MATHEMATICAL MODELS TO PREDICT WELD BEAD GEOMETRY OF ALUMINIUM IN GAS METAL ARC WELDING

K. Ravi Varma * and Prof Dr. T. Srihari **
* IV B.E Mechanical , Vasavi College of Engineering
** Department of Mechanical Engineering,
Hyderabad - 31, Andhra Pradesh, India.
E. Thirupathi Reddy and N. S. Raj Kumar
* IV B.E Mechanical , Vasavi College of Engineering.

Abstract Mathematical models are necessary to incorporate the increase in automated and robotic welding processes for achieving optimal results through supervisory control strategy and optimization and stimulation techniques. The effect of arc voltage, wire feed rate, welding speed, nozzle to plate distance on weld width (w), penetration (p), Reinforcement (R), %Dilution (D), shape factor (W/P), Weld Reinforcement Form Factor (W/R), have been investigated by using a statistical tool of fractional factorial technique in automated GMAW of high strength and low density alloy steels of aluminum. The weld width increases increased with increase in open circuit voltage, and decreased with increase in weld speed. The developed models have been tested for their adequacy by using students F-test and T-test and coefficients have been tested for their significance to arrive at the final mathematical models. Main and interactive effects of the control variables on weld width, depth of penetration, reinforcement were presented in graphical form that helps in selecting quickly the process parameters to achieve the desired quality of weld.

Keywords : *GMAW, Weld Bead Geometry, Development of Mathematical Models, Fractional Factorial Technique.*

1. INTRODUCTION

Gas Metal Arc Welding is the first successful automated welding process introduced in the fabrication industry in the year 1920.[1,2] This process was known for its economy, high deposition rate, high welding speed, good appearance, deep penetration, slag and flux free conditions, smoke reduction, high operator factor, high recovery of filler materials with little smoke, and all position welding capacity made it suitable for both nonferrous and ferrous metals.

The Gas metal arc welding process utilizes the heat of the arc between the continuously fed consumable electrode and the work to be welded. The heat of the arc melts the surface of the base metal and the end of the electrode. The metal melted off the electrode is transferred through the arc to the work where it becomes the deposited weld metal. Shielding is obtained from an envelope of gas, which may be an inert gas an active gas or a mixture. The shielding gas surrounds arc area to protect it from contamination from the atmosphere. The electrode is fed into the arc automatically, usually from a coil. The arc is maintained automatically and travel and guidance can be manually or by machine.

Welds made by the GMAW Process have high strength and good ductility with low hydrogen and nitrogen content. This process is highly suitable for welding pressure vessels, shipbuilding's, penstocks, turbines, boilers made of different steels, Viz., Carbon steels, High strength low alloy steels, Chromium steels, Austenitic stainless steels, petrochemical components, offshore structures, and storage tanks. The commercial advantage is that Aluminium can be welded in all positions.[2]

With ever increase in demand for both production rates and high precision, fully mechanized or robotic welding processes have made considerable advancements in welding field. The use of automatic, semi-automatic and mechanized welding equipment has relieved a large number of workers for employment. The rate at which robots are being introduced in the welding industry is astonishing, and it may be expected that with in no time we would find more robots than men in welding fabrication units. Computers play a critical role in running the automatic welding processes and the command given by the computer will be taken from the programs which , in turn, need algorithm of the process parameters in the form of mathematical equations. To make effective use of the automatic

Email: *varma_fila@yahoo.com,**sriahriwelding@yahoo.com

welding systems it is essential that a high degree of confidence is achieved in predicting the weld bead geometry and shape relationship to attain the desired mechanical strength in weldments.[4] So, it is essential to develop mathematical models to predict accurately the weld bead dimensions and shape relationship to be fed to the automated welding system.

