Volume 2, Issue 10, October 2012 ISSN: 2277 128X
International Journal of Advanced Research in Computer Science and Software Engineering
Research Paper
Available online at: www.ijarcsse.com

Optimisation of Process Parameters for Weld Bead Penetration of IS2062 Mild Steel for GMAW Process Using Response Surface Methodology

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Abstract: ***The weld quality depends on a large extent on the beadgeometry which is largely influenced by various process parameters in the process. Inadequacy of weld bead dimensions may lead to failure of the welded structure. This paper is a study of optimization of process parameters using Response Surface Methodology. Experiments were conducted based on central composite Face Centred Cubic design and mathematical models were developed correlating the important controllable GMAW process parameters like Voltage (V), welding speed (S) and gas flow rate (G) with weld bead penetration. Using these models the direct and interaction effects of the process parameters on weld bead penetration were studied and further the process parameters were optimised. The obtained results help in selecting quickly the process parameters to achieve the desired quality.***

Keywords: ***Gas Metal Arc Welding, Response Surface Methodology, Central Composite Face Centred Cubic Design, IS2062 Mild Steel, Weld Bead Penetration.***

I. Introduction

The gas metal arc welding (GMAW) process is generally accepted as the preferred joining technique and is mostly chosen for welding large metal structures such as bridges, automobiles, aircraft and ships due to its joint strength, reliability, and low cost compared to other joining processes.[1,2]
An electric arc is struck between a continuous filler metal electrode and the weld pool, with shielding from an externally supplied gas, which can 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 weld metal (weld bead). The quality of the welded material can be evaluated by many characteristics, such as bead geometric parameters (penetration, width and height). These characteristics are controlled by a number of welding parameters, and therefore, to attain good quality, it is important to set up the proper welding process parameters. But the underlying mechanism connecting then (welding parameters and quality characteristics) is usually not known.One of the most widely used methods to solve this problem is the Response Surface Methodology (RSM), in which the experimenter tries to approximate the unknown mechanism with an appropriate empirical model thus forming a function that represents it called a response surface model.[3]

II. Experiment

Analytical relationships between welding parameters and penetration were established by regression and dimensional analysis of experimental data. This data was obtained from a detailed GMA welding experiment in which the welding parameters were precisely controlled and the penetration precisely measured. The thickness of the plate taken is 5mm and a 0.8 mm diameter MW1 filler wire has been used to weld it. The shielding gas used is a mixture of Argon-80%, Carbon Dioxide-18% and 2% Oxygen.The upper and lower limits for the various input parameters were decided by performing a large number of experiments by varying the control variables in all possible combinations.[4]The final upper and lower limits for the input parameters are listed in table I.

Table-I

Parameters	Units	Symbols	Notation	Limits	
				Low(-1)	High(+1)
Arc voltage	Volts	V	1	26.0	32.0
Welding speed	cm/min	S	2	27	36
Gas flow rate	l/min	G	3	20	25

These experiments were run according to a random sequence or run order provided by the Design of Experiments fractional factorial technique. The penetrations as observed in the experimental run order are shown in Table II.

Table-II

	Standard Order	Run Order	Point Type	Block	A:Arc Voltage	B:Welding Speed	C:Gas Flow Rate	Bead Penetration
1	15	1	0	1	29	31.5	22.5	0.81
2	18	2	0	1	29	31.5	22.5	0.81
3	10	3	-1	1	32	31.5	22.5	0.89
4	2	4	1	1	32	27	20	1.01
5	16	5	0	1	29	31.5	22.5	0.83
6	13	6	-1	1	29	31.5	20	0.85
7	20	7	0	1	29	31.5	22.5	0.83
8	4	8	1	1	32	36	20	0.84
9	19	9	0	1	29	31.5	22.5	0.82
10	11	10	-1	1	29	27	22.5	0.82
11	9	11	-1	1	26	31.5	22.5	0.75
12	7	12	1	1	26	36	25	0.79
13	5	13	1	1	26	27	25	0.65
14	8	14	1	1	32	36	25	0.93
15	3	15	1	1	26	36	20	0.76
16	6	16	1	1	32	27	25	0.85
17	1	17	1	1	26	27	20	0.72
18	17	18	0	1	29	31.5	22.5	0.82
19	14	19	-1	1	29	31.5	25	0.83
20	12	20	-1	1	29	36	22.5	0.9

III. Results & Analysis

To find the functions of the responses with respect to the input variables, the regression analysis of the data was done and the values of coefficients for the various terms were obtained. The regression information is shown in the table III.

