Optimization of Process Parameters of Activated Tungsten Inert Gas (A-TIG) Welding for Stainless Steel 304L using Taguchi Method

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Abstract— The flux coated tungsten inert gas (A-TIG) welding mainly focusing on increasing depth of penetration of weld and reducing width of weld bead, it is possible to weld up to 10 mm thickness plate in single pass without any joint preparation over the conventional one. SiO_2 flux powder along with acetone is selected for A-TIG welding of austenitic stainless steel plate 304L plate of 6 mm thickness. The major influencing A-TIG welding process parameters, such as electrode gap, welding current, welding speed and gas flow rate are optimized to get desirable ultimate tensile strength (UTS) of weld. Hence this parameters are optimized by $L_9(3^4)$ orthogonal array and percentage contribution of each parameter if calculated by ANOVA a tool of Taguchi method. From experimental results it is observed that, the optimum process parameter are 1 mm electrode gap, 200 A welding current, 100 mm/min welding speed and 10 lit/min gas flow rate. The percentage contribution of process parameters for tensile strength are welding speed (44.87%), welding current (28.14%), arc gap (20.85%) and gas flow rate (6.12%).

1. INTRODUCTION

Gas Tungsten arc welding (GTAW), also known as Tungsten inert gas (TIG) welding which uses an arc between work piece to be welded and non consumable tungsten electrode under a shielding gas is an extremely important arc welding process. It has been a popular choice of welding process when a high level of weld quality or considerable precision welding operation is required. It is commonly used for welding hard-to-weld metals such as stainless steel, magnesium, aluminum and titanium. However the potential problem of TIG welding process is limited thickness of material which can be welded in single pass, poor tolerance to some material composition and the low productivity.
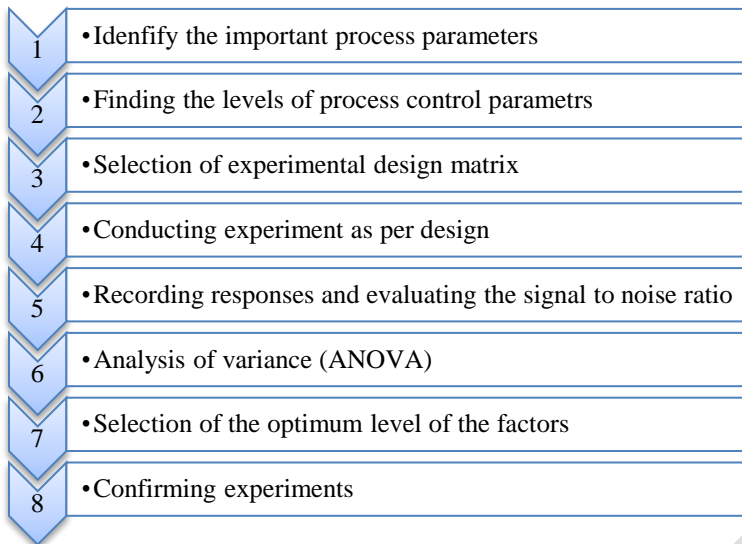
Improvement arc penetrations have long been sought in many arc welding processes. One of the notable technique to improve arc penetration is use of activated flux in TIG welding. In 1960s Paton Electric welding institute firstly proposed use of activated flux during welding process known as Activated Tungsten inert gas (A-TIG) welding [1]. Activated flux is mixture of inorganic material suspended in a volatile medium such as alcohol, acetone, ethanol etc. A thin layer of paste like material is applied before welding by use of brush. The United states navy joining centre has successfully used in every days production to reduce cost and improve production of aircrafts and navy ships, using A-TIG welding technique. In this technique it is possible to weld up to 8-10 mm thickness plate in single pass, without edge preparation. In fact the penetration capability is up to 300 % compared with the conventional TIG welding process [4].

The activated TIG (A-TIG) welding process mainly focuses on increasing depth of penetration and reducing width of weld pool. There for the geometry of weld pool is changes and it can be controlled by using process parameters like welding current, travel speed , arc gap and gas flow rate. These process parameters directly affect on mechanical properties of weld material due to this it is controlled and optimized by using Taguchi technique. Additionally optimum working conditions determined from the laboratory work can be reproduced in the real production Tensile strength of 304L stainless steel material with use of oxide flux using Taguchi technique. Some tools of Taguchi method such as, Orthogonal array (OA), experimental design, analysis of variance (ANOVA) are implemented.

