International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Email:editorijoer@gmail.com http://www.ijoer.in

Vol.4., Issue.3., 2016
(May-June)

RESEARCH ARTICLE

ISSN: 2321-7758

OPTIMIZATION OF GMAW WELDING PROCESS PARAMETER USING AUSTENTIC STEEL THROUGH CENTRAL COMPOSITE DESIGN METHOD OF RSM

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ABSTRACT

Gas Metal Arc Welding is a process in which the source of heat is an arc form between consumable metal electrode and the work piece metal, which heats the work piece metals, causing them to melt and join with an externally supplied gaseous shield of gas either inert such as argon, helium. The experimental study aims at optimizing various Gas Metal Arc Welding parameter including Arc voltage, welding current, Nozzle to plate distance (NPD) and welding speed whereas weld angle, welding pressure and physical environment are ignored during developing a mathematical model to decide near optimal setting of the welding process parameters. Response surface method (RSM) approach has been applied for finding the relationship between the various process parameters and objective function. The first order regression method was developed to study the correlations. The analysis from DOE method can give the significance of the parameters as it give effect to change of the quality and strength of product or does not. An Orthogonal array and analysis of variance (ANOVA) are employed to investigate the welding. Finally the conformations tests have been carried out to compare the predicated values with the experimental values confirm its effectiveness in the analysis of Depth of Penetration. Finally the constrained optimization method is then applied to this model to optimize process parameters for maximizing weld penetration. This study revealed that to increase the welding speed and current up to a certain limit, to small weld bead, poor penetration and wastage of electrode will occurs. While low speed and current further result in excessive pilling up, weak weld and wastage of electrode. Therefore for producing sound weld the constraints must under some limit.

KEY WORDS: Gas Metal Arc Welding (GMAW), Depth of penetration, Response Surface Methodology (RSM), Mathematical model.

1. INTRODUCTION

Gas metal Arc Welding, is a welding process in which an electric arc forms between a consumable wire electrode and the work piece metal, which heats the work piece metals, causing them to melt, and join. Along with the wire electrode, a shielding gas feeds through the welding gun, which shields the process from contaminants in the air. The process can be semi-automatic or automatic.

A constant voltage, direct current power source is most commonly used with MIG, but constant current systems, as well as alternating current, can be used. There are four primary methods of metal transfer in MIG, called globular, short-circuiting, spray, and pulsed-spray, each of which has distinct properties and corresponding advantages and limitations. Originally developed for welding aluminium and other non-ferrous materials in the 1940, MIG was soon applied to steels because it provided faster welding time compared to other welding processes. The cost of inert gas limited its use in steels until several years later, when the use of semi-inert gases such as carbon dioxide became common. Further developments during the 1950s and 1960s gave the process more versatility and as a result, it became a highly used industrial process. Today, MIG is the most common industrial welding process, preferred for its versatility, speed and the relative ease of adapting the process to robotic automation.

The gas metal arc welding is basically a semi automatic process, in which the arc lengths of the electrode and the feeding of the wire are automatically controlled. The welding operator's job is reduced to positioning the gun at a correct angle and moving it along the seam at a controlled travel speed. Hence less operator skill is required with this process as compare to TIG.

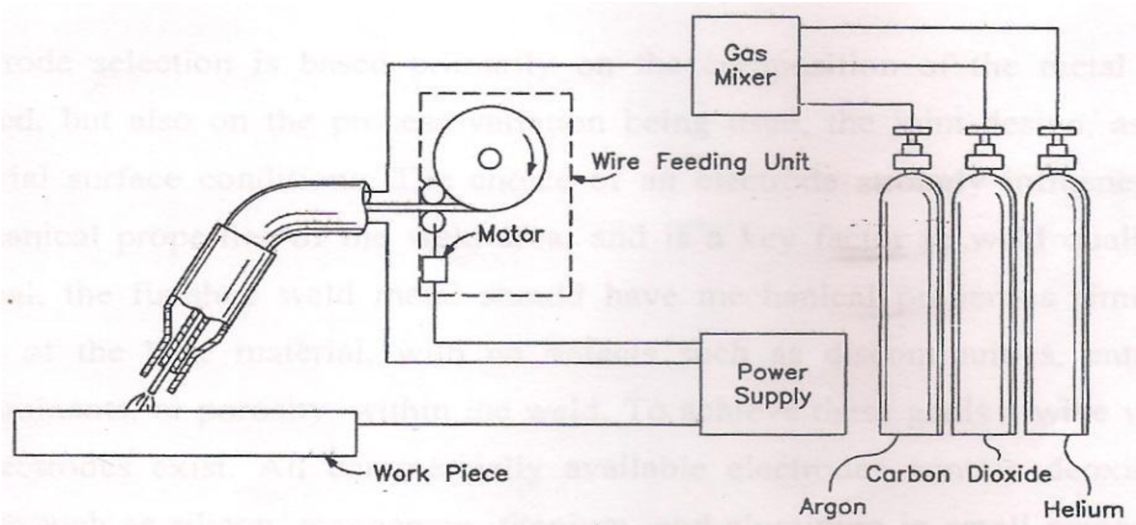

FIG:-1 GMAW CIRCUIT DIAGRAM

2. LITERATURE SURVEY ON OPTIMIZATION TECHNIQUE

Literature shows that work has been explored on various aspects of modelling, simulation and process optimization in TIG welding. In this study, detailed analysis has been made to establish relationships between welding parameters and weld bead geometry and weld quality leading to an optimal process.

