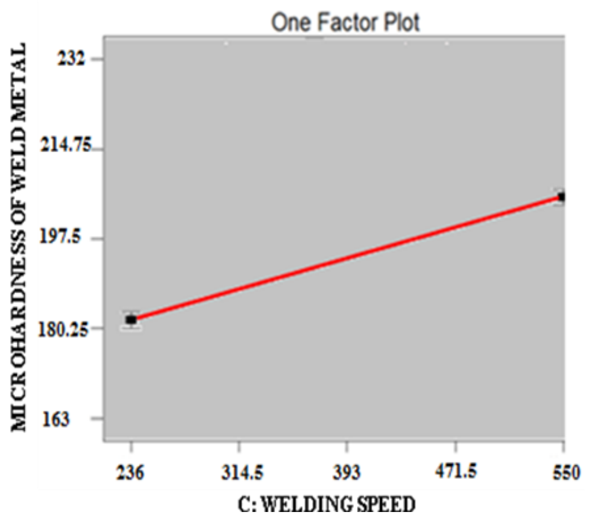


Fig. 4 : Effect of Arc voltage on hardness of HAZ and weld metal (welding current = 325 Amp, welding speed = 393 mm/min, NTPD = 20 mm)

➢ *Effect of welding speed*

It is observed from the figure that welding speed is directly proportional to the microhardness. With the increasing in welding speed from 236 mm/min to 550 mm/min the microhardness is also gradually increased. Because increasing in welding speed the heat input per pass as well as total heat input is reduced in multipass welding and average cooling rate is increased and due to this the hardness is increased.



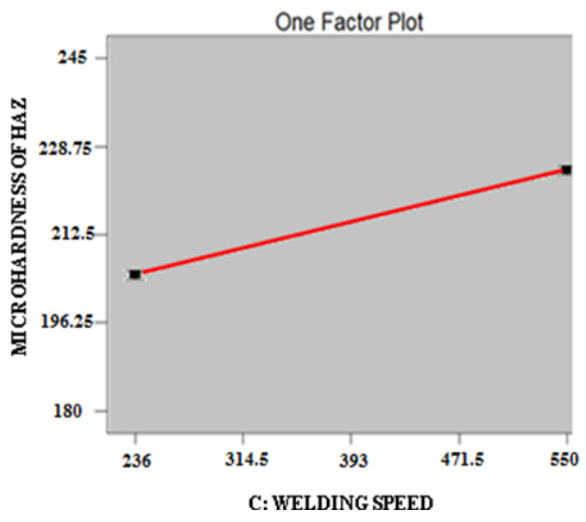


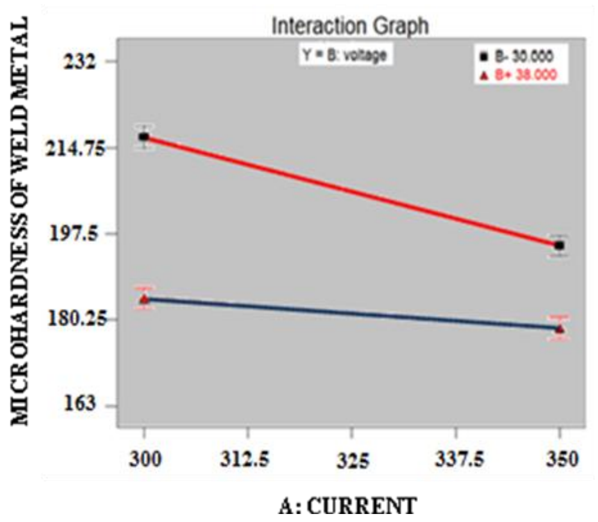
Fig.5 : Effect of welding speed on hardness HAZ and weld metal (welding current = 325 Amp, Voltage = 34 V, NTPD = 20 mm)

➢ *Interaction effect of parameters on Microhardness*

From the final mathematical models, it is noted the process variables have many interaction effect on the microhardness of weldmetal and HAZ but only a few select and important interaction effects are presented in graphical form for analysis.

