

Research Article

Design optimization of Process Parameters for TIG Welding based on Taguchi Method

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Abstract

The present study pertains to the improvement of ultimate load of stainless steel – mild steel weld specimen made of tungsten inert gas (TIG) welding. L_{16} orthogonal array (OA) of Taguchi method has been used to conduct the experiments using several levels of current, gas flow rate and filler rod diameter. Statistical techniques analysis of variance (ANOVA), signal-to-noise (S/N) ratio and graphical main effect plots have been used to study the effects of welding parameters on ultimate load of weld specimen. Optimum parametric condition obtained by Taguchi method. Confirmatory test has been conducted to validate the predicted setting

Keywords: Tungsten Inert gas Welding, Taguchi Method, Ultimate Load, Analysis of Variance, Signal-to-Noise Ratio, Optimum Parametric Condition.

1. Introduction

Tungsten inert gas (TIG) welding is an arc welding process that produces coalescence of metals by heating them with an arc between a non-consumable electrode and the base metal (Kumar and Sundarrajan, 2009). TIG welding offers several advantages i.e. joining of dissimilar metals, low heat affected zone, absence of slag etc. In TIG welding operation, weld quality mainly depends on features of bead geometry, mechanical-metallurgical characteristics of the weld and various aspects of weld chemistry. These features are greatly influenced by the welding parameters such as current, voltage, gas flow rate, electrode stick-out, edge preparation, position of welding, weld speed (Ghosh et al 2013) etc. Selection of filler rod material also has significant effect on weld quality. Selection of optimum parametric setting is essential for obtaining desired weld quality. Literature shows that work has been explored on different aspects of modeling, simulation and process optimization in TIG welding.

Tarnag and Yang (1998) used Taguchi application to analyze the significance of process parameters on weld bead geometry. Experiments have been planned as per orthogonal array of Taguchi method. Optimal parametric condition was obtained by Taguchi method. Again Datta et al (2008) applied Taguchi philosophy for obtaining optimal parametric combinations to achieve desired weld geometry and dimensions related to the heat affected zone in submerged arc welding. Esme et al. (2009) had done investigation on TIG welding process for an optimal parametric combination to yield favorable bead geometry

of welded joints. They used grey-Taguchi method application to optimize multi-responses bead width, bead height, penetration, area of penetration, HAZ and tensile load simultaneously. Kumar and Sundarrajan (2009) used Taguchi method to optimize the pulsed TIG welding process parameters of heat-treatable (Al-Mg-Si) aluminum alloy weldments for maximizing the mechanical properties. Another work presented by Zhang et al (2012) optimization of an aluminum profile extrusion process based on signal-to-noise ratio of Taguchi methodology. Anawa and Olabi (2008) applied CO₂ continuous laser welding process for joining a dissimilar AISI 316 stainless-steel and AISI 1009 low carbon steel plates. They used Taguchi approach as statistical design of experiment technique for optimizing the selected welding parameters in terms of minimizing the fusion zone and they found satisfactory results. Tarnag et al (2011) used neural network to construct the relationship between welding process parameters and weld pool geometry in TIG welding. Patil and Kadam (2013) applied artificial neural fuzzy interface system to maximize weld strength and optimum metal deposition rate in welding of dissimilar metals stainless steel and mild steel. Again Lenin et al (2010) optimized process parameters for maximizing weld strength in manual metal arc welding for joining of dissimilar metal stainless steel and carbon steel. They utilized Taguchi application to analyze the effects of each welding parameter on the weld strength by analysis of variance (ANOVA).

In the present work, it is planned to determine the optimal parametric condition in TIG welding of dissimilar metals mild - stainless steel to yield desired weld quality in terms of ultimate load. Taguchi approach for process

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optimization has been carried out to maximize the ultimate load of weldment. Confirmatory test has been carried out to check predicted result.

