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The Application of Taguchi Technique in Mild Steel Weld Prediction and Optimization

*IWHIWHU, MK; IKPESENI, SC; SADA, SO

Department of Mechanical and Production Engineering, Faculty of Engineering, Delta State University, Oleh Campus, Nigeria

**Corresponding Author Email:* iwhiwhumaurice@gmail.com
Co-Authors Email: scikpeseni@delsu.edu.ng; sosada@delsu.edu.ng

ABSTRACT: Welding is a key joining operation in many production and manufacturing industries, and it requires a scientific approach in obtaining a weld of high quality. This study focuses on the prediction and optimization of the weld parameters of a mild steel plate using Taguchi technique. For experimental examination, a mild steel plate of 10mm thickness, along with input process parameters such as weld current, arc voltage, gas flow rate, and output process parameter such as hardness were studied. With the statistical tool, ANOVA, further analysis performed to determine the significance of the data obtained shows that for all the responses, a Model F-value of between 64 and 129.85 was obtained, along with a P-value less than 0.05, implying that the model is significant. Furthermore, based on statistical evidence using P-values, all the model terms; welding current, arc voltage and gas flow rate recorded significant contribution to the outcome of the welding experiment, with the weld current having the most significant effect. The optimal result for the responses was obtained 192BHN for the hardness, at a combined process parameters as follows; 200amps, 20v and 20lt/min for the weld current, arc voltage and gas flow rate respectively.

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Welding is an excellent method of bringing together two or more materials of different structural elements or properties to form a joint through the application of thermal energy. With welding, the production of strong and durable connections ranging from very large machineries, to buildings, pipelines, trains, automobiles and bridges, has been actualized (Sada, 2018). Arising from the forge welding of iron, brazing, diffusion bonding and soldering days of joining metals, recent years has witnessed the development of newer, more innovative and adaptive inventions of the metal welding processes (Sada, 2020). The latest welding process inventions has seen the classification of a wide range of welding processes, namely; the Fusion welding and the Solid state welding. However, from the 19th century, the fusion welding process starting with the gas, arc and resistance welding became available on an industrial scale, and with the invention of the inert-gas welding process, welding processes have recorded remarkable rate of improvement, as a good number of metals which previously were of great concern are now currently been welded. However, despite these outstanding achievements, designing a weld joint of suitable quality within an approve time frame without any compromise, remains a huge challenge in the welding industry. Nevertheless, studies by Sada and Achebo (2021), Shunmugasundaram (2020) and Ambekar and Wadhokar (2015) reveals the welding process can be controlled through the evaluation of a large number of interrelated process parameters which can be further optimized through the application of optimization techniques. According to Meshram and Pohokar, (2013), parameter optimization problems can be solved by a good number of technologies/techniques classified as conventional and nonconventional

**Corresponding Author Email:* iwhiwhumaurice@gmail.com

optimization techniques. Hence, a more extensive study is required to establish the suitability of applying the optimization techniques in predicting the weld output based on the input parameters. The aim of this study is to Predict and Optimize Mild Steel Weld Parameters using the Taguchi Technique.

MATERIALS AND METHOD

This section gives detailed steps adopted in performing this study, starting from Identifying the key factors and levels, developing the design matrix, developing the response table based on experimental results obtained, and finally obtaining the optimal setting of the parameters. The selected workpiece for this experiment is a 10mm thick mild steel plate, cut into coupon with dimension of 120x30 mm (length x width) each as shown in Figure 1. As shown, a 30º chamfering is made on the plates, at 2mm depth to obtain the v shape design.

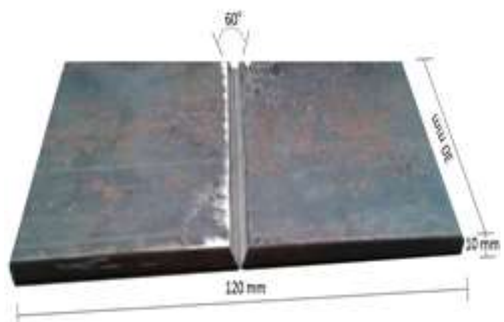

Fig 1: V-butt specimen of Mild Steel

The welding parameters and their limits as given in Table 1, were selected based the relevant parameters for heat input (Sada *et al.,* 2021).