➢ *Effect of Current and Voltage*

Fig shows the combined effect of welding current and open circuit voltage on microhardness of weld and HAZ. As shown in figure 5.28 reduction in microhardness is higher at the arc voltage 30 volt and reduction in microhardness is lower at arc voltage 38 volt for the current vary from 300 to 350 ampere. Micro hardness reduce from 216 VHN to 194 VHN in weld and from 240 VHN to 217 VHN in HAZ when welding current increase from lower to higher level and arc voltage at lower level. In the same way microhardness reduce from 184 VHN to 180 VHN in weld and from 209 VHN to 196 VHN in HAZ when current increase from lower to higher level and arc voltage is at higher level. Response surface due to interactive effect of welding current and voltage on hardness of weld and HAZ has been displayed in figure respectively.



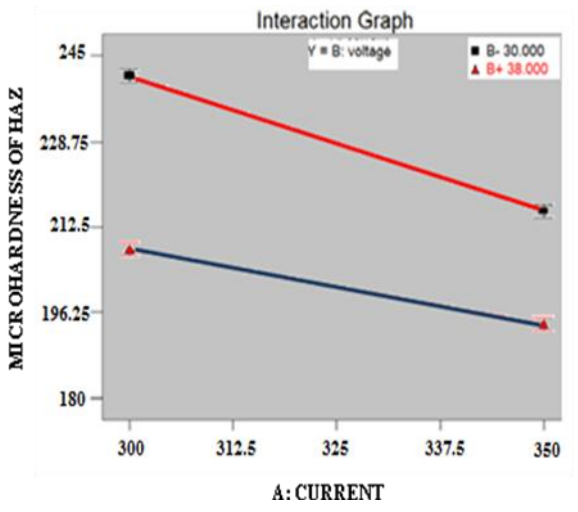
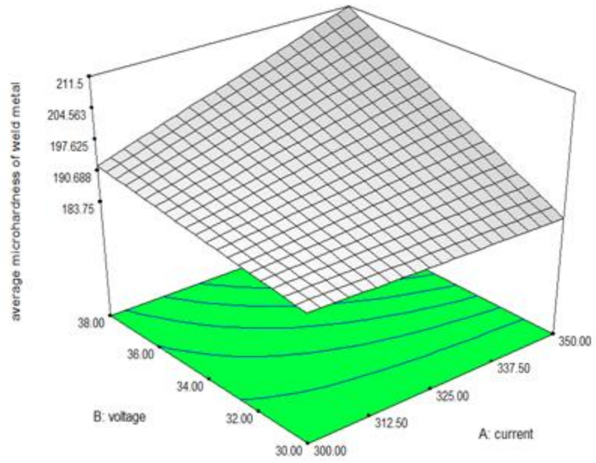
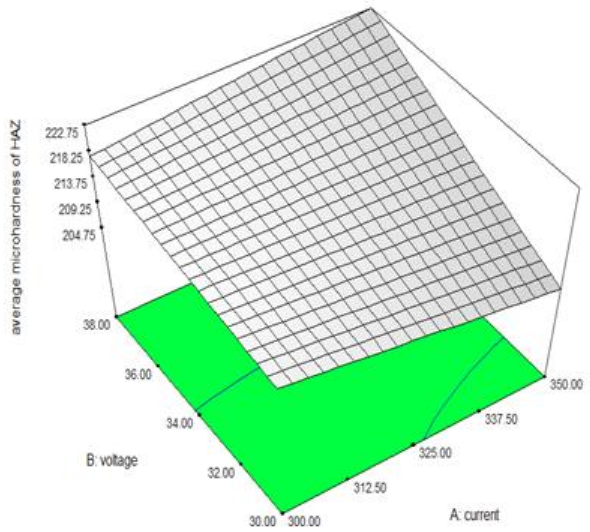
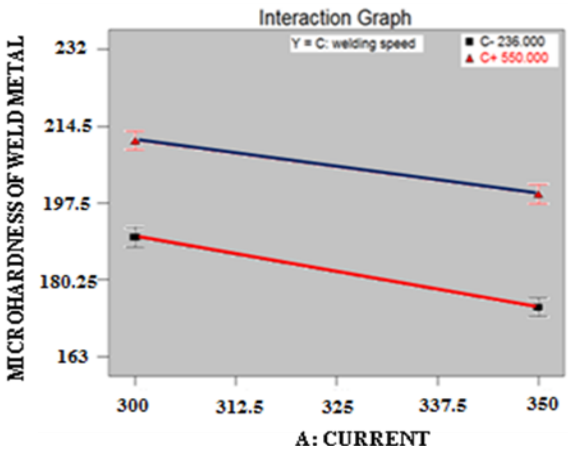