- (SauravDatta ,2008) developed a grey-based Taguchi method for multi-response optimization of bead geometry in submerged arc bead-on-plate welding process.
- (Jackson and Shrubsall ,1953) performed optimization, neural networks and regression analysis in submerged arc welding process.
- (Murugan et al ,1993) used response surface methodology (RSM) to establish quadratic relations between the welding process parameters and bead geometry, for depositing 316L stainless steel onto structural steel, using automated submerged arc welding (SAW) and MIG welding,
- Tarng 2000) used the modified Taguchi method to determine the process parameters for optimum weld pool geometry in TIG welding of stainless steel.The modified Taguchi method allowed the simultaneous consideration of all the

weld pool geometry quality characteristics for optimization.

- (Kim 2003) Developed a model for the prediction of process parameter values for optimum bead geometry settings in GMAW of mild steel using the Taguchi method. Algorithms were developed using the multiple regression analysis and neural networks and the results of the developed models were compared with the experimental results.
- The Taguchi method is very popular for solving optimization problems in the field of production engineering.

3. OBJECTIVE

Excessive research work has been performed in Gas Metal Arc Welding process. Even though many literature is available on optimization of weld bead of welding Process parameters, but no systematic research works so far to correlate the process Parameters with welding joint strength. The strength of weld joint depends on Process parameters such as welding current, arc voltage, nozzle to plate distance and welding speed .The methodology used for the optimization is Response surface methodology.

It deals with the statistical technique to design and develop a mathematical model for predicting weld strength as a function of welding process parameters. This technique is able to predict linear , quadratic , cubic , and two factors interactive effects of process parameters on welding joint.

Our objective of this project is to produce sound weld bead by producing good surface quality and mechanical strength. The shape and size of the weld bead are very important in the use of rapid prototyping.

This experimental study aims at optimizing of weld joint strength as influence by Response Surface Methodology process parameters so to produce sound weld .

For this project, after conducting the related literature survey I found that response function (Y) depends upon following variables

$$Y= f (V,I,S,D)$$

Where, V= Arc voltage

I = Welding current

S = Welding speed

D = Nozzle to plate distance

4.EXPERIMENTATION

4.1. MACHINE AND EQUIPMENTS

The following machines and components were used for conducting the experiment:

1) A constant current gas metal arc welding machine (Invertee V 350 – PRO advanced
2) Processor with 5 to 425 amps output range).
3) Welding manipulator.
4) Wire feeder.
5) Filler material stainless steel wire of 1.2 mm diameter.
6) Gas cylinder containing a mixture of 98% argon and 2% of oxygen.

4.2.Workpiece Material

From the literature survey of past researchers it is show that the material selection in manufacturing process is most important think as per process availability and customer's requirement. There is number of material used in modern industry but steel have corrosion resistive property and high strength, so it is widely use in modern industry. The materials used to carry out experiment are Stainless steel AISI 409. The chemical composition and mechanical properties of Stainless steel AISI 409.

Table Chemical composition Of AISI 409

Element	Weight%
C	0.08
Mn	1
Si	1
Cr	10.5-11.75
P	0.045
S	0.045
Ti	0.48-0.75

Table Mechanical Properties of AISI 409

Density(Kg/m^3)	7.8
Elastic Modulus(GPa)	190-210

Tensile Strength(MPa)	450
Yield Strength(MPa)	240
Elongation(%)	25
Hardness(HRB)	80 Max

4.2.EXPERIMENTAL TECHNIQUE(RSM)

The Response surface methodology (RSM) is a collection of mathematical and statistical technique useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response.

A first order model with 2 independent variables can be expressed as

$Y = f(x_1, x_2) + e$

The variables x_1 and x_2 are independent variables where the response Y depends on them. The dependent variable Y is a function of x_1, x_2 and the experimental error term denoted by e. The error term e represents any measurement error on the response.The approximate function of first order model can be expressed as

$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + £$

And for 2nd order

$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{11} x_{11}^2 + \beta_{22} x_{22}^2 + \beta_{12} x_1 x_2 + £.$

Here, $\beta_0, \beta_1, \beta_2, \beta_{11}, \beta_{22}, \beta_{12}$ are the regression coefficient which can be estimated using RSM.

