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Process Parameter Optimization of GTAW Process on 1018 Mild Steel by using Taguchi Method

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Abstract—*In the present study some aspects of GTAW on 1018 mild steel specimens have been studied under varied input parameters (current, gas flow rate and arc gap). Process parameter optimization has been made by analyzing the observed responses (ultimate tensile strength and percentage of elongation) at several levels of the welding parameters, by applying Taguchi method. It has been shown that Current has the maximum effect on UTS followed by Gas flow rate and Arc gap respectively. Again the Arc gap has the maximum effect on percentage of elongation followed by Current and Gas flow rate respectively. The combined effect of Current and Gas flow rate, Current and Arc gap, Arc gap and Gas flow rate on UTS and on Percentage of elongation have also been shown graphically in the present study. The optimum condition for welding has been shown in the present work.*

1. INTRODUCTION

Gas Tungsten Arc welding(GTAW) or Tungsten Inert Gas Welding(TIG) is an arc welding process where electric arc is produced between a non-consumable tungsten electrode and base metal. The weld pool and the red hot filler wire are shielded by inert gases like helium or argon to protect the same. The process can be used for joining common metals like steel, aluminum etc [1-4]. The process parameters largely affect the mechanical and other properties of the welded joint. Performance characteristics like ultimate tensile strength, yield stress, percentage of elongation, weld bead geometry, impact toughness are largely influenced by the process parameters and the phenomenon draws the attention of many researchers. So they tried to find out the relation between the input and output parameters. So, to derive the mathematical model of the process became essential. Welding experiments have been conducted by using Design of experiment (DOE) and Mathematical modeling by using ANOVA followed by Regression analysis. Taguchi based Grey relation analysis gave satisfactory understanding of the process by conducting minimum number of experiment. Sapkal and Teslang [5] optimized the welding process parameters i.e. current, voltage and welding speed by Taguchi method to obtain maximum penetration depth on mild steel. Srirangan and Paulraj [6] used Taguchi L9 array with Grey relation analysis to optimize the process parameters in TIG welding of Incoloy 800HT with ultimate tensile strength, yield strength and impact toughness as performance characteristics. Nagesh and Dutta [7] used Neural network for mathematical modeling and genetic algorithm for TIG welding process parameter optimization of weld bead geometry. Tchoumi *et al.* [8] analyzed the thermo-mechanical behavior of stainless steel plates during TIG welding by developing a finite element model of the process. Kannan *et al.* [9] used three optimization methods in investigations on the influence of welding speed on the distortion of thin stainless steel material. They used Taguchi method to identify most influencing process parameter, ANOVA method to evaluate the percentage of contribution of the process parameters and Genetic algorithm for validation of results obtained from both experimental value and optimization value. Kumar *et al.* [10] studied modified Taguchi method to identify optimum parameters in Pulsed Gas Tungsten Arc Welding of aluminium alloy using gas mixtures and pulsed current is seen to be the most effective parameter on the multiple quality characteristics.

In the present study TIG welding has been performed on 1018 mild steel and mathematical model has been derived between the input parameters (current, voltage, arc length) and the output responses (ultimate tensile strength and percentage of elongation) with the help of response surface regression analysis. The significant process parameters and the significance of other parameters on the output parameters have been analyzed by Taguchi analysis.

2. EXPERIMENTAL PLAN AND PROCEDURE

1018 Mild steel plates of dimension 70 x 35 x 6 mm was butt welded using Lincoln TIG machine, with Direct Current Straight Polarity [DCSP]. The chemical composition of the base material is given in Table 1.

Table 1: Chemical composition of base metal

1018 Mild (low-carbon) steel		
Chemistry	Iron (Fe)	98.81- 99.26%
	Carbon (C)	0.18%
	Manganese (Mn)	0.6 - 0.9%
	Phosphorus (P)	0.04%
	Sulfur (S)	0.05%

The TIG welding on 1018 Mild steel have been conducted by controlling three important factors of welding. The three factors are current, gas flow rate and arc length. The levels of the three factors have been given in Table 2. The experimental design matrix has been given in Table 3.

Table 2: Three factors and the levels of input parameter

Sl. No	Process parameters	Symbol	Unit	Level (1)	Level(2)	Level(3)
1.	Current	I	Amp	100	110	120
2.	Gas flow rate	G	Litre/min	12	14	16
3.	Arc length	A	mm	2	4	6

Table 3: Experimental Design Matrix

Sl No	Run no	Current(A)	Gas flow rate(litre/min)	Arc length(mm)
1.	1	1	1	1
2.	2	1	2	2
3.	3	1	3	3
4.	4	2	1	2
5.	5	2	2	3
6.	6	2	3	1
7.	7	3	1	3
8.	8	3	2	1
9.	9	3	3	2

The welded samples have been machined in a milling machine to obtain desired shape for tensile test shown in Fig. 2. Tensile test have been performed on a Universal Testing Machine.