Table 1: Process Parameters and their Range

Control factors	Levels for various control factors			**Unit**
	1	2	3	
Welding current (A)	90	100	110	Ampere (A)
Arc Voltage (B)	8	10	12	Volts (V)
Gas flow rate (C)	8	10	12	lit/min (l/min)

Experimental design: The traditional one-variable-at-a-time approach adopted commonly for evaluating the influence of process parameters involves numerous experimental runs to truly explore the entirety of the parameter space. Hence, the Taguchi experimental design method is employed to reduce the number of experiments without compromising the quality of the data collected (Amit 2015). For the design of experiments with three factors and three levels, a standard L9 orthogonal array based on the taguchi experimental design was employed using design expert software 2018 model. In this study, the factors and their level have been selected in three levels using the L9 Orthogonal Array as shown in Table 2.

Table 2 Experimental Layout using L9 Orthogonal Array

Expert. No.	Welding Current (amp)	Arc Voltage (volt)	Gas Flow Rate (lit/min)
1	1	1	1
2	1	3	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	1	1
7	3	2	3
8	3	2	1
9	3	3	2

Taguchi method: Taguchi experimental design is a core tool employed for robust design, as it offers a less complex and systematic approach for effective performance, quality and reduction of cost, using two key parameters; Signal to noise (S/N) ratio and orthogonal array. With Signal to noise ratio, product quality with emphasis on variation is measured, and with orthogonal arrays the identified many design factors are accommodated simultaneously. The S/N ratio characteristics when considered continuous can be divided into three categories (Ahmed *et. al*., 2022) as shown in equation 1 to 3:

(i) Larger the better

$$\frac{S}{N} = -10\log\frac{1}{n}\left[\sum\frac{1}{y^2}\right] \quad (1)$$

(ii) Norminal the best

$$\frac{S}{N} = 10\log\frac{\overline{Y^2}}{S^2} \quad (2)$$

(iii) Small the better

$$\frac{S}{N} = -10\log\frac{1}{n}\left[\sum Y^2\right] \quad (3)$$

Where y is the average observed response, Sy^2 the variance of y, n the number of observations. The S/N ratio with the highest value gives the most effective quality characteristics, and vice versa depending on how the optimal is defined. For this study, the larger the better is chosen, as the responses under study is expected to be of highest values. Furthermore, to ascertain the significance of the process parameters, a statistical analysis of variance (ANOVA) is employed. With the results obtained from the S/N and ANOVA analysis, the prediction of the optimal process parameters is actualized.

RESULT AND DISCUSSION

The table below shows the results of the welding experiment performed using the Gas Tungsten Arc Welding process based on the (9) nine experimental run generated from the orthogonal array using Taguchi technique. With the results obtained and tabulated as shown in Table 3, the following analysis using Analysis of Variance (ANOVA) were performed (1) To determine the significant contribution of each of the parameters, (2) To develop and validate a mathematical model and () To develop and validate the optimal process parameters

Analysis for the Hardness: This section provides the analysis for the data obtained for hardness. The result of the ANOVA test is present in Table 4. From Table 4, the result shows that a Model F-value of 543.37 was obtained, along with a P-value of 0.0021. Implying that the model is significant and there's only a slim chance (0.21%) an F-value of the magnitude can occur due to noise.

Table 3: Result of Welding Experiment

Exp. Run	**Weld Current (A)**	**Arc Voltage (V)**	**Gas Flow Rate (l/min)**	**Hardness BHN**
1	140	25	24	190.2
2	140	15	20	189.4
3	140	20	22	189.6
4	170	20	24	189.3
5	200	25	22	189.6
6	170	15	22	189.2
7	170	25	20	173.4
8	200	15	24	186.5
9	200	20	20	179.2

Table 4: ANOVA for selected factorial model (Hardness)

Source	Sum of Square	Df	Mean Square	F-value	P-value	
Model	76.17	6	12.70	543.37	0.0021	Significant
A-Weld current	29.05	2	14.52	688.00	0.0015	
B-Arc voltage	25.56	2	12.78	605.42	0.0032	
C-Gas flow rate	21.56	2	10.78	510.68	0.0024	
Residual	0.0422	2	0.02111			
Cor Total	76.22	8				

Furthermore, based on statistical evidence using P-values, all the model terms; welding current labelled as A, arc voltage labelled as B and gas flow rate labelled as C can be said to have significant contribution on the outcome of the welding experiment. As P values less than 0.0500 is an indication of significant model and values greater than 0.1000 indicate an insignificant model. Further observation from the ANOVA result, the weld current is the most significant, followed by the arc voltage and lastly the gas flow rate. This corresponds to the results obtained for the percentage elongation.