Fig. 6 : Interactive effect of welding current and open circuit voltage on hardness of weld metal and HAZ (welding speed = 393 mm/min, NTPD= 20 mm)







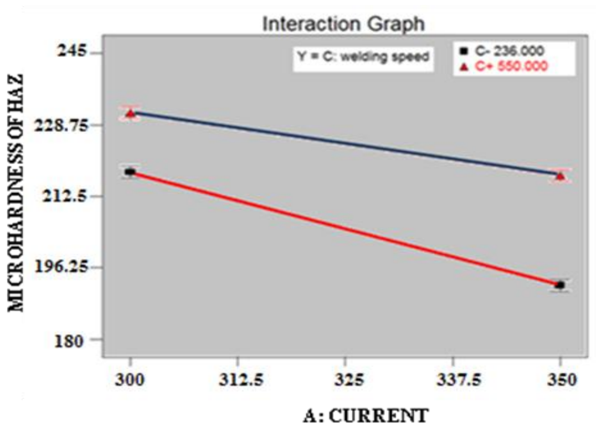
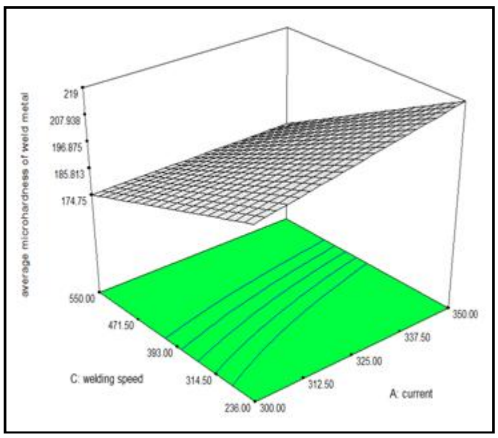


Fig.7 : Interactive effect of welding current and welding speed on hardness of weldmetal and HAZ (Voltage = 34 V, NTPD = 20 mm)

- *Effect of Current and Welding Speed*

Fig. show the combined effect of welding current and welding speed on microhardness of weld and HAZ. As shown in figure increased in microhardness is higher at the welding speed 236 mm/min and decreased in microhardness is very low at welding speed 550 mm/min for the current vary from 300 to 350 ampere. Micro hardness increased from 207 VHN to 219 VHN in weld and decreased from 235 VHN to 224 VHN in AZ when welding current increase from lower to higher level and welding speed at lower level. In the same way microhardness increase from 174 VHN to 177 VHN in weld and decreased from 204 VHN to 195 VHN in HAZ when current increase from lower to higher level and welding speed is at higher level. Response surface due to interactive effect of welding Current and welding speed on hardness of weld and HAZ has been displayed in figures.



