TAGUCHI METHOD APPLIED FOR THE INVESTIGATION OF CORROSION LEVEL ON METAL INERT GAS WELDING OF MILD STEEL

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Abstract. Mild steel has a wide range of uses, such as in the construction field, automotive field, machinery industry, cookware, and pipeline. Metal Inert Gas (MIG) welding acts as an assembly method for mild steel. Corrosion level is a common problem that occurs in MIG welding on mild steel. In this study, the suitable welding parameters such as voltage, number of passes, and method of welding were chosen in the experimental testing, and the experimental testing was planned by using the Design of Experiment (DoE) as part of the Taguchi method. The welded mild steel specimens were evaluated using a corrosion test. The data analysis was done by using the Taguchi method. For the parameter to be the optimum welding parameter, the corrosion level was as low as possible. In this case, the S/N ratio is smaller, and the best common interest is chosen. By using the Minitab 18 software, the S/N ratio was calculated. Hence, from the result, the optimum parameters are: 9V voltage, three passes, and the welding method was circle push.

Keywords: metal inert gas (MIG) welding, design of experiment (DoE), Taguchi method, corrosion level, optimum welding parameter

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1. INTRODUCTION

Mild steel has a wide range of uses, such as in the construction field, automotive field, machinery industry, cookware, and pipeline. Whereas, Metal Inert Gas (MIG) welding is one of the most common processes to strongly join mild steel in various engineering applications. The equipment is shown in Figure 1. The solid wire electrode will continue to be fed through a MIG torch and pass into the weld area, joining the two base metals together by melting the base metal. At the same time, a shielding gas is sent through the MIG torch. The purpose of the shielding gas is to protect the weld area from contamination. MIG welding is less portable than other welding methods as it is connected to the gas cylinder that provides shielding gas.
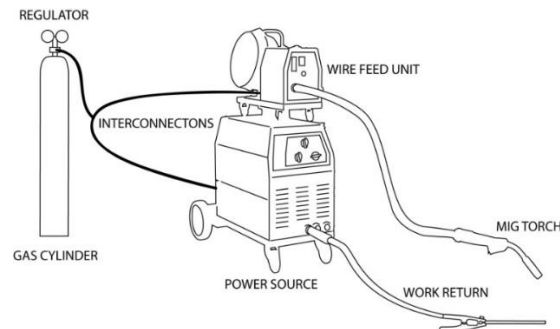

Figure 1. MIG welding equipment [1]

MIG welding electrodes are in coil form and are fed towards the base metal during the welding process. During the welding process, the inert gas, usually carbon dioxide, is around the electrode. The arc is formed between the electrode and the base metal, and heat is produced. At the same time, the heat melts the base metal and makes the base metal join together. The wire was connected to the positive polarity and the workpiece was connected to the negative polarity of the DC source [2].

The research [3] stated that the welding parameters in MIG welding majorly influence the surface texture, size, and shape of the weld bead, depth of penetration, quality, cost, and productivity. Work in [4] investigated the penetration level of the MIG welding parameter on three variables or parameters: current, voltage, and welding speed. When the welding current and voltage are increased, the depth of penetration is increased. The optimum parameters analyzed from the research are 150 A, 30 V, and 60 cm/min.

The Taguchi method is one of the major techniques for optimization in the field of MIG welding. As the work done by [5] used this method to perform an investigation on the optimization parameters of MIG welding. The results show that the voltage parameter shows a more tilted slope than the others on the Signal to Ratio (S/N) graph. The highest ratio value has a current of 60 A, a voltage of 25 V, and a welding speed of 2 lit/min. The voltage parameter has the highest percentage according to the analysis of variance method. whereas researchers in [6] investigated the Taguchi method for parametric optimization of the gas metal arc welding (GMAW) process. The parameters are current, flow rate, and nozzle to plate distance. From the research, the parameters of the best result are 100 A current, 20 l/min flow rate, and 15 mm distance from the nozzle to the plate. The yield strength of the best result is 322.74 MPa while the ultimate tensile strength of the best result is 591.18 MPa.

