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A Taguchi- Single Response Approach to Optimize Bead Geometry in TIG Mild Steel Weld

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Abstract

This study is aimed at applying the Taguchi single response optimization tool to welding technology. These tools aid in the selection of optimum process parameters, and optimum process parameters are responsible for the improvement in the quality of weld metal. The tool employed here is the Taguchi-single response concept. This approach uses the signal to noise ratio, ANOVA table and a confirmatory test method to determine the most economically desired process parameters. In this study, the optimum process parameters obtained is I_2 V_1 Wd_2 GFR_1 with a prediction error of 5.29dB. This means that for the existing process parameter with 5.29Db.To confirm the validity of the optimum process parameters, the estimated average at the single state of the process parameters were found to be within the predicted range of 95% confidence level. The additive law equation was used to generate the predictive value that was used to determine the performance of the process parameters.

1. Introduction

Welding is a process of joining two pieces of metal by the application of heat, pressure, and filler wire. This method has been the most reliable means of fabrication available to the manufacturing industry. Efforts have been put into this process to improve on the quality mechanical properties of the welded structure several optimization techniques have been developed and applied which includes Artificial Neural Network, Genetic Algorithm, Response Surface Methodology [1]. Three important parameters affect the weld pool shape, and they include the preheating temperature of the base metal, the arc-length and the heat-input. The influence of welding parameter such as current ratio and pulse frequency on the weld pool shape shows that for a stainless steel the choice of the peak current, background current and pulsed frequency affects considerably the weld pool shape [2]. In optimizing the weld pool geometry, there exists four smaller-the-better quality characteristics, i.e., the front height, front width, back height and back width of the weld pool. The modified Taguchi method is adopted to solve the optimal weld pool geometry with four smaller-the better quality. [3] An investigation based on three parameter such as speed travel, arc length and current on bead geometry was conducted. The study showed that welding speed, has a significant effect on the bead geometry, they found that Taguchi method is a very effective tool for optimization[4].Optimization studies of weld bead geometry was done considering of arc voltage, current, welding speed, wire feed rate and nozzle-to-plate distance on weld bead width[5] Taguchi's robust design coupled with fuzzy based desirability function approach was used to optimize multiple bead geometry parameters of submerged arc weldment[6] multi regressions method and a neural network mathematical model was also employed to predict bead geometry[7].Taguchi philosophy was employed to obtain optimal parametric combinations for best weld bead geometry and dimensions related to the heat affected zone (HAZ), such as HAZ width in submerged arc welding [8]. A comprehensive review of submerged arc welding parameters and its effects on the weld quality was investigated [9]. An investigation on the various welding parameters such as welding speed, voltage and gas flow rate on HSLA steel. The effects of these parameters on weld bead geometry such as penetration, width and height have been studied [10].

2. Methodology

The materials used in this study contain mild steel plates measuring 60mm x 40mm x 10mm. Two pieces of the mild steel plates were welded together using the input process parameters contained in Tungsten Inert Gas welding machine. 100% Argon gas was the shielding gas. The input process parameters comprise of the welding voltage, welding current, and gas flow rate. The layout of the input process parameters is made into a matrix design. The design matrix shows the random distribution of input parameters.

2.1 Material selection

The choice of material selected for this study was mild steel, it was chosen because of its availability. This grade has high corrosion resistance and can be operated at elevated temperatures, the Tungsten inert gas welding technique was selected because of its fine weld product quality. A matching filler wire having similar property of the base metal was selected. The need to protect the weld pool from environmental gaseous interference, a shielding gas such as Argon, Helium, or carbon dioxide is required.

2.2 Welding Process Parameters

The welding process parameters consists of current, voltage, gas flow rate, and wire diameter and their range of values shown in Table 1.

Table 1: Input factors

Code	Process Parameters	*Level* 1	*Level* 2
I	*Current*	140	160
V	*Voltage*	20	24
Wd	*Wire diameter*	1.6	3.2
GFR	*Gas Flowrate*, *L* / min	14	16

2.3 Experimental procedure

Weld samples were produced using a 10mm thick mild steel plate. For the welding current varying from 140 to 160 amps, wire diameter 1.6 to 3.2mm, gas flow rate 14 to 16 lit/min and voltage 20 to 24 volts. In the present work, mild steel plates of 10mm thickness and 60 mm lengths were butt joined using the desired filler rod at varying levels of current voltage and gas flow rate t by manual TIG welding process. These three parameters were taken as variable for present study and their three levels were chosen for which responses were measured, and the central composite design was selected as the experimental design method. These parameters with their levels are shown in Table 2. The experimental data for the heat affected zone and arc length are presented in Table 2.

