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Optimization of welding parameters for maximization of weld bead widths for submerged arc welding of mild steel plates

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Abstract

Taguchi's philosophy has been applied for obtaining optimal parametric combinations to achieve desired weld bead geometry and dimensions related to heat effected zone. The philosophy and methodology proposed by Dr. Genichi Taguchi can be used for continuous improvement in products that is produced by submerged arc welding. Based on Taguchi's approach, the present study centers around adoption of L_8 orthogonal array design and experiments have been accordingly conducted with two different levels of convenient process parameters e.g. welding current, arc voltage, welding speed and electrode stick out to obtain bead widths on the mild steel plates. Weld bead width measured for each experiment run. Finally an optimal parameter setting of weld bead width has been predicted.

Keywords: Multiple Regression Analysis, Submerged Arc Welding, Taguchi Method, Weld Bead Widths**.**

1. Introduction

Welding is a process of joining different materials. It is more economical and is a much faster process compared to both casting and riveting .Submerged Arc Welding (SAW) Process is one of the oldest automatic welding process introduced in 1930s to provide high quality of weld. The quality of weld in SAW is mainly influenced by independent variables such as welding current, arc voltage, welding speed and electrode stick out. The prediction of process parameters involved in submerged arc welding is very complex process. Researchers have many attempts to predict the process parameters of submerged arc welding to get smooth quality of weld. Kumaran S, et al. [4] elaborates the study of welding procedures generation for the submerged arc welding process. Prediction and optimization of the weld bead volume for SAW mathematical models was carried out by Gunaraj et al. [1].Prediction and control of weld bead geometry and shape relationship in SAW of pipes was studied by Gunaraj V, et al. [2]. A good numbers of works has already been carried out in the field of submerged arc welding .

Moon H.S.et al. [3] analyzed in development of adaptive fill control for Multitorch Multipass Saw and stated several advantages in sensor and process control technique for applications in SAW which combine to give a fully automatic system capable of controlling and adaptive the overall welding process. At present, the focus of many studies are more on the prediction of different welding processes on different configuration using Taguchi's methodology for optimization of welding parameters and regression analysis and validating with experimental results. The present study focuses on Taguchi method on design of experiments to build the mathematical model by multiple regression techniques for prediction of optimal parameter setting of weld bead width and weld bead width hardness.

2. Experimentation

The experiment was conducted at the Welding Centre of National Institute of Technical Teachers' Training and Research,Kolkata with the following set up. "TECHNOCRATS PLASMA SYSYTEMS PVT LTD", MODEL-1000,automatic SAW equipments with a constant voltage, rectifire type power source with a 1000A capacity was used to join the two mild steel plates of size 200mm(length)X 50mm(width)X 12mm (thickness)with a V angle of 30^o to 45^o ,4mm root height and 0.75 mm gap between the two plates. Copper coated Electrode Automelt EH-14 wire size:3.20mm diameter, of coil form and basic flouride type granular flux were used.

Table 1 Chemical composition of the base metal IS:2062,Gr.B

Element	Carbon	Manganese	Silicon	Sulphur	Phosphorous
Percentage	0.16	0.76	0.24	0.022	0.028

Table 2 Chemical composition of the weld metal Automelt EH-14 wire

Element	Carbon	Manganese	Silicon	Sulphur	Phosphorous
Percentage	0.06	1.5	0.30	Less than 0.03	Less than 0.03

Table 3 Chemical copmposition of the flux:Automelt,B 31

Compositions	SiO_2+TiO_2	CaO+MgO	Al_2O_3+MnO	CaF_2
percentage	25	20	30	35

Table 4 Welding parameters with different levels

Symbol	Welding parameters	Level 1	Level 2
A	Welding current, A	300	360
B	Arc voltage, V	25	28
C	Welding speed, mm/min	900	1000
D	Electrode stick out, mm	19	25

Table 6 Experimental layout using L_8 orthogonal array

Trial No.	A Welding Current(Amperes)	B Arc Voltage(Voltage)	C Welding Speed(mm/min)	D Electrode Stick Out(mm)
1	1	1	1	1
2	1	1	2	2
3	1	2	1	2
4	1	2	2	1
5	2	1	1	2
6	2	1	2	1
7	2	2	1	1
8	2	2	2	2

3. Methodology

3.1 Taguchi method

The quality engineering method of Taguchi, employing design of experiment (DOE), is one of the most important statistical tools for designing the high quality systems at reduced cost .The Taguchi methods provide an efficient and systematic way to optimized designs for performance, quality and cost. Optimization of process parameters is the key step in the Taguchi's method to achieve high quality without increasing cost. This is because, optimization of process parameters can be improve quality characteristic and optimal process parameters obtained from taguchi method are insensitive to the variation of environment conditions and other noise factors. Clssical process parameter design is complex and not an easy task. To solve this task, the taguchi method uses a special design of orthogonal arrays to study the entire process parameter space with a small number of experiments only. Taguchi has created a transformation of repetition data to another value, which is a measure of the variation present. The transformation is known as signal to noise(S/N) ratio. The S/N ratio consolidates several repetitions(at two data points are required) into one value, which reflects the amount of variation present. There are several S/N ratio depending on the characteristic;(i)Lower is better(LB),(ii)Nominal is better(NB),(iii)Higher is better(HB).The control factors that may contribute to reduce variation (improved quality) can be quickly identified by looking at the amount of variation present as a response. The bead width, weld reinforcement, depth of penetration of the weld bead geometries and weld bead hardness belong to higher the better quality characteristic. The loss function of the higher the better quality characteristic can be expressed as:

Higher the better

$$\text{MSD} = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where, y_i are the observed data (or quality characteristics) at the i^{th} trial, and n is the number of trials at the same level. As a result, four quality characteristic corresponding to the bead width, reinforcement, penetration of the weld bead geometry and hardness are obtained using equation (1) repetition data to another value, which is a measure of the variation present.

