Modeling and Parametric Optimization using Factorial Design Approach of Submerged Arc Bead Geometry for Butt Joint

Rati Saluja*, K M Moeed**
*(Mechanical Engineering Department, Goel Institute of Technology and Management, India)
** (Mechanical Engineering Department, Integral University, India)

ABSTRACT

Automatic and robotic welding systems could used effectively, when optimal process parameters for achieving the desired quality and relative effects of input parameters on output parameters can be obtained. Response surface methodology (RSM) technique is applied to determine and characterize the cause and effect relationship between true mean responses and input control variables influencing the responses. This paper deals with the application of Factorial design approach for optimizing four submerged arc welding parameters viz. welding current, arc voltage, welding speed and electrode stick out by developing a mathematical model for sound quality bead width, bead penetration and weld reinforcement on butt joint.

Keywords **- Factorial Design approach, Response Surface Methodology, Submerged arc welding, Weld geometry,**

I. INTRODUCTION

Submerged Arc Welding (SAW) is increasingly used in joining metals in metal fabrication techniques industry due to its reliability and capability of producing weld of sound quality. In SAW, various input parameters interact in an intricate manner and influences the bead geometry, bead quality as well as metallurgical characteristics. It produces invisible arc and minimal fumes; thus it provides a comfortable work environment. It also allows use of multiple arcs in one puddle which leads to its extremely high rate of deposition, which permits for more rapid heat penetration and arc stability [1]. Presently SAW can put up to five wires in one puddle, offering the opportunity to create a faster weld with distinctive, specialized properties.

Shigeo Oyama [1]had described the high-speed one-side submerged arc welding process (NH-HISAW) that dramatically increases the welding speed in the panel assembly process in shipbuilding at least twice as fast as the conventional process which lowers the time as well as cost of the process. A software system computing the bead geometry of submerged arc welds was developed by Chandel [2] had presented theoretical predictions of various input parameters on the melting rate and bead geometry in SAW. Murugan [3] gave an apparent design of relationship between the input process parameters and the weld bead geometry in GMAW by developing a four factor five level mathematical model for predicting weld bead geometry within the optimal region of control parameters for stainless steel surfacing.

An extensive study on the application of Taguchi technique and regression analysis to determine the optimal process parameters for submerged arc welding (SAW) had made by S Kumanan [4].

Automatic and effective welding systems can be used effectively when mathematical models that correlate with process parameters to bead geometry and bead quality are readily available. The various approaches for modeling in welding include Response Surface Methodology (RSM) and Factorial design, Artificial Neural Network (ANN) modeling and Hybrid Optimization techniques [9, 11].

This paper focus on the cause and effect relationship [7] between four important input process variables viz. welding current, arc voltage, welding speed and electrode stick out on output parameters viz. bead width, bead penetration and weld reinforcement. A mathematical model [4] is constructed and two level half Factorial design approach had been used for finding the relation between process variables on responses. This indicates application feasibility of the Factorial technique over Taguchi Analysis for continuous improvement in product quality in manufacturing industry.

1.1 Factorial Design approach and terminology

Factorial design planning is simply applied to determine and represent the cause and effect relationship between true mean responses and input control variables influencing the responses. Three kinds of design of experiments [5,12] are possible between output and input variables.

1. Screening designs are used in beginning of process where more than five factors are involved, to recognize the most critical factors.
2. Characterization deigns narrow the numbers of factors to only a few and permit for some quantitative understanding of the interactions among factors.
3. Optimization designs focus on only one or two factors, but in much more depth to gain a precise understanding of relationships between factors

A full Factorial design combines the levels for each factor with all the levels of every factor. It covers all combinations and provides best data. However it consumes more time and resources.

While a fractional Factorial design, uses too many of resources, or if a slightly non orthogonal array is accepted a fractional design is used. To analyze the data from a design of experiment, evaluating the statistic significance by computing one way ANOVA, or for more than one factor N-way ANOVA is essential. The practical significance can be evaluated through sum of squares, line or column charts, and normal probability chart.

II. Methodolgy

The work to be carried out was planned in the following order:

1. Identification of important process variables;
2. Finding different levels of the identified process variables;
3. Development of design matrix;
4. Conducting experiments as per the design matrix;
5. Recording the responses, viz. bead penetration, and bead width and weld reinforcement,
6. Development of mathematical model
7. Calculation of regression coefficients
8. Checking the adequacy of the developed model
9. Development of final mathematical model by testing the significance of regression models
10. Presenting the main and significant interaction effects of process parameters on bead penetration, and bead width and weld reinforcement of Butt weld.

