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Effect of Welding Process Parameters on Micro hardness and Microstructure

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Abstract—In this paper, the effect of welding process ***parameters of Gas Metal Arc Welding (GMAW) onvickersmicrohardness andmicrostructureare found out. The GMAW process is an important in many industrial operation. Experiments have been conducted as per central composite design matrix to find the effect of process control parameters: voltage, wire feed rate, welding speed and gas flow rate onvicker'smicrohardness and microstructure. The vicker'smicrohardness of the welded joint is tested by Vicker'smicrohardness testing machine and measurements were conducted on base metal (BM), heat affected zone (HAZ), and weld metal (WM). MINITAB software is used to draw the direct and interactive graphs which shows the effect of welding input process parameters onvicker'smicrohardness.***

Keywords:GMAW, **Design matrix, Hardness, Microstructure, etc.**

INTRODUCTION

The present trend in the fabrication industries is the use of automated welding processes to obtain high production rates and high precision. To automate a welding process it is essential to establish the relationship between process parameters and weld bead geometry to predict and control weld bead quality. The MIG welding process is easily found in any industry whose products require metal joining in a large scale. It establishes an electric arc between a continuous filler metal electrode and the weld pool, with shielding from an externally supplied gas, which may be an inert gas, an active gas or a mixture. The heat of the arc melts the surface of the base metal and the end of the electrode. The electrode molten metal is transferred through the arc to the work where it becomes the deposited welds metal (weld bead). MIG is a welding process which joins metals by heating the metals to their melting point with an electric arc. The arc is between a continuous, consumable electrode wire and the metal being welded. The arc is shielded from contaminants in the atmosphere by a shielding gas.

Generally, the quality of a weld joint is directly influenced by the welding input parameters during the welding process; therefore, welding can be considered as a multi-input multi-output process. Unfortunately, a common problem that has faced the manufacturer is the control of the process input parameters to obtain a good welded joint with the required bead geometry and weld quality with minimal detrimental residual stresses and distortion.

2. EXPERIMENTATION

The following machines setup and consumable wire electrodes used for the purpose of conducting experiment.

1) A constant current gas metal arc welding machine (3 Phase, 50Hz frequency, 300A, forced air cooling machine)

2) Welding manipulator

3) Wire feeder

4) Filler material Stainless Steel wire of 1.2mm diameter (309L).

5) Gas cylinder containing a mixture of 98% argon and 2% of oxygen.

6) Stainless steel plates (grade 3Cr12)

Test plates of size 125 x 100 x 10mm were cut from stainless steel plate of grade 3Cr12 and one of the surfaces is cleaned to remove oxide and dirt before welding. 309L stainless steel wire of 1.2mm diameter was used for depositing the clad beads through the feeder. Argon gas was used for shielding.The properties of base metal and filler wire are shown in Table 1.The selection of the welding electrode wire based on the matching the mechanical properties and physical characteristics of the base metal, weld size and existing electrode inventory.A candidate material for cladding which has excellent corrosion resistance and weld ability is stainless steel.These have chloride stress corrosion cracking resistance and strength significantly greater than othermaterials.These have good surface appearance, good radiographic standard quality and minimum electrode wastage.

Table1.properties of base metal and filler wire

Elements, Weight %									
Materials	C	Si	Mn	P	S	Mo	Cr	Cu	Ni
SS 3Cr12	0.014	0.580	0.907	0.012	0.009	0.043	10.625	0.069	0.794
ER309L	0.03	0.5	1.75	0.03	0.03	0.75	24	-	13

3. PLAN OF INVESTIGATION

3.1. Identification of Factors and Responses

The basic difference between welding and cladding is the percentage of dilution. The properties of the cladding is the significantly influenced by dilution obtained. Hence control of dilution is important in cladding where a low dilution is highly desirable. When dilution is quite low, the final deposit composition will be closer to that of filler material and hence corrosion resistant properties of cladding will be greatly improved. The chosen factors have been selected on the basis to get minimal d0ilution and optimal clad bead geometry. These are wire feed rate (W), welding speed (S), Gas flow rate contact tip to work to The following independently controllable process parameters were found to be affecting output parameters distance (N) and pinch (Ac), the responses chosen were clad bead width (W), height of reinforcement (R), Depth of Penetration. (P) and percentage of dilution (D). The responses were chosen based on the impact of parameters on final composite model.