(a)

(b)

Fig. 1.(a& b) Welded sample

Fig. 2. Tensile test specimen

3. RESULTS OF THE EXPERIMENT

Taguchi L9 orthogonal array was selected, and the experiments were carried out accordingly. The process parameter and their levels are given in Table 2. The ultimate tensile strength and percentage of elongation were chosen as the performance characteristics parameter.

Table 4: Results of the experiment

Exp no	Current(I)	Gas flow Rate(G)	Arc lecngth(A)	UTS(Mpa)	Percentage Elongation(%)
1	100	12	2	510	29.32
2	100	14	3	468	21.00
3	100	16	4	469	24.64
4	110	12	3	465	24.80
5	110	14	4	423	23.92
6	110	16	2	429	31.24
7	120	12	4	452	23.92
8	120	14	2	437	25.16
9	120	16	3	444	20.76

The tensile test results shown in Table 4 indicate that in seven out of nine welded samples the breaking points are on the base metal and in remaining two specimens the breaking points are in the welded zone.

4. MATHEMATICAL ANALYSIS

3.1. Taguchi Analysis: UTS vs. I, G, A (Current=I, Gas flow rate=G, Arc gap=A):

Table 5. Analysis of variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
I	2	1.18126	1.18126	0.59063	26.39	0.037
G	2	0.67224	0.67224	0.33612	15.02	0.062
A	2	0.08216	0.08216	0.04108	1.84	0.353
Residual error	2	0.04476	0.04476	0.02238		
Total	8	1.98042				

ANOVA analysis in Table 5 helped to decide which of the three process parameters has most significant effect on the UTS value of welded joints. The P-values of last column has been shown the significance of the input parameters. The process parameter which has the P-value less than 0.05 has the most significant effect on UTS. We can conclude that the process parameter Current has the significant effect on UTS.

Table 6. Response table for Signal to Noise ratios (Larger the better)

Level	Current(I)	Gas flow rate(G)	Arc gap(A)
1	53.66	53.53	53.20
2	52.84	52.91	53.23
3	52.95	53.01	53.02
Delta	0.82	0.62	0.22
Rank	1	2	3

The responses in Table 6 arrange the process parameters according to their effect on UTS. The last row gives the rank of parameters according to their effect. Thus we can conclude that Current has the maximum effect on UTS followed by Gas flow rate and Arc gap respectively.

The main effects plot for SN ratios is given in Fig. 3. The plots for Current, Gas flow rate and Arc gap have been given on A, B, C curve respectively. Fig. 3 graphically represents the effects of three process parameters on the Ultimate tensile strength of welded joints.

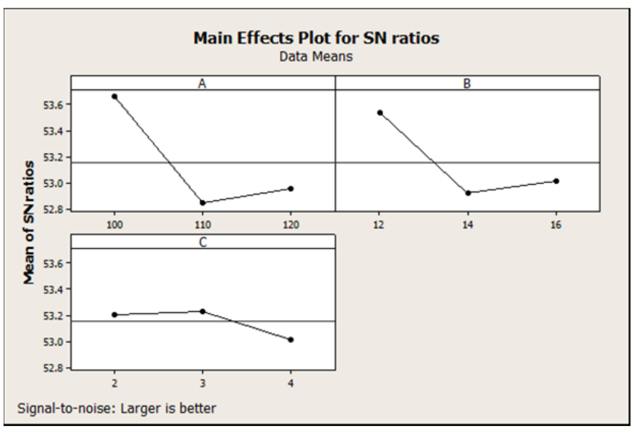

Fig. 3: Effects of three process parameters on Ultimate tensile strength

3.2. Taguchi Analysis: Percentage elongation vs. I, G, A (Current=I, Gas flow rate=G, Arc gap=A):

Table 7. Analysis of variance for S/N Ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
I	2	1.9547	1.9547	0.97734	25.91	0.037
G	2	1.3764	1.3764	0.68820	18.25	0.052
A	2	7.4165	7.4165	3.70823	98.32	0.010
Residual error	2	0.0754	0.0754	0.03771		
Total	8	10.8230				

The result in Table 7 decides which of the three process parameters has most significant effect on the Percentage Elongation value of welded joints. The P-values of last column has been shown the significance of the input parameters. The process parameter which has the P value less than 0.05 has the most significant effect on Percentage elongation. So we can conclude that the process parameter Current and Arc gap has significant effect on Percentage Elongation of the welded joints.