2.1 Identification of operating variables

Selection of process variables has considerable influence on the weld quality, weld geometry, and weld metallurgy [7]. Table1 shows independent controllable process variables, which were identified based on their significant effect on weld bead to carry out the experiments.

The experiment was conducted at RDSO, Lucknow, India, with a constant voltage, rectifier type semiautomatic SAW equipment with power source. It was used to join the mild steel plates of size 400 mm (length) × 60 mm (width) × 7 mm (height). Copper coated electrodes AWS ER70S-6, 3.15 mm diameter, of coil form (ESAB brand) and basic-fluoride-type (equivalent to DIN 8557) granular flux was used.

Fig. 1 Typical photographic view of weld sample

A V groove butt joint with angle 45^0 and root opening 1 mm was selected to join the plates in the flat position, keeping the electrode positive and perpendicular to the plate. Samples of 10 mm width were cut from the test piece and were polished, etched and the bead geometries were measured.

Table1-Welding parameters and their levels

Symbol	Welding parameters	Units	Level 1	Level 2
I	Welding current	Amp	360	390
V	Arc voltage	Volts	25	26
S	Welding speed	mm/min	400	420
L	Electrode stick out	mm	19	25

2.2 Finding different levels of the identified process variables

The levels for each factor were the highest value and the lowest value of the factors in between and at which the outcome was acceptable. These values were outcomes of trials runs. Highest value has been represented by '+' and the lowest value has been represented by '-' as mentioned in Table 2.

2.3 Development of design matrix

For conducting trial runs levels of these values were chosen randomly such that sampling fraction for these trials run was equal to zero, however rough range was taken from literature survey [4]. With the help of these trials run effective, representative levels were developed for each variable. The factorials are also known as 2-k factorials, where 2 is the number of levels and k is no of important process variables [12]. For full Factorial approach number of runs are equals to 2^k whereas for half factorial or fractional factorial number of runs are equal to 2^{k-1}.

If full Factorial approach had been practiced then number of possible runs will be 2^4 i.e.16. Half factorial approach had been applied according to which the number of treatment combinations becomes 2^{k-1} (2^{4-1} = 8).

Table2-Design matrix and their responses

S.No.	Design matrix				Bead width mm	Bead penetration mm	Weld Reinforcement mm
	I	V	S	L			
1	-	-	-	-	13.0	3.0	2.0
2	-	-	-	+	11.0	3.5	2.0
3	-	+	+	-	12.5	3.5	3.0
4	-	+	+	+	13.5	4.0	1.5
5	+	-	+	-	14.5	5.0	2.0
6	+	-	+	+	14.0	4.5	2.5
7	+	+	-	-	14.5	4.0	2.0
8	+	+	-	+	15.0	3.5	3.0

2.4 Mathematical Model Developed

Assuming the values of responses as y_1, y_2, y_3, y_4, y_5, y_6, y_7, y_8 against the treatment combinations 1, 2, 3, 4, 5, 6, 7, 8 respectively Y as the optimized value of response. The response function represents any of the weld dimensions can be expressed as the following equation:

Y = f (I, V, S, L) and the relationship selected, being a second degree response surface, expressed as follows:

$$Y = b_0 + b_1I + b_2V + b_3S + b_4L + b_{12}(IV) + b_{13}(IS) + b_{14}(IL) + b_{23}(VS) + b_{24}(VL) + b_{34}(SL) \quad (1)$$

2.5 Evaluation of coefficient of models

The values of the coefficient ware calculated with the help of following calculations:

$b_0 = [(y_1+y_2+y_3+y_4+y_5+y_6+y_7+y_8)]/8$

$b_1 = [(y_5+y_6+y_7+y_8)-(y_1+y_2+y_3+y_4)]/8$

$b_2 = [(y_3+y_4+y_7+y_8)-(y_1+y_2+y_5+y_6)]/8$

$b_3 = [(y_3+y_4+y_5+y_6)-(y_1+y_2+y_7+y_8)]/8$

$b_4 = [(y_2+y_4+y_6+y_8)-(y_1+y_3+y_5+y_7)]/8$

$b_{12} = [(y_1+y_2+y_7+y_8)-(y_3+y_4+y_5+y_6)]/8$

$b_{13} = [(y_1+y_2+y_3+y_4)-(y_5+y_6+y_7+y_8)]/8$

$b_{14} = [(y_1+y_4+y_6+y_7)-(y_2+y_3+y_5+y_8)]/8$

$b_{23} = [(y_1+y_3+y_6+y_8)-(y_2+y_4+y_5+y_7)]/8$

$b_{24} = [(y_1+y_2+y_5+y_6)-(y_3+y_4+y_7+y_8)]/8$

$b_{34} = [(y_1+y_4+y_5+y_8)-(y_2+y_3+y_6+y_7)]/8$

Table 3 Estimated value of the coefficient of the models

S No	Coeff-icient	Bead width W	Bead penetration P	Weld reinforcement R
1	b_0	13.5	3.8125	2.25
2	b_1	1	0.375	0.125
3	b_2	0.375	-0.125	0.125
4	b_3	0.125	0.375	0.002
5	b_4	-0.125	0.002	0.002
6	b_{12}	-0.125	-0.375	0.001
7	b_{13}	-1	-0.375	-0.125
8	b_{14}	0.25	0.001	-0.25
9	b_{23}	0.125	-0.25	0.375
10	b_{24}	-0.375	0.125	-0.125
11	b_{34}	0.5	0.001	-0.125

The values of different coefficients for different responses were calculated as per the modeling as given in table 3. These values of coefficients represent the significance of corresponding variable on the response [8]. Higher value of coefficients signifies higher influence of the variable on the response. Inverse relationship between variable and response is found when the value of coefficient is negative.

2.6 Checking the adequacy of models developed

The estimated value of the coefficient of the model indicates as to what extent the important process variables affect the responses quantitatively [6]. The result through analysis of variance as given in Figures 2, 3and 4 shows that welding current and arc voltage has the significant parameters that affect bead width while welding speed and electrode stick out has little effect on weld bead.

Similarly ANOVA is carried out for other weld parameters, which shows that welding current and welding speed have major influence on bead penetration whereas electrode stick out has minor effect. Weld reinforcement is equally influenced by welding current and arc voltage. The value of F- ratio for a desired level of confidence (95%) was achieved that indicated model may be considered adequate within the confidence limit.

2.7 Development of the final models

The final mathematical model as determined by the above analysis can be represented by following equation:

$$W = 13.5 + I + 0.75V + 0.125S - 0.125L - 0.125IV - IS + 0.5IL + 0.125VS - 0.375VL + 0.5SL \quad (2)$$

$$P = 3.8125 + 0.375I - 0.125V + 0.375S - 0.375IV - 0.375IS - 0.25VS + 0.125VL \quad (3)$$

$$R = 2.25 + 0.125I + 0.125V - 0.125IS + 0.25IL + 0.375VS - 0.125VL - 0.125SL \quad (4)$$

2.8 Analysis of the results

In fig 2, 3 and 4 main and significant interaction effects of process parameters on bead penetration and bead width sand weld reinforcement are plotted.

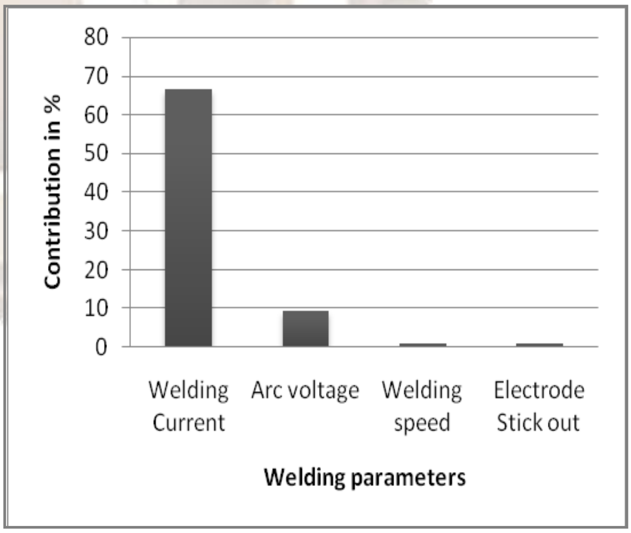

Fig.2: Influence of process parameters on bead width.

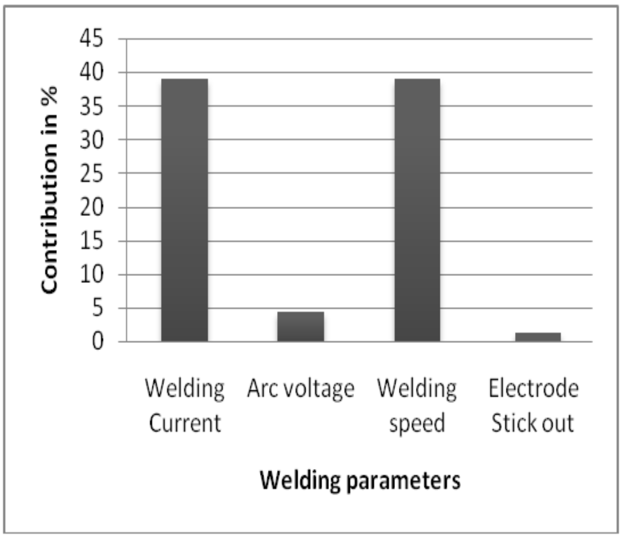

Fig.3 : Influence of process parameters on bead penetration.