4.3 EXPERIMENTAL APPROACH

For the experimental setup the concerned values of the different variables are taken into consideration. The low level value (-) and the high level value (+) are shown in the table 1. The below value are used to find the coefficient of regression and design model.

TABLE1

Parameters	unit	Notation	Low level	High level
Welding current	amp	I	200	300
Arc voltage	Volts	V	25	35
Welding speed	mm/min	S	40	50
NPD	mm	D	15	20

4.4 DESIGNMATRIX

Design matrix chosen to conduct the experiments was central composite rotatable design. The design matrix comprises of full replication of 2^4=16, factorial designs. The upper(+) and lower (-) levels of all the four variables as shown in table.2 has been established by trial runs prior to ensure the strength of an acceptable weld bead.

TABLE2

Natural variables Coded variables Response

I	V	S	NPD	A	B	C	D	Y
200	35	50	20	1	1	1	1	8.53
100	25	50	20	-1	-1	1	1	7.89
200	25	40	20	1	-1	-1	1	6.76
100	35	40	20	-1	1	-1	1	6.45
200	25	50	15	1	-1	1	-1	8.90
100	35	50	15	-1	1	1	-1	7.76
200	35	40	15	1	1	-1	-1	9.67
100	25	40	15	-1	-1	-1	-1	5.54
200	25	50	20	1	-1	1	1	8.13
100	35	50	20	-1	1	1	1	7.96
200	35	40	20	1	1	-1	1	6.87
100	25	40	20	-1	-1	-1	1	3.74
200	35	50	15	1	1	1	-1	9.86
100	25	50	15	-1	-1	1	-1	6.93

200	25	40	15	1	-1	-1	-1	5.94
100	35	40	15	-1	1	-1	-1	5.12

In order to simplify the calculation, it is appropriate to use coded variables for describing independent variables in the (-1, 1) interval. The independent variables are rescaled therefore 0 is in the middle of the center of the design, and ±1 are the distance from the center with direction. The variables I, V, Sand Dare usually called naturalvariables, because they are expressed in the natural units of measurement. Therefore, if I, V, Sand Ddenote the natural variables Welding current, Arc voltage, Welding speed, and Nozzle to plate distance respectively then the transformation of these natural variables to coded variables is:

A=$\frac{I-250}{50}$B=$\frac{V-30}{5}$C= $\frac{S-45}{5}$D= $\frac{NPD-17.5}{2.5}$