3.2. Finding the limits of process variables

Working ranges of all selected factors are fixed by conducting trial run. This was carried out by varying one of factors while keeping the rest of them as constant values. Working range of each process parameters was decided upon by inspecting the bead for smooth appearance without any visible defects. The upper limit of given factor was coded as 2 and lower -2. The coded value of intermediate values were calculated using the equation

$$\mathrm{Xi} = \frac{2(2\mathrm{x} - (\mathrm{Xmax} + \mathrm{Xmin}))}{(\mathrm{Xmax} - \mathrm{Xmin})} \qquad (1)$$

Where Xi is the required coded value of parameter, X is any value of parameter from Xmin – Xmax. Xmin is the lower limit of parameters and X is the upper limit parameters. The levels of the individual process parameters are given in Table 2.

Table 2 Process parameters and their values

Process parameters	Notation	Limits				
		-2	-1	0	+1	+2
Welding voltage (V)	V	28	30	32	34	36
Wire feed rate (F) (mm/min)	F	1.5	1.75	2.0	2.25	2.5
Welding speed (S) (mm/min)	S	65	70	75	80	85
Gas flow rate (G) (lit/min)	G	14	15	16	17	18

3.3Development of design matrix

Selection of design matrix is very important for conducting the experiments. The various design matrixes are used for conducting the experiments. Depending on the number of input process parameters and number of levels in welding process, design matrix is selected. This matrix consists of fraction point, star point and centre points. In this work, the four process parameters of GMAW process each at five levels have been decided for welding AISI 3Cr12 grade steel. These are very important controllable process parameters which will effects on weld bead and good appearance of weld bead. It is desirable to have five minimum levels of process parameters to reflect the true behaviour of response parameters. The working ranges of the parameter are chosen by rough trials for a smooth appearance of weld bead.

The central composite design matrix for conducting the experiments consist of 28 sets of trials. This design matrix depend on number of input process (k) and comprises of four Centre points (equal to number of input process parameters) and eight star points (twice the number of input process parameters) and sixteen factorial designs (2K), where 2 is the number of levels. The first 16 rows correspond to factorial portion, the row from 17 to 24 correspond to star point's position and last 4 rows from 25 to 28 correspond to centre point's position. Hence, final experimental design consist of 28 (i.e.16+08+04= 28) trial and given in table 3.

3.4Conducting experiments as per design matrix

In this work Twenty eight experimental run were allowed for the estimation of linear quadratic and two-way interactive effects of correspond each treatment combination of parameters on bead geometry as shown Table 3 at random. At each run settings for all parameters were disturbed and reset for next deposit. This is very essential to introduce variability caused by errors in experimental set up.

3.5 Recording of Responses

After the completion of 28 trials each response parameter is measured by using digital vernier calliper thrice and mean is calculated for each response parameter. These results are tabulated in table 3.

Table 3.Experimental results

Expt. No.	Design matrix							
	Coded form				Uncoded form			
	F	S	V	G	F	S	V	G
1	-1	-1	-1	-1	1.75	70	30	15
2	-1	-1	-1	1	1.75	70	30	17
3	-1	-1	1	-1	1.75	70	34	15
4	-1	-1	1	1	1.75	70	34	17
5	-1	1	-1	-1	1.75	80	30	15
6	-1	1	-1	1	1.75	80	30	17
7	-1	1	1	-1	1.75	80	34	15
8	-1	1	1	1	1.75	80	34	17
9	1	-1	-1	-1	2.25	70	30	15
10	1	-1	-1	1	2.25	70	30	17
11	1	-1	1	-1	2.25	70	34	15
12	1	-1	1	1	2.25	70	34	17
13	1	1	-1	-1	2.25	80	30	15
14	1	1	-1	1	2.25	80	30	17
15	1	1	1	-1	2.25	80	34	15
16	1	1	1	1	2.25	80	34	17
17	-2	0	0	0	1.5	75	32	16
18	2	0	0	0	2.5	75	32	16
19	0	-2	0	0	2	65	32	16
20	0	2	0	0	2	85	32	16
21	0	0	-2	0	2	75	28	16
22	0	0	2	0	2	75	36	16

