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The Effects of MIG Welding Parameters on the Penetration Depth of AISI4140

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Abstract

Metal Inert Gas welding (MIG) procedure is a chief component in many engineering operations. The GMA welding parameters are the most vital factors affecting the quality, productivity and cost of welding. This paper presents the influence of welding parameters like welding speed, wire feed rate, arc voltage and distance to nozzle on penetration depth of AISI 4140 material during welding. A plan of experiments based on RSM technique has been used to acquire the data. A central composite design, signal to noise (S/N) ratio and analysis of variance (ANOVA) are employed to investigate the welding characteristics of AISI 4140 material & modeled the welding parameters.

Keywords: RSM; Turning; CCD; MIG; steel

1. Introduction

Metal Inert Gas welding is one of the most widely used processes in industry. The input parameters play a very important role in influential the quality of a welded joint. In fact, weld geometry directly affects the complexity of weld schedules and thereby the construction and manufacturing costs of steel structures and mechanical devices. Therefore, these parameters affecting the arc and welding should be estimated and their changing conditions during process must be known before in order to obtain optimum results; in fact a perfect arc can be achieved when all the parameters are in conformity. These are combined in two groups as first order adjustable and second order adjustable parameters defined before welding process. Former are welding current, arc voltage and welding speed. These parameters will affect the weld characteristics to a great extent. Because these factors can be varied over a large range, they are considered the primary adjustments in any welding operation. Their values should be recorded for every different type of weld to permit reproducibility.

2. Literature Review

Kocabekir et al. (2008) [1]investigated the effect of weld time, different weld atmospheres and weld cooling conditions on the resistance spot weld quality of 3161_ stainless steel. Therefore, the microstructure of welded samples was evaluated and the hardness and tensile shear load bearing capacity of weldment was also determined. It was found that the final mechanical properties of welded samples are directly related to the parameters of the process used, knowing the weld time and weld atmosphere. Tensile shear load bearing capacity of welded samples increased with increasing heat input r fated with weld time due to the enlargement of nugget size. In addition, the tensile shear load bearing capacity of welded samples obtained in nitrogen atmosphere was found slightly higher compared to the normal atmosphere for all weld time.

Shanmugam et al. (2008) [2] Explained the effect of filler metals such as austenitic stainless steel, ferrite stainless steel and duplex stainless steel on fatigue crack growth behavior of the gas tungsten arc welded ferrite stainless steel joints was investigated. Rolled plates of 4 mm thickness were used as the base material for preparing single 'V' butt welded joints. Centre cracked tensile (CCT) specimens were prepared to evaluate fatigue crack growth behavior. Servo hydraulic controlled fatigue testing machine was used to evaluate the fatigue crack growth behavior of the welded joints. From showed superior fatigue crack growth resistance compared to the joints fabricated by ausenitic·and ferrite stainless steel filler metals. Higher yield strength, hardness and relatively toughness may be the reasons for superior fatigue performance of the joints fabricated by duplex stainless steel filler metal.

Kolukisa (2009) [3]explained the effect of welding temperature on the weld ability in diffusion welding of martenstic (AISI 420), stainless steel with ductile (spherical graphite-nodular) cast iron was investigated experimentally under protective atmosphere at various temperatures and coi¯Ttant prescribed pressure blow those which would cause macro detonation. Microstructure examinations were carried out by SEM and EDS

Kishore et al. (2010) [4]analyzed theeffect of process parameters in qualitative manner for welding of AlS11040 steel usin processes of Shielded Metal Gas Welding (MIG and TIG). Taguchi method is used to formulate the experimental layout. Exhaustive survey suggest that 5-7 control factors viz., a voltage, arc current, welding speed, nozzle to work distance and gas pressure predominant) influence weld quality, even plate thickness and backing plate too have their own effect Design of experiments based on orthogonal array is employed to develop the weldments. The weldments are subjected to testing to find the qualitative properties. The data obtained checked for adequacy based on ANOVA. The result computed is in form of contribution from each parameter, through which optimal parameters are identified for minimum defect The data in the present work is collected using ultrasound testing (UT), in which angle be technique is adopted for the testing of weldments and results are quantified accordingly. The testing of specimens indicated, the presence of defects like LOP, LOF, Blowhole, and Crack

