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OPTIMIZATION OF TIG WELDING PARAMETERS FOR MAXIMIZING WELDS STRENGTH OF TI 6AL 4V CRUCIFORM SHAPE JOINT

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Abstract

Tungsten Inert Gas (TIG) welding is one of the most widely used processes in industry. The welding parameters are the most important factors affecting the cost and quality of welding. This paper pertains to the improvement of ultimate tensile strength of Ti 6Al 4V weld specimen of cruciform shape which is made of tungsten inert gas welding. A plan of experiments based on Taguchi method has been used. L_9 orthogonal array has been used to conduct the experiments at different levels of welding parameters like welding current, welding voltage, travelling speed. These all parameters have different effect on welding quality. Signal-to-noise ratio (S/N ratio), analysis of variance (ANOVA) and graphical mean effect plots for S/N ratio are employed to investigate the optimal level of process parameters and influence of welding parameters on weld strength.

Key words: - Signal To Noise Ratio, TIG Welding, Taguchi Method, Process Parameters, ANOVA.

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1. INTRODUCTION

Ti–6Al–4V alloy has important characteristics such as high strength to weight ratio, excellent corrosion resistance, good toughness, low thermal expansion rate, high temperature creep resistance and good formability**.** The welds and welded joints of Ti–6Al–4V alloy fabricated in nuclear engineering, civil industries, transportable bridge girders, military vehicles, road tankers and aerospace vehicles are subjected to fluctuating loads. This kind of loading causes small cracks to grow during life of the component and leads to fatigue failure. A detailed study of this crack growth Measurement could prevent the failure with prediction, which could ensure that the crack will never propagate and fail prior to detection.

The welding technology of titanium is complicated due to the fact that at temperatures above 550°C, and particularly in the molten stage, it is known to be very reactive towards atmospheric gases such as oxygen, nitrogen, carbon or hydrogen causing severe loss of ductility of material. Shielding gases in welding titanium and titanium alloys are argon and helium, mixture of these two gases is used for shielding. Because it is more readily available and less costly, argon is more widely used. The primary purpose of shielding gas is to prevent exposure of the molten weld pool to oxygen, nitrogen and hydrogen contained in the air atmosphere [6]. The reaction of these elements with the weld pool can create a variety of problems, including porosity (holes within the weld bead) and excessive spatter. In the present work, the different input parameters in TIG welding to improve the ultimate tensile strength and reduce the elongation of the welding joint using Taguchi’s orthogonal array.

Nirmalendu Choudhary, Asish Bandypadhay & Ramesh Rudrapati [1] has presented their work on design optimization of process parameters of TIG welding using Taguchi method. They considered welding current, gas flow rate and filler rod as input process parameters and optimizes their values using Taguchi method to improve the ultimate load on weld materials. Kumar and S. Sundarrajan [2] studied the improvement of mechanical properties of AA 5456 Aluminum alloy welds through pulsed Tungsten Inert Gas (TIG) welding process. Taguchi method was employed to optimize the pulsed TIG welding process parameters of AA 5456 Aluminum alloy welds for increasing the mechanical properties Chavda, S. P. [4] investigated the effect of welding parameters: current, welding voltage, Gas flow rate and wire feed rate on weld strength, weld pool geometry of medium Carbon Steel material during welding by Taguchi method. Sapakal,S.V[5]presented optimization of influence parameters current, voltage and welding speed on penetration depth of MS material with the help of Taguchi‘s design.. The penetration obtained is 5.25mm with optimal welding parameters. M. Balasubramanian et.al [6] analyzed that Increase in use of pulsed current process creates dependency on the use of mathematical equations to predict the weld pool geometry. Hence, the development of mathematical models using four factors, five levels, central composite design was attempted. Pasupathy et al. [8] investigated the optimal process parameters of Tungsten inert gas welding for improving weld strength of low carbon steel - aluminum alloy 1050 weld specimen using Taguchi method.

