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DETERMINATION OF OPTIMAL PROCESS PARAMETERS FOR A MIG WELDED PLATE USING THE TAGUCHI OPTIMIZATION METHOD.

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Abstract

The desire for better weld quality and greater efficiency has continued to dominate the production requirements for manufacturers in the welding sector. One setback, the industry has continued to suffer is the deterioration in the quality of welds due to unguided application of heat. Identification of a suitable welding process and the Optimization technique of the weld input parameters have no doubt helped to address problem of poor quality welds. This study establishes the suitability of using Taguchi optimization method in obtaining optima process parameters for a Metal Inert Gas (MIG) welded joint. The study was performed on a 10mm thick mild steel plate using the metal inert gas arc welding process. The effect of certain process input parameters on the tensile strength of the welded plate was tested and analyzed using the Taguchi Optimization method with the aim of optimizing the tensile strength of the welded joint. ANOVA test showed that the welding current and gas flow rate had the most significant effect on the weld response Tensile Strength. Confirmatory analysis was made by comparing the experimentally obtained data and the predicted values, the residue was uniformly distributed. The model F-value of 12.69 showed that the model employed is significant. The following optima value were obtained, current setting of (180amp), voltage (18volt), gas flow rate (22L/min) and filler rod (4.5mm/sec).

Keywords: Mild Steel, MIG Welding, Signal/Noise Ration, Taguchi Optimization.

1. Introduction

Welding is a metal joining process in which two or more parts are joined or coalesced at their contacting surfaces by suitable application of heat and pressure. In some welding processes a filler material is added to facilitate coalescence. Some of the advantages welding provides are: permanent joining of metals, joints with strengths properties stronger than the parent materials in cases where proper filler metal is used. Welding can be performed in different environments, in air, underwater and in space. It is also applicable in different areas and industries such as construction, petroleum industries, aircraft industries, transportation, machine manufacture, household manufacture, repair and maintenance.

Notwithstanding the advantages of welding as a major means of joining metals, some factors such as the need for quality and efficiency has become a predominant challenge in deciding the choice or designs of welded joints. Most welding processes have been found to be very suitable for specific material kinds, thickness and joint design. In addition to utilizing the most suitable welding process, accurate predictions of the performance of welds, weld systems and the capability to model and analyze welded joints has also become an important development in improving the weld quality, as quality has now become a major concern. Among the various kinds of welding process in existence, the metal inert gas (MIG) welding process which is one of the many types of arc welding processes is widely used for different types of materials irrespective of their thickness. MIG is a multi-objective, multi-factor metal fabrication technique, several process parameters interact in a complex manner resulting in direct or indirect influence on bead geometry and hence on the mechanical behavior of the welds prepared by this process.

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Detailed analysis using statistical methods like Factorial design, Placket-Burman design, Taguchi design, Mixture designs, Graeco-Latin square design, Hyper-Graeco design, and Response Surface designs have been employed by researchers to correlate these parameters with weld bead geometry, weld quality, etc. Taguchi techniques have been used of late extensively for solving optimization problems in the field of production engineering. This method utilizes a well-balanced experimental design consisting of a limited number of experimental runs, called orthogonal array (OA) and signal-to-noise ratio (S/N) which serve as the objective function to be optimized within experimental limits. Input/output relationship for metal active gas welded pipelines has been established [1]. Regression analysis was performed on data collected as per the Taguchi design of experiments and the data accuracy was verified using ANOVA method. The influence of welding parameters such as welding current, welding voltage, welding speed on penetration depth of mild steel during welding using Taguchi design method has been investigated [2]. Result obtained showed that the welding voltage has a large effect on penetration.

