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Optimization of Weld Bead Geometry in Gas Metal Arc Welding of High Strength Low Alloy Steel Using Response Surface Methodology

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Abstract

The input parameters of welding play a very important role in determining the quality of a weld joint. The weld joint quality can be defined in terms of weld-bead geometry, mechanical properties, and distortion. Generally, all type of welding processes is used with the aim of obtaining a welded joint with the desired weld-bead parameters, excellent mechanical properties with minimum distortion. Response surface methodology is used to develop a mathematical relationship between the welding process input parameters and the output variables of the weld joint in order to determine the welding input parameters that lead to the desired weld quality.

Keywords: gas metal arc welding, regression equation, response surface methodology

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INTRODUCTION

The gas metal arc (GMA) welding process is a welding process that yields coalescence of metals by heating with a welding arc between continuous filler metal (consumable) electrode and the work piece. Molten weld pool and electrode wire are protected from contaminants in the atmosphere by a shielding gas obtained from various combinations. [1–8] The quality, efficiency and overall operating acceptance of the welding operation are strongly dependent on the shielding gas, since it dominates the mode of metal transfer.

The shielding gas not only affects the properties of the weld but also determines the shape and penetration pattern as well. Various techniques such as gas, slag, gas and slag, vacuum and self-protection can be used to protect the weld pool during the fusion welding. Obviously, different protection techniques provide different degrees of weld pool protection (Kacar et al., 2005)

Since empirical optimization of welding parameters is both time-consuming and costly, the application of statistical methods such as design of experiments (DOE) is preferred. Response surface methodology (RSM) which is one of the main applications of DOE can be used to estimate unknown mechanisms through the use of an empirical model. [9–12] Using RSM, it is possible to evaluate effects of many parameters on weld mechanical properties and to optimize them to achieve suitable results. [13] The use of a statistic approach (response surface methodology) to correlate welding parameters to weld joint properties is considered by researchers. Correia et al. [13] presented comparison between genetic algorithms and response surface methodology in

GMAW welding optimization. Paventhan et al. used response surface methodology for the optimization of friction welding process parameters for joining carbon steel and stainless. This study is focused on the RSM optimization of some crucial welding parameters namely welding voltage, welding current and shielding gas flow rate to achieve most favourable weld bead geometry.

Although some researchers have already applied DOE to optimize welding parameters, but no effort is yet made to perform this optimization on gas tungsten arc welding of AISI 4130 using RSM. HSLA steels has unique properties such as high strength, good weld ability and also exhibit outstanding low temperature impact toughness superior to that of other steels. HSLA steels are used in various applications like construction of large ships, oil, pressure vessels and gas transmission lines.

This study is focused on the RSM optimization of some important welding parameters such as welding current, welding voltage and shielding gas flow rate to achieve weld bead geometry.

MATERIALS AND EXPERIMENTAL SETUP

Materials

Rolled plates of HSLA (AISI 4130) steel with 10 mm thickness were cut into specimens of 50*50*10 mm by machining. V-groove with 60° configuration was prepared according to standards. The initial joint configuration was obtained by securing the plates in position using mechanical clamps. The direction of welding was normal to the rolling direction and it is a single pass welding. Argon and carbon dioxide in the ratio of (80% - 20%) were used as shielding gas. The filler metal was an AWS classification ER 308L with a 1.5 mm diameter electrode.

Chemical Composition

The composition of the alloying elements increases the properties of the base metal. The chemical composition of the base metal and the electrode which is chosen for the experiments is given by the Table 1.

Welding Preparation

The base material is prepared in the dimension of 50*50*10 and welded by means of gas metal arc welding. The GMAW is carried out on DC electrode positive polarity. DC output power sources are of a transformer-rectifier design with flat characteristics. Figure 1 shows a schematic representation of the weld joint preparation. The weld bead geometry which includes width, reinforcement and depth of penetration is given by the Figure 1 and weld bead profile is given by the Figure 2.