Table III

Regression Information Penetration						
Term	**Coefficient**	**Standard**	**Low CI**	**High CI**	**T**	**P**
Intercept	0.8289	0.0089	0.8127	0.8451	92.7584	5.55E-
A:Arc	0.085	0.0082	0.0701	0.0999	10.3405	1.17E-
B:Welding	0.017	0.0082	0.0021	0.0319	2.0681	0.0655
C:Gas	-0.013	0.0082	-0.0279	0.0019	-1.5815	0.1448
AB	-0.0338	0.0092	-0.0504	-0.0171	-3.6723	0.0043
AC	-0.0038	0.0092	-0.0204	0.0129	-0.408	0.6918
BC	0.0438	0.0092	0.0271	0.0604	4.7604	0.0008
AA	-0.0223	0.0157	-0.0507	0.0061	-1.4209	0.1858
BB	0.0177	0.0157	-0.0107	0.0461	1.1309	0.2845
CC	-0.0023	0.0157	-0.0307	0.0261	-0.145	0.8876

The Central Composite Design in RSM provides a quadratic relationship between the parameters.The adequacy of the model is evaluated using analysis of variance (ANOVA) technique. The best model is the most fitted function to the experimental data. The model adequacy checking includes test for significance of the regression model and test for significance on model coefficients. Based on ANOVA, the value of R^2 in the model is over 90% for weld bead penetration ($\alpha = 0.1$). This means that this model provides an excellent representation of the actual process in terms of Bead Penetration.[6]. The ANNOVA table for this data is shown in table IV.

Table IV

ANOVA Table for Penetration					
Source of	**Degrees**	**Sum of**	**Mean**	**F Ratio**	**P**
Model	9	0.1031	0.0115	16.9597	6.25E-
Linear	3	0.0768	0.0256	37.9012	9.02E-
Interaction	3	0.0245	0.0082	12.1046	0.0012
Quadratic	3	0.0018	0.0006	0.8734	0.4869
Residual	10	0.0068	0.0007		
Lack of Fit	5	0.0064	0.0013	15.8926	0.0043
Pure Error	5	0.0004	8.00E-05		
Total	19	0.1099			

The function obtained by using the coefficients calculated above is written as follows:

$P = 0.8289 + 0.085V + 0.017S - 0.013G - 0.0338VS + 0.0038VG + 0.0438SG - 0.0223V^2 + 0.0177S^2 - 0.0023G^2$

The Stepwise elimination process removes theinsignificant terms to adjust the fitted quadratic model. The associated P-value for this model is lower than 0.1; i.e. α=0.1 or 90% confidence level. The coefficients having a P value less than 0.1 are thus considered significant while those having α >0.1 are taken as insignificant.The final proposed models after eliminating insignificant coefficients are presented below:

$P = 0.8289 + 0.085V + 0.017S - 0.0338VS + 0.0438SG$

The fig I shows the scatter diagram ofobserved vs estimated penetration of bead. It clearly shows the adequacy of the function.

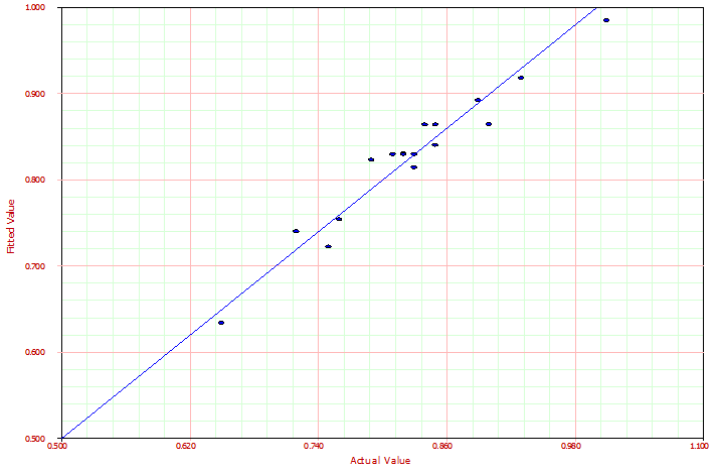


Fig 1

The effects of the various process parameters on the bead penetration are shown by graphs in figs II, III and IV.