23	0	0	0	-2	2	75	32	14
24	0	0	0	2	2	75	32	18
25	0	0	0	0	2	75	32	16
26	0	0	0	0	2	75	32	16
27	0	0	0	0	2	75	32	16
28	0	0	0	0	2	75	32	16

4. EXPERIMENTAL RESULTS

4.1Vicker's micro hardness measurement

.Vicker's hardness tester with diamond pyramid as per ASTM E384 standardwas used to measure the hardness.. Measurements were conducted on base metal (BM), heat affected zone (HAZ), weld metal (WM). The hardness across the weld cross-section has been measured using Vicker's micro-hardness testing machine and the values are presented in Table 4. Peak hardness was found in the HAZ in all the weld joints. The microhardness (VHN) tests were performed on the etched transverse cross-section of the welded zone using a load of 1 kg, which was applied for a duration of 20 s. Three measurements in each welded zone were taken at regular intervals and the average hardness values are presented in Table 4. The test was carried out to all specimens in air at room temperature.

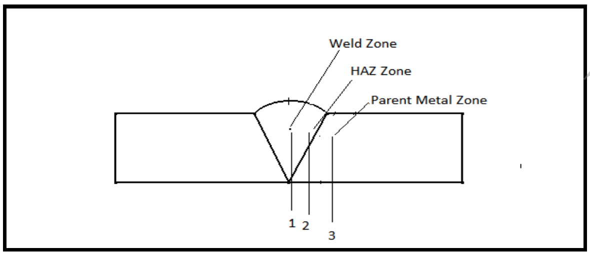


Fig. 1Location of Vickers hardness measurement

4.2 Measurement of microstructure

The multipass welded samples are cut and flatted by 220 and 320 grid silicon carbide emery papers and ground successively using finer grades of 500 to 1200 grids. It is then washed, cleaned by alcohol and dried. The etchant used is 10% oxalic acid to reveal the microstructure and observed by optical microscope at a magnification of 200X. The microstructure examination is carried out at cross section of the weldment as per ASTM E407 standard at the base metal, weld zone and HAZ regions.

Table 4. Vicker'smicrohardness values across different locations of Weld joint

Sample No.	PM	HAZ	WELD	Average values of VHR
1	180	236	204	206
2	185	223	207	205
3	178	232	203	204
4	180	235	207	207
5	187	230	201	206
6	181	226	204	203
7	185	229	205	206
8	178	237	207	207
9	175	234	200	203
10	184	232	208	208
11	189	221	198	202
12	190	227	205	207
13	175	224	203	200
14	179	234	206	206
15	180	232	210	207
16	182	230	210	207
17	172	240	208	206
18	179	231	206	205
19	182	237	205	208
20	187	236	207	210
21	180	229	213	207
22	169	226	210	201
23	175	222	208	201
24	180	230	210	206
25	178	232	202	204
26	179	230	207	205

27	180	223	213	205
28	182	229	215	208

5. RESULT AND CONCLUSION

The effect of the four input process parameter on the responses of is plotted. The effect of individual welding parameters and their Signification interaction on allVicker's hardness (VHR)the are calculated quantitatively and analyzed.

5.1 Direct effect of process parameters on responses

5.1.1 Effects of process parameters on Vicker's hardness (VHR)

From fig. 2, it is observed that increase in G and S the VHR increases whereas decreases with increases in F and V. The Hardness in weld zone and HAZ is due to over precipitation and increased carbon precipitation amount. If hardness exceeds, the weld strength is high and ductility is very low. The hardness decreases at a distance away from HAZ.