Kolahan & Heidari (2010) [1] used the regression modeling in order establish the relationships between input and output parameters for Gas Metal Arc Welding (GMAW) process. To gather the required data for modeling, actual tests were carried o t based on the proposed Taguchi experimental matrix design. The process variables considered include voltage (V); wire feed rate (F); torch Angle (A); welding speed (S) and nozzle - to-plate distance (D). The process output characteristics include weld bead height, width and penetration. To develop mathematical models, various regression functions have been fate on the experimental data. The adequacies of the models are then evaluated using analysis if variance (ANOVA) technique. The best and most fitted model is then selected based on t e ANOVA results and other statistical analysis. The ANOVA results recommend that t curvilinear model is the best fit in this case. In the next stage, the selected model is implant into a Simulated Annealing (SA) optimization algorithm. This optimization procedure h been developed in order to determine the best set of process variables levels for any desire weld bead geometry characteristics. Computational results show very good compatibility with experimental data and demonstrate the effectiveness of the proposed modeling and optimization approach.

Pekkarinena & Kujanpaaa (2010) [5] determined empirically, which micro structural changes occur in ferrite and duplex stainless steels when heat input is controlled by welding paraeters. Test welds were done autogenously bead-on-plate without shielding gas using 5 kW fi er laser.

For comparison, some gas tungsten arc welds were made. Used test materials were .4016 (AISI 430) and 1.4003 (low-carbon ferrite) type steels in ferrite steels group and 1.4162 (low-alloyed duplex, LDX2101) and 1.4462 (AISI 2205) type steels in duplex steels group. Micro structural changes in welds were identified and examined using optical metal °graphic methods.

Haragopal et al. (2011) [6] used Taguchi method to design process parameters that optimize mechanical properties of weld specimen for aluminum alloy (A1-65032), used for construction of aerospace wings. Process parameters of MIG welding setup considered and ANOVA analyse gas pressure, current, groove angle and pre-heat.AssigningprocessparametertoL-9orthogonal array, experiments were conducted and optimization condition was obtained along with he identification of most influencing parameters using S/N analysis, mean response analysis and ANOVA.

Patel &Patel (2013) [7] explained that the welding parameter and effect of these parameter can be predict so if want to varies input the parameter can directly predict the effect of output by using the Artificial Neural Network. Welding is a manufacturing process, which is carried out for joining of metals. Metal Active Gas (MAG) this is a variation of MIG welding, in which identical equipment is used but the inert gas is replaced by carbon dioxide, which is chemically active. Shielding gas CO2 is used and consumable electrode is used which also plays role of conductor. MAG-0O2 welding is versatile, gives very little loss of alloying elements and can be operated as semi as well as fully automated. Artificial Neural Network (ANN) is a powerful empirical modeling tool, suitable for problems which are not amenable to exact analytical solutions, or, where interrelationships between variables are not fully understood but which provide an abundance of data from which ANN can learn and predict. All welds will be prepared by MAG-0O2 welding and TIG welding techniques. They studied Design of Experiments for this work and by use of the experimental data have performed ANN (Artificial Neural Network) prediction and make comparison with experimental data. Where inputs parameters for MAG-0O2 welding are welding current, wire diameter and wire feed rate and for TIG welding are welding current, wire diameter output parameter is weld strength for both MAG-0O2 welding and TIG welding techniques.

2.4 Experimental Details

2.4.1 Experimental Conditions and Planning of Experiment

The experiments are performed, on the basis of central composite design (CCD) with three process parameters namely welding speed, wire feed rate, arc voltage, distance to nozzle for penetration, reinforcement, WPSF. The experimental setup of MIG welding is shown in figure 1.

The experimental conditions on which the experiments are performed are given below:

Table 1 Experimental Conditions

Machine tool	Manufactured by Mark Industries, Gujrat, India
Work material	8 mm thickness , 10 cm length
(Work material	M4 steel
Electrode size (mm)	Diameter = 1.2

Figure 4.1 MIG welding set up

2.4.2 Work material

Alloy steels are designated by AISI four-digit numbers. They comprise different kinds of steels having composition exceeding the limitations of B, C, Mn, Mo, Ni, Si, Cr, and Va set for carbon steels.