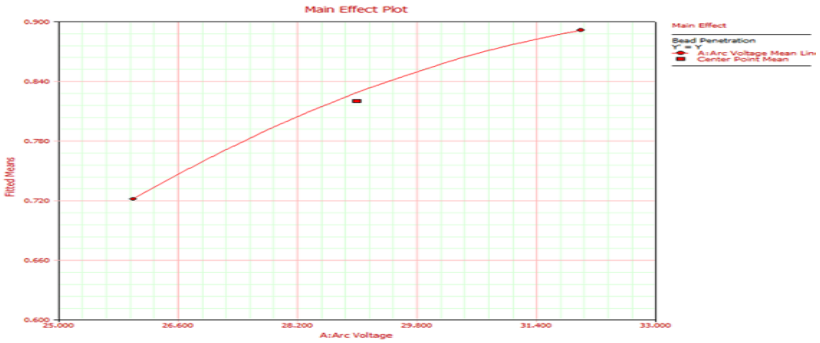


Fig. II

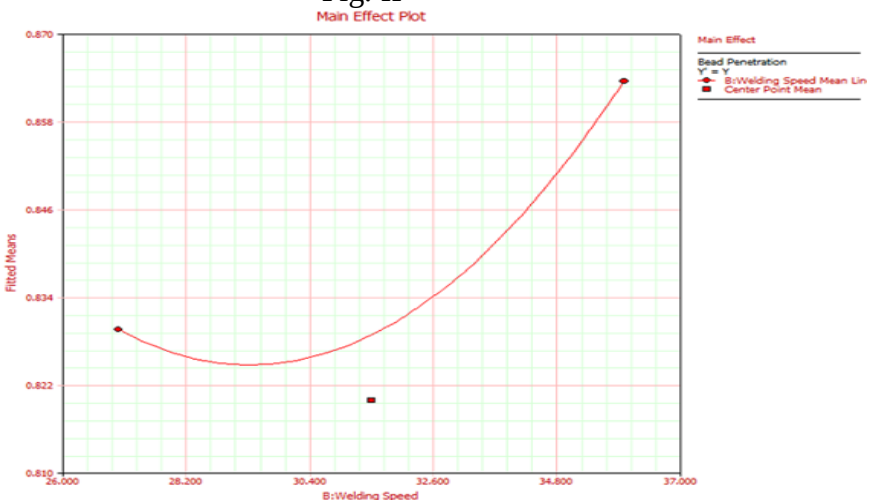


Fig. III

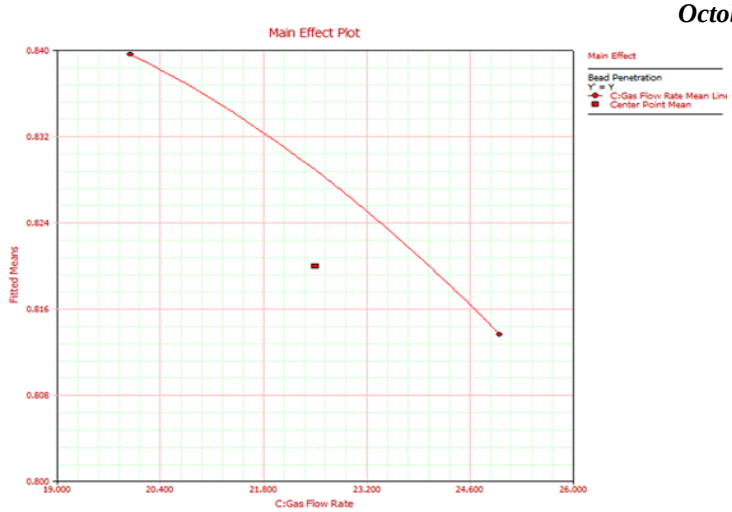


Fig. IV

The fig V shows the interaction matrix including the interaction effects of two input parameters taken at a time for Penetration.The parameter on the left hand side is taken at two levels shown by different colours and the parameter shown on the horizontal axis is varied from one level to another. The value of penetration at various points is shown on left or vertical axis.