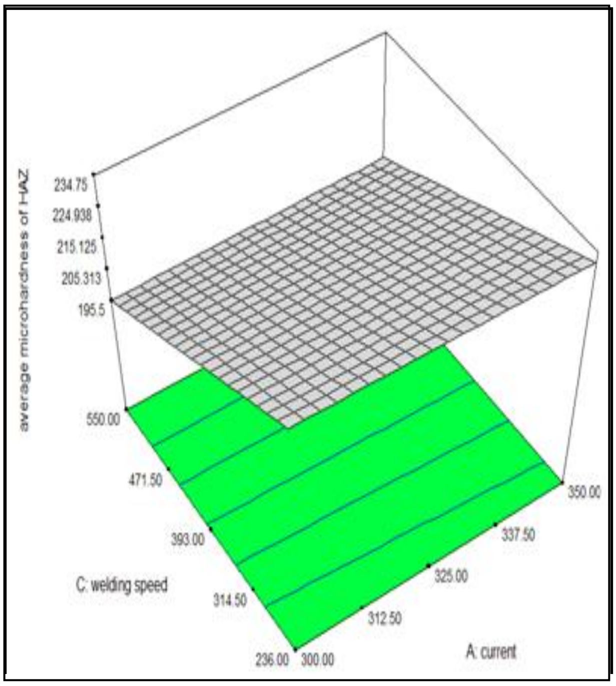
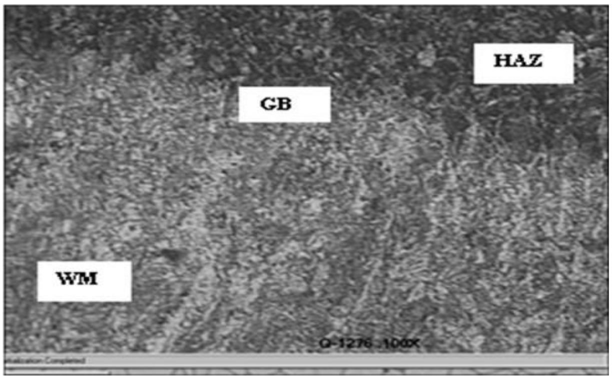


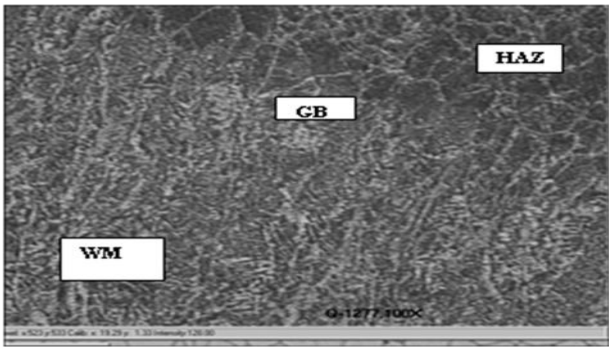
Fig. 8

- *Microstructure*

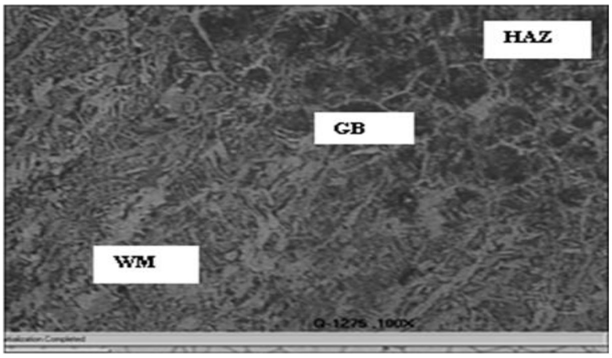
The effect of multipass welding on the microstructure of the weld metal was that grain size increased at the reheated portion of the weld metal. In the multilayer welds, the thermal effect of upper runs had a tendency to normalize the structure of those previously solidified, leading to a refinement of the structure and thus giving variation in the hardness values in these zones**.** At the number of passes increase, the total heat input increase, the grains HAZ are larger in size due to repeated heating and grain refinement as compared to the weldment having Medium and low heat input in multipass welding. The larger columnar grains are formed by high heat input as compared to medium and low heat input. . Microstructure shows columnar grains at weld bead and coarse grains of pearlite and ferrite at HAZ in low heat input. It can be observed that columnar grains coarsen with the increase of heat input. Each weld pass shows different orientation of the grains. Grains are mostly coarse and cellular near centreline of the bead. In multipass welding fusion zones of a weld of weld pass is replaced by HAZ of subsequent passes which is evident from the Primarily shows two phases namely ferrite (light etched) and pearlite (dark etched) and fine carbide particles are not visible at low magnification. Grain coarsening near the fusion boundary (in HAZ) results in coarse columnar grains in the weld metal.