AISI 4140 alloy steel is chromium, molybdenum, manganese containing low alloy steel. It has high fatigue strength, abrasion and impact resistance, toughness, and torsional strength. The following datasheet gives an overview of AISI 4140 alloy steel.

Chemical Composition

The following table shows the chemical composition of AISI 4140 alloy steel.

Iron, Fe	96.785 - 97.77
Chromium, Cr	0.80 - 1.10
Manganese, Mn	0.75 - 1.0
Carbon, C	0.380 - 0.430
Silicon, Si	0.15 - 0.30
Molybdenum, Mo	0.15 - 0.25
Sulfur, S	0.040
Phosphorous, P	0.035

3.4 Response Surface Methodology

For the present work, RSM has been applied for developing the mathematical models in the form of multiple regression equations for the quality characteristic of machined parts produced by turning process. In applying the response surface methodology, the dependent variable is viewed as a surface to which a mathematical model is fitted. For the development of regression equations related to various quality characteristics of turning process, the second order response surface has been assumed as:

$$y \quad = b_o + \sum_{i=1}^{k} \mathrm{b_i x_{i+}} \sum_{i=1}^{k} \mathrm{b_i x_i^2} \;_+ \sum_{i<j=2}^{2} \mathrm{b_i x_i\, x_{j\pm} e_r} \qquad (1)$$

This assumed surface Y contains linear, squared and cross product terms of variablesxi‟s. In order to estimate the regression coefficients, a number of experimental design techniques are available. Box and Hunter (1957) have proposed that the scheme based on central composite rotatable design fits the second order response surfaces quite accurately.

3.4.1 Central composite design

Box and Hunter [38] proposed that the scheme based on central composite design (CCD) fits the second-order re- sponse surfaces quite accurately. Also, CCD[8] is the most popular among the various classes of RSM designs due to its flexibility, ability to run sequentially, and efficiency in providing the overall experimental error in a minimum number of runs. Therefore, it has been selected in the present work. In CCD, each factor is varied at five levels (−α, −1, 0, 1, α) for developing a second-order model as given in Eq. (2). When the number of factors (k)isfive or greater, it is not necessary to run all combinations of factors. The factorial part of the design can be run using a fraction of the total number of available combinations. The possible designs options can either be regular fractional factorials.

4. Experimental Results

The MIG welding experiments were conducted, with the process parameter levels set as given in Table 2, to study the effect of process parameters over the output parameters. Experiments were conducted according to the test conditions specified by the second order central composite design (Table 2). Experimental results are given in Table 3 for penetration. Altogether 18 experiments were conducted using response surface methodology.

Table 2 No. of Process Parameters & Levels (CCD)

Coded	**Parameters**	**Levels**		
Factors		**(-1)**	**(0)**	**(+1)**
A	Wire Feed Rate	5	112	8
B	Arc voltage	32	45	36
C	Welding speed	25	35	45
D	Distance to nozzle	12	15	18

Table 3: Observed Values for Performance Characteristics

		Factor 1	Factor 2	Factor 3	Factor 4	Response 1
Std	**Run**	**A:Wire feed Rate**	**B:Arc Voltage**	**C:Welding Speed**	**D:distance to nozzle**	**penetration**
14	**1**	6.5	34	51.817	15	6.012
13	**2**	6.5	34	18.182	15	9.000
8	**3**	5	32	25	12	5.59
16	**4**	6.5	34	35	20.04	7.41
6	**5**	5	32	45	12	5.47
5	**6**	8	32	25	18	8.81
15	**7**	6.5	34	35	9.954	7.56
2	**8**	8	36	25	12	11.37
3	**9**	8	32	45	18	7.27
12	**10**	6.5	37.36	35	15	7.9
1	**11**	8	36	45	12	7.81
9	**12**	3.97	34	35	15	6.046
11	**13**	6.5	30.63	35	15	7.105
17	**14**	6.5	34	35	15	7.236
7	**15**	5	36	45	18	6.01
4	**16**	5	36	25	18	7.25
18	**17**	6.5	34	35	15	7.4
10	**18**	9.022	34	35	15	9.233