Statistically designed experiments based on the 'fractional factorial technique' not only reduce the cost, but also give the required information about the main and interactive effects on the response parameters.[5] So it was decided to use the well established statistical tool i.e., factorial technique to develop mathematical models from practical data. Metal inert gas (MIG) welding was carried out on aluminium plates under direct current electrode positive (DCEP), and the observed data was used for calculating the coefficients and to develop the model. The process parameters, Viz., Arc voltage, wire feed rate, welding speed, nozzle to plate distance on weld width (w) are to be controlled and kept in optimum working region for achieving the required quality. The quality of the weld bead depends mainly on the weld bead geometry and shape relationship Viz., penetration, weld width, reinforcement, dilution, weld penetration shape factor (WPSF), and the weld reinforcement form factor (WRFF). The bead geometry and the shape relationship are depicted in fig 1.

2. PLAN OF INVESTIGATION

The research work was planned and to be carried out in the following steps:

Step 1: Identification of important control variables.

Step 2: Finding out the upper and lower limits of the control variables, Viz., open circuit voltage (V), welding speed (S), wire feed rate (WFR), nozzle to plate distance (NPD), under DCEP.

Step 3: Developing the design matrix.

Step 4: Conducting the experiments as per design matrix.

Step 5: Recording the responses, Viz., depth of penetration (P), weld width (W), height of reinforcement (R), Dilution (D), weld penetration shape factor (WPSF) and weld reinforcement form factor (WRFF).

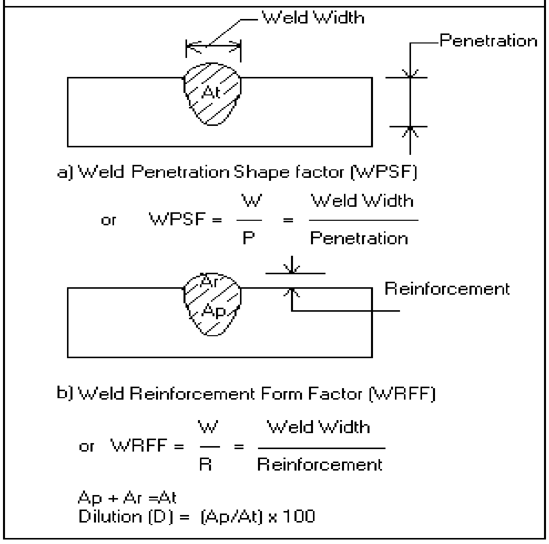
Step 6: Developing the mathematical models.

Step 7: Calculating the coefficients of the polynomial.

Step 8: Checking the adequacy of the developed models.

Step 9: Testing the significance of the coefficients.

Figure 1:
WELD BEAD GEOMETRY AND SHAPE RELATIONSHIP



Step10: Development of final mathematical models.

2.1. Identification of Process Variables

The process variables or control parameters such as, V, WFR, S, and NPD were identified and to carry out the experiment and to develop the mathematical models. Experiments were conduced taking the polarity as DCEP. The responses were measured after cross-sectioning the weld bead at its mid point. The responses were W, P, R, D, WPSF, WRFF. Thus all the control parameters and responses required for the investigation were identified.

2.2. Finding of the Limits of the Process Variables

Trials runs were conducted by changing the one of the process variables, keeping the rest of them constant. The working range was decided by inspecting the bead for smooth appearance and absence of any defect, Viz., porosity, blowholes, undercut, etc.

The upper and the lower limits of the of the factors were coded as +1 (or simply as +) and –1 (or simply –)[6] respectively. The coded values for the intermediate values can be calculated from the relationship.

$$\text{Coded value} = \frac{[\,(VUC) - (UL + LL) / 2\,]}{(UL - LL) / 2}$$

Table 1
CONTROL PARAMETERS, THEIR UPPER AND LOWER LIMITS IN DCEP POLARITY

PARAMETER	UNITS	NOTATION	LIMITS				
			-1	-0.5	0	0.5	1
Voltage	volts	V	28	28.5	29	29.5	30
Wire Feed Rate	m/min	WFR	2.25	2.625	3	3.375	3.75
Welding Speed	m/min	S	0.15	0.213	0.275	0.338	0.4
NPD	mm	NPD	10	12.5	15	17.5	20

DESIGN MATRIX: s

Table : 2

S.No	X1	X2	X3	X4
1	1	1	1	1
2	-1	1	1	1
3	1	-1	1	1
4	-1	-1	1	1
5	1	1	-1	1
6	-1	1	-1	1
7	1	-1	-1	1
8	-1	-1	-1	1
9	1	1	1	-1
10	-1	1	1	-1
11	1	-1	1	-1
12	-1	-1	1	-1
13	1	1	-1	-1
14	-1	1	-1	-1
15	1	-1	-1	-1
16	-1	-1	-1	-1

Where, VUC = Value under consideration,

UL = Upper Limit,

LL = Lower Limit.

