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Modeling and Optimizing the Hardness of the Melted Zone in Submerged Arc Welding Process Using Taguchi Method

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Abstract. One of the important characteristics of weld quality, which is influenced by welding parameters, is the hardness of the melted zone (HMZ). In this paper, experiments were conducted by Taguchi experimental design and Minitab 14 statistical software, and the interaction of input parameters was not taken into account. After collecting data, the signal to noise ratio (S/N) was calculated to obtain optimal levels for all input parameters. Then, using analysis of variance (ANOVA), the significance level of (P) for each input parameter was determined and validated for the hardness of the melted area. The results show that current intensity, welding speed, arc voltage, nozzle distance from work piece and thickness of magnesium oxide nanoparticles had respectively the highest impact on the hardness of melted zone.

Introduction

One of the most common methods of industrial metal welding is submerged arc welding that is used for joining massive metal pipes in extensive lines of gas and oil transfer as well as huge metal pieces [1,2]. In welding processes, geometry and quality of welded joints is greatly dependent on the input parameters. In this regard, given the large number of parameters involved, the correct determination of input parameters is of paramount importance to achieve the desired geometrical characteristics aimed at reducing costs of production and maintaining the quality of products. That is, obtaining a weld with the desired quality requires complete control and optimization of parameters involved in this process [3-6]. There are several methods for achieving optimal parameters among which Taguchi design is one of the most efficient as it can reduce the number of tests. Taguchi design is a powerful method for reducing the production costs, improving quality and reducing the interval between incremental development process [7, 8].

Thus, many studies have been carried out to understand the relationship between the input parameters of submerged arc welding and HMZ. Yang [9] reported that the hardness of the melted zone increased with decreasing inlet temperature. Hall [10] reported that welding speed could influence HMZ in submerged arc welding process. Kolhe and Datta [11] investigated the effect of welding parameters on the HMZ concluding that the hardness of the weld was a variable of input thermal variation.

In this paper, the effect of welding input parameters on the HMZ in submerged arc welding process was studied. Therefore, the arc voltage (V), the intensity of welding current (I), nozzle distance from the workpiece (N), welding speed (S) and the thickness of magnesium oxide nanoparticles (F) were determined as input parameters and HMZ was considered as the response variable. The results show that Taguchi method is able to predict HMZ with lower error.

Experiment Design

Test method. To weld pieces, the surface of workpiece was covered with magnesium oxide nanoparticles. Then, the wielding process was carried out using PARS FEED 1202G semi-automatic machine with direct current reverse polarity (DCRP) on the surface through bead on plate wielding method. Workpieces were made of St37 steel with 15 mm × 50 mm × 150 mm dimensions and (DIN EN 756) S1 welding wire with a diameter of 3.2 mm. The chemical composition of welding wire is shown in Table 1.

Table 1 Chemical composition of the welding wire

Type of welding wire		**Weight percent**				
brand	DIN/EN	carbon	silicon	manganese	molybdenum	Chromium
50-11	S1	0.04-0.08	0.5-0.8	0.9-1.3	-	-

Experiment Design based on the Taguchi method. Experiments are used extensively in various disciplines such as engineering sciences. The aim of an experiment is to investigate the effect of input parameter and to offer a model that obviates the need for the replication of the experiment under the same circumstances, and thus reduce the costs and time and improve the efficiency. The values of the input parameters at different levels are shown in Table 2. Also, considering the values of signal to noise ratio (S /N) and analysis of variance (ANOVA), the optimum levels of the input parameters were determined. All analyses were performed by Minitab 14 Statistical Software and the interaction of input parameters were ignored in this study.

Table 2 Welding parameters and their range

	Symbol	**Coding**					**Unit**
Input Variable	---	1	2	3	4	5	
Current intensity	I	500	550	600	650	700	*Ampere*
Arc voltage	V	24	26	28	30	32	*Volt*
nozzle distance from the work piece	N	30	32.5	35	37.5	40	*mm*
Welding speed	S	300	350	400	450	500	*mm/min*
Thickness of nanomaterial	F	0	0.25	0.5	0.75	1	*mm*

Results and Discussion

Analysis of Variance. In order to validate and select the most efficient models, the statistical tests are used. Table 3 shows the analysis of variance for the hardness of the melted zone. Based on statistical analysis of the data, this method can show which parameters have the most important and the greatest effect on output parameters. In ANOVA tables, the p value is important. That is, the low value of p indicates that the input parameter has greater impact and significance on output parameter. In this article, when p value is lower than 0.05, the input and output parameters will have their greatest effect. We chose 95% confidence level for this matter.