2. Design of experiments (DOE)

The competition in the market has forced the manufactures to design and develop product / process with minimal cost as well as time. The design of experiment has emerged as an important tool for achieving objectives. DOE is a statistical technique that allows to run minimum number of experiments to optimize process. Major approaches in DOE are: factorial design, Taguchi method and response surface methodology. In the present work, Taguchi method is used to design and analyze the TIG welding process.

2.1 Taguchi Method

Taguchi design of experiment provides a simple, efficient and systematic approach for the optimization of manufacturing process / systems to minimize / maximize the output responses with minimum number of experiments. This technique has been proved efficient tool to optimize many manufacturing problems [Rudrapati et al (2011), Dongxia et al (2012) and Pan et al (2005)]. The traditional experimental design procedures focus on the average product or process performance characteristics. But the Taguchi method concentrates on the effect of variation on the product or process quality characteristics rather than on its averages. Taguchi approach recommends that this can be done by the proper design of parameters. Orthogonal arrays (OA) is a standard design by which simultaneous and independent evaluation of two or more parameters for their ability to affect the variability of a process characteristic / output response can be done in a minimum number of tests. Subsequently, decision is made for the optimum combination of these parameters (Shaji and Radhakrishnan, 2003). Three quality characteristics in Taguchi method are shown in below.

Nominal is the best:
$$\frac{S}{N} = 10 \log \frac{\bar{y}}{s_y^2} \tag{1}$$

Lower is the best:
$$\frac{S}{N} = -10 \log \frac{1}{n} \left(\sum y^2 \right) \tag{2}$$

Higher is the best:
$$\frac{S}{N} = -10 \log \frac{1}{n} \left(\sum \frac{1}{y^2} \right) \tag{3}$$

Where, \bar{y} is the average of observed data, s_y^2 is the variation of y, n is the number of observations, and y is the observed data.

The parameter design phase of the Taguchi method generally includes the following steps:

1. Identify the objective of the experiment
2. Identify the output responses and its measurement systems / instruments
3. Identify the factors that may influence the output response, their levels and possible interactions

4. Select the appropriate orthogonal array (OA)
5. Conduct the test described by the trials in the OA
6. Analysis of the experimental data using the statistical techniques signal-to-noise (S/N) ratio, analysis of variance (ANOVA) and factor effects to identify the significance of process parameters.
7. And find out the optimum levels of factors
8. Verification of the optimal design parameters through confirmation experiment.

3. Experimental Details

The plan has been made and work-piece materials (i.e. mild steel and stainless steel) have been cut into desired dimensions. The setup has been made ready and prepared for doing TIG welding. Now butt joints are made under varied conditions of welding as given L_{16} orthogonal array of Taguchi method. The selected process parameters and its levels are given in Table 1. Photographic view of the experimental set up is shown in Fig. 1. Mild and stainless steel welded sample is shown in Fig.2. Ultimate load tests are conducted in Universal Testing Machine (UTM). After ultimate load test, failure occurred at mild steel portion (Fig.3). The specifications of the Mild and stainless steel samples and UTM are given below.

Universal Testing Machine:
 Make: Instron (model 8801);
 Capacity: Maximum 1000KN;
 Accuracy: $\pm 0.4\%$;

Table 1 Input parameters and their levels

Process parameters	Units	Levels			
		1	2	3	4
Current (A)	A	90	100	110	120
Glass flow rate (B)	l/min	12	14	16	18
Filler rod (C)	mm	1.6	2	2.5	3



Fig. 1 Experimental setup

Mild steel: length = 85 mm; width = 21mm; thickness = 3mm;
 Stainless steel: length = 90 mm; width = 25 mm; thickness = 4mm;
 Working length is 10 mm..



Fig. 2 welded sample



Fig. 3 Failed sample after ultimate load test

4. Experimental results and discussion

Experimentation has been completed and ultimate load is measured by conducting the tests on universal tensile machine. Output response is shown in Table 1, these data is used to further analysis i.e. to determine the optimum welding condition to maximize the ultimate load.