4.1 Analysis and Discussion of Results

The experiments were designed and conducted by employing response surface methodology (RSM). The regression equations for the selected model were obtained for the response characteristics, metal removal rate [32]. These regression equations were developed using the experimental data (Table 4.2) and were plotted to investigate the effect of process variables on various response characteristics. The analysis of variance (ANOVA) was performed to statistically analyze the results.

4.1.1 Selection of Adequate Model

To decide about the adequacy of the model, three different tests viz. sequential model sum of squares, lack of fit tests and model summary statistics were performed for penetration depth of MIG welding process. The Table 3 display three different tests to select an adequate model to fit various output characteristics. The sequential model sum of squares test in each table shows how the terms of increasing complexity contribute to the model. It can be observed that for all the responses, the quadratic model is appropriate. The „lack of fit" test compares the residual error to the pure error from the replicated design points. The results table 3 indicate that the quadratic model in all the characteristics does not show significant lack of fit, hence the adequacy of quadratic model is confirmed. Another test „model summary statistics" given in the following sections further confirms that the quadratic model is the best to fit as it exhibits low standard deviation, high "R-Squared" values, and a low "PRESS"

4.3.2 Effect of Process Variables on penetration

The regression coefficients of the second order equation are obtained by using the experimental data (Table 3). The regression equation for the cutting rate as a function of four input process variables was developed using experimental data and is given below. The coefficients (insignificant identified from ANOVA) of some terms of the quadratic equation have been omitted.

$$\begin{aligned} penetration = & -26.67748 + 2.34253 * Wire\ feed\ Rate + 0.61776 * Arc\ Voltage \\ & + 0.70972 * Welding\ Speed + 0.017310 * Wire\ feed\ Rate \\ & * Arc\ Voltage - 0.031167 * Wire\ feed\ Rate * Welding\ Speed \\ & - 0.068497 * Wire\ feed\ Rate * Nozzle\ To\ distance - 0.019625 \\ & * Arc\ Voltage * Welding\ Speed + 7.28408E - 003 * Arc\ Voltage \\ & * Nozzle\ To\ distance + 5.06796E - 003 * Welding\ Speed \\ & * Nozzle\ To\ distance \end{aligned}$$

From the figure 4.1a, the penetration is found to have an increasing trend with the increase of wire feed rate and arc voltage. .From the Fig.4.1b at lower value of welding speeds and higher the value of wire feed rate maximum 9.9 mm penetration can be achieved. figure 4.1c depicts that when welding set up is set at lower nozzle distance and higher wire feed rate 8.7 mm penetration can be attained. At the value of lower welding speed and higher arc voltage 8.8 mm penetration can be achieved. With the combination setting as shown in figure 4.1 d, the penetration depth is 8.92 mm. for the interaction surface 4.1e 8.2 penetration depth is obtained., it is evident that P increases with the increase in welding current for all values of welding speed.. The rate of increase in penetration depth with the increase in current decreases gradually as speed increases. These effects on Penetration are due to the reasons that current has positive effect but speed has a negative effect on penetration as discussed already in the direct effects of current and speed on penetration.