Taguchi method was employed to optimize the pulsed TIG welding process parameters for increasing the mechanical properties [3]. AA5456 Al alloy of 2.14mm was employed as the specimen for the experiment with welding current of 40-90Amp range and welding speed of 210-230mm/min range as process parameters. A Regression model was developed and the microstructures of all the welds were studied and correlated with the mechanical properties. 10-15% improvement in mechanical properties was observed after planishing due to or redistribution of internal stresses in the weld. A modified Taguchi method has been adopted to analyze the effect of each welding process parameter (arc gap, flow rate, welding current and speed) on weld pool geometry (front and back height, front and back width) and then to determine the TIG welding process parameters combination associated with the optimal weld pool geometry [4]. It was experimentally reported that, the four smaller-the-better quality characteristics, 'four responses' of the weld pool in the TIG welding of S304 stainless steel of 1.5 mm in thickness are greatly improved by using this approach. The optimization of Process Parameters of gas metal arc welding was studied on a 12.5 mm stainless steel plate using taguchi experimental design method [5]. Tensile strength increased with increase in voltage. But in case of current and gas flow rate, it increased up to the optimum level and decreased on further increasing these values. The experiment showed that voltage has the greatest percentage contribution followed by current and gas flow rate. The voltage is the significant factor for tensile strength but current and gas flow rate are the non-significant parameters in weld process. The welding input process parameters for obtaining greater welding strength in manual metal arc welding of dissimilar metals has been optimized and predicted using the higher-the-better quality characteristic of the taguchi method. The effect of each welding process parameters and optimal process parameters were obtained [6].

The aim of the study is the determination of the optimal process parameters using the taguchi optimization process.

2. METHODOLOGY.

This study was planned in the following steps; selection of material, joint design of the material, identification of factors and responses, identification of range for Process Parameters, development of design matrix, conducting of experiments as per design matrix, testing and recording of the responses, development of mathematical models, checking the adequacy of developed models, validation of experiment.

Mild steel plate measuring 60x40x10mm was used for the experiment. The preselected variables for this experiment are the current (AC), inert gas (argon) and metal plate (mild steel). And the variables selected for study are current, voltage, gas flow rate, filler rod diameter. At the completion of the welding process, each specimen was cut at the cross section for tensile strength testing. The range of the values of the process parameters were obtained from literature and each parameter has two levels which comprises of the high and low. Details are presented in Table 1

Table 1: Welding Parameters and their Levels

Parameters	Unit	Symbol	Coded Value	Coded Value
			Low (-)	High (+1)
Welding Current	Amp	A	140	200
Arc Voltage	Volts	V	15	25
Gas Flow Rate	Lit/min	F	20	24
Filler Rod	Mm	T	2.4	3.2

The Figures 1 and 2 below shows the welding setup and a sample of the welded plate. The welding setup comprises the welding machine, gas cylinder etc.

Figure 1. Welding Machine Setup.

Figure 2. Welded Mild Steel Plate

2.1 EXPERIMENTAL DESIGN

There are two aspects of any experimental problem, namely: (i) Design of Experiment DOE. (ii) Statistical analysis of the data. With the use of a statistical software known as Minitab and design expert, these two aspects were carried out. Taguchi Optimization method which is one of the techniques of DOE was employed for this study. The Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments. Orthogonal arrays are special standard experimental design that requires only a small number of experimental trials to find the main factors effects on output [7]. Before selecting an orthogonal array, the minimum number of experiments to be conducted is to be fixed based on the formula:

N Taguchi = 1+ NV (L – 1)……. (1)

Where N Taguchi = Number of experiments to be conducted, NV = Number of parameters, L = Number of levels.

For this study, NV = 4 and L = 3, Hence N Taguchi = 1+ 4 (3-1) = 9

Hence at least 9 experiments are to be conducted. Based on this, L9 orthogonal array (OA) was selected which has at least 9 rows i.e., 9 experimental runs. Taguchi experimental design of experiments suggests L9 orthogonal array as shown in Table 2, where 9 experiments are sufficient to optimize the parameters. Based on main factor, the variables are assigned at columns, as stipulated by orthogonal array. Haven selected the orthogonal array, the experiments were selected and conducted as per the level combinations and their response (tensile strength) according to each experimental run was recorded for analysis.

