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Effect of Submerged ARC Welding Parameters on Weld Bead Hardness of AISI 1020 Mild Steel by Taguchi Method

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

In this study, the influence of three submerged arc welding process parameters, namely welding current, welding voltage and travel speed on weld hardness of AISI 1020 mild steel plates has been studied by the application of Taguchi method and analysis of variance (ANOVA). The experiments were designed using Taguchi L9 orthogonal array. S/N ratio and ANOVA were performed on the measured response to determine optimal welding conditions. The optimal welding parameter setting for bead hardness was obtained at level 2 (450 A) welding current, level 3 (28 V) welding voltage and level 3 (13 mm/s) travel speed. The results of analysis of variance (ANOVA) shows that all the three factors have influence on weld bead hardness but welding voltage has the most significant influence. The confirmation test at optimal welding conditions shows the effectiveness of the Taguchi method in investigating the influence of SAW process parameters on weld bead hardness.

Keywords: Submerged arc welding; weld bead hardness; Taguchi method; ANOVA; mild steel.

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1. INTRODUCTION

Submerged arc welding (SAW) is widely used in industries welding because it offers high production rate, high melting efficiency, ease of automation and low operator skill requirement. The operating variables used in the submerged arc welding process result in varying heat input in the welded joints. The consequence of this is the deterioration of the chemical constituents of the weld bead. As a result, the properties of the parent metal cannot adequately match those of the welded joints to ensure good performance in service, especially in low temperature services [1]. In full factorial design of experiments, the number of experiments increases exponentially as the number of factors and levels increases. This results in considerable loss of time and cost. The Taguchi method is preferred over other methods because it is a simple and robust technique for optimizing the process parameters and it can be effectively used to quickly identify the problems that are incurred during a manufacturing process from data already in existence [2,3]. The optimization of process parameters using Taguchi method permits evaluation of individual parameters independent of other parameter and also their interactions on the identified quality characteristic that is the weld bead hardness. Using a signal-to-noise ratio to analyze the experimental data could help to easily find out the optimal parametric combinations. Researchers like Kumanan et al. [4] applied Taguchi technique and regression analysis to determine optimal parameters for submerged arc welding (SAW) process. The experiments were designed using Taguchi L8 orthogonal array and signal-to-noise ratios were computed to determine the optimum parameters. The percentage contribution of each factor was determined using analysis of variance technique. A mathematical model was developed to predict the bead geometry for any given welding conditions by applying multiple regression analysis using statistical package for social science (SPSS) software. Tarng et al. [5] also worked on the use of grey-based Taguchi method to determine optimum process parameters for submerged arc welding (SAW) in hard facing with consideration of multiple weld qualities. In this study, the Taguchi robust design method and ANOVA method were applied for the selection and optimization of submerged arc welding process parameters for maximizing weld bead hardness of AISI 1020 low carbon steel. The experiments were designed using Taguchi L9 orthogonal array to determine optimal welding conditions of SAW parameters that have influence on the weld bead hardness. The welding process parameters selected in this study were welding current, welding voltage and travel speed. Patel et al. [6] investigated the influence of welding current, wire feed rate and wire diameter on weld bead hardness for tungsten inert gas (TIG) and metal inert gas (MIG) welding of AISI 1020 carbon steel plates using Taguchi's method and Grey Relational Analysis (GRA). The study reveals welding current as the most influencing factor. Datta et al. [7] optimized bead geometry (bead width, reinforcement, depth of penetration and depth of HAZ) using grey relational analysis. Taguchi's L25 orthogonal array (OA) was used in the work for design of experiment and experiments were conducted to obtain bead-on-plate weldment on mild steel plates. Welding parameters were determined for bead width, reinforcement and depth of HAZ with lower-the-better and for depth of penetration with larger-the-better criterion. Nandi et al. [8] conducted experiment using Taguchi's L25 Orthogonal Array (OA) to produce bead on- plate weld on mild steel plates by four bead geometry parameters: depth of penetration, reinforcement, bead width and percentage dilution have been determined in terms of voltage, wire feed rate, traverse speed and electrode stick-out. Kumar et al. [9] studied optimization of GMAW process parameters of mild steel 1018 joints by Taguchi's experimental design method. The L9 orthogonal array was selected to design the experiments. The input welding parameters considered in the study were welding voltage, welding current and gas flow rate. The optimal settings suggested were: welding current of 220 A, welding voltage of 40V and gas flow rate of 17 lit/min. Aghakhani et al. [10] proposed a mathematical model by applying Taguchi Design of Experiment (DOE) to predict weld dilution. Nozzle-to-plate distance, wire feed rate, welding speed, gas flow rate and welding voltage were selected as input process variables. Analysis of response reveals that arc voltage and wire feed rate have positive effect while welding speed and nozzle-to-plate distance have negative effect on weld dilution. The focus of this study is to investigate the effect of submerged arc welding process parameters on weld hardness of AISI 1020 mild steel plates by the application of Taguchi robust design method and analysis of variance (ANOVA). The selected process parameters are welding current, welding voltage and travel speed.