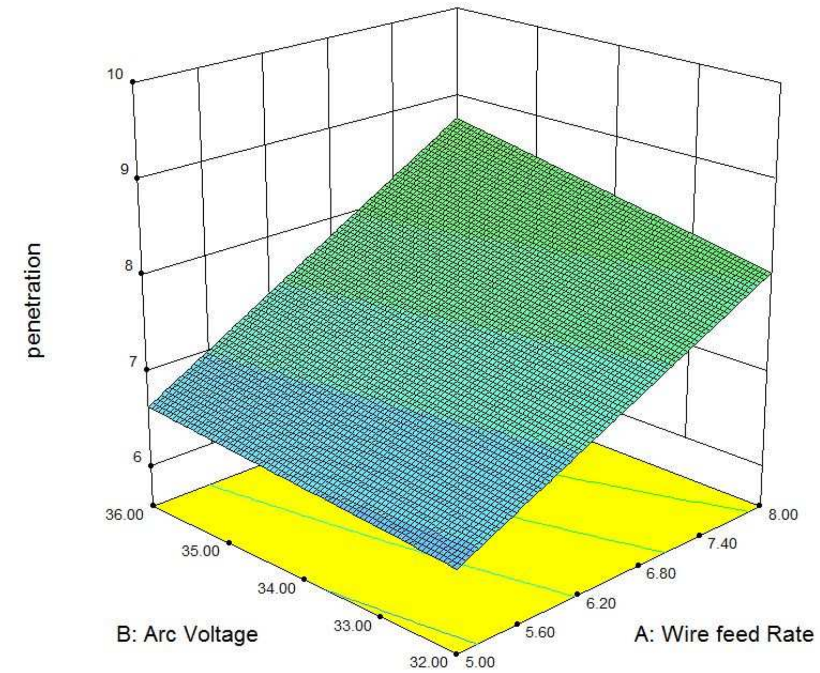

Figure 4.1a: Combined wire feed rate and arc voltage on penetration

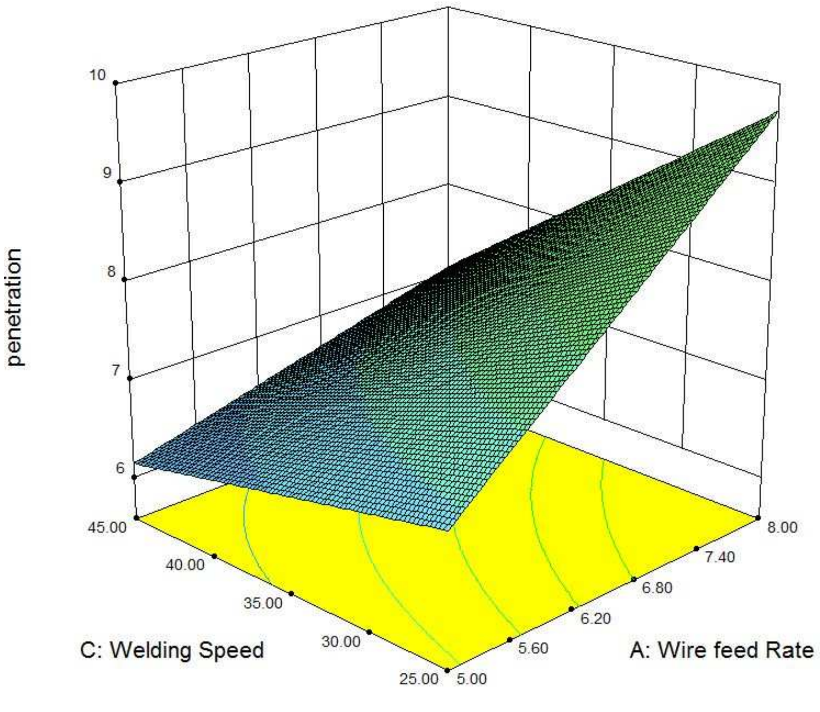

Figure 4.1b: Combined Effect Of welding speed and wire feed rate on penetration

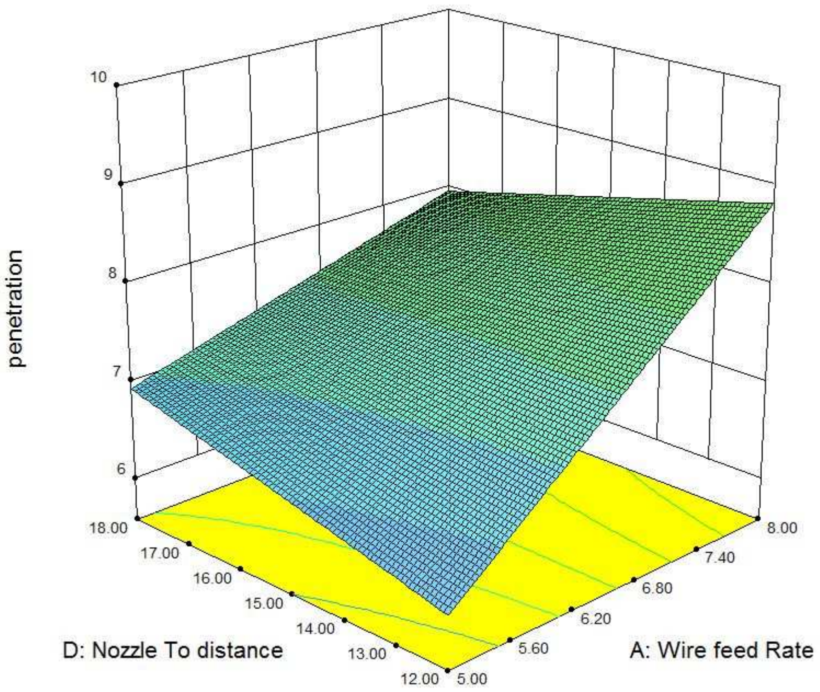

Figure 4.1c: Combined Effect Of wire feed rate and distance to nozzle on penetration

