ON THE OPTIMIZATION OF GAS METAL ARC WELDING PROCESS PARAMETERS

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ABSTRACT

Abstract— Gas metal arc welding (GMAW) is a widely used fusion welding process. Such process is extensively used in joining various ferrous and nonferrous alloys. In the present investigation, an optimization of the GMAW process parameters was carried out using Taguchi's optimization approach. This approach has been adopted to find out the optimum GMAW process parameters, typically, the welding voltage, wire diameter, wire feed rate and the CO_2 gas flow rate that achieve the best ultimate tensile strength of mild steel welded joints. Optimizations results revealed that joints welded using welding voltage of 30 V, wire diameter of 1.2 mm, feed rate of 4 m/min and gas flow rate of 15 liter/min exhibited the highest ultimate tensile strength of 459 MPa.

1. INTRODUCTION

Gas metal arc welding (GMAW) is a fusion welding technique that uses a consumable metal electrode and an inert or an active shielding gas. This process offers several advantages over other fusion welding processes such as: continuously feed electrode, flux free operation, relatively low operator skills required, ease of automation [1-2]. GMAW is used welding of several metals such as carbon steels, aluminum and its alloys, nickel and its alloys, stainless steels …etc. [1-3]. However, the quality of weld obtained from GMAW depends on various welding parameters like voltage, current …etc. [4].

The Taguchi's approach is a systematic application of design and analysis of experiments for designing purpose and product quality improvements. The Taguchi's approach was used to optimize the GMAW welding process parameters [4-5]. For example, *Sapakal et al.* [4] studied the effect of welding parameter, typically, welding current, welding voltage and welding speed on the penetration depth of mild steel using Taguchi's approach. They showed that the welding voltage has large effect on penetration. *Haragopal et al.* [5] investigated the mechanical properties of Al-65032 alloy using Taguchi technique. Thy showed that current is the most influencing parameter for ultimate tensile strength and pressure is most significant parameter for proof stress. It has been observed that the literature about the optimization of the GMAW process parameters is very limited and the effect of GMAW process parameters on the tensile strength of low carbon steel weldments is not well documented [4,5-7]. However, this steel has a wide application in several industries.

Accordingly, In the present investigation, an optimization of the GMAW process parameters, typically, the welding voltage, wire diameter, wire feed rate and the CO_2 gas flow rate was carried out to find out the highest tensile strength of low carbon steel weldments. Optimization of the GMAW process parameters was carried out using the Taguchi's optimization approach. The analysis of signal to noise (S/N) ratio was used to obtain the optimum level for each process parameter. The level of significance of the parameters and optimum parameter combination were determined using analysis of variance (ANOVA) approach.

2. EXPERIMENTAL PROCEDURES

2.1. Materials & Weld Configurations

In the present study, low carbon steel (St37) plates of dimensions 150 mm × 100 mm × 10 mm figure (3) were joined by GMAW welding. The chemical composition of the low carbon steel plates is listed in Table (1). The welded joints were machined into single V-groove as shown in Figure (1). The welds were carried out in three pass using ES-SG3 filler wires having different diameters using several feeding rates. The chemical composition of the filler wires is listed in Table (2). Carbon dioxide (CO_2) gas was used as a shielding gas. The CO_2 shielding gas was provided with different flow rates.

Table (1). Chemical Composition of St37 low carbon steel in weight percent (wt.-%).

Element	%C	%Si	%Mn	%P	%S	%Cr	%Ni	Fe
wt.-%	0.11	0.03	0.56	0.007	0.005	0.07	0.3	Bal.

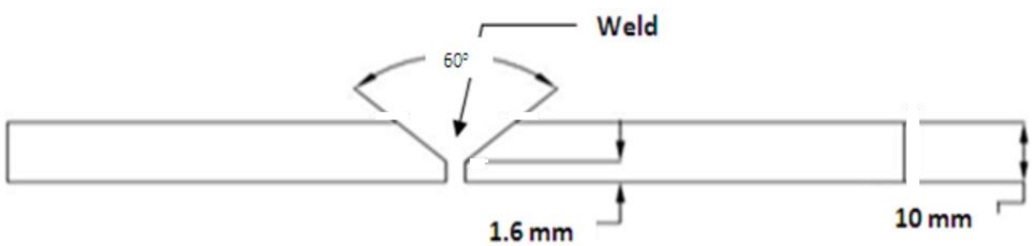

Fig. 1. Weld joint configurations.

Table (2). Chemical Composition of ES-SG3 filler metal.