Whereas the investigation in [7] tried to find the optimum parameter of MIG welding by using the method of Taguchi. The orthogonal array that was used was L9 which has three variables and three levels. The experiment was done on the titanium specimen. For the penetration testing, the S/N ratio shows the most important parameter was voltage and the least important was the welding speed. For the tensile strength testing, the important parameter was the welding speed but the least important parameter was voltage.

The Taguchi method has also been used in other fields of engineering, such as for the design of line-start permanent magnet synchronous motors [8], multi-parameters optimization of electrical discharge machining with titanium powder mixed into dielectric fluid [9], and cutting tool wear optimization in the machining of fly ash geopolymer [10]. Other studies in the field of engineering also applied the Taguchi method, including optimization of the mechanical properties of hybrid composites [11], computational fluid dynamic optimization of a tactical vehicle platform [12], process parameters optimization for eco-friendly high-strength building blocks [13], turning parameters in machining [14], and optimization of the surface roughness in machining of titanium alloy [15].In this investigation, the objective is to find the optimum MIG

welding parameters that can provide a lower corrosion level. The welded specimens are submerged in a seawater container and Taguchi method is applied to find the optimum parameters and the parameter that has the most effect on the welding quality.

2. RESEARCH METHODS

The steps of analysis of the MIG welding parameters are as follows: Each specimen of mild steel (ASTM A36) was cut into pieces of 2 mm in thickness, 5 cm in length, and 10 cm in width. Next, the mild steel was ground until the surface was smooth and shiny. Two pieces of mild steel were butt welded together by MIG welding equipment with different parameters as presented in the Design of Experiment (DoE) Table 1. In this study, DoE was used as a part of the Taguchi method. DoE was used to plan the experiment for this investigation. DoE was also used to determine the relationship between the variables affecting the process.

In this investigation, the experimental steps are as follows: Firstly, the objective of the experiment was set. Then, followed by choosing the correct variables, the level of each variable was decided. The variables in this investigation are voltage, number of passes, and method of welding. Each of the variables has three levels. The details are shown in Table 1. The next step was to choose a suitable orthogonal array n. There are three variables and three levels in this experiment, so the suitable orthogonal array was L_9 as presented in Table 2. The data was analyzed by the Taguchi method and the optimum parameter for MIG welding can be selected.

Table 1. Level distribution of variables

Level	1	2	3
Voltage (V)	3	6	9
Pass	1	2	3
Welding Method	Circle Pull	Circle Push	Straight

Table 2. Design of Experiment planning table

Test Specimen	Voltage (V)	Pass	Welding Method
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

The welding fabrication was executed based on the parameters presented in Table 2. Each row in the matrix has three sets of specimens. After the specimen was prepared, the corrosion experiment was run. The result of each experiment was noted, and the average result of each experiment was calculated. The result of each variable was plotted. The higher the slope of the variable, the greater the effect on the investigation. The result of the intersection variable was plotted. From the slopes, the most affecting parameters can be defined.

2.1 Taguchi Method

The purpose of the Taguchi method is to obtain an optimal combination of parameters that has the smallest variance in performance. The signal-to-noise ratio (S/N ratio) is an effective way to find significant

parameters by evaluating minimum variance. A higher S/N ratio means better performance for the combination of parameters. The steps involved in the Taguchi method to analyze data are as follows: Firstly, the objective of the experiment was set. Followed by deciding the variable and the level of each variable. The details of variables and levels in this project are shown in Table 1. A suitable orthogonal array was chosen. The matrix experiment is in Table 2. The result of each experiment was noted, and the average result was calculated. A suitable S/N ratio of common interest was chosen. There are two types of common interest, such as smaller is better (SB) and larger is better (LB). Using the S/N ratio and the appropriate common interest, choose the best parameter for each test. The formula for the S/N ratio is as presented in Eq. (1) – (4).

$$SB, S/N = - 10\ Log_{10}[S] \tag{1}$$

$$S = \frac{y_1^2 + y_2^2 + \ldots y_n^2}{n} \tag{2}$$

$$LB, S/N = - 10\ Log_{10}[L]s \tag{3}$$

$$L = \frac{\frac{1}{y_1^2} + \frac{1}{y_2^2} + \ldots \frac{1}{y_n^2}}{n} \tag{4}$$

With *S* refers to the average squares of the measured values, y_i refers to the value received by experiment (i = 1/n) and *n* refers to the number of experiments.