Table 2: Experimental data

Levels				Responses	
I	*V*	*Wd*	*GFR*	*BP*	*BW*
1	1	1	1	8.24	9.10
1	1	2	2	6.30	10.50
1	2	1	2	5.45	11.98
1	2	2	1	9.80	8.22
2	1	1	2	10.58	3.92
2	1	2	1	11.23	4.43
2	2	1	1	7.43	10.85
2	2	2	2	8.88	12.32
Total (T)				64.91	71.32
Average $\left(\overline{T}\right)$				8.1138	8.9150

The 5-point Likert scale was used by the welding expert inspectors to score the results obtained from the experiment. the 5-point Likert scale table is shown in Table 3.

Table 3: Likert Scale Criteria for Expert Evaluation

Score	*Classification*
5	*Excellent*
4	*Very Good*
3	*Good*
2	*Poor*
1	*Very Poor*

The weld inspectors have converted the weld bead geometries to expert scores. The expert weighted scores are shown in Table 4

The responses obtained are used for determining the individual weight allocated to each weld property the weight allocated to bead penetration is 0.53 and that for bead width is 0.47 as shown in Table 5.

3. Results and Discussion

The Taguchi tool is used in this study, the relevant criteria adopted here, are as expressed hereunder;
The smaller the better, the signal to noise (S/N) ratio, η, becomes

$$\eta_S = -10\log_{10}\left[BW^2\right]$$

The larger the better, the S/N ratio, η, becomes

$$\eta_L = -10\log_{10}\left[\frac{1}{BP^2}\right]$$

Table 4: Expert Evaluation of Weld Properties

Exp. Run	*Bead Penetration*	*Bead Width*	$\sum_{ij}^{n}\sum_{ij}^{n}$
1	4	3	
2	4	3	
3	3	3	
4	5	4	
5	5	5	
6	5	5	
7	4	3	
8	3	3	
Total, $\sum_{m}^{n}$	33	29	62

Table 5: Weighted Average of Weld Properties

Mean, $\frac{\sum_{m}^{n}}{\sum_{ij}^{n}\sum_{ij}^{n}}$	$\frac{33}{62} = 0.53$	$\frac{29}{62} = 0.47$	

The values from the S/N ratio were used to generate the ANOVA.
The analysis of variance ANOVA is a technique used to check for the fitness and significance of the model and to also the percentage contribution of each parameter towards the optimization of the desired response which is the bead penetration. Table 6 shows the ANOVA results obtained for the bead penetration (BP).

The analysis of variance ANOVA was also employed to check for the model adequacy, the significance of the model and percentage contribution of process parameters. Table 7 shows the ANOVA results obtained for the bead width (BW).

To compute the noise to signal ratio for each response, the means are required, the calculated means for the bead width and bead penetration at different Levels are presented in Table 8.

Table 6: ANOVA Results for Bead Penetration (BP)

Process paramaters	*SS*	*DOF*	*MS*	*F*	*C*(%)
I	0.8800	1	0.8800	1.1997	17.18
V	1.9013	1	1.9013	2.5921	37.12
Wd	0.0685	1	0.0685	0.0934	1.34
GFR	0.0722	1	0.0722	0.0984	1.41
Error	2.2006	3	0.7335		
Total	5.1226	7			

$F_{(3)(4)}$ at 0.05 confidence level = 6.59

Table 7: ANOVA Results for Bead Width (BW), mm

Process paramaters	*SS*	*DOF*	*MS*	*F*	*C*(%)
I	2.1424	1	2.1424	30606	20
V	7.4112	1	7.4112	105874	69
Wd	0.0040	1	0.0040	57	0.04
GFR	1.1704	1	1.1704	16720	11
Error	0.0002	3	0.0007		
Total	10.7282	7			

