Application of RSM to Optimize MIG welding Process Parameters for Hardness

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Abstract – The present work is intended to optimize the existing MIG welding process parameters utilized by an industrial firm engaged in fabrication of generator set fuel tanks. The optimized process parameters will improve the overall weld quality by attaining desirable hardness of the fusion zone. Design of experiment based on Box Behnken Design of Response Surface Methodology was developed in Design Expert software, which was used for analysis of results.

Index Terms – Box Behken Design, Hardness, Response Surface Methodology

1. INTRODUCTION

The current scenario of manufacturing industries is to raise the profits by producing good quality of products with good accuracy. For permanently joining metals, welding is considered as an efficient and economical process and is extensively used by industries. Out of many welding processes, MIG welding is adopted for joining steels, aluminium and non-ferrous materials at a much faster pace and also fulfilling the quality characteristics. Optimization of welding parameters is thus necessary for obtaining good quality of weld joints. Many optimization techniques can be used for the desired output responses. Design of experiment fulfill the need for generating model for conducting experimental runs. Several mathematical models can establish the relation between the input and output responses. The use of various design of experiments with optimization techniques proved to be effective for achieving the objective function.

2. LITERATURE REVIEW

Ambekar and Wadhokar [1] studied the effects of welding process parameters on weld penetration of Stainless Steel AISI 410 in Gas Metal Arc welding. The input process parameters selected were, welding speed, current, wire diameter and 4 levels were taken to carry out study and Taguchi method is used as a design of experiment. Sixteen experiments with the help of orthogonal array of Taguchi method were done. ANOVA method was used for obtaining percentage contribution. Aghakhani et al. [2] studied the five variable process parameters, wire feed rate, welding voltage, welding speed, nozzle to plate distance, gas flow rate for Steel ST-37 at five levels using taguchi design of experiments and their effect on weld dilution. Results have shown that, the effect of wire feed rate is significant among all the other parameters. When the wire feed rate and voltage are increased, weld dilution also increases, but on increasing welding speed and nozzle to plate distance lead to decrease in dilution of weld. Dhobale and Mishra [3] determined the effect of welding variables such as heat input which was controlled by welding current, speed and voltage on mechanical properties of low carbon steel of grade EN-3A in gas metal arc welding process. From the experimental results, with decrease in amount of heat input, tensile strength increases and no significant effect of shielding gas has been found. Butola et al. [4] studied the effect of welding parameter on microhardness of synergic (both pulse and spray) MIG welding of 304L Stainless steel. The process parameters considered were Plate thickness, gas flow rate, current, travel speed. All experiments were carried out with a contact-tip to work distance of 20 mm using the mixture of Argon and CO_2 as shielded gas at five different flow rates. The microhardness value was maximum in HAZ, results in conclusion that grain size are finest in HAZ and microhardness value increases from base metal to HAZ. Mishra et al. [5] applied the taguchi method for finding the optimal input parameters for penetration. Welding process parameters taken were welding current, welding voltage and welding speed. From the optimal process parameters values, with current of 60A, voltage of 25V, and welding speed of 240 mm/min, the penetration is 5.82 mm and S/N ratio is 15.01. Adak et al. [6] carried out the experimental work to see the effect of MIG process parameters like wire feed rate, contact tip to workpiece distance and voltage on the characteristics of weld bead by using ANOVA and regression analysis. The depth of penetration considerably increases with increase in wire feed speed. Heat input and contact tip to workpiece distance have shown positive impact and the remaining variables have shown diminishing effect on the width of HAZ. Also, with increase in heat input, grain size of the fusion zone increases. Kalita and Barua [7] studied the effect of the three important parameters, namely welding voltage, current, shielding gas flow rate having three levels each, on the tensile strength of C20 steel using Taguchi's L9 orthogonal Array. Joshi et al. [8] have taken the process parameters, which are welding current, gas flow rate, wire feed rate to investigate their influence on MIG and TIG welding process and used the full factorial design to find out numbers of readings. The grey relational grade has been used to evaluate the optimum parameters and ANOVA for finding the percentage contribution of each input parameter. Kumar V and Murugan [9] carried out the experiments to study the effects of input variable process parameters on weld bead geometry by developing the mathematical models. The welding process parameters taken were welding speed, current, nozzle-to-plate distance, open circuit voltage and electrode angle. The increase in welding current results in increase of weld bead geometry that is weld bead width, penetration and reinforcement. Kanwal and Jadoun [10] has carried out study for the optimization of MIG welding parameters for getting better hardness with the use of taguchi method. The material used were aluminium alloys of grades 6061 and 5083. So, the higher value of hardness was obtained at optimum values of current, voltage and welding speed. Kocher et al. [11] has taken welding speed as the process parameter, while, wire feed rate, current, voltage and distance between the nozzle and the plates were fixed. The output parameters were welding wetting angle and fusion angle to see the effect of welding speed on them, with taking into consideration of other parameters like weld dilution, penetration and reinforcement area to experimentally establish the influence of welding speed on them. Narayana and Srihari [12] have developed the mathematical relations between input and output by using RSM. The input parameters selected were welding speed, nozzle to plate distance, wire feed rate and voltage. So, to obtain good quality weld in real time, optimized parameters were obtained with the help of graphs, which shows the weld bead geometry changes, when input parameters were being changed. Vagh and Pandya [13] have taken AA-2014 T6 aluminium alloy as a base material and friction stir welding was performed on it. The mechanical strength was checked at different process parameters, run order of which was designed by using taguchi method. It has been obtained experimentally that at tool travel speed of 20mm/min and tool rotation speed of 1400 rpm has given the highest strength. Also stepped pin tool design with tool travel speed of 20mm/min and rotation speed of 1000 rpm has given the highest elongation. Tool design was the main input parameter as suggested by ANOVA. Tool design also gives the statistical influence of 74.01% on tensile strength and 86.74% on nugget hardness. Srijeeth S Nair [14] has studied the effect of welding input parameters like current and filler diameter on tensile strength, hardness and penetration of SS304 Steel in TIG welding. The central composite design methodology of Response Surface Methodology has been used to perform the experiments. The most important factors which have affected the tensile strength and also penetration are found out to be diameter of filler wire, and welding current for the hardness. The optimum process parameters for TIG welding of SS304 steels are found out to be at wire diameter of 3mm, and Welding Current of 140 A.