4.1 Effect of welding parameters

The statistical techniques analysis of variance and signal-to-noise ratio have been applied on observed data to identify the significant input parameters which expected to influence output response (ultimate load). Result of analysis of variance (ANOVA test) is shown in Table 2. In the ANOVA test, F-tests value of the parameters are comparing with the standard F table value ($F_{0.05}$) at 5% significance level (95% confidence level). If P-values in the table are less than 0.05 then the corresponding variables considered as statistically significant. It is found from Table 4 that P values for current, glass flow rate and filler road are greater than 0.05. This means that none of these parameters do have significant effect on the ultimate load at 95% confidence level.

S/N ratio of UL is calculated for each parametric combination using Taguchi method and shown in Table 3. On examination of the Delta values, glass flow rate (B) is found to be most significant factor, next is current and followed by filler road. By using these S/N ratio values given in Table 3, the main effect plots have been made using MINITAB 16 software and shown in Figure 2. While calculating S/N ratios values, larger-the-better criteria have been applied, because ultimate load needs to maximize. So Eq. 3 is used for determining the S/N ratios, shown in Table 3. In a main effect plots, if inclination of the line is more, then the corresponding parameters is more significant parameter and inclination is less, then the effects of the corresponding factor is less. From main effect plots (Figure 4), it is found that current (A) and glass flow rate (B) are considerably significant on ultimate load whereas filler rod (C) has lesser effect. Optimum parametric setting can be found from the main effect plots at highest S/N ratio values of UL corresponding to each factor. From Figure 4, it is observed that the optimum

condition is **A2 B3 C2** (i.e. current (A) = 100 A, glass flow rate (B) = 18 l/min and filler rod (C) = 2 mm).

Table 1 L_{16} orthogonal array and output response

S.No.	A	B	C	Ultimate Load
1	90	12	1.6	13.8
2	90	14	2.0	13.7
3	90	16	2.5	12.2
4	90	18	3.0	13.1
5	100	12	2.0	13.9
6	100	14	1.6	12.1
7	100	16	3.0	14.8
8	100	18	2.5	14.5
9	110	12	2.5	12.8
10	110	14	3.0	12.1
11	110	16	1.6	13.9
12	110	18	2.0	13.2
13	120	12	3.0	13.7
14	120	14	2.5	12.8
15	120	16	2.0	13.8
16	120	18	1.6	14.8

Table 2 Analysis of variance for ultimate load

Source	DF	Seq SS	Adj MS	F	P
A	3	0.82	0.27	0.72	0.57
B	3	1.47	0.49	1.30	0.35
C	3	0.38	0.12	0.34	0.79
Error	6	2.27	0.37		
Total	15	4.97			

Table 3 Response table for signal-to-noise ratio of ultimate load

Level	Current (A)	Gas flow rate (B)	Filler road (C)
1	22.40	22.63	22.68
2	22.79	22.05	22.70
3	22.27	22.70	22.31
4	22.77	22.85	2.54
Delta	15	4.97	0.39
Rank	2	1	3