Element	%C	%Si	%Mn	%P	%S	%Cr	%Ni	%Mo	%Cu
wt.%	0.06-0.14	0.8-1.20	1.6-1.9	Max 0.025	Max 0.025	Max 0.15	Max 0.15	Max 0.15	Max 0.35

2.2. Design of Experiments

In the present investigation, the Taguchi's design of experiment (DOE) approach was adapted in order to study the effect of GMAW process parameters (i.e. voltage, wire diameter, wire feed rate and CO_2 flow rate) on the response (tensile strength of low carbon steel). Each of GMAW process parameter have three levels as listed in Table (3). The arc gap was kept constant at 3 mm. Alternating current (AC) electrode polarity was used. It is important to mention that the welding current changes automatically with wire feed rate. The standard Taguchi's orthogonal array (OA) L9 was chosen in the present study. Table (4) lists the experimental design matrix according L9 OA. This design of experiment gives a total of (9) welded plates. The analysis of experimental results was performed using the analysis of variance (ANOVA) statistical approach. From results of ANOVA one can obtain the most and lowest significant parameters. The analysis was carried out for a level of significance of 5 per cent (i.e. the confidence limit is equal to 95 per cent). The signal-to-noise (S/N) ratio is defined as:

$$S/N = -10 \log (M.S.D.) \qquad \ldots(1)$$

where, M.S.D. is the mean square deviation for the output characteristic. To obtain optimal tensile strength of the joints, higher-the-better quality characteristic for penetration must be taken. The M.S.D. for higher-the-better quality characteristic can be expressed by:

$$M.S.D = \frac{1}{m}\sum \frac{1}{P_i^2} \qquad \ldots(2)$$

Where, P_i is the value of ultimate tensile strength of the welded joint. The design of experiments, S/N and ANOVA calculations were performed using *Minitab* commercial statistical software.

Table (3). GMAW process parameters and their levels.

Parameters	Symbol	Unit	Level 1	Level 2	Level 3
Welding voltage	V	Volt	20	25	30
Wire diameter	ϕ	mm	0.8	1.2	1.6
Wire feed rate	F	m/min	2	4	6
CO_2 Gas flow rate	L	Liter/min	10	15	20

Table (4). Experimental design matrix according to L9 orthogonal array.

No.	Voltage (Volt)	Wire diameter (mm)	Wire feed rate (m/min)	Gas flow rate (Liter/min)
1	20	0.8	2	10
2	20	1.2	4	15
3	20	1.6	6	20
4	25	0.8	4	20
5	25	1.2	6	10
6	25	1.6	2	15
7	30	0.8	6	15
8	30	1.2	2	20
9	30	1.6	2	10

2.3. Tensile Tests

Transverse tensile specimens were machined from the welded plates so that the welded zone was located at the middle of the specimen gage length. Figure 2 shows the main dimensions of the tensile specimen. The tensile tests were performed at room temperature using Shimadzu universal testing machine with at constant crosshead speed of 1 mm/min. The data for the tensile tests was taken from the average of three measurements.

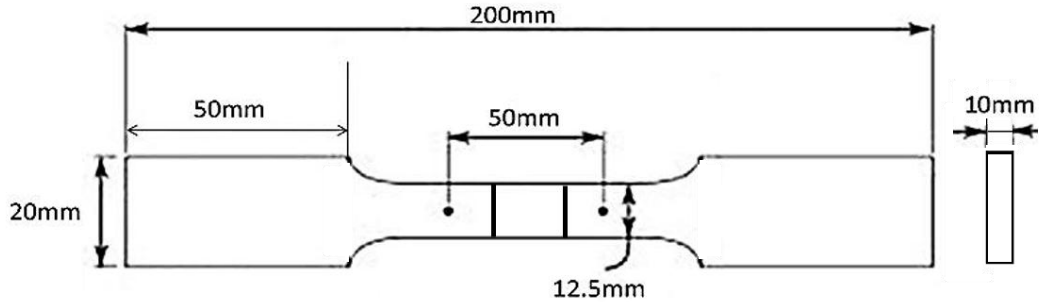

Fig. 2. Tensile Test Specimen. (Dimensions in mm).

3. RESULTS & DISCUSSION

Table (5) lists the tensile strength experimental results as well as the signal-to-noise (S/N) ratio. Figure 3 shows the main effects plot for means (raw data) of the ultimate tensile strength (in MPa) of the welded joints. It is clear that increasing the welding voltage from 20 V to 30 V increases the tensile strength of the low carbon steel welded joints. Increasing the wire diameter form 0.8 mm to 1.2 mm increases tensile strength of the welded joints. Further increase in the wire diameter (i.e. from 1.2 mm to 1.6 mm) reduces the tensile strength. The same behavior was observed for wire feed rate, in which increasing the wire feed rate from 2 m/min to 4 m/min tends to increase the tensile strength of the welded joints. Increasing the wire feed rate from 4 m/min to 6 m/min reduces the tensile strength of the welded joints. It seems that, within the studied experimental range, increasing the gas flow rate from 10 Liter/min to 20 Liter/min has slight or practically no effect on the tensile strength of the welded joints.