3. EXPERIMENTAL SETUP

Experimental setup is an important step for any experimental research. It plays a vital role in the completion of the research. In this study, MIG welding machine is used to perform the experiments. The Power Compact 255 MIG welding machine has been used for the experimentation in the industry with shielded gas taken as 100% CO_2.

3.1 WORK MATERIAL & FILLER WIRE

Commercial mild steel IS 2062 sheet of dimension 60mm x 40mm x 5mm is selected as workpiece material for experimentation.

Table 3.1 Composition of IS 2062 Steel

Steel	**C %**	**Mn%**	**S%**	**P%**	**Si%**
IS2062-Grade A	0.23	1.50	0.045	0.045	0.40

The filler wire material used is ES70S-3. The chemical composition of filler wire is given in table 3.2.

Table 3.2 Composition of ER70S-3 welding wire

Welding wire	**C%**	**Mn%**	**S%**	**P%**	**Si%**
ER70S-3	0.15	1.4	0.035	0.025	0.45

3.2 DESIGN OF EXPERIMENT

In present work, RSM is used to design the experiments for MIG welding with the help of Box Behnken design method in Design Expert-10 software. Welding voltage, current and gas flow rate are taken as input process parameters and three levels for each parameter has been selected according to the pilot experiments.

After selecting the input process parameters and their levels, the experimental run order is generated by using Response surface methodology with the help of BBD (Box behnken design) for MIG welding, which has given 15 experiment runs and experiments conducted according to the run order produced by the RSM.