2. TAGUCHI METHOD FOR OPTIMIZATION OF PROCESS PARAMETERS

Taguchi method is a systematic application of design and analysis of experiments for the purpose of designing. Optimization of process parameters is key step in Taguchi method to achieving high quality without increasing cost. The Taguchi method uses a special orthogonal array to study all the designed factors to minimum experiment levels. In orthogonal array each factor is independently evaluated and the effect of one factor does not interface with another factor.

Table 1. Steps of Taguchi method

1. • Idenfify the important process parameters

2. • Finding the levels of process control parametrs

3. • Selection of experimental design matrix

4. • Conducting experiment as per design

5. • Recording responses and evaluating the signal to noise ratio

6. • Analysis of variance (ANOVA)

7. • Selection of the optimum level of the factors

8. • Confirming experiments

The orthogonal array experimental design method with L_9 (3^4) is used to determine experimental plan. The L_9 (3^4) means that to investigate 4 factors on a qualitative index with 3 levels of each factor. Totally nine experiments were conducted. For this most influencing four different process parameters welding current, arc gap, travel speed and gas flow rate are selected [9]. Taguchi method recommends the signal to noise ratio (S/N) ratio, which is a performance characteristic, instead of average value. S/N ratio is used to determine optimal conditions of experimental results. There rate three S/N ratios commonly used for optimization of statistical problems i.e. nominal is better (NB), higher is better (HB) & lower is better (LB). The larger S/N ratio represents the better performance characteristic. The mean S/N ratio at each levels of experiments for various factors was calculated. Analysis of variance (ANOVA) indicates which process parameter is statistically significant; the optimal conditions of the process parameters can then be represented. If the predicted results are confirmed then the suggested optimum working conditions should be adopted.

3. EXPERIMENTAL WORK

3.1 Base metal

The base metal used in this study is austenitic stainless steel 304L plate of 6 mm thickness. The plate is cut into nine eighteen specimens of size 150×50×6 mm and cleaned with silicon carbide paper to remove dust, dirt. The chemical composition of base metal is shown in table 2 [5].

Table 2. Chemical composition (wt%) of the base metal

Alloy element	C	Si	Mn	P	S	Cr	Ni	Fe
Stainless steel 304L	0.06	0.42	1.89	0.032	0.014	18.67	8.53	Balance

3.2 Taguchi design of experiment

As per Taguchi design of experiment four process parameters each having three different levels was selected by taking trials before welding.

Table 3. Levels of process parameters

	Original levels			Coded		
Process parameters	Low	Medium	High	Low	Medium	High
Electrode gap (mm)	1	2	3	1	2	3
Travel speed (mm/min)	100	150	200	1	2	3
Current (A)	140	170	200	1	2	3
Gas flow rate (lit/min)	7	10	13	1	2	3

In this study, an L_9 (3^4) orthogonal array with 4 columns and 9 rows was used. This array can handle three level process parameters. Nine experiments were necessary using this orthogonal array. In order to evaluate the influence of each selected parameter on the responses, the S/N ratios and means. The experiments were conducted by using process parameters given in table 4 of design of experiment.

Table 4. Taguchi design of experiment

Trial no	Parameters / factors							
	Electrode gap (mm)		Welding speed (mm/min)		Current (A)		Gas flow rate (lit/mm)	
	Original value	Coded value	Original value	Coded value	Original value	Coded value	Original value	Coded value
1	1	1	100	1	140	1	7	1
2	1	1	150	2	170	2	10	2
3	1	1	200	3	200	3	13	3
4	2	2	100	1	140	2	13	3
5	2	2	150	2	170	3	7	1
6	2	2	200	3	200	1	10	2
7	3	3	100	1	140	3	10	2
8	3	3	150	2	170	1	13	3
9	3	3	200	3	200	2	7	1