Table 1. *Chemical Composition of the Base Metal and the Electrode.*

	Fe	C	Mn	Si	Mo	Ni	V	P	S	Cr
HSLA 4130	97.03-98.22	-	0.40-0.60	0.280-0.33	0.15-0.25	-	-	0.035	0.040	0.80-1.10
ER308L		0.03	1.0-2.5	0.30-0.65	0.75	-	-	0.03	0.03	19.5-22.0

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Fig. 1. *Weld Bead Geometry Which Includes Width, Reinforcement and Depth of Penetration.*

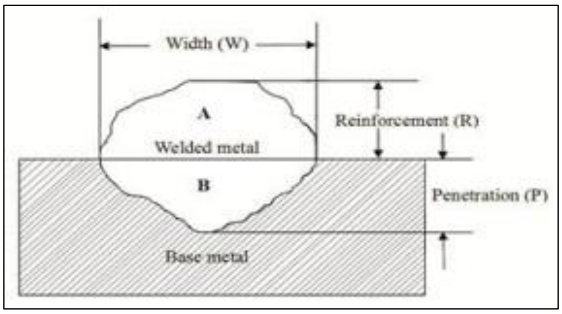


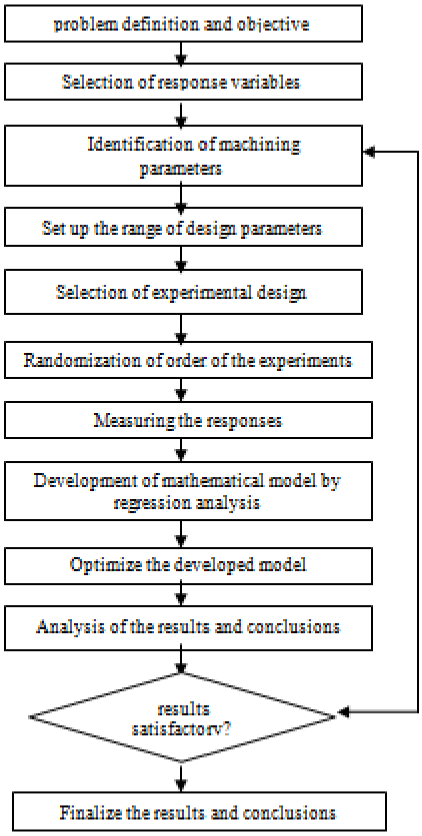
Fig. 2. *Weld Bead Profile.*

WELDING PARAMETERS AND RESPONSE VARIABLE

Three convenient welding parameters that are identified are current, voltage and gas flow rate. Because of preliminary experiments conducted using one variable at a time approach, the level of the voltage, current and gas flow rate are chosen as a range of 210 to 260 volts, 20 to 28 V and 10 to 14 l/min.

The lowest level is expressed as –1 and the highest level is expressed as +1 as in Table 2.

EXPERIMENTAL PROCEDURE



DESIGN OF EXPERIMENTS

Measuring Depth of Penetration

To measure the depth of penetration the front end of the welded joint is polished using the grinding wheel. The weld profile is obtained by video machining system at M/s Candid Micron, Coimbatore. The profile is fed into the AUTOCAD 10.0 software to measure the dimension of depth of penetration from weld bead profile.

Table 2. *Lowest Level Is Expressed as –1 and the Highest Level Is Expressed as +1.*

Parameter	Notation	unit	-1	0	1
voltage	V	volt	210	235	260
current	I	amp	20	24	28
Gas flow rate	G	l/min	10	12	14

Response Surface Methodology

In the present investigation, experiments are designed on the root of the Design of Experiments (DOE) technique explained by (Kiaee N, 2014). Box behnken second-order rotatable design is used to enhance the reliability of results and to diminish the size of experimentation with no loss of accuracy.

In this effort box behnken rotatable design is selected for experimentation. The primary advantage of using this method is addressing the issue of where the experimental boundaries should be and in particular to avoid treatment combinations that are extreme. By extreme means the corner points and the star points in terms of region in which the experiment is conducted. The selected design parameters such as voltage, current and gas flow rate and their effect of these design parameters on the depth of penetration has been studied. The levels of each factor are chosen as - 1, 0 and 1 these values form a closed rotatable design. The coded values for intermediary values of a variable are determined using the formula:

$$Xi=\frac{2[2X-(X_{max}+X_{min})]}{(X_{max}-X_{min})}$$

Where, X_i is the adequate coded value of design variable X, X few value of the variable from X_{min} to X_{max}.

X_{min} – The lower limit of the variable. X_{max} – The upper limit of the variable.