Table 3.3 Level of control factors for MIG welding

Level	Voltage (V)	Current (A)	Gas flow rate(lit/min)
-1 (low)	25	110	15
0 (medium)	30	130	20
1 (high)	35	150	25

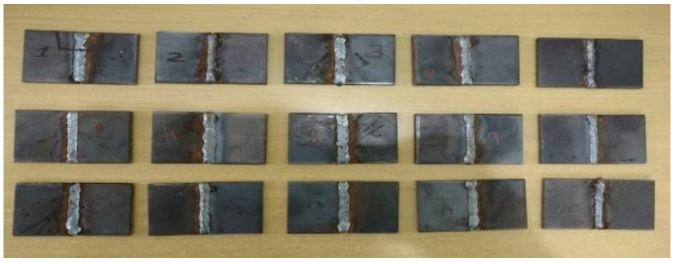

Figure 3.1 MIG welded samples

4. RESULTS AND DISCUSSIONS

After we obtained the welded specimen, each specimen cut from crossection into the size of 25mm x 25mm with the help of wire cut electric discharge machine.

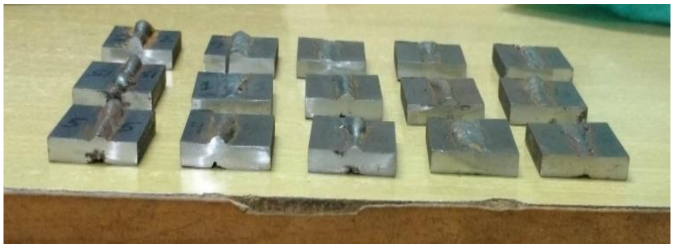

Figure 4.1 MIG samples after wire cut EDM

4.1 VICKERS HARDNESS TEST

Hardness value of the welded zone is measured for all the welded specimens at the cross section to understand the change in mechanical property of the welded zone. The hardness values are measured at three distinct points on the weld bead and an average value of hardness is calculated for each specimen at the welded cross section.

Figure 4.2 FIE VM-50 Hardness Testing Machine

Table 4.1 Hardness for MIG welded specimens

Experiment no.	Voltage (V)	Current (A)	Gas flow rate (lit/min)	Hardness value at point 1	Hardness value at point 2	Hardness value at point 3	Average value of Hardness
1	35	130	15	197	199	198	198
2	25	130	25	221	226	225	224
3	35	150	20	202	204	203	203
4	30	150	25	210	211	209	210
5	25	130	15	230	231	229	230
6	30	110	25	204	200	202	202
7	30	130	20	200	204	202	202
8	35	130	25	180	182	181	181
9	30	130	20	207	209	208	208
10	25	110	20	228	230	229	229
11	35	110	20	186	187	184	186
12	30	150	15	209	207	206	207
13	30	110	15	216	215	217	216
14	30	130	20	202	205	203	203
15	25	150	20	226	229	230	228

4.2 ANOVA FOR HARDNESS

Linear model is selected for weld bead hardness analysis. The analysis of variance for weld bead hardness in MIG welding is given in table 4.2,

Table 4.2 ANOVA table for hardness

Source	Sum of squares	DF	Mean square	F- value	p-value Prob > F	
Model	2728.75	3	909.58	28.35	< 0.0001	significant
A-Voltage	2556.12	1	2556.12	79.66	< 0.0001	
B-Current	28.13	1	28.13	0.88	0.3693	
C-Gas flow rate	144.50	1	144.50	4.50	0.0574	
Residual	352.98	11	32.09			
Lack of Fit	332.32	9	36.92	3.57	0.2378	not significant
Pure Error	20.67	2	10.33			

Table 4.3 Coefficient table for hardness

Factor	Coefficient estimate	Standard Error	P
Intercept	208.47	1.46	
A-voltage	-17.88	2.00	< .0001
B- current	1.88	2.00	0.3693
C-Gas flow rate	-4.25	2.00	0.0574

Regression equation for weld hardness obtained through linear regression is given by the equation 4.1