The process parameters, their notations as well as their upper and lower limits are given in table 1.

2.3. Developing Design Matrix

For the construction of the design matrix a statistical tool of fractional factorial technique[7] was used. The matrix was developed by confounding four factors is shown in table 2. The number of runs were calculated for the relation, 2^n , where n stands for number of control parameters. In this case, 2^4=16 runs were required to investigate the effect of four parameters individually and

Y = f (V, WFR. S, NPD)

Where Y, the response of yeild. Eg., reinforcement, dilution etc.,

V = Arc Voltage (Open circuit voltage).

WFR = Wire Feed Rate.

S = Welding Speed.

NPD = Nozzle to plate distance.

For four factors the linear equations could be expressed as:

$$Y = [\ bo + b1X1 + b2\,X2 + b3\,X3 + b4\,X4 + b12\,X1X2 + b13\,X1\,X3 + b14\,X1X4 + b23\,X2\,X3 + b24\,X2\,X4 + b34\,X3\,X4 + b123\,X1\,X2\,X3 + b234\,X2\,X3\,X4 + b134\,X1\,X3\,X4 + b124\,X1\,X2\,X4\ ]$$

2.4. Testing of Coefficients:

Th Coefficients of the polynomial were found by using MS-Access (an RDBMS package) with functional database put in it, and the mathematical models were constructed. These models were checked for their adequacy and Significance by using F-test and T-test respectively with the values taken from MS-Access and were are found satisfactory.

2.5. Developing of final Mathematical Models:

After determining the significance coefficients, the final mathematical model were constructed by using the coefficients.

$$Yp = 1.234 + 0.247\ V + 0.91\ W + 0.191\ V\,W\,S - 0.191\ S\,N\,V + 0.278\ V\,W\,N$$

$$Yw = 7.962 + 0.675\ W + 0.994\ VW + 0.581\ W\,S - 0.65\ W\,S\,N - 0.744\ S\,N\,V + 0.6\ V\,W\,S$$

$$Yr = 4.406 - 0.837\ S - 0.219\ N + 0.21\ V\,N - 0.287\ S\,N - 0.188\ W\,S$$

$$Yd = 13.477 + 2.824\ S + 2.886\ N + 2.628\ V\,N\ 2.238\ V\,W\,S - 1.886\ S\,N\,V + 3.629\ V\,W\,N$$

$$Ywpsf = 7.898 - 1.729\ V - 1.364\ S - 0.891\ N + 1.477\ W\,N - 0.787\ V\,W\,S - 1.981\ V\,W\,N$$

$$Y\ wrff = 1.856 + 0.142\ W + 0.183\ S + 0.299\ V\,W + 0.199\ V\,W\,S - 0.162\ S\,N\,V + 0.222\ V\,W\,N$$

2.6. Analysis of Results:

The mathematical models furnished above can be used to predict and compare weld bead geometry and shape relationship merely by substituting the values in the coded form, of the respective factors. . Also the reverse calculations, ie, substitution of the values of the bead geometry and shape relationship will give the values of the factors in coded form.

The responses calculated from the mathematical models were plotted against the respective observed values. The results obtained were quite convincing.