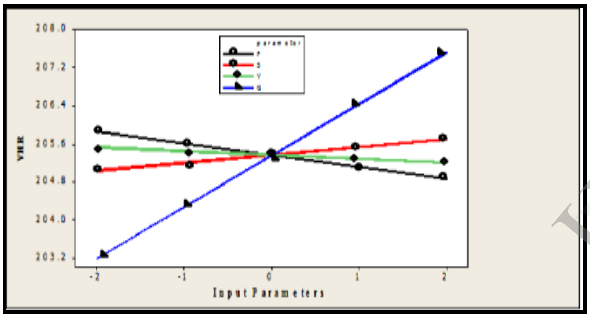


Fig. 2Effects of process parameters on Vicker'shardness

5.2 Interaction effects of process parameters on responses

5.2.1Interaction effect on wire feed rate and gas flow rate on vicker's hardness

Fig. 3 shows the interaction effect of F and G onVHR. It is cleared from figure that the VHR decreases with decrease in G for zero levels of F. And VHR decreases with decrease in F for zero level of G.The hardness decreases at a distance away from HAZ.

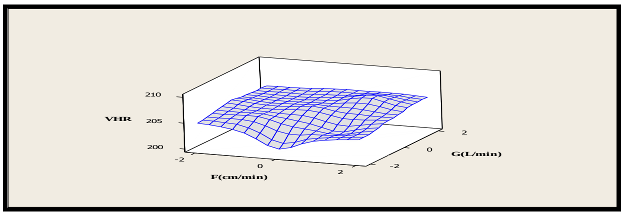


Fig.3 Interaction surface plot of VHR vs. F,G

5.2.2 Interaction effect on wire feed rate and welding speed on vicker's micro hardness

Fig. 4 shows the interaction effect of F and G on VHR. It is cleared from figure that the VHR increases with increase in S for zero levels of F. And VHR increases with increase in F for zero level of S.The hardness decreases at a distance away from HAZ.

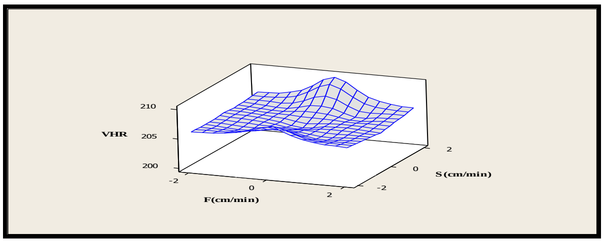


Fig. 4 Interaction surface plot of VHR vs. F,S

5.2.3 Interaction effect on wire feed rate and voltage on vicker'smicrohardness.

Fig. 5 shows the interaction effect of F and V on VHR. It is cleared from figure that the VHR increases with increase in S for zero levels of F. And VHR increases with increase in F for zero level of V.The hardness decreases at a distance away from HAZ.

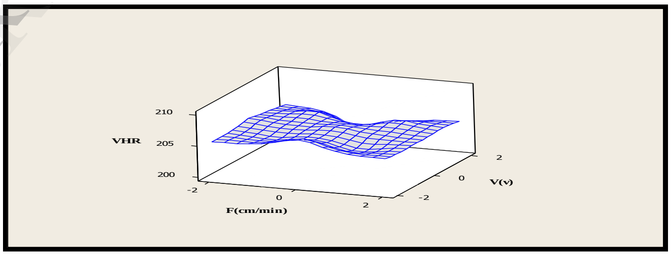
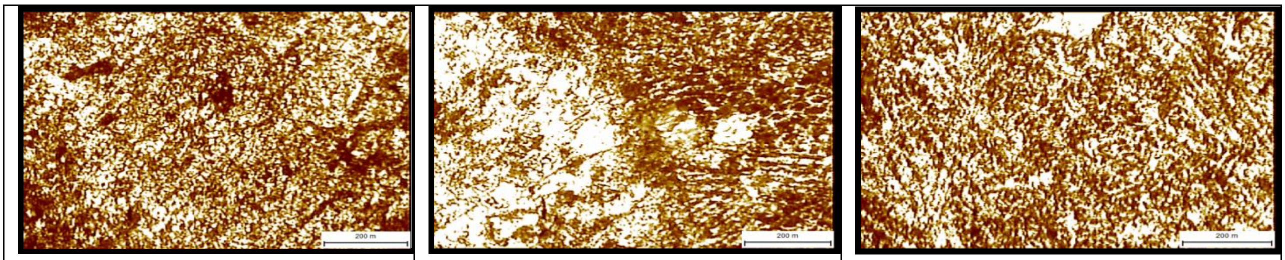


