Optimization of Joint Strength in Gas Metal Arc Welding by Response Surfaces Methodology

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Abstract
The present study is aimed at investigating the effect of six process parameters on ultimate tensile strength (UTS) of mild steel parts welded by a Gas Metal Arc Welding (GMAW) process. A Box-Behnken design was used to determine the optimum operating conditions for the GMAW process. The six welding parameters are: wire feed rate, welding voltage, welding speed, travel angle, tip-to-work distance and shielded gas flow rate. A WIN welding machine (model: Migweld350SEF) and an electrode ER70S-6 with rod size diameter of 0.8 mm were used in the experimentation. The welding specimens were randomly prepared and tested. The result at the significance level of 0.05 indicated that the optimal conditions for welding were 19 m/min of wire feed rate, 30 volts of welding voltage, 8 in/min of welding speed, 60 degree of welding angle, 7mm of tip-to-work distance, and 10 l/min of shielded gas flow rate.

Keywords*: Gas Metal Arc Welding, Optimization, Response Surface Methodology, Box-Behnken design*

1 Introduction

The Gas Metal Arc Welding (GMAW) process as shown in Figure 1 is an important component in the fields of industrial manufacturing, construction, agriculture and shipbuilding [1]. A continuous consumable wire electrode is used in the GMAW process, and a molten weld puddle is covered by shielded gas [2].

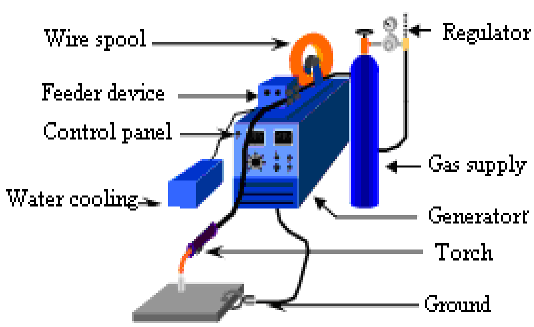

Figure 1: A schematic diagram of GMAW setup

The aim of the present work is to determine the optimal operating conditions for the GMAW process of mild steel parts. Based on Ganjigatti *et al.* [3] and the previous study [4] the input parameters in Figure 2 were found to be significantly affected the mean UTS in the GMAW process. Therefore, the chosen process parameters in this study are as follows: wire feed rate (F), welding voltage (V), welding speed (S), travel angle (A), tip-to-work distance (D) and shielded gas flow rate (G). Two levels are considered for each process parameter.

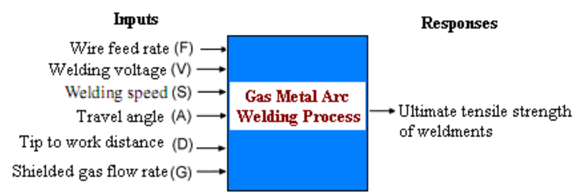

Figure 2: Input-output parameters of GMAW process [3]

2 Experiment details

2.1 *Specimen preparation*

In this work, two mild steel specimens with a dimension of 125 mm×100 mm×6 mm were welded together as illustrated in Figure 3. Then a test specimen was cut and prepared for testing ultimate tensile strength (see Figure 4).

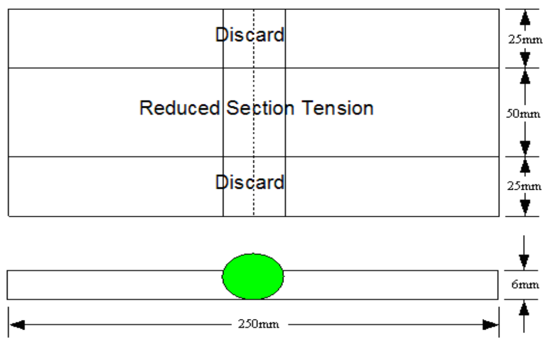

Figure 3: Dimension of Specimen

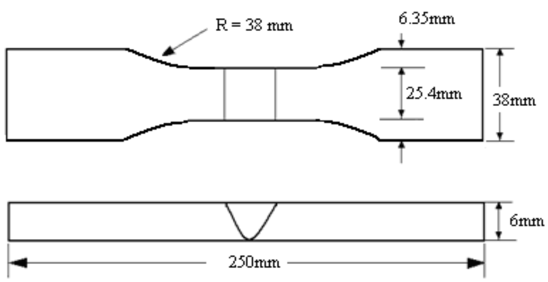

Figure 4: Tensile test Specimen

2.2 *Equipment*

A Win welding machine (model: Migweld350SEF) is used in this study. The power source is a constant voltage dc welder. An electrode wire AWS A5.18 ER70S-6 with rod size diameter of 0.8 mm is used as the welding consumable. Carbon dioxide is utilized as the shielding gas in the experiment. Welding is performed by single pass bead-on-plate technique. Direct current electrode positive (DCEP) polarity is used for welding.