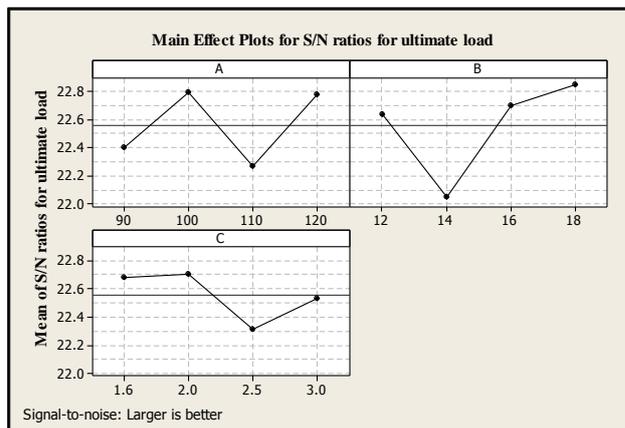


Fig. 4 Main effect plots for ultimate load

The adequacy of the model has been investigated by the examination of residuals. The difference between the respective observed response and the predicted response is called residuals; those are examined by using normal probability plot and plot of the residuals vs. predicted response. If the model is adequate, the residual points on the normal probability plot should form a straight line. On the other hand the plot of residuals vs. predicted response should be structure less i.e. it should contain no obvious pattern. From the normal probability plot (Fig. 5), it is found that the residuals fall on a straight line; it implies that the errors are distributed normally. The plot of residual vs. predicted / fitted surface roughness values (Fig. 6) reveals there is no obvious pattern and unusual structure. This implies that the proposed model is adequate and there is no reason to suspect any violation of the independence or constant variance assumption (Ashvin and Nanavati (2013), Noordin et al (2004).

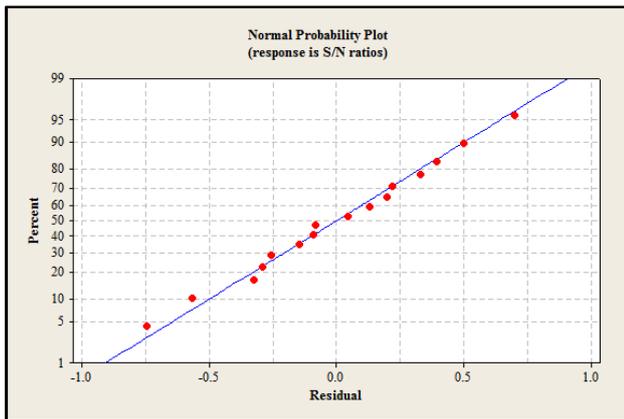


Fig.5 Normal probability plot of residual for ultimate load

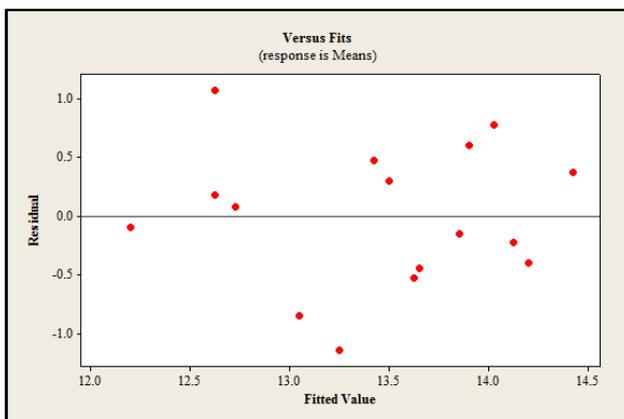


Fig.6 Plot of residual vs. fitted ultimate load values

5. Confirmatory test

Confirmatory test is conducted at optimal parameter combination (A2 B3 C2) to check the validity of the optimum welding condition. From the results of confirmatory test, it is found that optimum welding parametric condition produced maximum UL, this value shows the validation of the proposed optimization methodology.

Table 4 confirmatory test results

Obtained optimum parametric condition by Taguchi method		Obtained ultimate load by confirmatory test
Current (A)	100 A	Ultimate load = 15.1 MPa
Glass flow rate (B)	18 l/min	
Filler rod (C)	2 mm	

6. Conclusions

This paper has described the use of Taguchi method and statistical techniques ANOVA and S/N ratio for analyzing and optimizing the ultimate load in TIG welding of stainless steel – mild steel specimens. From the study, the following conclusions are drawn

1. From the ANOVA results, it is found that none of the welding parameter does not effecting the ultimate load.
2. Main effects plots reveal that current and gas flow rate are the factors which has considerable influence on ultimate load. Filler rod has small / lesser influence.
3. The optimum welding condition obtained by Taguchi method is: current = 100 A, gas flow rate = 18 l/min and filler rod = 2 mm.
4. Confirmation test is confirms the improvement of the UL which also indicates the validity of the present optimization procedure by using Taguchi methodology.

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