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

Level	Current(I)	Gas flow Rate(G)	Arc gap(A)
1	27.87	28.27	29.08
2	28.45	27.34	26.89
3	27.31	28.02	27.66
Delta	1.14	0.92	2.19
Rank	2	3	1

The responses in Table 8 arrange the process parameters according to their effect on Percentage elongation. The last row gives the rank of parameters according to their effect. Thus we can conclude that Arc gap has the maximum effect on percentage of elongation followed by Current and Gas flow rate respectively.

The main effects plot for SN ratios is given in Fig. 4. The plots for Current, Gas flow rate and Arc gap have been given on A, B, C curve respectively.

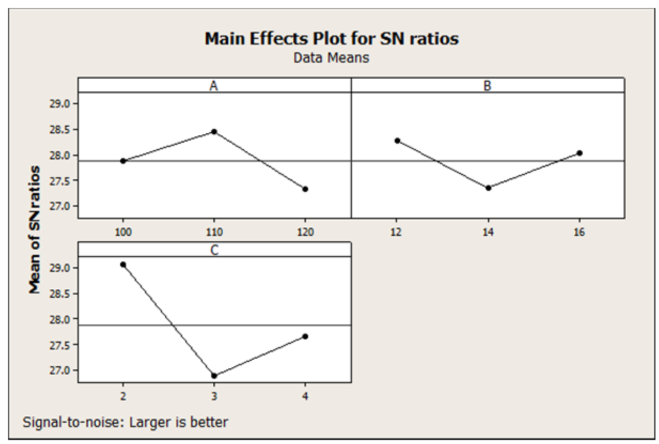

Fig. 4. Effects of three process parameters on Percentage elongation

The Fig. 4 graphically represents the effects of three process parameters on the Percentage elongation of welded joints

3.3. Response Surface Regression: UTS vs. I, G, A:

Table 9. Estimated Regression coefficients for UTS.

Terms	Coefficient	SE Coeff.	T	P
Constant	787.889	926.188	0.851	0.485
I	3.771	9.854	0.383	0.739
G	40.667	82.0826	0.496	0.669
A	-523.762	289.146	-1.811	0.212
I×G	-0.829	0.856	-0.968	0.435
I×A	2.529	1.712	1.477	0.278
G×A	16.571	8.562	1.935	0.193

S=18.4962, R-Sq=87.88%, R-Sq(adj)=51.50%

Table 9 gives the mathematical model for UTS in relation with process parameters and their interaction. So the mathematical model can be written as,

UTS = 787.889 + (3.771×I) + (40.667×G) - (523.762×A) - (0.829×I×G) + (2.529×I×A) + (16.571×G×A)

The combined effect of Current and Gas flow rate have been shown graphically in Fig. 5. The Arc gap value has been kept constant at 2 while plotting Fig. 5.

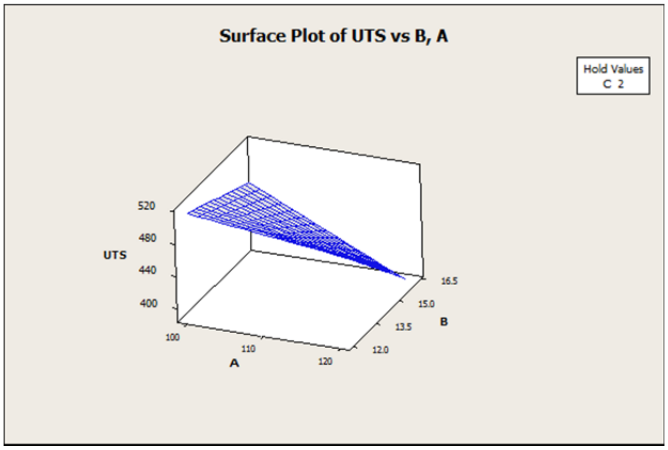

Fig. 5. Surface plot of UTS vs. Current and Gas flow rate

The combined effect of Current and Arc gap on UTS have been shown graphically in Fig. 6. The Gas flow rate value has been kept constant at 13.78 litre/min while plotting Fig. 6.