Fig. 5 Interaction surface plot of VHR vs. F,V

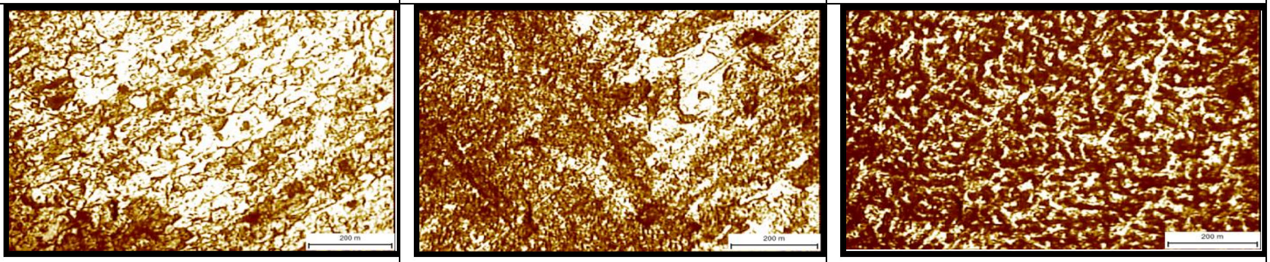
5.3 Effect of process parameters on microstructure

The observations of microstructure of three distinct regions such as 1) Base metal 2) Heat affected zone 3) Welded zone were carried out in the following manner.

Microstructure of base metal shows the two phases namely ferrite (light etched) and pearlite (dark etched). The average size of grains in this region is nearly 18 micron. The reduction in the size of the both pearlite and ferrite phases can be seen in HAZ.



Sample 1 Parent metals | Sample 1 Heat affected zone | Sample 1welded zone



Sample 17 Parent metals | Sample 17 Heat affected zone | Sample 17 welded zone

Fig.6 Microstructure of welded sample at different zone

HAZ showed the average grain size 11 micron. Grain coarsened zone showed significant coarsening of phases. Pearlite 60% and ferrite 45% are present near the fusion boundary area in HAZ. Acicular ferrite is mainly present along the grain boundary of pearlite in welded zone. Pearlite grains near the fusion boundary in the weld metal are very coarse (140 micron) compared to that of ferrite (30 microns). The volume fractions of acicular ferrite was from the obtained by optical microscopy at x 200 magnification. The weld metal microstructure basically consists of around 80% acicular ferrite. The volume fraction (percentage) of grain- boundary ferrite amounts to around 5-15% and the volume fraction of M-A constituent to around 5-10%.

6. CONCLUSIONS

The direct and interactive effects of process parameters on vicker's hardness of weldment shows that the selection of proper values of input parameters gives good weld bead geometry. The effect of welding Input process parameters such as welding voltage, wire feed rate, welding speed and gas flow rate influences on mechanical properties i.e. vicker'smicrohardness and microstructure shows in the above graph and fig 6. Minitab software is used for showing the proportionality between input parameters and vicker'smicrohardness values in the above graph and interaction effects of process parameters on responses also shows in above graph. It is clearly found that the microstructure of the above sample no.1 and sample no.17 shows the three different region of the weldments which is affected by the welding process parameters.

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