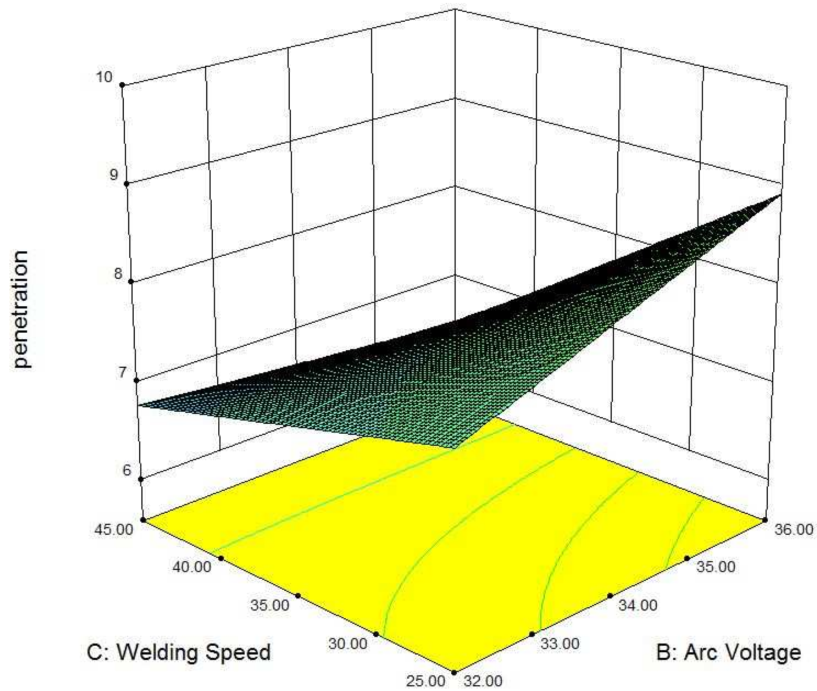

Figure 4.1d: Combined effect of arc voltage and welding speed on penetration

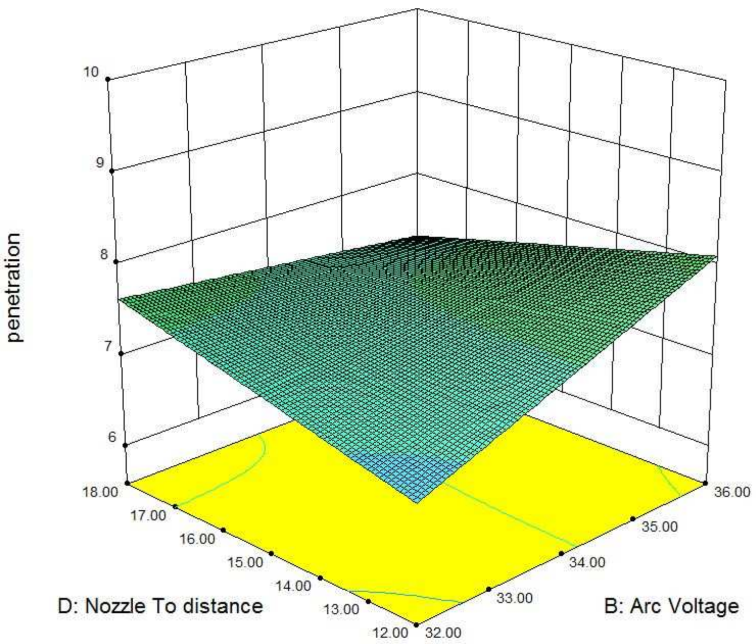

Figure 4.1e: Combined effect of distance to nozzle and arc voltage on penetration