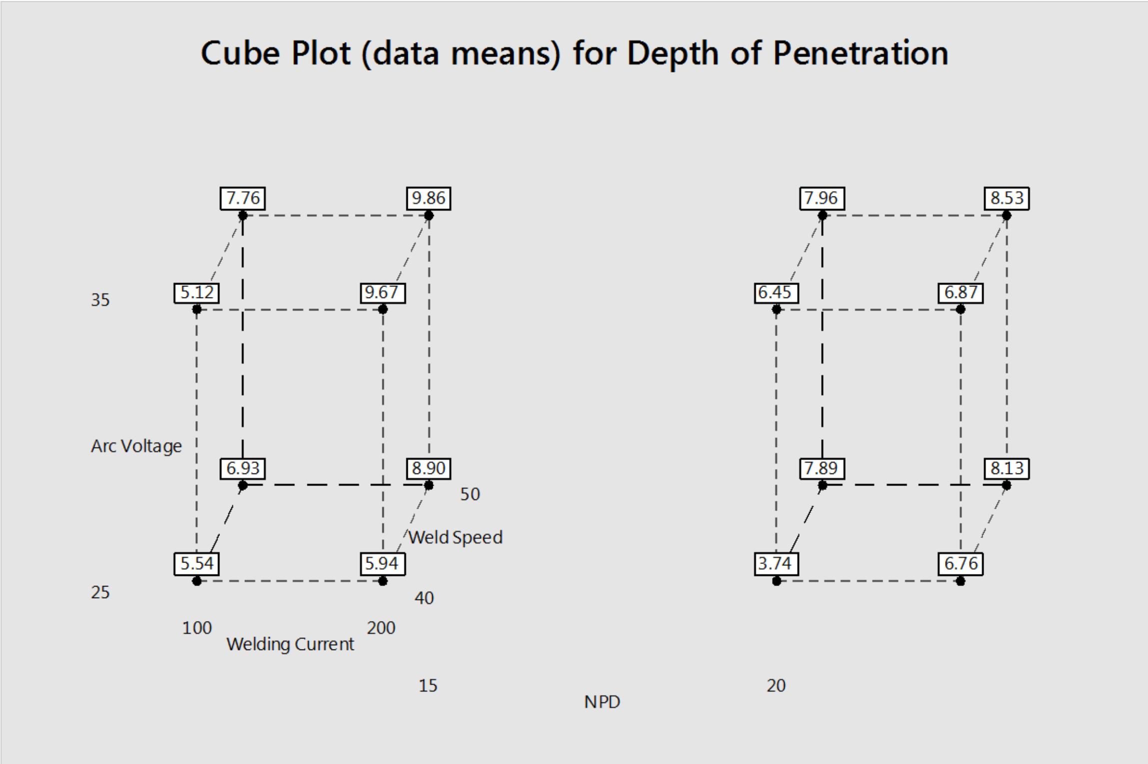

Fig2 The Geometric view of the Response variable Depth of Penetration

5. DEVELOPMENT AND ANALYSIS OF MODEL

5.1 SELECTION AND DEVELOPMENT OF THE MODEL

The response function representing weld bead geometry can be expressed as

Y = f (V,I,S,D) + £

Where Y = Response variable, V= arc voltage I= welding current in amps, S = welding speed in mm/min, D = contact tip to work distance (mm) and £=random error .

The first order surface response model can be expressed as

$Y= \beta_0 + \beta_1 I+ \beta_2 V+ \beta_3 S+ \beta_4 D+ £$

Where β_0 is the free term of the regression equation, the coefficient β_1, β_2, β_3 and β_4 are linear terms.

$$X=\begin{bmatrix}1&1&1&1&1\\1&-1&-1&1&1\\1&1&-1&-1&1\\1&-1&1&-1&1\\1&1&-1&1&-1\\1&-1&1&1&-1\\1&1&1&-1&-1\\1&-1&-1&-1&-1\\1&1&-1&1&1\\1&-1&1&1&1\\1&1&1&-1&1\\1&-1&-1&-1&1\\1&1&1&1&-1\\1&-1&-1&1&-1\\1&1&-1&-1&-1\\1&-1&1&-1&-1\end{bmatrix}$$

$$XX^1=\begin{bmatrix}16&0&0&0&0\\0&16&0&0&0\\0&0&16&0&0\\0&0&0&16&0\\0&0&0&0&16\end{bmatrix}$$

$$(XX^1)^{-1}=\begin{bmatrix}0.0625&0&0&0&0\\0&0.0625&0&0&0\\0&0&0.0625&0&0\\0&0&0&0.0625&0\\0&0&0&0&0.0625\end{bmatrix}$$

$$X^1=\begin{bmatrix}1&1&1&1&1&1&1&1&1&1&1&1&1&1&1&1\\1&-1&1&-1&1&-1&1&-1&1&-1&1&-1&1&-1&1&-1\\1&-1&-1&1&-1&1&1&-1&-1&1&1&-1&1&-1&-1&1\\1&1&-1&-1&1&1&-1&-1&1&1&-1&-1&1&1&-1&-1\\1&1&1&1&-1&-1&-1&-1&1&1&1&1&-1&-1&-1&-1\end{bmatrix}$$

FIG3 MULTIPLE LINEAR MODEL

The regression coefficient can be obtained by using the formula $\beta = (x^1x)^{-1}x^1y$.

$$X^1Y=\begin{bmatrix}116.05\\13.27\\8.39\\15.87\\-3.39\end{bmatrix}\qquad \beta=\begin{bmatrix}7.25\\0.83\\0.52\\0.99\\-0.21\end{bmatrix}$$

The fitted regression model for depth of penetration is

Y =7.25+ 0.83I + 0.52V + 0.99S - 0.21D

5.2 MODEL ADEQUACY CHECKING

In this section, I am going to analyze the adequacy. It is important to examine the fitted model if the model provides an adequate approximation of the true response surface. I will use normality, analysis of variance, regression and lack of fit test to examine the model. I used minitab to conduct the regression analysis of response surface. The results are shown in TABLE3

REGRESSION ANALYSIS

TABLE3

Predictor	Coef	SE	Coef T	P	Constant
	7.25	0.525944 13.78	0.000	0.830.525944	1.580.003
V	0.52	0.525944	0.99	0.000	
S	0.99	0.525944	1.88	0.000	
NPD	-0.21	0.525944	-0.40	0.003	

S = 2.26635 R^2 = 76.3% R^2= 67.5%

TABLE4

ANALYSIS OF VARIANCE

Source	DF	SS	MS	F	P
Regression	4	31.83	7.96	8.94	0.000
Residual Error	11	9.78	0.89		
Total	15	41.60			

Even though, the Tables 3 and 4 can be produced using a variety of computersoftware, it is imperative for me to show how to calculate and analyze them. The table ofanalysis of variance for significance of the regression is given as follows:

TABLE5

Variation	Sum of Squares	Degrees of Freedom	Mean Square	F
Regression	SS_R	q	MS_R	MS_R/MS_E
Error or Residuals	SS_E	N - q - 1	MS_E	
Total	SS_T	N -1		