The overall loss function is further transformed into the signal to noise ratio. In the Taguchi method, the S/N ratio is used to determine the deviation of the quality characteristic from the desired value. The S/N ratio (η) can be express as

$$\eta = -10\log_{10}(\text{MSD}), \quad \text{for higher is better characteristic.} \quad \ldots\ldots (2)$$

3.2 Multiple regression analysis

Multiple regression analysis technique is used to ascertain the relationships among variables. The most frequently used method among social scientists is that of linear equations. The multiple linear regression take the following form:

$$Y=a+b_1X_1+b_2X_2+b_3X_3+\ldots\ldots+b_kX_k \quad \ldots\ldots(3)$$

Where Y is the dependent variable, which is to be predicted; $X_1, X_2, X_3 \ldots\ldots X_k$ are the known variables on which the predictions are to be made and a, b_1, b_2, $b_3, \ldots b_k$ are the co- efficient, the values of which are determined by the method of least squares.

Multiple regression analysis is used to determine the relationship between the dependent variables of bead width and weld bead hardness with welding current, arc voltage, welding speed, and electrode stick out. The regression analysis was done by Minitab 15 version.

4. Results and discussion

After completion of the welding process the welded specimen has been kept properly on a table and the weld bead width has measured.with the help of a measuring scale.

Similarly S/N ratio for weld bead width has been found separately. The largest signal to noise ratio (mean) is considered to be the optimum level, as a high value of signal to noise ratio indicates that the signal is much higher than the random effects of the noise factors. Table 10 shows the mean S/N ratios for the welding current, arc voltage, welding speed and electrode stick out. From the Table 10, it is evident that largest signal to noise ratio (average) is the optimum level, because a high value of signal to noise ratio indicates the signal is much higher than the random effects of the noise factors. The largest S/N_{avg} for parameter is indicated by Optimum in the Table 10 .

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Table 8 Measured weld bead width

Trial No	Welding current, A	Arc voltage	Welding speed ,mm/min	Electrode stick out, mm	Bead width measured ,mm
1	300	25	900	19	15.00
2	300	25	1000	25	15.00
3	300	28	900	25	16.00
4	300	28	1000	19	15.00
5	360	25	900	25	14.50
6	360	25	1000	19	14.00
7	360	28	900	19	19.00
8	360	28	1000	25	20.00

Table 9 Experimental layout using L_8 orthogonal array and S/N ratio for weld bead width

Trial No.	A Welding current (A)	B Arc voltage (V)	C Welding speed (mm/ min)	D Electrode stick out (mm)	Measured bead width (mm)	Mean square deviation	S/N ratio (dB)
1	300	25	900	19	15.00	225.00	23.52
2	300	25	1000	25	15.00	225.00	23.52
3	300	28	900	25	16.00	256.00	24.08
4	300	28	1000	19	15.00	225.00	23.52
5	360	25	900	25	14.50	210.25	23.23
6	360	25	1000	19	14.00	196.00	22.92
7	360	28	900	19	16.00	256.00	24.08
8	360	28	1000	25	16.00	256.00	24.08

Table 10 Mean S/N ratio for weld bead width

Weld parameters	Levels	Mean S/N ratio
Welding current(A)	1(300)	23.66 (Optimum)
	2(360)	23.58
Arc voltage(V)	1(25)	23.30
	2(28)	23.94(Optimum)
Welding speed (mm/min)	1(900)	23.73(Optimum)
	2(1000)	23.51
Electrode stick out (mm)	1(19)	23.51
	2(25)	23.73(Optimum)

From Table 10 it can be predicted that the optimum level parameters for achieving optimum result of weld bead width if the path A1-B2-C1-D2 is followed:

[Welding current (A1) 300A, Arc voltage (B2) 28V, Welding speed (C1) 900mm/min, electrode stick out (D2) 25 mm].

Multiple regression analysis has been used to determine the relationship between the dependent variables of bead width with welding current, arc voltage, welding speed, and electrode stick out. The regression analysis has been performed by Minitab 15 software. The regression analysis of the input parameters is expressed in linear equation as follows:

Predicted Weld bead width =13.7-0.125A+1.13B-0.375C+0.375D ………………… (4)

=13.7-0.125xwelding current+1.13 x Arc voltage - 0.375 x welding speed + 0.375 x Electrode stick out.

From the above equations, predicted values of weld bead width has been found out and tabulated with the measured value at Table 11.

Table 11. Measured and predicted value of weld bead width

Trial No	Measured weld bead width	Predicted weld bead width
1	15.00	14.705
2	15.00	14.705
3	16.00	16.21
4	15.00	15.46
5	14.50	14.955
6	14.00	14.205
7	16.00	15.71
8	16.00	15.71

5. Confirmation test for weld bead width

A test sample, having same size and dimension as per earlier specification has been taken and performed welding at the optimum predicted process parameters at path, welding current,300A,Arc voltage 28V,Welding speed 900mm/min and Electrode stick out 25mm.Then, measured the weld bead width and found 15.0mm.It is within 95% confidence level.

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