2. METHODOLOGY

In this experimental study, the Taguchi method is used for optimization of process parameters of TIG Welding of Titanium alloy (Grade5). Taguchi approach is a robust design method that uses experimental design called orthogonal arrays (OAs). Taguchi method is to study a large number of decision variables with a small number of experiments [12]. By using and understanding the Taguchi method, welding quality and experimentation process were developed and improved. The range of parameter of welding current, welding voltage and welding speed were obtained by several preliminary experiments. The parameters (factors) and its levels are shown in Table 3 shows the L16 orthogonal array (OA) which were selected for the analysis.

The Taguchi method has become an influential tool for improving output during research and development, so that better quality products can be produced quickly and at minimum cost. Dr. Taguchi of Nippon Telephones and Telegraph Company, Japan has established a method based on "ORTHOGONAL ARRAY" experiments which gives much reduced "variance" for the experiment with "optimum settings" of control variables. Thus the marriage of Design of Experiments with optimization of control parameters to find best results is attained in the Taguchi Method. "Orthogonal Arrays" (OA) gives a set of well balanced (minimum) experiments and Dr. Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions in optimization, help in data analysis and estimation of optimum results. The S/N ration in Taguchi’s method is calculated by giving formulas

(i) Smaller the better

$\eta = -10 \log [(\Sigma Yi^2)/ n]$

(ii) Larger the better

$\eta = 10 \log [(\Sigma 1/Y_i^2)/ n$

Y_i= i th observed value of response

n = no. of observations in a trial

y = average of observed response

Smaller the better approach is followed for the response parameter which we wants to be minimum and larger the better approach is followed for response parameter which we wants maximum. In the present work Taguchi's parameter design approach is used to study the effect of process parameters on the Tensile strength by varying different parameter such as welding current, voltage, gas flow.

The steps followed in Taguchi optimization are as follows:

1. Select control and noise factors
2. Select levels for each factor
3. Select Taguchi orthogonal array
4. Conduct the experiments
5. Measure the response factor
6. Calculate Signal-to-noise ratio
7. Calculate mean S/N ratio and plot mean S/N ratio graph
8. Predict optimal process parameter level
9. Formulate ANOVA table
10. Run confirmation experiment

3. EXPERIMENTAL PROCEDURE

3.1. Welding equipment

It is precision engineered range of inverter based TIG machines, which are in compliance with set industrial benchmarks. Fabricated from superior quality raw materials, these machines are used to weld mild steel, stainless steel, copper & titanium. Our Inverter TIG Welding Machines are known amidst clients for accurate dimension and capability to deliver optimum performance for long time. The welding technology of titanium is complicated due to the fact that at temperatures above 550°C, and particularly in the molten stage, it is known to be very reactive towards atmospheric gases such as oxygen, nitrogen, carbon or hydrogen causing severe embrittlement.

Fig 1:-Specimen of Ti 6 Al 4V welded plate

3.2. Work Piece Material:

Table 1 :-Chemical composition of work material

Chemical composition of base metal and filler metal (mass fraction, %)							
Ti Gr 5	C	Al	V	Fe	H	N	0
ASTM B265	0.08	5.8-6.0	3.9-4.0	0.2-0.3	0.015	0.03	0.2-0.25