Table 2:L9 Orthogonal Array

Exp. No.	Current	Voltage	Gas Flow Rate	Filler Rod
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

2.2 Signal to Noise Ratio

In Taguchi's design method the design parameters (factors that can be controlled by designers) and noise factors (factors that cannot be controlled by designers, such as environmental factors) are considered influential on the product quality. The Signal to Noise (S/N) ratio is used in this analysis which takes both the mean and the variability of the experimental result into account. The S/N ratio depends on the quality characteristics of the product/process to be optimized. Usually, there are three categories of the performance characteristics in the analysis of the S/N ratio; that is, the lower-the-better, the higher-the-better, and the nominal-the-better [8].

The S/N ratio for each response is computed differently based on the category of the performance characteristics and the category the larger S/N ratio corresponds to a better performance characteristic. In the present study the tensile strength which is the response is "the-higher-the-better" performance characteristics. Once all of the S/N ratios have been computed for each run of an experiment, Taguchi advocates a graphical approach to analyze the data [9]. As earlier mentioned, the weld strength belongs to the higher-the-better quality characteristic. The loss function of the higher-the-better quality characteristic can be expressed as:

$L_{ij} = {}^{1}/n \Sigma^{1}/y^{2}_{ijk}$……(2)

where L_{ij} is the loss function of the *i*th quality characteristic in the *j*th experiment, n the number of tests, and y*ijk* the experimental value of the *i*th quality characteristic in the *j*th experiment at the *k*th test. The loss function is further transformed into the S/N 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 nj in the *j*th experiment can be expressed as:

$n_j = -10 \log (L_{ij})$……..…(3)

The effect of each welding process parameter on the S/N ratio at different level can be separated out because the experimental design is orthogonal.

In the graphical approach, the S/N ratios and average responses are plotted for each factor against each of its levels. From the graphs, higher the better the values were selected and the confirmation tests were conducted.

3. RESULTS AND DISCUSSION

The experiments was performed as per standard L9 orthogonal array and the analyzed S/N ratio (η values) corresponding to each experimental run was obtained using the minitab software and tabulated as shown in Table 3.

Table 3: Experimental Results and Corresponding S/N Ratio.

Exp. No.	Current	Voltage	Gas Flow Rate	Filler Rod	Tensile Strength Mpa	SNRA1
1	1	1	1	1	490.20	53.8075
2	1	2	2	2	481.35	53.6492
3	1	3	3	3	478.50	53.5976
4	2	1	2	3	478.70	53.6013
5	2	2	3	1	479.60	53.6176
6	2	3	1	2	480.30	53.6303
7	3	1	3	2	486.35	53.7390
8	3	2	1	3	494.60	53.8851
9	3	3	2	1	496.10	53.9114

The response analysis, represented by graphs in Figure 3, indicates the change in response when a given factor varies from lower to higher level. Figure 3 represents the main effects plot for the mean value of tensile strength against the input process parameters. It can be seen that greater current and voltage gives a better tensile strength. On the other hand, it experienced inverse effects for filler rods.

Table 4. Response Table for Signal to Noise Ratios

Level	Current	Voltage	Gas Flow Rate	Filler Rod
1	53.68	**53.72**	**53.77**	**53.78**
2	53.62	53.72	53.72	53.67
3	**53.85**	53.71	53.65	53.69
Delta	0.23	0.00	0.12	0.11
Rank	1	4	2	3

The mean S/N ratios for the four parameters at three levels are calculated as shown in Table 4 using the larger the better characteristics. The optimum parameter level for maximum value of tensile strength is $A_3B_1C_1D_1$. Tabulated in Table 4, the optimal combination of the parameters for the tensile strength could be achieved by using a weld current of 200Amp, voltage of 15Volts, gas flow rate of 20lit/min, and filler rod diameter of 2.4mm. The ANOVA table of the S/N ratio for the tensile strength as shown in Table 5 clearly indicates that, the weld current, followed by the filler rod diameter has the greatest effect on the tensile strength. However, the other parameter gas flow rate, followed by voltage has the least significant effect.