Hardness = +208.47 – 17.88*voltage + 0.18*current – 4.25*gas flow rate………… (4.1)

4.3 INDIVIDUAL PLOTS OF EFFECT OF PROCESS PARAMETERS ON HARDNESS

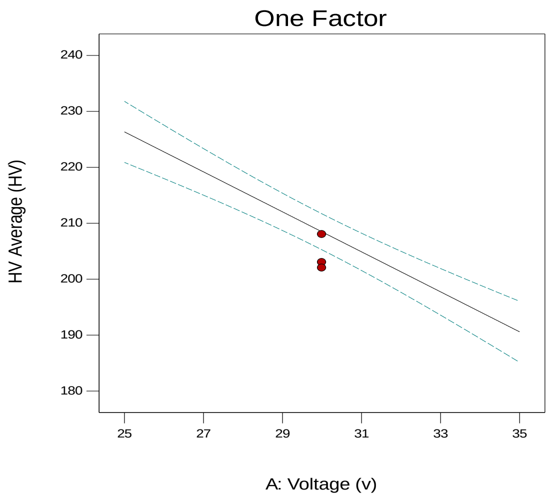

Figure 4.3 Effect of voltage on hardness

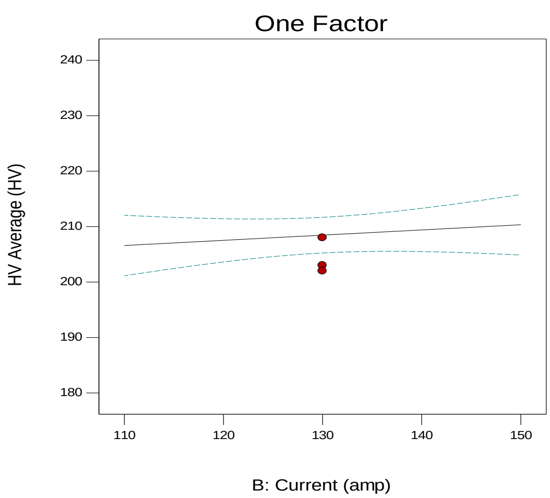

Figure 4.4 Effect of current on hardness

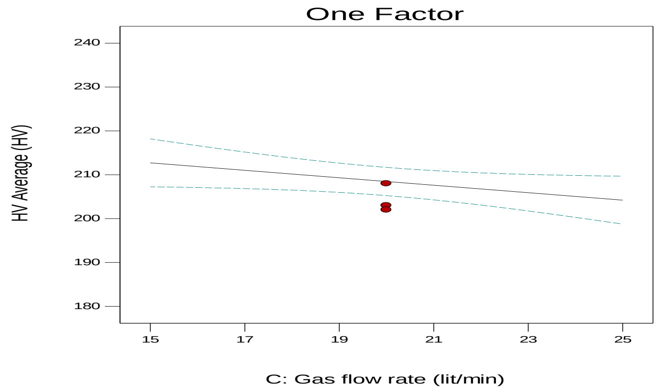

Figure 4.5 Effect of gas flow rate on hardness

4..4 SURFACE PLOT BETWEEN TWO PARAMETERS OF HARDNESS

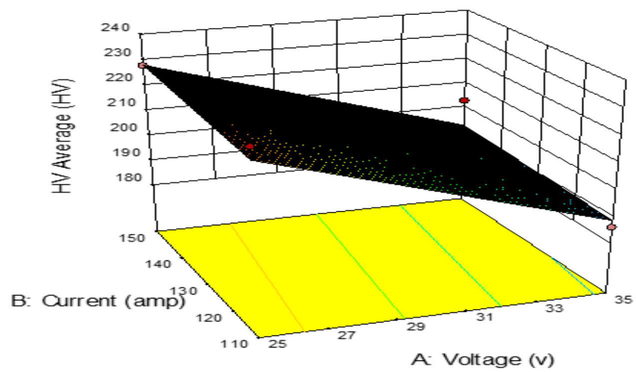

Figure 4.6 Surface plot between hardness vs voltage and current

The observation made from above figure 4.6 indicates that the hardness is maximum at current of 130A and voltage 25V.