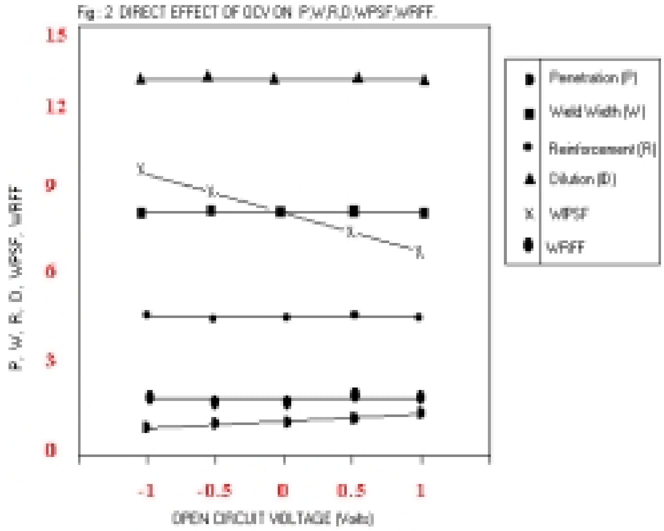


Fig 2

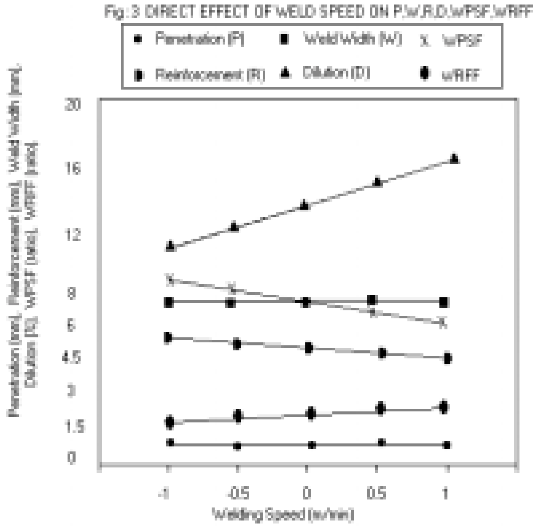


Fig 3

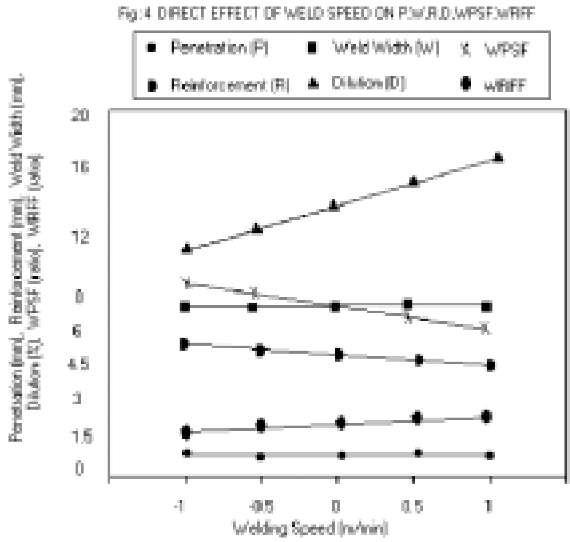


Fig 4

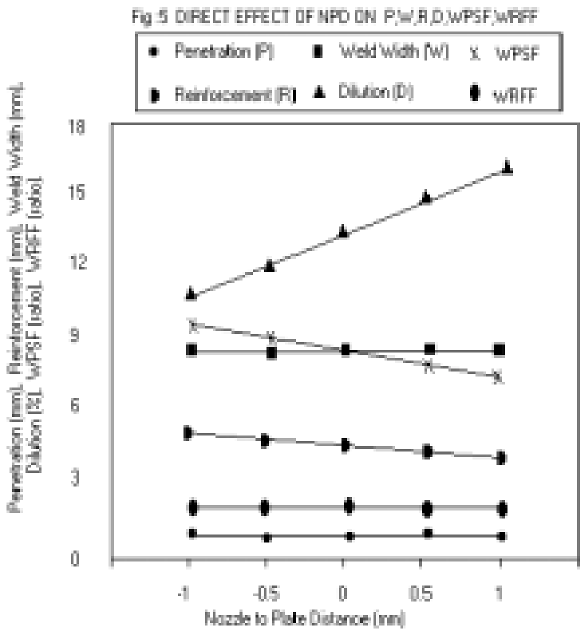


Fig 5

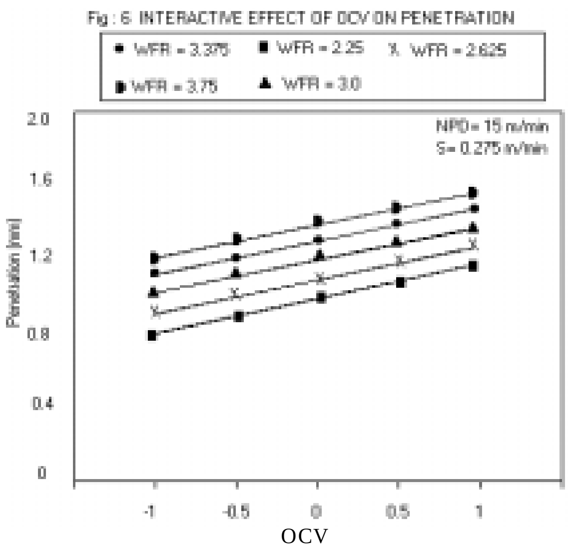


Fig 6

The effect of open circuit voltage (OCV) on weld width, penetration, reinforcement, dilution, WPSF and WRFF under is shown in fig 2. The increase in OCV causes an increase in arc voltage. Arc voltage lengthens the arc which has resulted in spread of the arc at its base and hence increase in weld width. Penetration increases with increase in voltage and may be attributed with the widening of the arc cone. Fig 2 depicts that, with the increase in open circuit voltage there is no change in reinforcement and dilution and also predicts that with the increase open circuit voltage WPSF decreases and there is no variation in the WRFF.

The effect of Wire feed rate (WFR) on penetration under the DCEP is shown in the fig 3. Here penetration increases with increase in WFR keeping voltage (V), speed (S) and nozzle to plate distance (NPD) constant. This was obviously due to the fact that weld current increases with increase in WFR. The increase in current causes the temperature of the droplet to increase, and hence the heat content of the droplet increases, resulting in more heat of the droplet transferred to the base plate. Hence deeper penetration occurs. Increase in current also increases the momentum of the droplets, which on striking the weld pool causes deeper penetration. With the increase in WFR weld width also increases and no change on reinforcement.