2.3 *Experiment design*

This experiment was conducted using response surface methodology as it is useful for the modelling and analysis of problems involving several variables [5]. This method is also found to be useful for optimizing responses in welding and other processes [6-8]. Table 1 shows the input factors and levels of the GMAW process used in this study. The Box-Behnken design [9] with six center points was performed. This design requires 54 experimental runs. The experimental setup shown in Table 2 was obtained from a software package MINITAB [10].

Table 1: Input factors and levels of GMAW process

S. No.	Factor	Units	Notation	Level	Value
1	Welding speed	in/min	S	–	8
				+	20
2	Welding voltage	V	V	–	20
				+	30
3	Wire feed rate	m/min	F	–	7
				+	19
4	Shielded gas flow rate	l/min	G	–	10
				+	20
5	Tip to work distance	mm	D	–	7
				+	15
6	Travel angle	o	A	–	60
				+	80

3 Result and discussion

3.1 *Test of Assumptions in Regression*

The 54 experimental parts were run and tested. The ultimate tensile test (UTS) obtained from the experiment are shown in Table 2.

Table 2: Set up and result of the experiment

Std. order	Run order	F	V	S	A	D	G	UTS (kgf)
1	1	-1	-1	0	-1	0	0	2820
2	2	1	-1	0	-1	0	0	4320
3	3	-1	1	0	-1	0	0	2180
4	4	1	1	0	-1	0	0	8320
5	5	-1	-1	0	1	0	0	2540
6	6	1	-1	0	1	0	0	4260
7	7	-1	1	0	1	0	0	2180
8	8	1	1	0	1	0	0	8440
9	9	0	-1	-1	0	-1	0	4600
10	10	0	1	-1	0	-1	0	6640
11	11	0	-1	1	0	-1	0	3160
12	12	0	1	1	0	-1	0	4840

Std. order	Run order	F	V	S	A	D	G	UTS (kgf)
13	13	0	-1	-1	0	1	0	3300
14	14	0	1	-1	0	1	0	3640
15	15	0	-1	1	0	1	0	2400
16	16	0	1	1	0	1	0	3400
17	17	0	0	-1	-1	0	-1	6880
18	18	0	0	1	-1	0	-1	4220
19	19	0	0	-1	1	0	-1	5900
20	20	0	0	1	1	0	-1	4060
21	21	0	0	-1	-1	0	1	5140
22	22	0	0	1	-1	0	1	3740
23	23	0	0	-1	1	0	1	5260
24	24	0	0	1	1	0	1	4420
25	25	-1	0	0	-1	-1	0	3080
26	26	1	0	0	-1	-1	0	8560
27	27	-1	0	0	1	-1	0	3300
28	28	1	0	0	1	-1	0	7460
29	29	-1	0	0	-1	1	0	1780
30	30	1	0	0	-1	1	0	4900
31	31	-1	0	0	1	1	0	1940
32	32	1	0	0	1	1	0	5000
33	33	0	-1	0	0	-1	-1	4840
34	34	0	1	0	0	-1	-1	6960
35	35	0	-1	0	0	1	-1	2920
36	36	0	1	0	0	1	-1	3420
37	37	0	-1	0	0	-1	1	4340
38	38	0	1	0	0	-1	1	5200
39	39	0	-1	0	0	1	1	2440
40	40	0	1	0	0	1	1	3080
41	41	-1	0	-1	0	0	-1	2200
42	42	1	0	-1	0	0	-1	6740
43	43	-1	0	1	0	0	-1	1560
44	44	1	0	1	0	0	-1	4300
45	45	-1	0	-1	0	0	1	1760
46	46	1	0	-1	0	0	1	5980
47	47	-1	0	1	0	0	1	1980
48	48	1	0	1	0	0	1	4300
49	49	0	0	0	0	0	0	4240
50	50	0	0	0	0	0	0	4200
51	51	0	0	0	0	0	0	4060
52	52	0	0	0	0	0	0	4680
53	53	0	0	0	0	0	0	4040
54	54	0	0	0	0	0	0	4580

Table 3 shows the estimated regression coefficients and the analysis of variance for UTS obtained from the MINITAB software.

Table 3: Response Surface Regression

Response Surface Regression: UTS versus F, V, S, A, D, G

The analysis was done using un-coded units.