Table 5. Experimental Results for the ultimate tensile strength (UTS) and S/N Ratio.

No.	Voltage (V)	wire diameter (mm)	wire feed rate (m/min)	gas flow rate (Liter/min)	Sample 1 UTS (MPa)	Sample 2 UTS (MPa)	Sample 3 UTS (MPa)	Average UTS (MPa)	S/N
1	20	0.8	2	10	106.900	390.1482	399.624	299.123	49.5170
2	20	1.2	4	15	537.924	414.2495	400.336	450.836	53.0804
3	20	1.6	6	20	252.796	396.272	393.623	347.630	50.8223
4	25	0.8	4	20	416.562	356.1795	386.266	386.336	51.7393
5	25	1.2	6	10	546.320	347.107	440.029	444.486	52.9572
6	25	1.6	2	15	394.623	300	406.179	366.934	51.2918
7	30	0.8	6	15	415.517	386.697	390.709	397.641	51.9898
8	30	1.2	2	20	579.198	388.3989	411.879	459.825	53.2519
9	30	1.6	4	10	477.000	432	433.360	447.533	53.0165

Figure 4 shows the signal-to-noise (S/N) ratio plots for the ultimate tensile strength. The calculated S/N ratio has been tabulated in Table (5). The optimal process parameters can be established by analyzing response curves of S/N ratio associated with raw data. From Figure 5 and 6 it is can be concluded that third level of voltage (30 V), second level of wire feed rate (4 m/min), the second level of wire diameter (1.2 mm) and the second level of the CO_2 gas flow rate (15 Liter/min) gives the higher tensile strength.

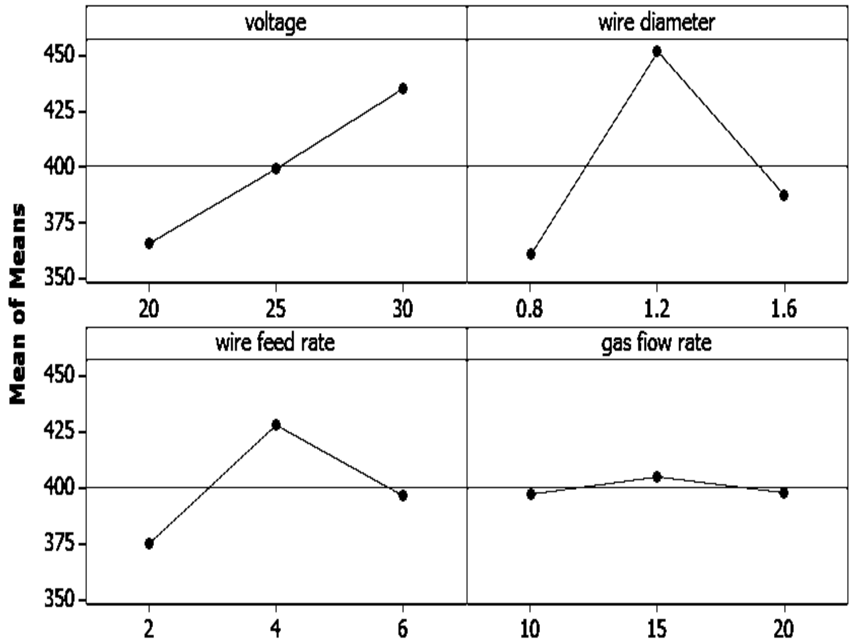

Fig. 3. Effects of GMAW process parameters on ultimate tensile strength raw data.