N is observations

q is the number of independent variable

The error sum of squares $SS_E$is a measurement of the amount of variation explained by the regression, the smaller the SS_E, the better the regression model. The following is called the decomposition of the total variation

$SS_E = SS_T - SS_R$

$SS_T = Y^1Y - \frac{(\sum_{i=1}^{n} Y_i)^2}{n}$ and $SS_R = \beta^1X^1Y - \frac{(\sum_{i=1}^{n} Y_i)^2}{n}$

$SS_E = Y^1Y - \frac{(\sum_{i=1}^{n} Y_i)^2}{n} - (\beta^1X^1 - \frac{(\sum_{i=1}^{n} Y_i)^2}{n})$, hence

$SS_E = Y^1Y - \beta^1X^1Y$

The process of the decomposition of variance for Weld area Responseis shown as follows: - Y^1Y = 883.33, β^1X^1Y = 873.55and

$\frac{(\sum_{i=1}^{n} Y_i)^2}{n}$ = 841.73

SS_E = 883.33 – 873.55 = 9.78, **SS_R** = 873.55 – 841.73 = 31.83

SS_T = 883.33 – 841.73 = 41.60

$MS_R = \frac{SS_R}{q}$ = 31.83/4 = 7.96$MS_E = \frac{SS_E}{N-q-1}$ = 9.78/(16-4-1) = 0.89

Therefore the static F = MS_R/MS_E = 8.94

5.3 The Test for Significance of Regression

A good estimated regression model shall explain the variation of the dependent variable in the sample. There are certain tests of hypotheses about the model parameters that can help the experimenter in measuring the effectiveness of the model. The first ofall, these tests require for the error term e_i's to be normally and independently distributedwith mean zero and variance S^2. To check this assumption, I graphed the normalprobability of residuals.

If the residuals plot approximately along a straight line, then the normality assumption is satisfied. In this study, the residuals can be judged as normally distributed; therefore normality assumptions for both of the responses are satisfied. The error term is the difference between the observed value y_i^1 and the corresponding fitted value y_i, that is,$x_i = y_i - y^1{}_i$ As a result of this assumption, observations y_i are also normally and independently distributed. Therefore, the test for the significance of the regression can be applied to determine if the relationship between the dependent variable *y* and independent variables x_1, x_2……, x_q exists. The proper Hypothesis are

$H_0:\beta_1=\beta_2= .....=\beta_q=0$ Vs $H_0:\beta_j\neq 0$ for atleast one j.

The statistic F is compared to the critical $F_{(a,q,N-q-1)}$,if observed F-value is greater than the critical F, then H_0 will be rejected. Equivalently, H_0 will be rejected when P- value for the statistic F is less than significant level 'a'.