Figure 2. Nine specimens labelled with testing number

2.2 Corrosion Test

The steps of corrosion level testing are as following. The lubricant oil on the surface of the specimen was removed if it was applied. A big container with a pump and seawater was prepared before the experiment started. The first set of the 9 specimens is weighted by weight scale as in Figure 3 before submerging into the seawater. The seawater was poured into the container. All the specimens are taken out after 24 hours of submersion and weighed on a weighing scale. The data outcome was collected before the submersion and 24 hours after the submersion. For this experiment, the data outcome was weightage. The lower the weight of the specimen, the higher the corrosion resistance of the specimen, and thus it was the optimum parameter of the welding process.
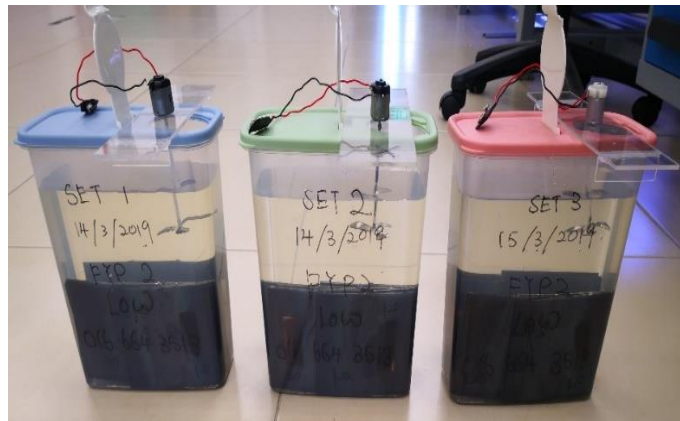
Figure 3. Weight specimen by weighing scale

Figure 4. Submersion method of specimen in seawater

3. RESULTS AND DISCUSSION

All of the specimens were weighed before and after submerging using seawater, and the average value was calculated from the three sets of the specimens. The data results of the three sets of specimens and their average value are shown in Table 3 and Table 4. While Figure 5 shows the submersion condition of the specimen. The figure shows 24 hours after the submersion.

Figure 5. Submersion condition of the specimens 24 hours after submersion

From Figure 5, it can be observed that the condition of the seawater changed from clear to yellowish-orange and finally dark cloudy. The change of colour shows the reaction between the seawater and the test specimens.

Table 3. Weightage of all the specimens before submersion

Test Specimen	Set 1 (g)	Set 2 (g)	Set 3 (g)	Average (g)
1	203.32	203.59	203.46	203.46
2	207.23	212.31	213.09	210.88
3	198.19	199.52	198.57	198.76
4	201.75	201.59	200.95	201.43
5	196.65	195.17	195.99	195.94
6	214.00	220.01	221.03	218.35
7	193.67	193.47	193.78	193.64
8	206.15	206.25	208.13	206.84
9	211.33	211.09	214.21	212.21

Table 4. Weightage of all the specimens after 24 hours of submersion

Test Specimen	Set 1 (g)	Set 2 (g)	Set 3 (g)	Average (g)
1	204.23	204.41	204.26	204.30
2	208.02	213.15	214.33	211.83
3	199.02	200.33	199.5	199.62
4	202.41	202.39	201.72	202.17
5	197.43	195.98	196.83	196.75
6	215.16	222.04	220.79	219.33
7	194.33	194.24	194.44	194.34
8	206.98	207.05	208.83	207.62
9	212.16	211.77	214.68	212.87

To analyze the data of the corrosion level, the important data is the weightage increment from 24 hours after submersion. The data analysis was done by using the Taguchi method. For the parameter to be the optimum welding parameter, the corrosion level must be as low as possible, hence the weight increment must be as small as possible. In this case, the S/N ratio is smaller, and the best common interest is chosen. By using the Minitab 18 software, the S/N ratio was calculated. Table 5 shows the weightage increment and the S/N ratio of the weightage increment 24 hours after the submersion. Figure 6 shows the graph of the S/N ratio for three factors: voltage, number of passes, and welding method. The main effects of the welding parameters are shown in Table 6.