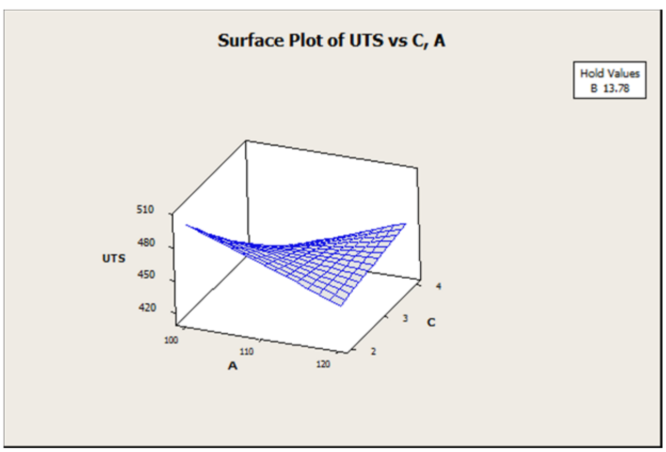

Fig. 6. Surface plot of UTS vs. Current and Arc gap

The combined effect of Arc gap and Gas flow rate on UTS has been shown graphically in Fig. 7. The Current value has been kept constant at 100 amp while plotting Fig. 7.

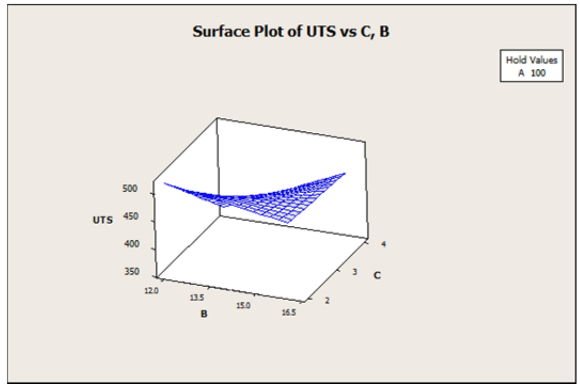

Fig. 7. Surface plot of UTS vs. Arc gap and Gas flow rate

3.4. Response Surface Regression: Percentage elongation vs. I, G, A:

Table 10. Estimated Regression Coefficients for Percentage elongation

Term	Coef	SE Coef	T	P
Constant	-132.067	215.550	-0.613	0.602
I	1.695	2.293	0.739	0.537
G	19.613	19.090	1.027	0.412
A	-47.158	67.293	-0.701	0.556
I×G	-0.189	0.199	-0.951	0.442
I×A	0.311	0.399	0.781	0.516
G×A	0.629	1.993	0.315	0.782

S=4.3060, R-Sq=60.62%, R-Sq (adj)=0.00%

Table 10 gives the mathematical model for Percentage elongation in relation with process parameters and their interaction. So the mathematical model can be written as,

Percentage elongation = - 132.067 + (1.695×I) + (19.613×G) - (47.158×A) – (0.189×I×G) + (0.311×I×A) + (0.629×G×A)

The combined effect of Current and Gas flow rate on Percentage Elongation have been shown graphically in Fig. 8. The Arc gap value have been kept constant at 2 while plotting Fig. 8.

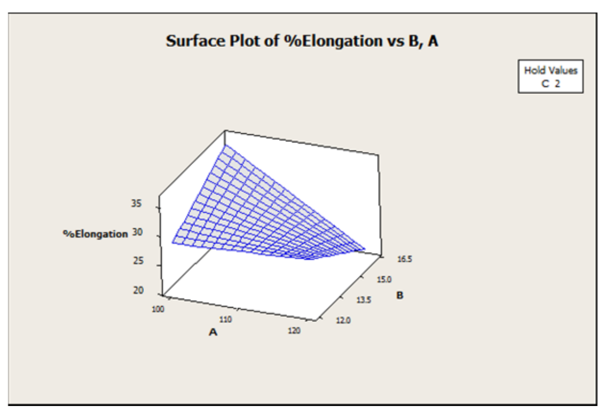

Fig. 8. Surface plot of Percentage elongation vs. Current and Gas flow rate

The combined effect of Current and Arc gap on Percentage Elongation have been shown graphically in Fig. 9. The Gas flow rate value has been kept constant at 13.78 while plotting Fig. 9.