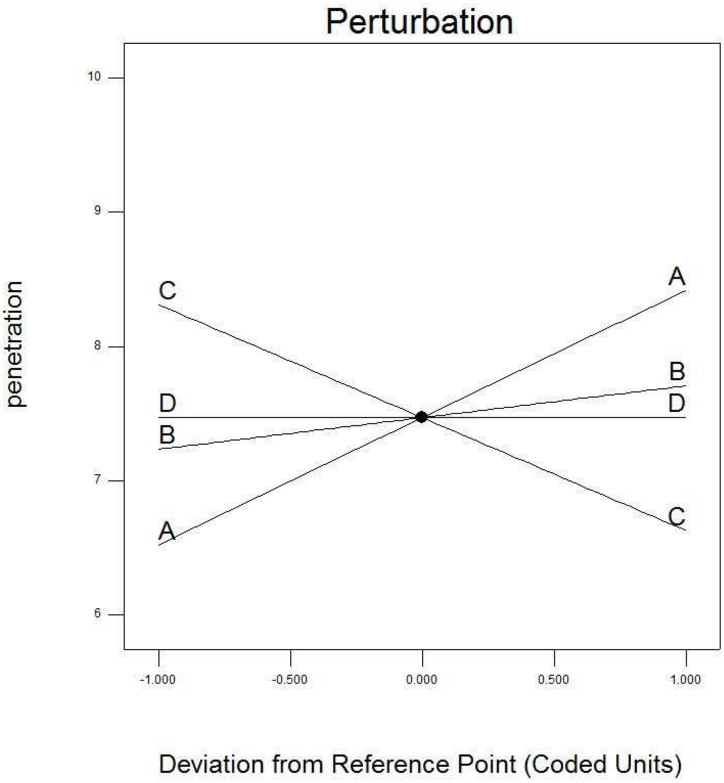

Figure 4.1f: Overall performance of penetration

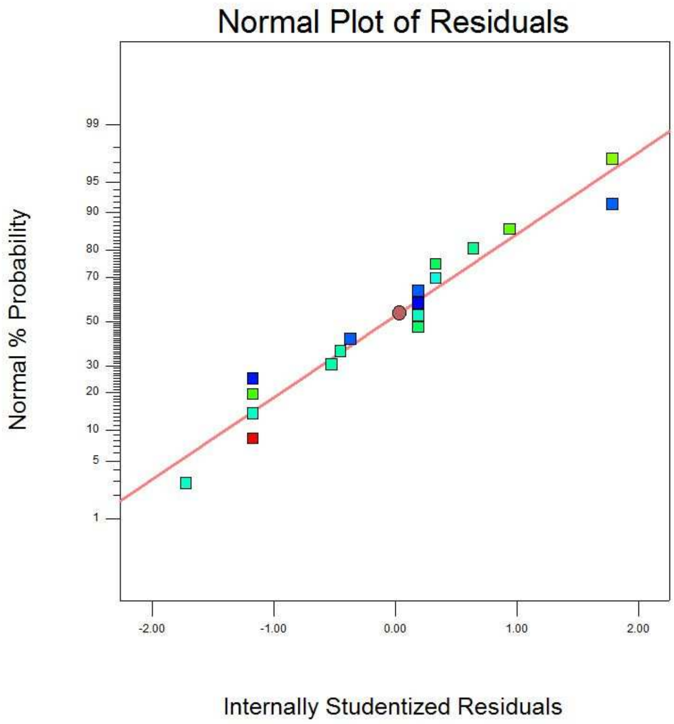

Figure 4.2: Normal Plot of Residuals for penetration

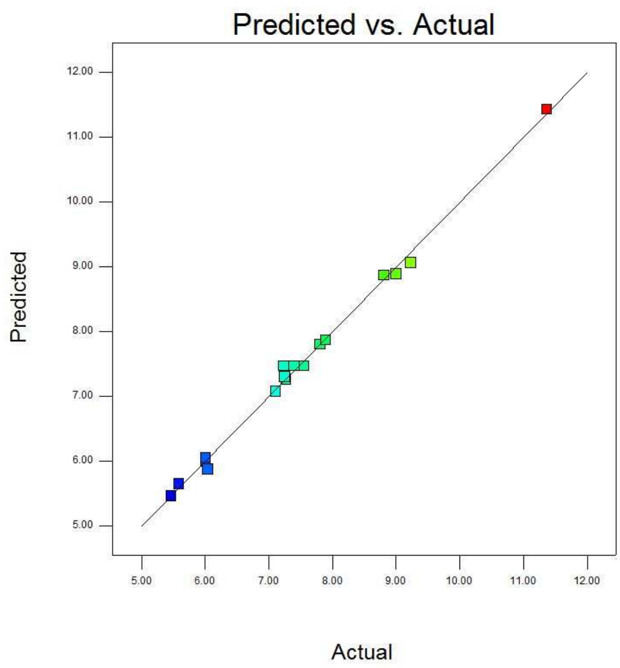

Figure 4.3: predicted and actual value for penetration

The residual analysis as a primary diagnostic tool is also done. Normal probability plot of residuals has been drawn (Figure 4.2). All the data points are following the straight line. Thus the data is normally distributed. It can be seen from Figure 4.3 that all the actual values are following the predicted values and thus declaring model assumptions are correct.

Table 4.8: Pooled ANOVA- penetration

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	36.70700164	9	4.078556	204.4664414	< 0.0001	significant
A-Wire feed Rate	5.079165099	1	5.079165	254.6290598	< 0.0001	
B-Arc Voltage	0.315284751	1	0.315285	15.80587715	0.0041	
C-Welding Speed	9.657451794	1	9.657452	484.1480484	< 0.0001	
AB	0.10125	1	0.10125	5.075872078	0.0543	
AC	1.74845	1	1.74845	87.65341762	< 0.0001	
AD	0.602537564	1	0.602538	30.20645529	0.0006	
BC	1.23245	1	1.23245	61.78526955	< 0.0001	
BD	0.584359333	1	0.584359	29.29514292	0.0006	
CD	0.10125	1	0.10125	5.075872078	0.0543	
Residual	0.15957849	8	0.019947			
Lack of Fit	0.14613049	7	0.020876	1.552333748	0.5514	not significant
Pure Error	0.013448	1	0.013448			
Cor Total	36.86658013	17				
Std. Dev.	0.14123495		**R-Squared**	0.995671459		
Mean	7.471383499		**Adj R-Squared**	0.990801851		
C.V. %	1.890345348		**Pred R-Squared**	0.96405212		
PRESS	1.325275386		**Adeq Precision**	56.68117143		

5. Conclusions

In the previous chapter, the effect of welding parameters on the response variables such as welding speed, wire feed rate, arc voltage and distance to nozzle has been discussed. Also the optimal levels of the machining parameters for each of response variables have been found out using response surface methodology (RSM). The important conclusions drawn from the present study are summarized below:

1. For welding maximum penetration, lower value of welding speed and higher the value of wire feed rate. when welding set up is set at lower nozzle distance and higher wire feed rate 8.7 mm penetration can be attained. At the value of lower welding speed and higher arc voltage 8.8 mm penetration can be achieved. For the interaction surface 4.2 mm penetration depth is obtained. It is evident that P increases with the increase in welding current for all values of welding.

2. The experimental values are in good agreement with the predicted values, thus the optimized results are validated.

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