Table 5. Weightage increment and the S/N ratio of the weightage increment before submersion and 24 hours after the submersion

Test Specimen	Before Submersion (g)	24 hours After Submersion (g)	Increment (g)	S/N Ratio
1	203.46	204.30	0.84	1.4800
2	210.88	211.83	0.96	0.3848
3	198.76	199.62	0.86	1.3438
4	201.43	202.17	0.74	2.5763
5	195.94	196.75	0.81	1.7946
6	218.35	219.33	0.98	0.1460
7	193.64	194.34	0.70	3.0980
8	206.84	207.62	0.78	2.1953
9	212.21	212.87	0.66	3.6091

According to the category of welding quality, a greater S/N ratio corresponds to a better quality of the welding specimen. Hence, the optimal welding parameter is the level with the highest S/N ratio, with the S/N preference being smaller is better. From Table 5, the highest S/N ratio is 3.6091 and the lowest S/N ratio is 0.1460, which is specimen 9 and specimen 6 respectively. It also shows that specimen 9 has the lowest weight increment, which indicates that the corrosion level is the lowest. Therefore, the optimum welding parameter set is from specimen 9, which is 9V voltage, three passes, and the welding method is circle push.
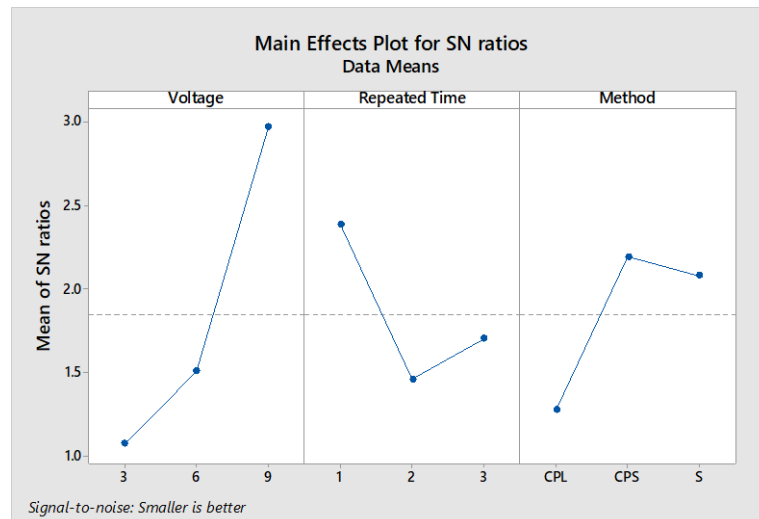
Figure 6. Graph of S/N ratio of the weightage increment before submersion and 24 hours after the submersion

Table 6 Response table for S/N ratio of the weightage increment before submersion and 24 hours after the submersion.

Level	Voltage	Pass	Welding Method
1	1.070	2.385	1.274
2	1.506	1.458	2.190
3	2.967	1.700	2.079
Delta	1.898	0.927	0.916
Rank	1	2	3

The slope in Figure 6 shows the optimum welding parameter for high corrosion resistance. The main effect parameter in corrosion resistance was the voltage factor. Whereas Table 6 shows the ranking of the parameters which affect the corrosion resistance of the welding specimen. The highest ranking was the voltage factor, followed by the number of passes, and the lowest ranking was the welding method.

4. CONCLUSIONS

The Taguchi method was applied to find the optimum MIG welding parameters that could provide a lower corrosion level. This was done by analyzing the result based on the S/N ratio and the preference of smaller is better. Based on the result, the most recommended welding parameters are 9V voltage, three passes, and the welding method is circle push. The evaluation using the response table for the S/N table showed the parameter that affected the most welding quality is the voltage factor, followed by the number of passes, and the lowest ranking is the welding method. There are several avenues for future work related to this study, including an X-ray test that can be used to show welding penetration levels. A fatigue examination is recommended to test the behavior of the welded part after a repeated cycle of load stress is applied. Experimental data collection, storage, and sharing based on the Internet of Things (IoT) is also recommended, so wider collaboration between other researchers can be achieved.

collaboration with Faculty of Manufacturing and Mechatronic Engineering, Universiti Malaysia Pahang, Pekan Pahang, 26600, Malaysia.

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