2. METHODOLOGY

2.1 Experimental Design

In this study, submerge arc welding (SAW) welding is used to make weld deposits using an automatic submerge arc welding machine. AISI 1020 mild steel plates measuring 100mm by 50mm by 6mm were used to make weld deposits. The chemical composition and mechanical properties of the test sample is shown in Table 1 and Table 2 respectively. The experiment is designed using Taguchi experimental design method with the selected welding parameters and their levels shown in Table 3. Welding current, welding voltage and travel speed were chosen as the welding process parameters while weld bead hardness is the response parameter. Table 4 shows the design matrix of welding parameters using Taguchi L9 orthogonal array. Nine experiments were conducted and for each experiment three trials were performed. The micro hardness tests were conducted on the welded specimens by a digital micro hardness Indenter in accordance with the ASTM E92-82 standard.

Table 1. Chemical composition of AISI 1020 carbon steel

Element	Content (%)
Manganese, Mn	0.30-0.60
Carbon, C	0.18-0.23
Sulphur, S	0.05 (max)
Phosphorous,P	0.04 (max)
Iron, Fe	Base metal

Table 2. Mechanical properties of AISI 1020 carbon steel

Properties	Metric
Tensile strength	420 MPa
Yield strength	350 MPa
Modulus of elasticity	205 GPa
Hardness, Vickers	126

Table 3. Welding process parameters and their levels

Symbol	Welding parameters	Unit	Level 1	Level 2	Level 3
A	Welding Current	A	400	450	500
B	Welding Voltage	V	22	25	28
C	Travel Speed	mm/s	7	10	13

Table 4. Design matrix of welding parameters using Taguchi L9 orthogonal array

Experiment Number	Welding Current (A)	Welding Voltage (V)	Travel Speed (mm/s)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 5. Experimental layout using L9 orthogonal array

Experiment Number	Welding Current (A)	Welding Voltage (V)	Travel Speed (mm/s)
1	400	22	7
2	400	25	10
3	400	28	13
4	450	22	10
5	450	25	13
6	450	28	7
7	500	22	13
8	500	25	7
9	500	28	10

2.2 Taguchi Method

Taguchi method uses a statistical measure of performance called signal-to-noise (S/N) ratio to evaluate the significance of process parameters. The method explores the concept of quadratic quality loss function. The S/N ratio is the ratio of the mean (signal) to the standard deviation (noise). The ratio depends on the quality characteristics of the process to be optimized. The most common types of S/N ratios generally used are nominal-is-best (NB), lower-the-better (LB) and higher-the-better (HB). The bead hardness of the welded joints is the quality characteristic to be optimized. It is desired that the value of weld bead hardness should be as large as possible. Hence, in this study, the higher-the-better quality characteristic is chosen to optimize weld bead hardness.

Taguchi's S/N ratio for higher-the-better is given by:

$$S/N\ ratio = -10 \ln 10 \frac{1}{n} \sum_{i=1}^{n} \frac{1}{y_i^2} \quad (1)$$

Where $n =$ Number of tests conducted
$y_i =$ Response measured to the ith time

3. RESULTS AND DISCUSSION

The results of the weld bead hardness obtained using Taguchi L9 orthogonal array experimental method are presented in Table 6. The results indicate that many of the welded specimens test are satisfactory. The highest value of bead hardness (129.34 HV) is obtained by experiment number (6); which is welding current 450 A, welding voltage 28 V and travel speed 7 mm/s. While experiment number (1) had the lowest result for bead hardness (118.25 HV), corresponding to welding current 400 A, welding voltage 22V and travel speed 7 mm/s.