The experiment has been carried out according to the run order in the experiment design matrix. At the end of each run, settings for all four parameters are changed and reset to the next run. This is an essential to introduce variability as a result of errors in experimental settings. The function representing any of the response variables with respect to variable can be expressed using,

$$Y=f(X_1, X_2, X_3) + €$$

where Y is the response (e.g. depth of penetration), € is the error, X_1 the voltage (V), X_2 the current (I), X_3 the Gas flow rate(l/min).

The above second order comeback surface model equation should be articulated as follows:

$$Y=C_0+C_1V+C_2I+C_3G+C_4V^2+C_5I^2+C_6G^2+C_7VI+C_8VG+C_9IG$$

Std order	Run order	Voltage	Current	Gas flow	penetration
12	1	235	28	14	2.958
11	2	235	20	14	3.152
3	3	210	28	12	2.810
15	4	235	24	12	3.271
7	5	210	24	14	3.032
6	6	260	24	10	2.812
13	7	235	24	12	3.125
1	8	210	20	12	2.800
14	9	235	24	12	3.208
10	10	235	28	10	2.781
4	11	260	28	12	3.752
5	12	210	24	10	3.412
8	13	260	24	14	3.075
9	14	235	20	10	2.562
2	15	260	20	12	3.352

where C_0 is the constant term of the regression equation, the coefficients C_1, C_2 andC_3 are linear terms, the coefficients C_{11}, C_{22} andC_{33} are the quadratic terms, and the coefficients C_{12}, C_{13} andC_{23} are the interaction terms of the regression equation. The values of the coefficient of the polynomial are computed as shown below

$C_0=0.142857\Sigma Y-0.035714\Sigma\Sigma(X_{ii}Y)$
$C_i=0.041667\Sigma 0X_iY)$
$C_{ii}=0.03125\Sigma 0X_{ii}Y)+0.0357144-0X_{ii}Y)-0.0357155-0$
$C_{ij}=0.0625\Sigma 0X_{ij}Y)$

The C coefficients, used in the above model can be found by means of using least square method. The regression coefficients are calculated using MINITAB R17 software and generate the mathematical models. The insignificant coefficients which hare obtained are eliminated without affecting the accuracy of the developed model. This is done using back elimination technique, available in MINITAB R17 software. The Mathematical models developed for the response variables with input parameters in coded form are shown in equation below (Figures 3–5).

DEPTH OF PENETRATION (DOP) (mm)
Y (mm) = 7.23969 – (0.12757*V) + (0.30284*I) + (0.94222*G) + (0.00016*V*V) – (0.00757*I*I) – (0.05423*G*G) + (0.00097*V*I) + (0.00322*V*G) – (0.01291*I*G)