Table 3 Analysis of variance parameters for the hardness of the melted zone

Source	DF	Seq SS	Adj SS	Adj MS	F	P
I	4	4990.8	4990.8	1247.70	23.59	0.005
V	4	394	394	98.50	1.86	0.281
N	4	342.8	342.8	85.70	1.62	0.326
S	4	436.4	436.4	109.10	2.06	0.250
F	4	172.4	172.4	43.10	0.81	0.576
Error	4	211.6	211.6	52.90		
Total	24	5365.75				

In which DF is Degree of Freedom, Seq SS is Sequential Sum of Squared, Adj SS is Adjusted Mean Squared, Adj MS is Adjusted Mean Squared, parameter of F is Fisher's F ratio and P is Probability of Significance.

According to Table 3 and *p* value, the parameters influencing HMZ are respectively current intensity, arc voltage, nozzle distance from workpiece and thickness of nanoparticles. Another important criterion for evaluating the accuracy and quality of the fitted modes is the correlation coefficient. This coefficient shows the degree of dependency between input and output parameters of a system.

Confirmatory Analysis for the Hardness of the Melted Zone. Confirmatory test by considering the specific combination of factors and levels, which were already identified through a series of calculations as the optimal combination, guarantee the accuracy or inaccuracy of results and decision makings. If the mean value of confirmatory test results is in the confidence level, they are confirmed; otherwise, the results are rejected, meaning that the significant parameters are not selected, factors are not positioned at a proper level or calculations and experiments have high error rate. In Table 4, five experiments outside the design are given along with a confirmatory analysis of the results.

Table 4 Factors input for confirmatory testing.

level	I	V	N	S	F
1	1	4	5	3	2
2	2	4	4	1	3
3	5	2	3	4	1
4	4	1	5	2	3
5	3	2	1	5	4

Table 5 shows the confirmatory results of the test for the hardness of the melted zone. As can be seen, the errors obtained for the hardness of the melted zone are within an acceptable range with the results suggesting that Taguchi design experiment is able to predict external values of the design for the hardness of the melted zone.

Table 5 The results of confirmatory test for the hardness of the melted zone

No.	Experiment	Prediction	Error
1	180	176.6	1.88
2	163	175.4	7.60
3	146	139.6	4.38
4	148	143.6	2.97
5	181	157.8	7.72
Average			`4.91

Optimization. The optimal value for the hardness of the melted zone can be calculated by utility function. For this purpose, using Minitab 14 software, the overall utility function is introduced based on utility functions of means and variances of five input parameters at five levels. The results are presented in Table 6. Also, the optimal solution for five effective parameters is given in Table 6. In this method, the utility of each purpose is determined and then using a method like geometric mean, the total utility is calculated. If the utility function y_i (x) is a monotonically increasing, the utility value is calculated according to Eq. 1 [12]:

$$d_i = \begin{cases} 0 & \hat{y}_i(x) \le y_i^{\min} \\ \left[\dfrac{\hat{y}_i(x) - y_i^{\min}}{y_i^{\max} - y_i^{\min}} \right]^t & y_i^{\min} \le \hat{y}_i(x) \le y_i^{\max} \\ 1 & \hat{y}_i(x) \ge y_i^{\min} \end{cases} \tag{1}$$

where $\hat{y}_i(x)$ is an estimate of $y_i(x)$ and $y_i^{\min}$ is the minimum acceptable value of $y_i(x)$ from the view of decision-makers, $y_i^{\max}$ is the value of $y_i(x)$ with the maximum utility for the decision maker and after which the utility is constant, and *t* is the parameter that determines the form of the utility function.

Although utility function is an efficient method, it has its own problems. One problem is the difficulty of drawing indifference curves and determining utility. Determining utility relative to the view of the decision maker is critical. On the other hand, the above techniques are only useful when the utility of dependent variables is monotonically rising or declining. In other words, the greater (or lower) is the response variable, the higher is desirability. However, it is always possible that the utility function is quadratic. In this case, the most appropriate value of a response may be in the middle of variation range.

Table 6 The optimal values of the input parameters for the hardness of the melted zone

Min hardness of the melted zone	I	V	N	S	F
126 VHN	5	2	5	1	1

The optimal conditions of factors in the range of selected levels include a current intensity of 700 amps, an arc voltage of 24 V, a 30 mm distance of nozzle from workpiece, a welding speed of 400 mm/min and a 0 mm thickness of nanoparticles.

Conclusion

This study sought to find the optimal values for improving the welding quality and the desired mechanical properties. According to the results of the tables and confidence level of 95%, the input parameters of current intensity, speed, arc voltage, nozzle distance from the work piece and the thickness of nanoparticles on the hardness of the melted zone had the greatest impact. Also the results of variance analysis, the correlation coefficient of 80.6% and the utility value of 0.714 were achieved.

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