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Design of Shielded Metal Arc Welding Parameters For Optimum Tensile Strength Using Taguchi Method

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ABSTRACT

Shielded Metal Arc Welding (SMAW), an arc welding process, is widely used in applications. In practice, SMAW is widely applied to the welding process on hollow square pipe. Performance expected from this welding is the tensile strength of weld joint. The tensile strength is influenced by parameters process which have possibility for an optimization process to become 'robust'. Robust is a design which less sensitive to the effect of uncertain quantities or noise factors. Taguchi method is the most efficient optimization method which accommodates the noise factors effect and requires less experiment. This study is focusing on optimizing the welding process on hollow square pipe. Parameters process such as welding current (I), electrode angle (θ), root gap (d) and electrode type (E) are adopted as parameters design. Taguchi method are chosen as a strategy and L_9 fractional orthogonal array are chosen as the design experiment, which only 9 experiment samples needed from 81 experiments that should have been carried out for full factorial design. The objectivity is to maximize the tensile strength of weld joint. Three replications of L_9 fractional orthogonal array Taguchi had been performed to generate the tensile strength and estimates the fluctuation of the output caused by noise factors. This study found that the welding current of 100A (I), electrode angle (θ) of 90°, root gap (d) of 2 mm, and electrode type (E) of E7018 produce the optimum results. Tensile strength improved from this robust parameter design is about 98,39 MPa based on initial parameter design.

Keywords: *Robust optimization, SMAW, Taguchi method, tensile strength*

I. Introduction

SMAW is an essential welding process in the manufacturing and constructing field because of its efficiency, flexibility, and cheap cost welding process. In the construction field, this type of welding is widely used in application to welding on a hollow square pipe. To increase the welding output, improving the SMAW parameters process is needed as part of the engineering process [1], [2]. SMAW is the most used arc welding in Indonesia due to its easier operating, flexibility and high efficiency [3]. ASTM A500 of the hollow square pipe is the most used material in the construction sector, widely used in the construction field. Tensile strength is the expected performance of this welding process, which is generated as strains can be held by the workpiece before it goes to fractures[4].

SMAW performance is affected by parameters processes. Most of the parameters process is welding current, electrode angle, root gap, and electrode type. To find the optimum combination of the SMAW parameters process, it is needed an optimization strategy to improve and optimize the tensile strength [5]. The Taguchi method is the most efficient optimization strategy that is widely used. Taguchi method objectivity is to improve a parameters process to become "robust". Robust is defined as a less sensitive design due to

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the effect of noise factors. These noise factors include inaccuracies during the manufacturing process, variations in loading, material properties, or variations in other operating conditions. Taguchi S/N ratio compared between the signal (expected output) and the noise (unexpected error) to determine the robust design [6].

Some of the previous studies were conducted by some authors. Nair [4] used Taguchi to improve the tensile strength of SMAW welded joint of SS316L plates and found the optimum parameters are welding current of 100A, welding angle of 15^o, and filler electrode of E316L. On the other hand, Ahire [7] used the Taguchi method supported by RSM and GA based techniques to optimize the tensile strength on SS304 and mild steel plates welded joint. They found that the optimum parameters are welding current of 91.4A, welding speed of 6.7 mm/s, electrode angle of 30^o, and root gap of 1 mm. Qazi [8], using the Taguchi method to optimize the tensile strength on SA516, found the optimum parameters are welding current of 120A, welding speed of 4 mm/s, and root face of 2 mm.

The previous studies do not fully adopt robust design optimization due to the effect of noise factors. It can be seen and indicated by a single measurement for each combination of parameters used in the experiment. For this work, three replications will be used in the experiment to estimate the fluctuation caused by the noise factor [9]. The main objectives of this study are to optimize the SMAW parameters process to obtain the robust design parameter using three replications for each combination parameter to estimate the fluctuation caused by noise factors effect on the tensile strength.

II. Material and Methods

A. Material

The material used in this research was a hollow square pipe of ASTM A500. Dimensions of the hollow square pipe are 50 mm x 50 mm with a thickness of 2.8 mm. The material is cut into two parts with a length of 150 mm and will be welded together. Then, the welded material was cut off into a specimen for tensile testing. The standard testing used in this study was the IACS weldments standard, as shown in Figure 1. Diameter electrodes of 2.6 mm are used in this study. Tensile testing was conducted using a universal testing machine [7] to obtain the tensile strength of welded joints.