(a) low heat input



(b) Medium heat input



(c) High heat input

Fig. 10

IV. RESULT AND DISCUSSION

- In the multipass welding process parameters are directly affect the number of passes and total heat input. The individual effect of current, voltage, speed on hardness of weld and HAZ is higher. It is observed that the hardness is higher in the HAZ than the weld metal. With increasing cooling rate, hardness increases by 4.29% in the weld metal and 3.33% in the HAZ at cooling rate 2.75^{0}C/sec and hardness increases by 2.20% in weld metal and 2.97% in the HAZ at cooling rate 6.15^0C/sec.

- The reduction in microhardness is higher at the arc voltage 30 volt and reduction in microhardness is lower at arc voltage 38 volt when the current vary from 300amp to 350amp. Microhardness reduces by 10.18% in weld and 9.5% in HAZ when welding current increase from 300 Amp to 350 Amp and arc voltage at 30 V. In the same way microhardness reduces 2.17% in weld and 6.22% in HAZ when current increase from 300 Amp to 350 Amp and arc voltage is at 38 V.
- The reduction in microhardness is lower at the 550 mm/min welding speed and increment in microhardness is higher at 236 mm/min welding speed for the current vary from 300 to 350 ampere. Micro hardness increase by 5.97% in weld and reduce 4.91% in HAZ, when welding current increase from 300 Amp to 350 Amp and welding speed at 236 mm/min. In the same way microhardness increases by 1.72% in weld and decreases 4.41% in HAZ when current increase from 300 Amp to 350 Amp and welding speed is at 550 mm/min.
- It is observed from multipass submerged arc welding more ferritic structures are observed for low heat input with more number of welding passes and rapid cooling rate whereas more graphite structure are observed at high heat input due less number of passes and slow cooling rate. Percentage of ferrite increases due to more refined grains as the number of passes is more at low heat input. Whereas for increasing heat input percentage of graphite and pearlite is decreased and ferrite increased which result better mechanical properties. The increases in ferrite phase due to change of temperature distribution the hardness of HAZ increase and weld metal hardness decreases.

V. REFERENCES

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[13] Heat input was low (3,381 KJ/mm) the maximum hardness value (270 VHN) at fusion boundary was observed as compared to the hardness (186) achieved by high heat input (5.886 KJ/mm).

[14] It is observed that the hardness is higher in the HAZ than the weld metal. With increasing cooling rate, hardness increases by 4.29% in the weld metal and 3.33% in the HAZ at cooling rate 2.750C/sec and hardness increases by 2.20% in weld metal and 2.97% in the HAZ at cooling rate 6.150C/sec.

[15] It is observed from the multipass welding that the number of passes increases, the total input increases from 3.381KJ/mm to 5.886 KJ/mm as well as the distortion increased 5 mm to 13mm.The distortion is higher at high heat input and the total distortion increases by 61.53% and 7.69 times.

[16] In multipass welding fusion zones of a weld of weld pass is replaced by HAZ of subsequent passes which is evident from the micrographs. Primarily shows two phases namely ferrite (light etched) and pearlite (dark etched) and fine carbide particles are not visible at low magnification. Grain coarsening near the fusion boundary (in HAZ) results in coarse columnar grains in the weld metal. An increase in heat input increased the average size of different phase present in the weld metal and weld centre line shows columnar size structure. It is observed from multipass submerged arc welding more ferritic structures are observed for low heat input with more number of welding passes and rapid cooling rate whereas more graphite structure are observed at high heat input due less number of passes and slow cooling rate. Percentage of ferrite increases due to more refined grains as the number of passes is more at low heat input. Whereas for increasing heat input percentage of graphite and pearlite is decreased and ferrite increased which result better mechanical properties. The increases in ferrite phase due to change of temperature distribution the hardness of HAZ increase and weld metal hardness decreases.

[17] It is also observed by macrostructure at “10X” that the weld bead width formed by the high total heat input (5.886 KJ/mm) is bigger than the weld bead width formed by the low total heat input (3.381 KJ/mm) and width of HAZ is also increased by increasing, the number of passes and heat input in multipass welding.

[18] Knowledge of maximum temperature rise will be useful in the estimation of maximum temperature attained by different region of the base plate during multipass welding. Likely change in the microstructure and consequently degradation in mechanical property can be estimated from the information.

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