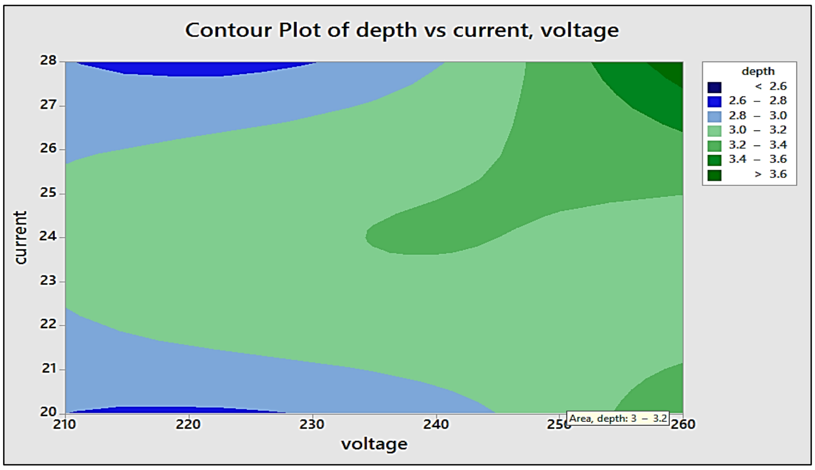


Fig. 3. *Contour Plot Between Depth of Penetration Vs Current and Voltage.*

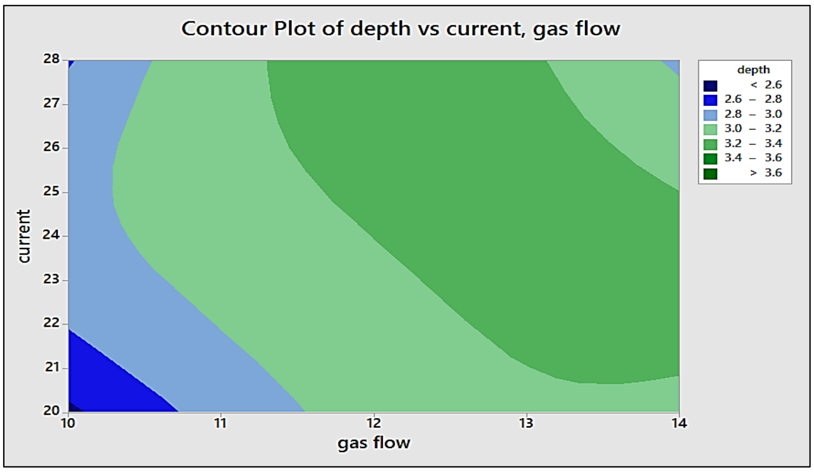


Fig. 4. *Contour Plot Between Depth of Penetration Vs Current and Gas Flow Rate.*

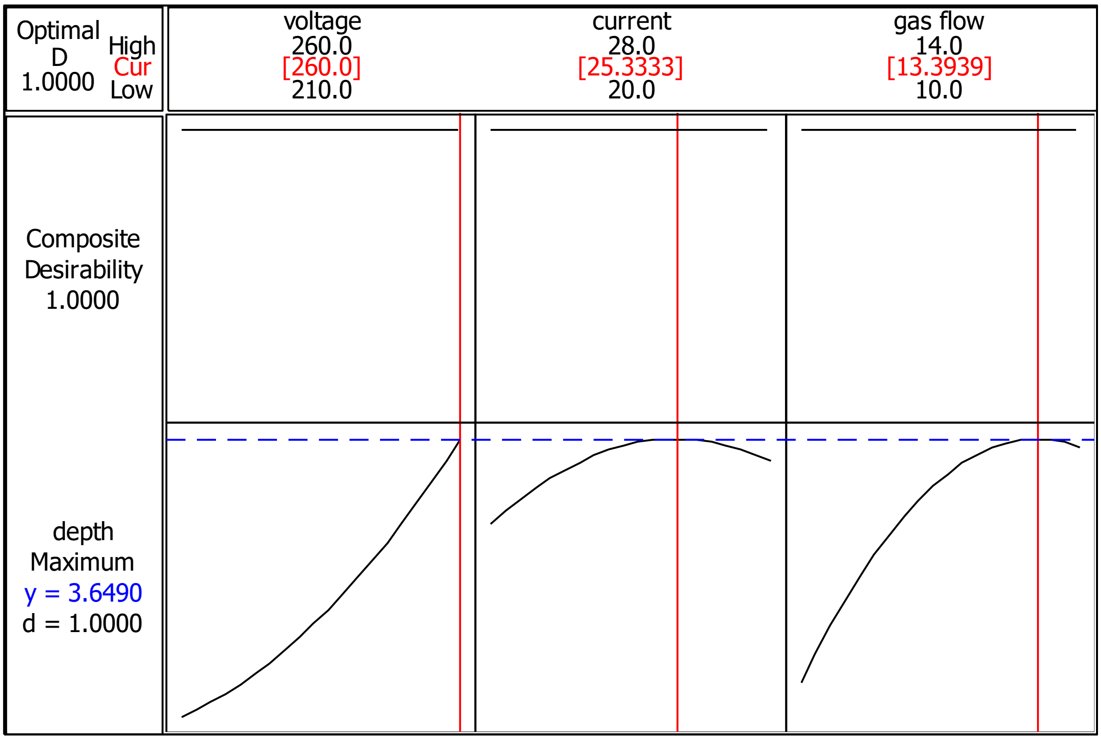


Fig. 5. *Plot Between Depth of Penetration Vs Voltage, Current and Gas Flow Rate.*

CONCLUSIONS

The optimum value of depth of penetration is found to be 3.6490 which are obtained under optimum welding parameters by response surface methodology.[14,15] The confirmatory test is done by considering the optimum welding parameters (voltage V=260, Current I=25.3333 and gas flow rate G=13.399) to verify the predicted response value. By means of Selective sensitive analysis it is found that the current and the gas flow rate has the most influence in the response variable.

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