3.1 Analysis of S/N Ratio

It is recommended by Taguchi that analysis of S/N ratio be done using graphical method for studying the effects and identifying the factors that appear to be significant visually. In the study of mechanical properties, higher the hardness is expected. Thus, S/N ratio of the higher-the-better characteristic is applied in this study and it can be calculated using Eq. (1). Analysis of the S/N ratio is done using Minitab 18 software package. Larger S/N ratio values mean that better signals are obtained. In each experimental run, corresponding S/N ratio is determined and the results shown in Table 7. It is found that maximum value of S/N ratio (42.23 dB) for bead hardness is obtained by applying welding current of 450 A, welding voltage 28 V and travel speed 7 mm/s. Table 8 shows the mean response for S/N ratio for bead hardness. Delta values for every given factor are differences between highest S/N ratio and lowest S/N ratio of factors. The factor with the highest delta value is ranked first accordingly.

The highest values of S/N ratios are shown bold with an asterisk. From Table 8, Level 2 for welding current, 450 A is indicated as the optimal condition resulting in S/N ratio of 41.96 dB for bead hardness. Level 3 (28 V) for welding voltage is indicated as the optimal condition resulting in S/N ratio of 42.12 dB, while level 3 (13 mm/s) for travel speed is indicated as the optimal condition resulting in S/N ratio of 41.92 dB. In Table 8, it is observed that welding voltage is rank 1, welding current rank 2 and travel speed rank 3. The ranking shows that welding voltage is the most influential parameter on bead hardness, followed by welding current, while travel speed has little or no influence on bead hardness.

Table 6. Experimental results using Taguchi L9 orthogonal array

Experiment Number	Welding Current (A)	Welding Voltage (V)	Travel Speed (mm/s)	Bead Hardness (HV)
1	400	22	7	118.25
2	400	25	10	123.44
3	400	28	13	128.28
4	450	22	10	120.43
5	450	25	13	126.17
6	450	28	7	129.34
7	500	22	13	119.86
8	500	25	7	121.57
9	500	28	10	125.33

Where A= Amperes, V= Volts and HV= Hardness (Vickers)

Table 7. S/N ratio of bead hardness

Experiment Number	S/N ratio (dB)
1	41.46
2	41.83
3	42.16
4	41.61
5	42.02
6	42.23
7	41.57
8	41.70
9	41.96

Table 8. Rank of S/N ratio of bead hardness

Level	Welding Current (A)	Welding Voltage (V)	Travel Speed (mm/s)
1	41.82	41.55	41.80
2	**41.96***	41.85	41.80
3	41.74	**42.12***	**41.92***
Delta	0.21	0.57	0.12
Rank	2	1	3

3.1.1 Main effect plot

The main effects plot for signal-to-noise ratios of welding current, welding voltage and travel speed on weld bead hardness generated by submerged arc welding is shown in Fig. 1. It is observed that as welding current increased from 400 A to 450 A, there was increase in signal to noise for bead hardness. But with further increase in current from 450 A to 500 A, a gradual decrease in signal to noise ratio was observed. Similar result was observed Optimal signal to noise ratio for bead hardness was achieved with welding current of 450 A. The signal to noise ratio for bead hardness is observed to increase as welding voltage is increased from 22 V to 28 V. Optimal signal to noise ratio for bead hardness was achieved with welding voltage of 28 V. Increase in travel speed had little influence on the signal to noise ratio for bead hardness. Optimum bead hardness was achieved with travel speed of 13 mm/s. The optimum welding conditions for maximum weld bead hardness is welding current 450 A, welding voltage 28 V and travel speed 13 mm/s (A2B3C3).

3.1.2 Analysis of variance

Table 9 shows the analysis of variance (ANOVA) results for signal to noise ratio of bead hardness. The ANOVA analysis was done using Minitab 18 software. From the result, it can be seen that only welding voltage has statically significant effect on the variation and mean of bead hardness of the weld with percentage contribution of 81.942%, followed by welding current with percentage contribution of 11.934% while travel speed contributed the smallest percentage of 4.823%. Similar result was reported by Rajesh [11]. Table 10 shows the model summary. R^2 value of 98.70% shows that the model used is suitable for the analysis.