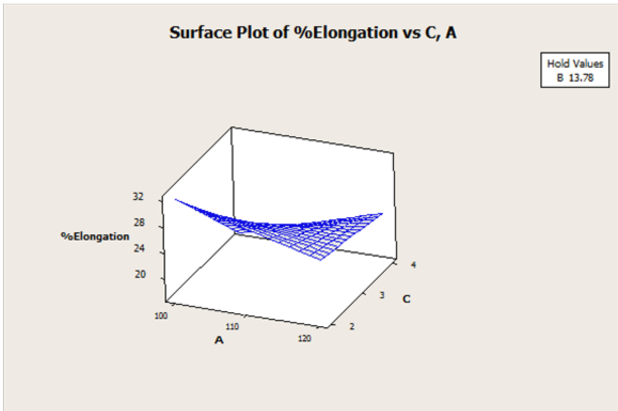

Fig. 9. Surface plot Percentage elongation vs. Current and Arc gap

The combined effect of Arc gap and Gas flow rate on Percentage Elongation has been shown graphically in Fig. 10. The Current value has been kept constant at 100 while plotting Fig. 10.

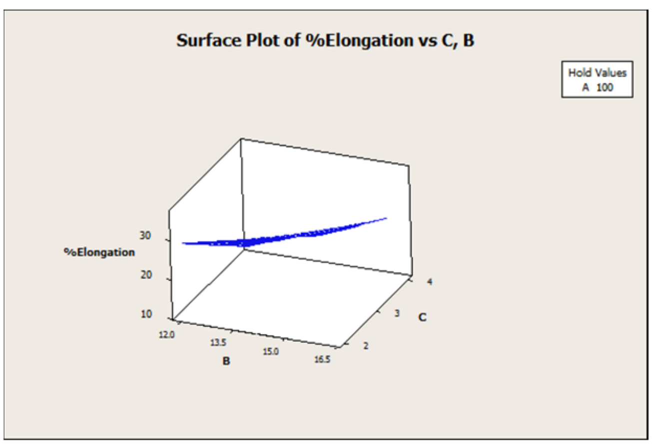

Fig. 10. Surface plot of Percentage elongation vs. Arc gap and gas flow rate

3.5. Response Optimization:

Table 11. Response optimization

Parameters	Goal	Lower	Target	Upper	Weight	Import
UTS	Maximum	423.0	500	500	1	1
% Elongation	Maximum	20.76	32	32	1	1

Global Solution:

Current (I) = 100 Gas flow rate (G) = 13.7778 Arc gap (A) = 2

Predicted Responses:

UTS = 498.566,

Desirability = 0.981378

Percentage Elongation=31.985,

Desirability = 0.998663

Composite Desirability=0.989983

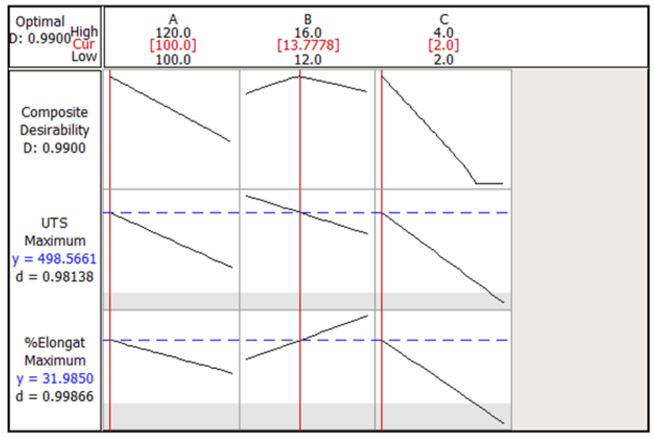

Fig. 11. Optimum condition for welding

Hence the optimum condition for welding will be obtained when the values of the process parameters are Current=100 amp, Gas flow rate=13.7778 litre/min and Arc length=2 mm.

5. CONCLUSIONS

In present study, Taguchi L9 orthogonal array and Response surface regression analysis have been used to optimize the GTAW process and to obtain the mathematical model. It has been seen that the optimum condition for the adapted welding process can be obtained when the process parameters have the value of Current=100 amp, Gas flow rate=13.7778 litre/min and Arc gap= 2 mm. The ANOVA analysis helped to obtain the significant input parameter in the process and it gave that Current (P-value=0.037) is the significant factor for Ultimate tensile strength and Arc gap (P-value=0.010), Current (P-value=0.037) are the significant factors for Percentage elongation. It has been found from SN Ratio that the most effective process parameter obtained is Current followed by Gas flow rate and Arc gap respectively for UTS and for Percentage elongation the most effective process parameter obtained is Arc gap followed by Current and Gas flow rate respectively. The obtained surface plots shows the combined effect of Current and Gas flow rate, Current and Arc gap, Arc gap and Gas flow rate on UTS and also on Percentage of elongation.

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