3.3 Conduct experiment as per design

Austenitic stainless steel 304L is used as base metal in this process. For test purpose eighteen specimens of 150×50×6 mm size were cut. Each specimen surface was roughly polished with silicon carbide abrasive paper of 400 grit and then cleaned by acetone. A direct current electrode negative (DCEN) power source of MOGORA TIG 200 machine is used. In this autogenous TIG welding the torch is moved with desired speed. Activated flux, SiO_2 where prepared in powder form, is mixed with acetone [2,7]. The paint like material is painted with brush of 0.2 mm thickness and 15 mm width prior to welding. The welding parameters are taken from DOE table. Single pass autogenous TIG welding was performed along the center line of test specimen to produce bead on plate weld [3]. Welding variables as follow

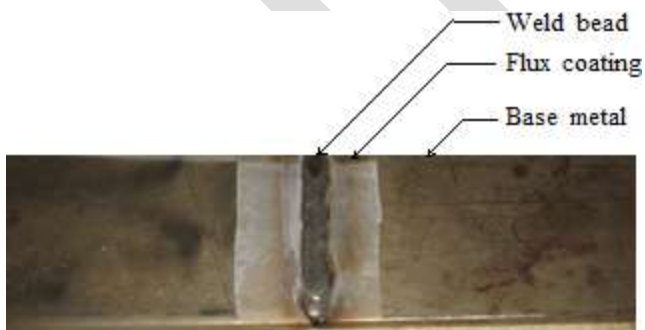|	
Electrode diameter	2.4 mm with 2% thorium, tungsten electrode
Oxide flux powder	SiO_2 along with acetone
Welding voltage	18 V
Electrode angle	60^0
Shielding gas	Pure argon (99.99)
Joint design	Close square butt joint
Root gap	0 mm
Filler material	No filler metal was used

Fig 1. Photographic view of sample no 1 after welding

4. RESULTS AND DISCUSSION

4.1 Evaluation of SN ratio

The tensile strength of specimens is calculated after testing it on servo hydraulic UTM machine having 40 Tones of capacity. All the specimens are fails at weld section because it is weaker than base metal. Signal to noise ratio represents the desirable and undesirable

values for the output characteristics, respectively. The Taguchi method uses S/N ratio to measure the quality characteristics deviating from desired values. The S/N ratio calculated from Minitab 15 software differs for different quality characteristics. In the present study tensile strength of weld specimen is response value, there for "higher is better" characteristics are chosen for analysis.

Higher is better,   S/N ratio = $-10\log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}Y_i^{-2}\right]$

Were,
Y_i represents the experimentally observed value of the ith experiment,
n is the number of repetition for an experimental combination.

Table 5. Experimental results and SN ratio

Trial No	Electrode gap (mm)	Travel speed (mm/min)	Current (A)	Gas flow rate (lit/min)	Tensile strength (MPa)	S/N ratio
1	1	75	140	7	486	53.7327
2	1	130	170	10	480	53.6248
3	1	160	200	13	460	53.2552
4	2	75	170	13	474	53.5156
5	2	130	200	7	468	53.4049
6	2	160	140	10	415	52.3610
7	3	75	200	10	498	53.9446
8	3	130	140	13	400	52.0412
9	3	160	170	7	422	52.5062