3.2 Confirmatory Test

The confirmation experiment is a very important step recommended by Taguchi to verify experimental results [12]. In this study, a confirmation test was carried out to validate the optimum parameters setting that were suggested by our experiments. The predicted S/N ratio and mean of weld hardness using the optimum level of the parameters are calculated using equation (2).

$$Y = Y_m + \sum_{i=0}^{q}(Y_i - Y_m) \quad (2)$$

Where Y_m is the total mean of S/N ratio, Y_i is the mean S/N ratio at the optimum level and q is the number of significant parameters from analysis of variance (ANOVA) result. Equation (2) was used to obtain the results of the confirmation test using optimal welding process parameters and comparing it with initial processes. The result of the confirmation test is shown in Table 11. From the result obtained for the confirmation test, there is improvement in weld hardness.

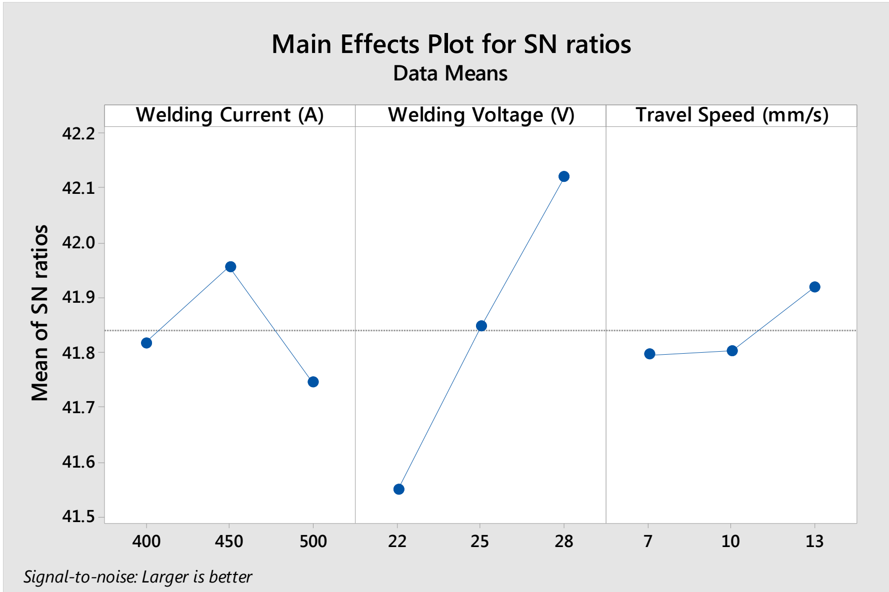

Fig. 1. Main effect plot for S/N ratios of bead hardness

Table 9. Analysis of variance for bead hardness

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Percentage Contribution %	Remark
Welding Current (A)	2	14.469	7.2343	9.17	0.098	11.934	Insignificant
Welding Voltage (V)	2	99.350	49.6750	62.96	0.016	81.942	Significant
Travel Speed (mm/s)	2	5.848	2.9242	3.71	0.212	4.823	Insignificant
Error	2	1.578	0.7890			1.301	
Total	8	121.245				100	

DF= Degree of freedom, Adj SS= Adjusted Sum of Squares, Adj MS= Adjusted Mean Squares

Table 10. Model summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.8883	98.70%	94.79%	73.64%

able 11. Confirmation test result

	Initial process parameter	Predicted process parameter
Level	$A_1B_3C_3$	$A_2B_3C_3$
Weld hardness (HV)	125.34	127.65
S/N ratio (dB)	41.23	42.34

4. CONCLUSION

The effect of welding current, welding voltage and travel speed on weld bead hardness was studied by applying the Taguchi method and analysis of variance (ANOVA). Taguchi L9 was used in designing the experiments and optimal factors conditions were determined using S/N ratio and main effect plots. The significance of each factor on the response variable was examined by analysis of variance (ANOVA).

The results obtained from this study are summarized as follows:

1. Based on the analysis of the S/N ratio and main effects plot, the optimal factor levels for weld hardness were obtained at level 2 (450 A) of welding current, level 3 (28 V) of welding voltage and level 3 (13 mm/s) of travel speed.
2. All three process parameters have effect in determining the weld hardness.
3. Welding voltage has the most significant effect on weld hardness with percentage contribution of 81.942 %.
4. From the results of confirmatory test, it is found that optimum welding conditions produced maximum weld bead hardness.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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