Fit Statistics: To further analyze the ability of the model to make prediction, the parameters of the fit statistics as shown in Table 5 are employed.

Table 5: Fit Statistics for the Hardness

Std Dev.	4.22	R-Squard	0.9221
Mean	483.53	Adj R-Squared	0.8495
C.V. %	0.87	Pred R-Squared	0.5518
PRESS	1541.13	Adeq.Precision	12.092

From Table 5, the parameter R^2, Adjusted R^2, and Predicted R^2 all reveal the ability of the model to predict the response is excellent, as a value of 92.21%, 84.95% and 55.18% was obtained for the R^2, Adjusted R^2, and Predicted R^2 respectively. Further observation of the result base on the Adeq Precision which measures the signal to noise ratio shows that the ratio of 12.09 obtained signifies an adequate signal, as a ratio greater than 4 is desirable and therefore the model is very suitable in navigating the design space.

Mathematical Model: The mathematical model for the percentage elongation is given in Equation (4),

$$Hardness = +23.12 - 3.32A_1 + 2.34A_2 - 0.417B_1 + 3.11B_2 + 2.31C_1 - 0.12C_2 \quad (4)$$

Where A, B, and C are the process parameter weld current, arc voltage and gas flow rate, while the subscript $_1$ & $_2$ represent the low and high levels respectively.

The Equation (4) above, presents a model capable of predicting the responses based on each factor considered at their given levels. The high and low levels of each of the factors are coded as +1 and -1 respectively by default.

Graphical Analysis of the Process Parameter and Response: From Figure 2, the graphs reveals that the error between the predicted and the actual values of the response is insignificant and uniformly distributed. From Figure 3, the plot shows the varying effect of the parameters on the responses percentage elongation. For the weld current and arc voltage, the graph shows that a further increase in the value of the process parameter leads to an increase in the percentage elongation. However, for the gas flow rate, the reverse was recorded. The plot of gas flow rate against the response reveals that further increase in the value of the gas flow rate resulted in a drop in the value of the percentage elongation obtained.

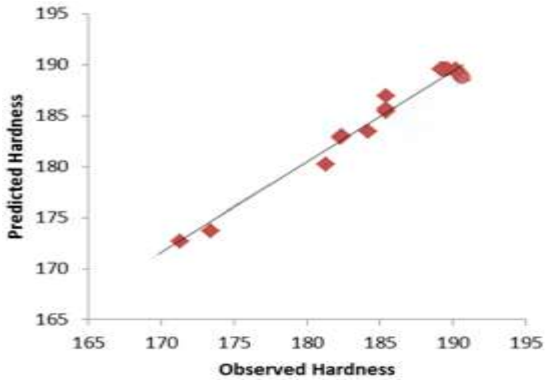

Fig 2: Plot of Predicted vs Actual Responses for the Hardness

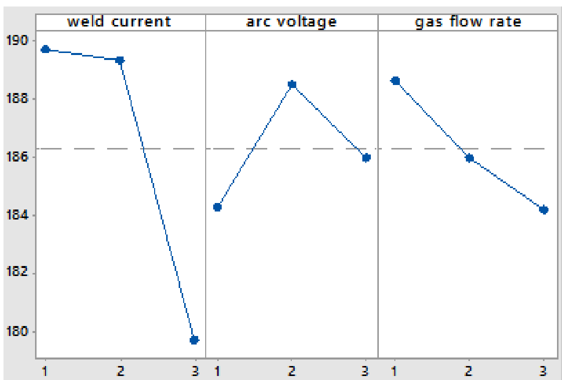

Fig 3: Plot of Each Process Parameter vs the Response for the Hardness

Conclusion: The prediction and optimization of a mild steel weld parameters using the taguchi technique was successfully carried out. With the application of Analysis of variance, the model significance reflecting a Model F-value of 129.85 was obtained, along with a P-value less than 0.05, implying that the model is significant and there's only a slim chance (0.77%) an F-value of the magnitude can occur due to noise. Furthermore, it can be deduced based on statistical evidence using P-values, that all the model terms; welding current labelled as A, arc voltage labelled as B and gas flow rate labelled less C, significantly contribute to the outcome of the welding experiment, with the weld current having the most significant effect, followed by the gas flow rate and lastly the arc voltage.

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