The effect of WFR on percentage dilution is shown in the fig 3. It is interesting to know that as WFR increases dilution increases sharply. In DCEP polarity, increase in dilution with the increase in WFR could be attributed to the fact that the increase in the area of the molten metal due to he increase in welding current as a consequence of increase in WFR was more than the increase in area of the metal deposited across a given cross-section. In DCEP, as the plate is negative, more heat is generated at the work. With the increase in welding current, the base plate melted is also more. So, dilution increases with the increase of WFR. It is evident from the figure that as WFR increases WPSF is constant. This is due to the fact as WFR increases both weld width and penetration increases and leads in getting a constant value. WRFF also increases as there is increase in WFR.

Fig 4 shows the variations of P, W, R, WFR on weld speed. From this it is clear that as speed increases there is no change in penetration and weld width. Since at lower speeds the weld bead is larger in mass, where as at higher welding speed it is smaller in mass. Regarding the reinforcement, it decreases with increase in speed. There is no effect on dilution though there is change in the speed. WPSF decreases and WRFF increases sharply with the increase of weld speed.

The effect of nozzle to plate distance on various parameters are shown in the fig 5 and found that with increase of NPD there is no change in penetration and weld width. But with the increase of NPD reinforcement increased slightly and dilution increased sharply. Wi6h the increase of NPD weld penetration shape factor decreased.

The interactive effects of the OCV on penetration is shown in the fig 6.

3. CONCLUSION

Factorial technique is a fast, easy and accurate method for developing mathematical models for predicting weld bead geometry and shape relationship with in the working region of the process variables. The developed models can be used in the automatic or robotic welding systems in the form of program for obtaining the desired quality of welds.

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