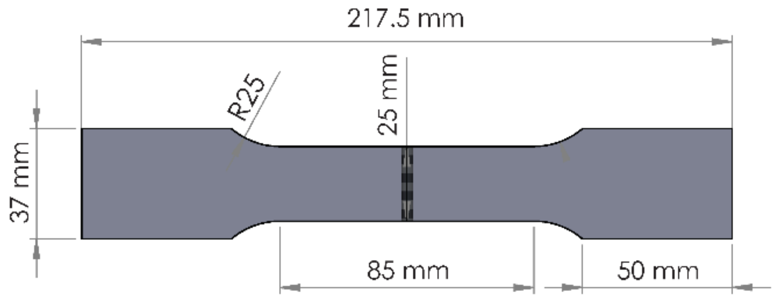

Fig. 1. Specimen design

B. Experimental Procedure

This study begins with identifying the parameters process, optimization problem formulation, the experiment design, running the experiment, results analyze using ANOM and predicting the optimum parameter using an effect plot, experimental verification results, and analyzing the optimization improvement. The last was running ANOVA to calculate the parameters effect in this study.

C. Optimization Problem Formulation

Objective Max. (σ_u)

Parameters Welding Current; Electrode Angle; Root Gap; Electrode Type

The objectivity of this study was to maximize the tensile strength (σ_u) of SMAW welded joints affected by several parameters, including welding current (I), electrode angle (θ), root gap (d), electrode type (E). The practical parameters range was selected as the design parameters process and listed as shown in Table 1.

D. Design of Experiment (DoE)

This study used three levels of parameters as a design parameters process in this study with the lower range of parameter as level 1 and the upper range for parameter level 3, while level 2 is selected to be the middle range parameters as shown in Table 1.

Table 1. Parameter range

Parameters	Lower	Upper
Welding current (*I*)	60A	100A
Electrode angle (θ)	30^o	90^o
Root gap (*d*)	0 mm	2 mm
Electrode type (*E*)	E6013	E7018

L_9 fractional orthogonal array Taguchi is selected as a design of experiment with the smallest experiment needed from the total possible combinations of 81 experiments for four 3-level parameters, which is only needed for 9 samples of the experiment as shown in Table 2 [10]. Three replications were used in the tensile testing generating data [11] to estimate the fluctuation affected by the noise factors in this study. Since maximizing the tensile strength is the objectivity of this optimization case, the larger the better S/N ratio will be selected as a robustness index in this study, as shown in Equation 1.

$$S/N_{\mathrm{LTB}} = -10 \cdot \log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \qquad (1)$$

III. Results and Discussions

A. Tensile Strength

The data was generated from the field experiment using a designed experiment of L9 fractional orthogonal array with three replications for 4 three-level parameters. Results of the experimental data are listed as shown in Table 2. Then from these three replications, the tensile strength average and the standard deviation are calculated. The larger the better S/N ratio formulation is used as a robustness index since the objectivity is to maximize the tensile strength [10]. The best design of L9 design experiment is number three experiment with 50.26 in S/N ratio, as shown in Table 2. The initial design that is usually used in practice is number five experiment.

Table 2. L_9 design of experiment

Parameter				Exp	Average tensile strength	Standard deviation	S/N ratio
I	θ	*d*	*E*				
1	1	1	1	**1**	174.67	15.53	44.74
1	2	2	2	**2**	261.61	49.86	47.90
1	3	3	3	**3**	328.02	22.20	50.26
2	1	2	3	**4**	312.38	52.31	49.54
2	2	3	1	**5**	259.45	10.14	48.26
2	3	1	2	**6**	253.18	24.78	47.95
3	1	3	2	**7**	305.61	35.23	49.53
3	2	1	3	**8**	276.81	36.23	48.63
3	3	2	1	**9**	312.20	29.80	49.77

B. Optimum Parameter Analysis

An analysis of mean (ANOM) is executed to calculate the effect of parameters process on the tensile strength response based on the experiment data from L_9 design experiment. ANOM is executed for the S/N ratio, and the main effect of each parameter process then be plotted as shown in Figure 2.