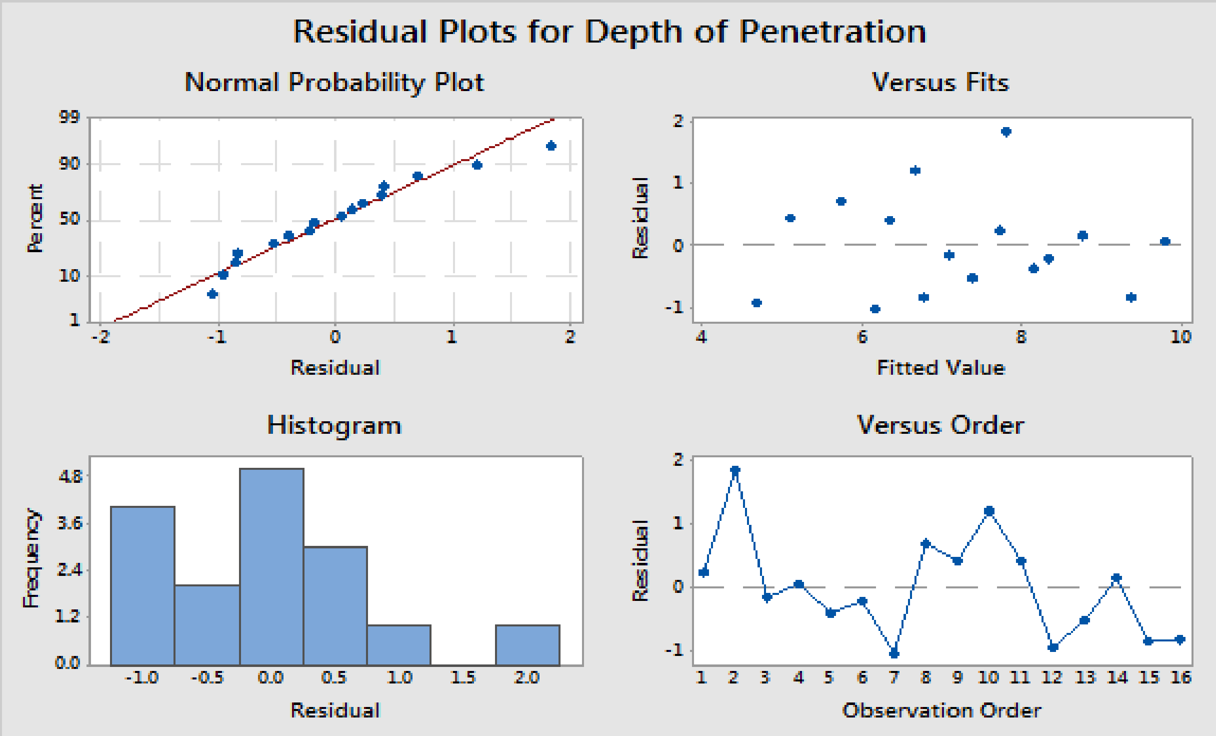

Fig 4 Normal probability plot

Using a % 5 level of significance, the critical value $F_{(0.05,4,11)}$= 3.36 is < the observed F = 8.94.Also, P-value from Figure4 for the statistic Fis less than a.It implies that at least one of the independent variables – Welding Current (I), Arc Voltage (V), Welding speed (S), and NPD (D) contributes significantly to the model.

How well the estimated model fits the data can be measured by the value of R^2. The R^2lies in the interval [0,1]. When $R^2$is closer to the 1, the better the estimation of regression equation fits the sample data. In general, the R^2measures percentage of the variation of Yaround $\overline{Y}$that is explained by the regression equation. However, adding a variable to the model always increased R^2, regardless of whether or not that variable statistically significant. Thus, some experimenter ratherusing$\overline{R}^2$. When variables are added to the model, the$\overline{R}^2$will not necessarily increase. In actual fact, if unnecessary variables are added, the value of $\overline{R}^2$will often decrease. I showed these results earlier in Table 3.

$$R^2 = \frac{SS_R}{SS_T} = 1-\frac{SS_E}{SS_T} = 1-\frac{9.78}{40.60} = 0.76$$

$$\overline{R}^2 = 1-\frac{SS_E/(n-q-1)}{SS_T/(n-1)} = 1-\frac{9.78/(11)}{40.60/(15)} = 0.67$$

Both of $R^2$and $\overline{R}^2$are statistically significant for the response variables Weld area. The result shows that the estimated regression equation fits the data well. Therefore at this point ,there is no sufficient reason to reject the initial regression equation.

5.4 The Test for Individual Regression Coefficients

In order to determine whether given variables should be included or discluded from the model, I need to test hypotheses for the individual regression coefficients. The simple analysis starts with a main effects plot. A main effects plot is a plot of the means of the response variable for each level of a factor. It allows me to obtain a general idea of which main effects may be important. The main effect is calculated by subtracting the overall mean for the factor from the mean for each level.