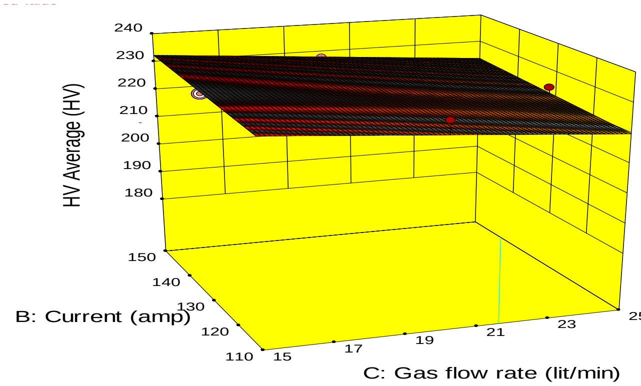

Figure 4.7 Surface plot between hardness vs current and gas flow rate

The observation made from figure 4.7 above indicates that the hardness is maximum at current of 130A and gas flow rate of 15lit/min.

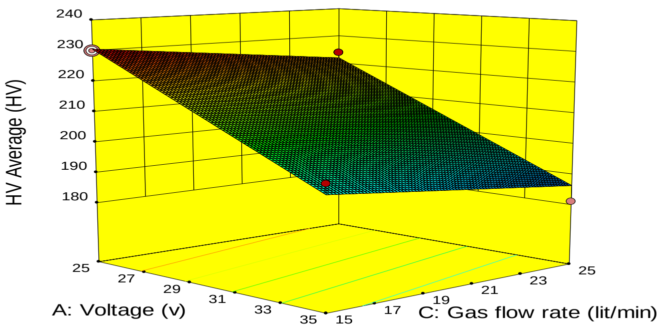

Figure 4.8 Surface plot between hardness vs gas flow rate and voltage

The observation made from figure 4.8 above indicates that the hardness is maximum at voltage 25V and gas flow rate of 15lit/min.

4.5 OPTIMIZATION FOR HARDNESS

Table 4.4 Weighted table for hardness

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A: Voltage	is in range	25	35	1	1	3
B: Current	is in range	110	150	1	1	3
C: Gas flow rate	is in range	15	25	1	1	3
Hardness	maximize	181	230	1	1	3

From the below figure 4.9, the maximum value of Hardness 230.864 HV at voltage 25.1885V, current of 146.712A and gas flow rate of 15.7296lit/min, which had desirability value of 1 which means the experimental result is closer to predicted results.

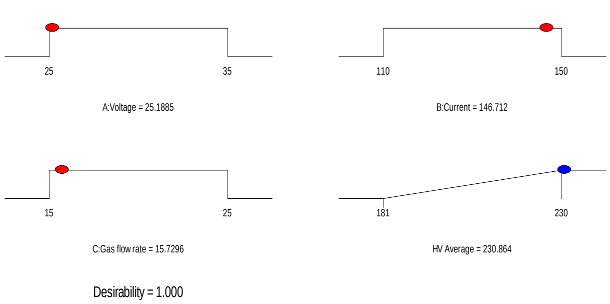

Figure 4.9 Results for Hardness

5. CONCLUSIONS

The following conclusions are as follows:

- With increase in voltage and gas flow rate, hardness started decreasing, whereas for increase in current, hardness also increased.
- The maximum predicted value of Hardness obtained is 230.864 HV at voltage 25.1885V, current of 146.712A and gas flow rate of 15.7296lit/min.
- The hardness increased from 178 HV to 230 HV by using optimum parameters for welding, an increase of 29.21% in the hardness.
- The value of Prob>F for voltage, current and gas flow rate were less than 0.05, which indicate their significant effect on hardness.
- Increasing order of the parameters affecting the hardness was found out to be, welding voltage , gas flow rate, welding current respectively.

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