From the main effect plot data it is observed that as electrode gap increases, tensile strength decreases for all level of samples. If welding torch travel speed from 100 to 150 mm/min sharp decrease in S/N ratio and after that from 150 to 200 A slowly decraese in S/N ratio. The range of S/N ratio values has maximum range for torch travel speed. For welding current increase in value, observed incresase in S/N ratio. Gas flow rate increases from 7 to 11 lit/min there is smoothly increase in S/N ratio and for 11 to 13 lit/min there is rapidly decrese in S/N ratio. It is due to fact that as gas flow rate increses then oxide flux moves away from torch because of low density. It must be necessary that oxide flux will be in contact of base metal. The optimum values of process parameters to incresse the tensile strength of weld specimens are 1 mm electrode gap, 100 mm/min travel speed,   200 A welding current and 10 lit/min gas flow rate.
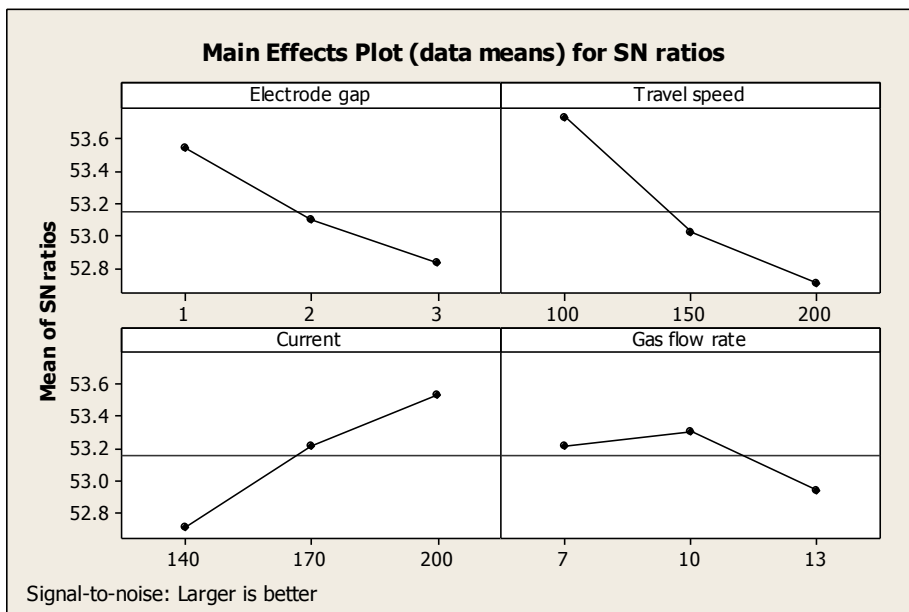

Fig 2. Main effect plot for SN ratio

The response tables 6 shows the average of each response characteristic (S/N ratios) for each level of each factor. The tables 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. Minitab assigns ranks based on Delta values; rank 1 to the highest Delta value, rank 2 to the second highest, and so on. Use the level averages in the response tables to determine which level of each factor provides the best result.

Table 6. S/N response table for S/N ratio

Notation	Parameter	Level 1	Level 2	Level 3	Delta = Maximum—Minimum	Rank
A	Electrode gap	53.54	53.09	52.83	0.71	3
B	Travel speed	53.73	53.02	52.71	1.02	1
C	Current	52.71	53.22	53.53	0.82	2
D	Gas flow rate	53.21	53.31	53.94	0.37	4

4.2 Analysis of variance (ANOVA)

The analysis of variance was carried out at 95% confidence level. The main purpose of ANOVA is to investigate the influence of the designed process parameters on Tensile strength by indicating that, which parameter is significantly affected the response. This is accomplished by separating the total variability of the S/N Ratios, which is measured by the sum of squared deviations from the total mean of the S/N ratio, into contributions by each welding process parameter and the error. The percentage contribution by each of the welding process parameters in the total sum of the squared deviations can be used to evaluate the importance of the process parameter change on the quality characteristic. Degrees of freedom (DOF) for OA should be greater than or at least equal to those for the parameters. In this study, the experimental DOF is 8 (number of trails –1), while the parameters has 2 DOF.

Table 7. Results of ANOVA

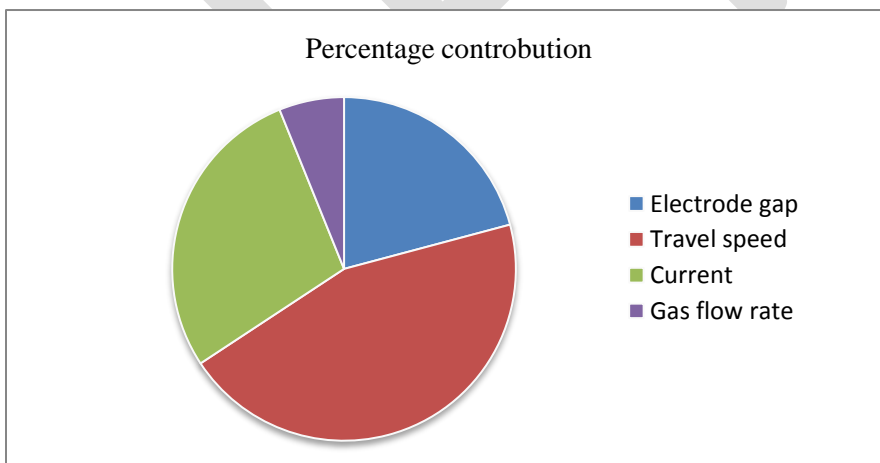| Notation	Parameter	Degree of freedom	Seq SS	Adj SS	Adj MS	Contribution %
A	Electrode gap	2	0.76585	0.76585	0.38293	20.85
B	Travel speed	2	1.64783	1.64783	0.82393	44.87
C	Current	2	1.03366	1.03366	0.51683	28.14
D	Gas flow rate	2	0.22502	0.22502	0.11251	6.12
Error		0	0	0	0	0
Total		8	3.67236			