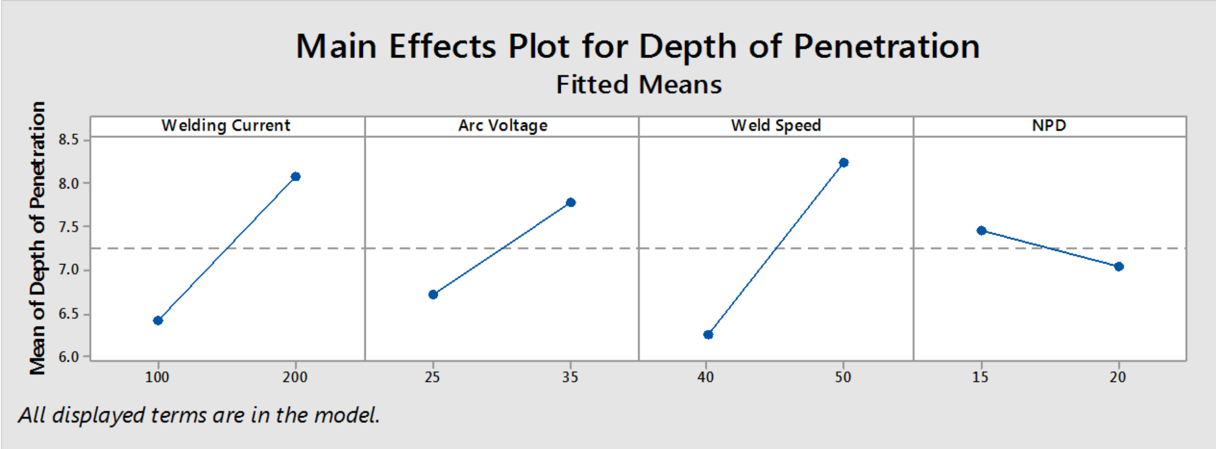

Fig 5. Main Effects Plot for Depth of penetration

My analysis indicates that the factors A, B, C, and Dincrease when they move from the low level to the high level of Depth of Penetration. Each level of the factors affects the response differently. Each factor at their high level results in higher mean responses comparing to that at the low level. Alternatively, the factors Aand Cappear to have a greater effect on the responses, with a steeply slope. If the slope is close to zero, the magnitude of the main effect would be small. The main effect plots are helpful in visualizing which factors affect the response the most, but in order to determine the significance of the factors, I have to conduct an appropriate statistical test, a T-test, to identify the significance of the main factors. In general, an F-test is used to test for more than one coefficient or, joint hypotheses. When the hypotheses test is particular to one coefficient at a time, then T-test is more common. To examine the significant contribution of the independent variables to the weld area, I did the following calculations for the following hypotheses:

H_0: $\beta_{Current} = 0$ H_1: $\beta_{Current} \neq 0$

H_0: $\beta_{Voltage} = 0$ H_1: $\beta_{Voltage} \neq 0$

H_0: $\beta_{Weld\ Speed} = 0$ H_1: $\beta_{Weld\ Speed} \neq 0$

H_0: $\beta_{NPD} = 0$ H_1: $\beta_{NPD} \neq 0$

The test for this hypothesis is called T-statistic, expressed as

$T_0 = \frac{\beta_j}{\sqrt{\sigma^2 w_{jj}}}$ where w_{jj} is the diagonal element of $(X^1X)^{-1}$ corresponding to β_j.The denominator $\sqrt{\sigma^2 w_{jj}}$ is called the standard error of the regression coefficientβ_j.

Now the value of $\beta = \begin{bmatrix} 7.253 \\ 0.830 \\ 0.524 \\ 0.991 \\ -0.212 \end{bmatrix}$, $(X^1X)^{-1}$

$$= \begin{bmatrix} 0.0625 & 0 & 0 & 0 & 0 \\ 0 & 0.0625 & 0 & 0 & 0 \\ 0 & 0 & 0.0625 & 0 & 0 \\ 0 & 0 & 0 & 0.0625 & 0 \\ 0 & 0 & 0 & 0 & 0.0625 \end{bmatrix}$$

And $\sigma^2 =$ 0.212Consequently, t-statistics are computed below:

$T_A = \frac{\beta_1}{\sqrt{\sigma^2 w_{11}}} = \frac{0.830}{\sqrt{0.212*0.0625}} = 7.21$ $T_B = \frac{\beta_2}{\sqrt{\sigma^2 w_{22}}} = \frac{0.524}{\sqrt{0.212*0.0625}} = 4.52$

$T_C = \frac{\beta_3}{\sqrt{\sigma^2 w_{33}}} = \frac{.991}{\sqrt{0.212*0.0625}} = 8.61$ $T_D = \frac{\beta_4}{\sqrt{\sigma^2 w_{44}}} = \frac{0.212}{\sqrt{0.212*0.0625}} = 1.84$

These T-statistic values are compared with the critical T-values. The null hypothesis H0:β_j= 0 is rejected if the observed T_0> critical value$T_{\frac{\alpha}{2},N-q-1}$.

The level of significance is at 5 percent, that is, a = .05. Noting that

$T_A = 7.21 > T_{\frac{\alpha}{2},N-q-1} = 2.22$,

$T_B = 4.52 > T_{\frac{\alpha}{2},N-q-1} = 2.22$

$T_C = 8.61 > T_{\frac{\alpha}{2},N-q-1} = 2.22$ and $T_D = 2.84 > T_{\frac{\alpha}{2},N-q-1} = 2.22$.

Therefore the null hypotheses H_0: $\beta_{Welding\ Current} = 0$, H_0: $\beta_{Voltage} = 0$, H_0: β_{Weld} Current = 0, are rejected.

All T-statistics are larger than the critical T-value expect NPD(D) which is less than critical value. I concluded that the independent variables, the Welding current (I), the voltage (V), the Welding Speed (S), and NPD all contribute significantly to the model.

6. Constrained Optimization of Response function Depth of penetration

The Response Variable Depth of Penetration is Shown by the Equation

$$Y = 7.25 + 0.83I + 0.52V + 0.99S - 0.21D$$

Subjected to Constrained

$100 \leq I \leq 200$

$25 \leq V \leq 35$

$40 \leq S \leq 50$

$15 \leq D \leq 20$

The Result therefore obtained for Depth of penetration = 9.86mm

And the value of variables are

I = 200 Amp

V = 35 Volts

S = 50mm/Min

NPD = 15 mm.

7. Results and discussions

In addition to the adequacy test performed, the validity of the results of mathematical modelling for Depth of Penetration was also tested by the help of design graph and models.