Table 5: ANOVA for selected factorial model (Response: Tensile Strength)

Source	Sum of Square	Df	Mean Square	F-value	P-value	
Model	384.37	6	64.06	20.27	0.0478	Significant
A-Current	115.00	2	57.50	19.19	0.0411	
B-Voltage	123.52	2	61.76	19.54	0.0487	
D-Filler Rod Dia	145.85	2	72.92	23.08	0.0415	
Residual	6.32	2	3.16			
Cor Total	390.69	8				

The **Model F-value** of 20.27 implies the model is significant. There is only a 4.78% chance that an F-value this large could occur due to noise. **P-values** less than 0.0500 indicate model terms are significant. In this case B, D are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

Table 6: Fit Statistics

Std. Dev.	1.78	R^2	0.9838
Mean	485.08	Adjusted R^2	0.9353
C.V. %	0.3665	Predicted R^2	0.6724
		Adeq. Precision	10.4924

Final Equation in Terms of Coded Factors

The second-order response surface representing the response can be expressed as a function of the input process parameters. From the observed data, the response function was obtained in coded factors units as:

Tensile Strength = 485.08 – 2.01A_1 – 3.01A_2 – 5.19B_1 + 2.01B_2 + 1.97D_1 – 5.61D_2……..(4)

Equations in terms of coded factors are suitable for making predictions about the response for given levels of each factor. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

3.1Experimental Validation

Experimental validation is the final step in the modeling process to investigate the accuracy and robustness of the established model. Table 7 presents the experiments order, the actual values, the predicted values and their deviations (percentage errors). It is a common practice for a nonlinear process, if the average error deviation is less than 15 %, then the optimization can be considered valid for the model to be accepted. The final analysis involves comparing the predicted values of the established model with experimentally validated values; it was found that the average error was below 15 %, confirming and concluding the methodology in establishing the model was systematic in performing this scientific research.

Table 7: Diagnostics Case Statistics Report of Observed and Predicted Tensile Strength

Run Order	Actual Value	Predicted Value	Residual	Leverage	Internally Studentized Residuals	Externally Studentized Residuals	Influence on Fitted Value
1	490.20	489.89	0.3056	0.778	0.365	0.267	0.499
2	481.35	480.51	0.8389	0.778	1.001	1.002	1.875
3	478.50	479.64	-1.14	0.778	-1.366	-3.717	-6.953(1)
4	478.70	479.84	-1.14	0.778	-1.366	-3.717	-6.953(1)
5	479.60	479.29	0.3056	0.778	0.365	0.267	0.499
6	480.30	479.46	0.8389	0.778	1.001	1.002	1.875
7	486.35	486.04	0.3056	0.778	0.365	0.267	0.499
8	494.60	495.74	-1.14	0.778	-1.366	-3.717	-6.953(1)
9	496.10	495.26	0.8389	0.778	1.001	1.002	1.875

Figure 3 below shows a plot of the predicted values verus the estimited values. The straight line grapgh reveals that the errors are uniformly distributed.

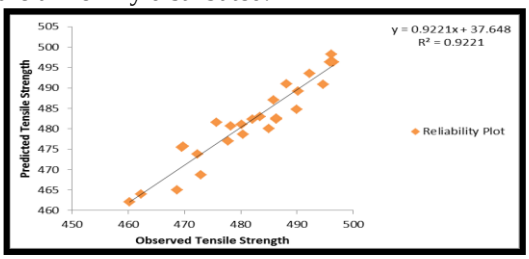

Figure 3: Reliability Plot of Observed and Predicted Tensile Strength Values.

4. CONCLUSION

The experiment reveals the suitability of using Taguchi Optimization process in predicting the response tensile strength of a metal inert gas welded plate. The higher-the-better quality characteristic was considered in the weld strength prediction. The Taguchi method was adopted to solve this problem and the experimental results showed that the weld strength is greatly improved by current. The following optima parameters were obtained; weld current 200Amp, voltage 15Volts, gas flow rate 20lit/min, and filler rod diameter 2.4mm.

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