Estimated Regression Coefficients for UTS

Term	**Coef**	**SE Coef**	**T**	**P**
Constant	4300.00	149.84	28.698	<0.001
F	1885.83	74.92	25.172	<0.001
V	681.67	74.92	9.099	<0.001
S	-652.50	74.92	-8.709	<0.00
A	-49.17	74.92	-0.656	0.517
D	-1031.67	74.92	-13.770	<0.001
G	-265.00	74.92	-3.537	0.002
F*F	-563.89	114.44	-4.927	<0.001
V*V	-139.72	114.44	-1.221	0.233
S*S	-143.06	114.44	-1.250	0.222
A*A	786.11	114.44	6.869	<0.001
D*D	-19.72	114.44	-0.172	0.865
G*G	9.44	114.44	0.083	0.935
F*V	1147.50	129.76	8.843	<0.001
F*S	-462.50	129.76	-3.564	0.001
F*A	-65.00	91.76	-0.708	0.485
F*D	-432.50	129.76	-3.333	0.003
F*G	-92.50	129.76	-0.713	0.482
V*S	37.50	129.76	0.289	0.775
V*A	57.50	129.76	0.443	0.661
V*D	-263.75	91.76	-2.874	0.008
V*G	-140.00	129.76	-1.079	0.291
S*A	172.50	129.76	1.329	0.195
S*D	262.50	129.76	2.023	0.053
S*G	242.50	91.76	2.643	0.014
A*D	142.50	129.76	1.098	0.282
A*G	242.50	129.76	1.869	0.073
D*G	180.00	129.76	1.387	0.177

S = 367.0   R-Sq = 97.9%   R-Sq (adj) = 95.6%

Analysis of Variance for UTS

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	27	160357273	160357273	5939158	44.09	<0.001
Linear	6	134010517	134010517	22335086	165.80	<0.001
Square	6	8539131	8539131	1423189	10.56	<0.001
Interaction	15	17807625	17807625	1187175	8.81	<0.001
Residual Error	26	3502408	3502408	134708		
Lack-of-Fit	21	3140808	3140808	149562	2.07	0.215
Pure Error	5	361600	361600	72320		
Total	53	163859681				

The analysis of variance for UTS is also shown in Table 3. The output contains the usual degrees of freedom, sums of squares, mean squares, test statistic (F) and p-value. It is noted that the p-value is lower than 0.001. This indicates that the model conditions are extremely significant. The R^2 of 0.979 is in logical agreement with the adjusted R^2 of 0.956.

3.2 *Regression analysis*

A regression analysis was carried out using MINITAB software (see Table 3). The mathematical regression model is given in Equation 1.

$$\begin{aligned}\textbf{Maximize} = {} & 4300.00+1885.83(F)+681.67(V)-652.50(S) \\ & -49.17(A)-1031.67(D)-265.00(G)-563.89(F*F) \\ & -139.72(V*V)-143.06(S*S)+786.11(A*A) \\ & -19.72(D*D)+9.44(G*G)+1147.50(F*V) \\ & -462.50(F*S)-65.00(F*A)-432.50(F*D) \\ & -92.50(F*G)+37.50(V*S)+57.50(V*A) \\ & -263.75(V*D)-140.00(V*G)+172.50(S*A) \\ & +262.50(S*D)+242.50(S*G)+142.50(A*D) \\ & +242.50(A*G)+180(D*G)\end{aligned} \qquad (1)$$

3.3 *Response optimization*

The result of the optimum conditions for GMAW is shown in Table 4, and the response optimization of the parameter is illustrated in Figure 5.

Table 4: Optimum conditions for GMAW

Goal	Lower	Target	Upper
UTS Maximum	8,000	8,500	8,500

Global Solution:		
Wire feed rate	= 19.00	m/min
Welding voltage	= 30.00	volt
Welding speed	= 8.00	in/min
Travel angle	= 60.00	degree
Tip to work distance	= 7.00	min
Shielded gas flow rate	= 10.00	liter/min
Predicted Responses:		
Ultimate tensile strength = 12,500		
desirability = 1.00000		
Composite Desirability = 1.00000		

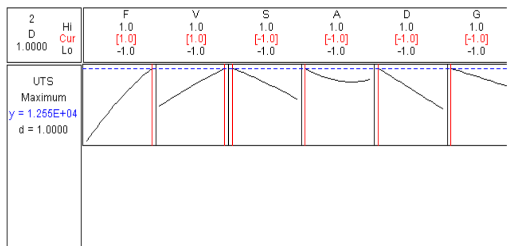

Figure 5: Response optimization of the parameters

4 Conclusions

The selection of the optimal parameters in the GMAW in order to maximize the UTS of mild steel has been investigated in this research. The modified Box-Behnken design method was conducted on six process parameters. The result at the significance level of 0.05 indicated that the optimal conditions for welding are 19 m/min of wire feed rate, 30 volts of welding voltage, 8 in/min of welding speed, 60° of welding angle, 7 mm of tip-to-work distance, and 10 l/min of shielded gas flow rate. The optimum UTS is 12,500 kgf.

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