1. A four level four factor full factorial design matrix was used for the mathematical development of model to find the regression coefficient of first order surface response model for optimization of GMAW process parameters.
2. The optimization result shows penetration will be maximum when welding current, arc voltage, weld speed will be at maximum value while NPD is at minimum possible value. The physical reasons for the above results are discussed below

- Increase in welding current (I) increases the Depth of Penetration. It is known that the molten metal droplets transferring from the electrode to the plate are strongly overheated. As current increases the temperature of the droplets and hence the heat content of the droplets increases which results in more heat being transferred to the base plate. Increase in current reduces the size but increases the momentum of the droplets which on striking the weld pool causes a deeper Penetration or Indentation.
- Increase in Arc Voltage (V) resulted in an increase in Depth of Penetration, because of increase in heat inputs due to increase in current.
- Increase in Welding Speed (S) causes a increase in penetration but at the same time it causes too small bead, weak weld and wasted of electrode. This may be attributed at higher speed heat input is less but the momentum is very high causes deeper penetration but too small weld bead. So the investigation say the value of Welding Speed (S) must be chosen carefully.
- Decrease in Nozzle to Plate Distance (NPD) increases the Depth of Penetration because smaller the distance higher the heat inputs and larger the distance lesser the heat inputs.

1. From fig. 6 it is apparent that weld speed has maximum influence on the Depth of Penetration followed by Welding Current and Arc Voltage while the Nozzle to Plate Distance has negative influence on Depth of Penetration.
2. Fig.7 shows the interaction plot for Depth of Penetration which shows that Depth of Penetration increases when the value of Welding Current, Arc Voltage and Weld Speed increase from lower value to higher value but converse is true for NPD.

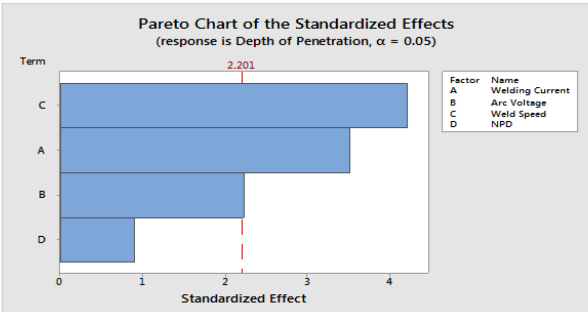

Fig6. Effects of factors on Response variable

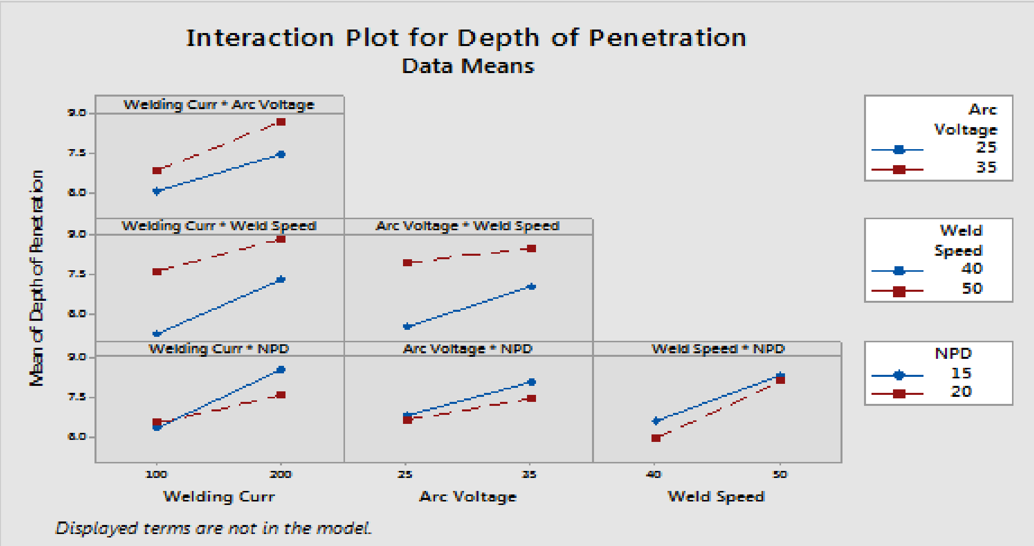

Fig 7. Interaction Plot for Depth of Penetration

8. Conclusion

Based on the mathematical model and graphical tool ,it can be observed that the developed model can be used to predict the weld bead area. This RSM technique of predicting process parameters can be used to get optimum value of parameters to get good weld bead area. The good weld bead area and weld penetration used to determine the stress carrying capacity of the joint. Therefore this method will help in reducing the manufacturing error and eliminates the need of skill operator for performing the welding process. The statistical method for modelling and optimization method used can be found great applications in industry because of its easiness and economically cheap. The GMAW process used in this research work is one of the most versatile welding technique and can be used to weld almost all kind of material .Hence we can say it is more efficient experimental method compared to other conventional method.

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