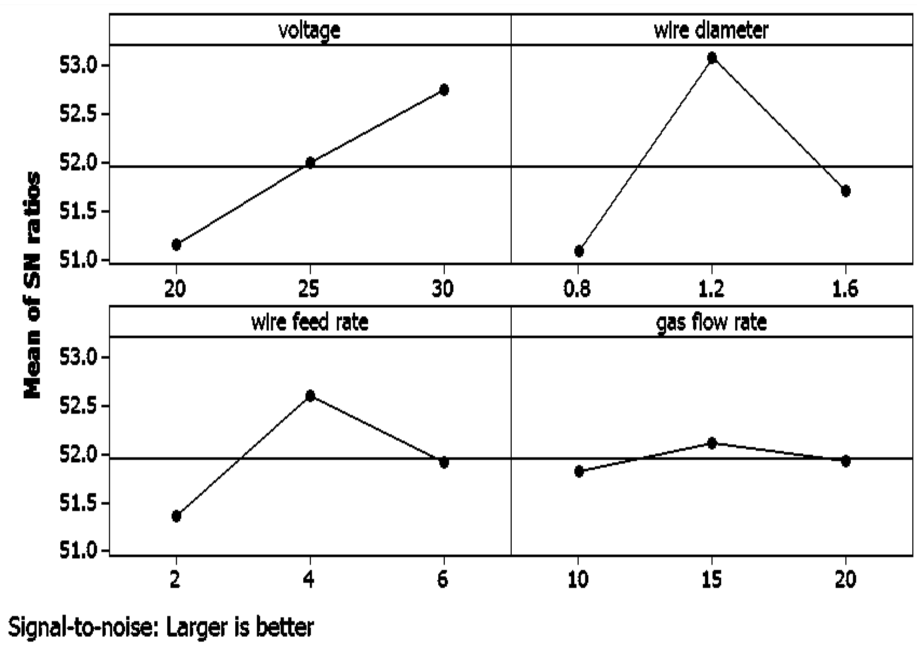

Fig. 4. Effects of process parameters on ultimate tensile strength S/N ratio.

The ANOVA for raw data is listed in Table (6). The ANOVA calculations were performed for only welding voltage, wire diameter and wire feed rate process parameters. The gas flow rate was excluded from ANOVA calculations, since as shown above, it has practically no effect on the tensile strength of the welded joints. The last columns in the tables show the percentage of contribution (P_c) of each factor on the total variation indicating the influence of the factors on the results. The higher the value of the P_c, the more statistical and physical significant the factor is. It is observed that wire diameter is the most prominent factor which effects tensile strength ($P_c \approx 53.069\%$) followed by welding voltage ($P_c \approx 29.15\%$) then the wire feed rate ($P_c \approx 17.31\%$). The response values for S/N ratio and mean (raw data) for each level of identified process parameters are listed in Table (7) and Table (8), respectively, with the factor level values of each factor and their ranking. Table (7) and Table (8) include ranks based on *Delta* statistics, which compare the relative magnitude of effects. The Delta statistic is the highest minus the lowest average for each factor. Based on Delta values; rank 1 with the highest Delta value is wire diameter, the second highest factor is rank 2 that is voltage, then wire feed rate (rank 3) and gas flow rate gas flow rate (rank 4).

Table (6). The ANOVA results for the ultimate tensile strength of low carbon steel joints.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	P_c
Voltage (V)	2	7172.6	7172.6	3586.3	61.31	0.016	29.15
wire diameter (mm)	2	13057.7	13057.7	6528.8	111.61	0.009	53.069
wire feed rate (m/min)	2	4257.8	4257.8	2128.9	36.39	0.027	17.31
Error	2	117.0	117.0	58.5			0.476
Total	8	24605.0					
S = 7.64822 R-Sq = 99.52% R-Sq(adj) = 98.10%							

Table (7). Response table for means of ultimate tensile strength.

Level	Voltage (V)	wire diameter (mm)	wire feed rate (m/min)	Gas flow rate (Liter/min)
1	365.9	361.0	375.3	397.0
2	399.3	451.7	428.2	405.1
3	435.0	387.4	396.6	397.9
Delta	69.1	90.7	52.9	8.1
Rank	2	1	3	4

Table (8). Response Table for Signal to Noise Ratios (Larger is better).

Level	Voltage (V)	wire diameter (mm)	wire feed rate (m/min)	Gas flow rate (Liter/min)
1	51.14	51.08	51.35	51.83
2	52.00	53.10	52.61	52.12
3	52.75	51.71	51.92	51.94
Delta	1.61	2.01	1.26	0.29

Rank	2	1	3	4

4. CONCLUSIONS

Based the aforementioned results, the following conclusions can be concluded:

1. Joints welded using welding voltage of 30 V, wire diameter of 1.2 mm, feed rate of 4 m/min and gas flow rate of 15 liter/min exhibited the highest ultimate tensile strength of 459 MPa.
2. The wire diameter is the most prominent factor which effects tensile strength followed by welding voltage then the wire feed rate.
3. Within the studied experimental range, increasing the gas flow rate from 10 Liter/min to 20 Liter/min has slight or practically no effect on the tensile strength of the welded joints.

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