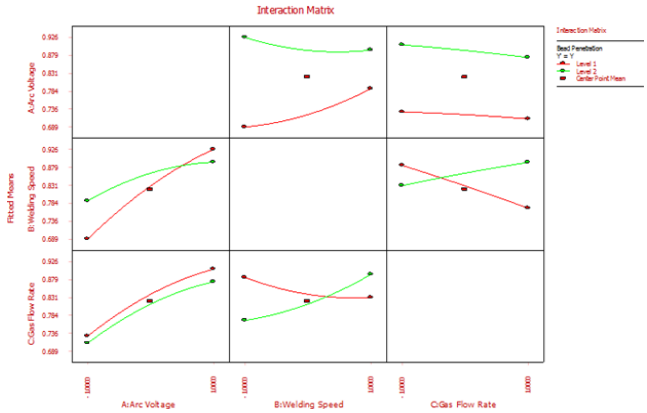


Fig. V

The surface plots showing the effect of input parameters taken two at a time on bead penetration are shown in figs. VI to VII. The different coloured surfaces show that the values of penetration obtained for the corresponding values of input parameters.

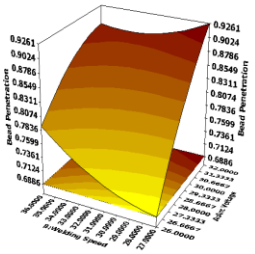


Fig. VI

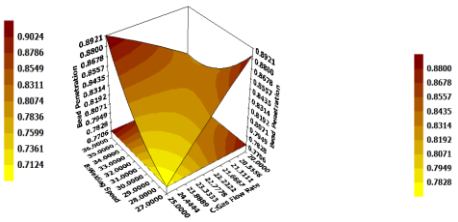


Fig. VII

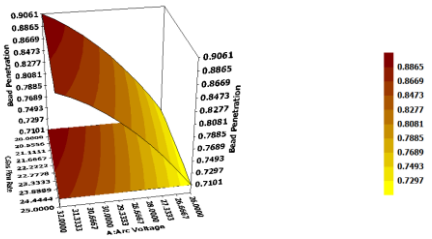
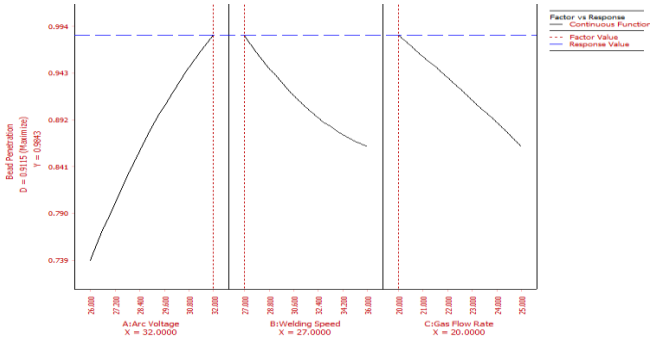


Fig. VIII

IV. Optimisation of Parameters for Maximising Bead Penetration

As penetration increases the strength of the weld, so without any doubt it should be maximised and to determine the optimum values of the input process parameters for maximum penetration the graphs were plotted between the various values of penetration against the varied input parameter values, taken one at a time. The graph gives the optimised values for the three input parameters. Fig shows the three graphs.



V. Conclusions

The optimised values of the various input parameters can be summarized as:
Optimum Arc Voltage – 32 V
Optimum Welding Speed – 27cm/min
Optimum Gas Flow Rate – 20 l/min

The Maximised Bead penetration obtained corresponding this data is 0.9843mm.

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