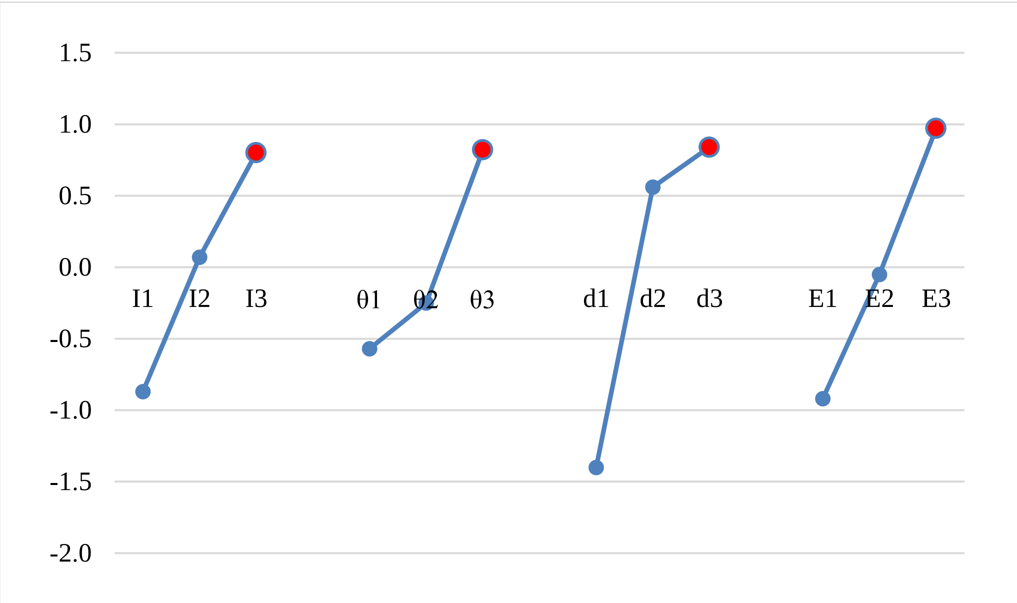

Fig. 2. Effect plot for S/N ratio

The S/N ratio gives the optimum response in the high level (level 3) of parameters process, as shown in Figure 2. Then, predicted from these effects plot as shown in Figure 2 which the level of the parameter 3 of welding current (100A), level 3 of electrode angle (90^o), level 3 of root gap (2 mm), and level 3 of electrode type (E7018) will give the optimum tensile strength for welded joint. Since this optimum SMAW parameter is still estimated, an experiment field is needed to verify this predicted optimum to clarify the prediction.

C. Verification Optimal Design

An experimental field was performed to verify the predicted optimum parameter. The results of the experimental field verify that the average tensile strength is 357.84 MPa with a standard deviation of 22.05, and the value of S/N ratio is 51.02. This verified optimum parameters then compared with the initial design to evaluate the optimization results.

D. Optimization Gain

The gain of the robust parameter design compared to the initial design give an improvement of about 98.39 MPa in tensile strength and 2.76 of S/N ratio. The comparison results of the robust design and initial design shown in Table 3.

Table 3. Comparison results

Design parameters	Welding current	Electrode angle	Root gap	Electrode type	S/N ratio
Initial design	80A	60^o	2 mm	E6013	48.26
Robust design	100A	90^o	2 mm	E7018	51.02
Gain					2.76

E. Analysis of Variance (ANOVA)

To evaluate contribution for each SMAW parameter analysis of mean is performed [10]. The main effect for parameters process is calculated, but the parameters process interaction is not calculated. Average tensile strength ANOVA is presented as shown in Table 4.

Table 4. ANOVA

	SS	DoF	MS	F_0	F_t	C
I	8505.04	2	4252.52	3.78	3.55	11.70%
θ	6433.86	2	3216.93	2.86		8.85%
d	22833.98	2	11416.99	10.16		31.41%
E	14686.47	2	7343.23	6.53		20.20%
Error	20230.06	18	1123.89			27.83%
Total	72689.41	26				100.00%

Based on Table 4, root gap (*d*) is the most parameter contributing to the tensile strength response because it gives the optimum weld penetration. The electrode type (*E*) is the second parameter contribution because each type has a different composition, which is the level 3 gives the optimum tensile strength. The welding current (A) is also affected by the weld penetration given by the next parameter contributions after electrode type. While the electrode angle (θ) does not give a significant contribution to the tensile strength response. The contribution of interactions between parameters that can't be calculated in this study is represented by the error in Table 4. The Taguchi method only considers the linear main effect of each variable, so the high pool error percentage in ANOVA may be due to interaction effect between variables or higher-order main effect of each variable [10]. This ANOVA has confirmed the Taguchi analysis as presented in the previous sections, as shown in Figure 2.

IV. Conclusions

This optimization of SMAW parameters can be concluded as follows: The welding current of 100A, electrode angle of 90°, root gap of 2 mm, and electrode type of E7018 is selected as robust optimum parameter design. The gaining of optimization is 98.39 MPa in tensile strength and 2.76 in S/N Ratio. The contribution of each parameters process is welding current of 11.70%, electrode angle of 8.85%, root gap of 31.41%, and electrode type of 20.20%.

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