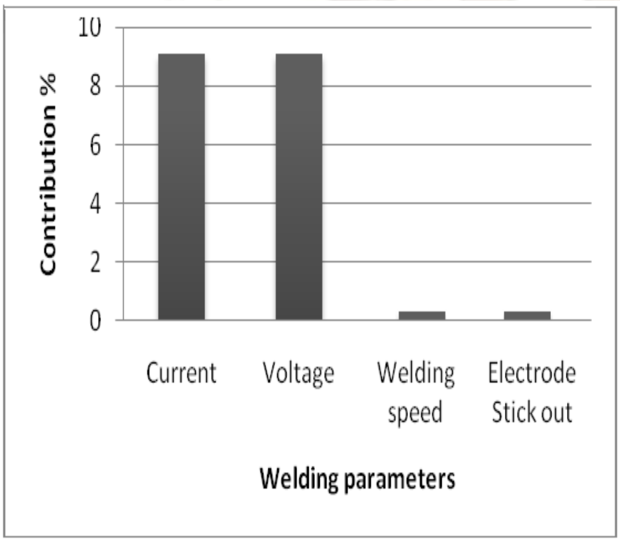

Fig.4: Influence of process parameters on weld reinforcement.

III Conclusions

The study of the previous work reviews that a two level Factorial technique can be employed easily for developing mathematical models for predicting sound quality bead width, bead penetration, and weld reinforcement. Results indicate that process variables influence Submerged arc bead geometry for butt joint to a significant extent. Welding current has more predominant effect on the weld geometry than that of other parameters.

Welding current and arc voltage has the considerable factors that affect bead width while welding speed and electrode stick out has minor effect on bead width. Welding current and welding speed have major influence on bead penetration whereas electrode stick out has minor effect.

Weld reinforcement is equally influenced by welding current and arc voltage. Welding speed and electrode stick out had little or negligible effect on weld reinforcement that indicates critical parameters for weld reinforcement may be different process variables viz. type of current used, polarity used, flux-type or width of flux layer.

REFERENCES

[1] Shigeo Oyama, Tadashi Kasuya, High-speed One-side Submerged Arc Welding Process "NH-HISAW", *Nippon Steel Technical Report No. 95*, 2007, pp. 17-21
[2] N. Murugan, R. S.Parmar, Effects of MIG process parameters on the geometry of the bead in the automatic surfacing of stainless steel", *Journal of Materials Processing Technology, vol. 41*, 1994, pp. 381-398.
[3] M.Singla , D.Singh , Parametric optimization of Gas Metal Arc Welding Processes by using Factorial Design approach, *Journal of Minerals & Materials Characterization & Engineering, vol. 9*, 2010, pp.353-363
[4] S. Kumanan , J. E. Dhas Raja, Determination of submerged arc welding process parameters using Taguchi method and regression analysis , *Indian Journal of Engineering & Materials Sciences, vol. 14,* 2007, pp. 177-183.
[5] M. Aghakhani, E. Mehrdad, Parametric Optimization of Gas Metal Arc Welding Process by Taguchi Method on Weld Dilution, *International Journal of Modeling and Optimization, vol. 1,* 2011, pp. 216-220
[6] K.C. Jang, D.G. Lee, Welding and environmental test condition effect in weldability and strength of Al alloy", *Journal of Materials Processing Technology, vol. 164-165*, 2005, pp.1038-1045.
[7] W Omer Blodgett., R. Scott Funderburk, *Fabricators, and Erectors guide to Welded steel construction*, 1999.
[8] J. H. Nixon, J. Norrish, Determination of pulsed MIG process parameters, *Welding and Metal Fabrication*, 1988, pp. 4-7.
[9] F.Wang and W. K Hou., Modelling and analysis of metal transfer in gas metal arc welding", J. Phys. D: Appl. Phys., vol. 36, 2003, pp.1143-1152.
[10] *Welding Handbook, vol.1,* The American Welding Society, 1987.
[11] S. Datta, S. S.Mahapatra, Multi-Objective Optimization of Submerged Arc Welding Process, *The Journal of Engineering Research, vol. 7,* 2010, pp. 42-52.
[12] *Six Sigma*, http://www.iactglobal.in/, 2010.