Fig 2. Pie chart showing percenrage contribution

4.3 Residual plot

Residual plot is graph that is used to examine the goodness-of-fit in regression and ANOVA. Examining residual plots helps us to determine whether the ordinary least squares assumptions are being met. If these assumptions are satisfied, then ordinary least squares regression will produce unbiased coefficient estimates with the minimum variance. A residual plot is a graph that shows the residuals on the vertical axis and the independent variable on the horizontal axis.

The normal probability plot of residuals, use the normal plot of residuals to verify the assumption that the residuals are normally distributed. The residuals versus fits, use the residuals versus fits plot to verify the assumption that the residuals have a constant variance. The histogram of the residuals, use the histogram of residuals to determine whether the data are skewed or whether outliers exist in the data. The residual versus order of data, use the residuals versus order plot to verify the assumption that the residuals are uncorrelated with each other.
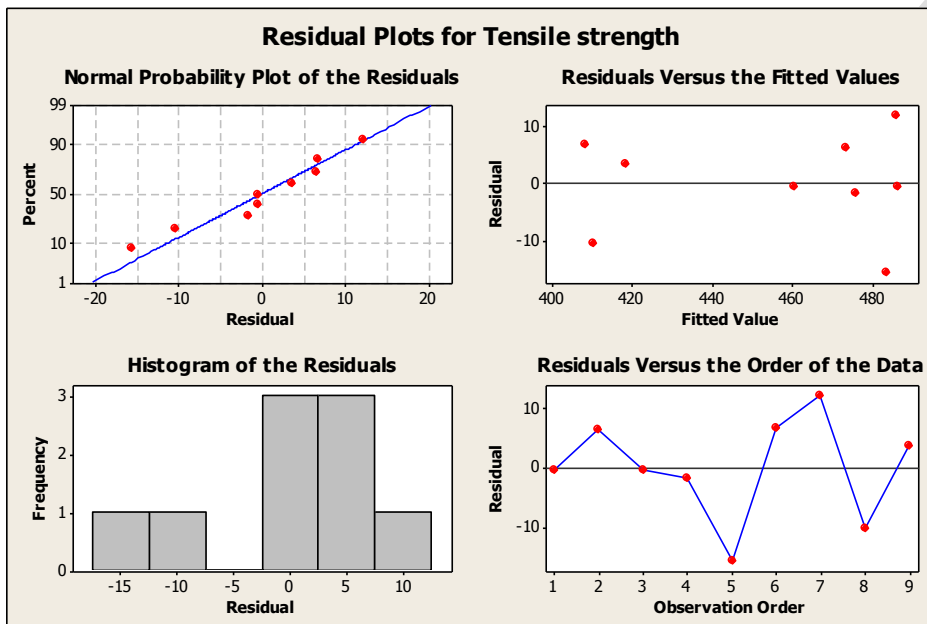

Fig 3. Residual plot for SN ratio

CONCLUSION

The present work studied the effect of welding process parameters on tensile strength of weldment AISI 304L stainless steel sheet produced by Activated flux tungsten inert gas (A-TIG) welding process, The following conclusions can be drawn,

1) Good joint strength is exhibited by all the joints which shows that the welding of 6 mm thick AISI 304L stainless steel sheet with A-TIG welding is possible without any joint preparation and in single pass.
2) Taguchi design of experiment technique can be very efficiently used in the optimization of process parameters
3) In A-TIG welding percentage contribution of weld process parameters for tensile strength are observed as electrode gap, welding current, welding speed and gas flow rate
4) The optimum values of process parameters for weld specimens are, 1 mm electrode gap, 100 mm/min travel speed, 200 A welding current and 10 lit/min gas flow rate.
5) Percentage contribution of process parameters for tensile strength are welding speed (44.87%), welding current (28.14%), arc gap (20.85%) and gas flow rate (6.12%).

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