Table8: Means of Bead Width and Bead Penetration at Different Levels

	Mean Values of BP (*mm*)				*Mean Values of BW* (*mm*)			
Process parameters	*I*	*V*		*GFR*	*I*	*V*	*Wd*	*GFR*
Level								
1	$\frac{[8.24+6.30+5.45+9.80]}{4}=7.45$	$\frac{[8.24+6.30+10.58+11.23]}{4}=9.09$	$\frac{[8.24+5.45+10.58+7.43]}{4}=7.93$	$\frac{[8.24+9.80+11.23+7.43]}{4}=9.18$	$\frac{[9.10+10.50+11.98+8.22]}{4}=9.95$	$\frac{[9.10+10.50+3.92+4.43]}{4}=6.99$	$\frac{[9.10+11.98+3.92+10.85]}{4}=8.96$	$\frac{[9.10+10.50+3.92+4.43]}{4}=6.99$

2	$\frac{\left[10.58+11.23+7.43+5.88\right]}{4}=8.78$	$\frac{\left[5.45+9.80+7.43+5.88\right]}{4}=7.14$	$\frac{\left[6.30+9.80+11.23+5.88\right]}{4}=8.30$	$\frac{\left[6.30+5.45+10.58+5.88\right]}{4}=7.05$	$\frac{\left[3.9+4.43+10.85+12.32\right]}{4}=7.88$	$\frac{\left[11.98+8.22+10.85+12.32\right]}{4}=10.84$	$\frac{\left[10.50+8.22+4.43+12.32\right]}{4}=8.87$	$\frac{\left[10.50+11.98+3.92+12.32\right]}{4}=9.68$

To obtain the combined interaction input factors and the responses the total weighted mean is computed which is used to determine the total noise to signal ratio. The total weighted signal to noise ratios at two levels of process parameters is shown in Table 9.

Table 9: Mean Values of η_{abs}

Level Pr*ocess parameters*	*I*	*V*	*Wd*	*GFR*
1	$\frac{\left[0.6938-1.1262-2.3317+1.9072\right]}{4}=0.2142$	$\frac{\left[0.6938-1.1262+5.2826+5.0578\right]}{4}=2.4770$	$\frac{\left[0.6938-2.3317+5.2826-0.5005\right]}{4}=0.7861$	$\frac{\left[0.6938+1.9072+5.0578-0.5005\right]}{4}=1.7896$
2	$\frac{\left[5.2826+5.0578-0.5005-2.0963\right]}{4}=1.9359$	$\frac{-2.3317+1.9072-0.5005-2.0963}{4}=-0.7553$	$\frac{\left[-1.1262+1.9072+5.0578-2.0963\right]}{4}=2.4770$	$\frac{\left[-1.1262-2.3317+5.2826-2.0963\right]}{4}=-0.2716$

The optimum process parameters which captured the best combination of current, voltage, wire diameter and gas flow rate that will produce a weld with minimum bead width and maximum bead penetration are shown in Table 10.

Table 10: Optimized and Predicted Process Parameters

Weld Pr*operty*	*Optimum Parameter level*	Predicted *Optimum Value*
BP	$I_2\ V_1\ Wd_2\ GFR_1$	10.10*mm*
BW	$I_2\ V_1\ Wd_2\ GFR_1$	3.50*mm*

The Taguchi model employed the noise to signal ratio, considering the single response approach which compared the optimal solution and the experimental values which is shown in Table 11.

Table 11: Single Response Optimal Solution

	Performance Characteristics	*Optimal Parameters*	Pr*edicted OptimalValue*	*Existing Experimental Values*
Single response	*BP*	$I_2\ V_1\ Wd_2\ GFR_1$	10.10*mm*	8.96*mm*
optimization process	*BW*	$I_2\ V_1\ Wd_2\ GFR_1$	3.50*mm*	4.82*mm*

4. Conclusion

This study adopted a new way of optimizing process parameters to improve weldment properties and strength in order to sustain designed loads. In this study, the Taguchi-single response concept approach was used. This approach uses the signal to noise ratio as the values to generate the optimum process parameters in accordance with the Taguchi criterion. The concept was used to validate the potency of the optimum process parameters where the estimated average of capacity based on the single response stage were within the optimal range of the process parameters at 95% confidence level. The ANOVA tables were developed for both the single responses of bead penetration and bead width. In each case, it was found that the welding voltage has the most significant role to play in improving the weldment of mild steel plate joints. Also, a confirmation test was done to evaluate the performance of the optimum process parameters compared to the existing process parameters. It was found that the optimum process parameters performances surpassed that of the existing process parameters. In this study, the Taguchi-single response concept approach has been successfully applied to the optimization process of weld metal properties.

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