Table 2:- Mechanical Properties of a material

Mechanical Properties			
Ti Gr 5	UTS(Mpa)	YTS	% EI
ASTM B265	1170 Mpa	890	16

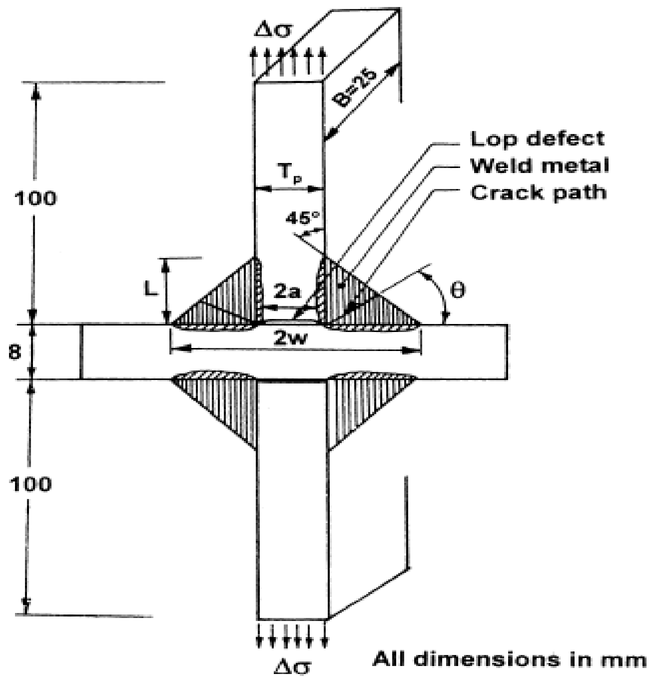


Fig 2:- Dimensions of Specimen

3.3. EXPERIMENTAL SET UP

Titanium alloy (Ti-6Al 4V) plate (Grade 5) with chemical composition presented in Table 1 was used as work piece material. The dimension of main plate was 120 mm long × 16 mm width with thickness of 8 mm. cross plate dimension was 100 mm long × 16 mm width with thickness of 8 mm. The basis for success weldment starts with perfect selection of welding parameters like welding current, welding voltage, welding speed, shielding gas and filler rod diameters. Tungsten inert gas Arc welding is done to join the plates in cruciform shape by using ER Ti5 filler rod material with help of TIG welding machine.

In the present study, in order to identify the process parameters with the maximum ultimate tensile strength in the TIG welding of Titanium grade 5, the Taguchi method was used. Three three-level process parameters, i.e. welding current, voltage and welding travelling speed were considered. Based on theoretical and experimental viewpoints, the respective levels are set. The levels of parameters are listed in Table 3.

Table 3:- Control parameters and their levels

Control parameters					
Parameter	Symbol	Level			Unit
		1	2	3	
Welding current	A	80	100	120	Ampere
Welding voltage	B	10	14	18	Volts
Travelling speed	C	60	70	80	mm/min

This basic design uses up to three control factors, each with three levels. A total of nine runs must be carried out, using the combination of levels for each control factor. The addition of noise factors is optional, and requires each run to be conducted once for each combination of noise factor.

All nine welding experiments were performed with the help of orthogonal array on tensile testing machine as shown in fig 3 . For the calculation of the response of Ultimate tensile strength the work pieces were machined into standard shape of tensile specimens. On these specimens tensile test were performed on for calculation of ultimate tensile strength

Fig 3:- Tensile testing machine

For performing the experiments Taguchi L9 orthogonal array was selected for 3-factor and 3-levels process parameters. Which reduces the number of experiments and is gives as in Table 4.

Table 4:- Experimental layout using L_9 orthogonal array

Expt No	Welding parameters				
	welding current	welding voltage	Travelling speed	Response	S/N ratio (dB) of Response
1	1	1	1	850.55	58.594
2	1	2	2	900.78	59.0924
3	1	3	3	980.56	59.8295
4	2	1	2	920.32	59.2788
5	2	2	3	995.69	59.9625
6	2	3	1	1050.65	60.4292
7	3	1	3	930.5	59.3743
8	3	2	1	1020.75	60.1784
9	3	3	2	1120	60.8279

3.4. Analysis of S/N ratio

Taguchi has created a transformation of repetition data to another value, which is a measure of the variation present. The transformation is known as signal-to-noise (S/N) ratio. In Taguchi Method, the term ‘signal’ represents the desirable value (mean) for the output characteristic and the term ‘noise’ represents the undesirable value (standard Deviation) for the output characteristic. Therefore, S/N ratio is the ratio of mean to the standard deviation. S/N ratio used to measure the quality characteristic deviating from the desired value. S/N ratio is log function of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results. The S/N ratio S is defined as

S/N = - 10 log10 (M.S.D)

Where, M.S.D. is the mean square deviation for the output characteristic. According to Quality Engineering, the characteristic that higher observed value represents better performance, as in case of tensile strength, is known as “larger is better”. In this research, for welded joints, higher value of ultimate tensile strength is preferred so only weld can withstand more load. Therefore, for ultimate tensile strength “larger is better” is selected for obtaining optimum machining performance characteristics. Using Minitab 16 software, S/N ratio is calculated as shown in Table 4. Results show that among main input welding parameters the effect of the welding speed is significant. Increasing the welding current and decreasing the travelling speed increases the ultimate tensile strength of welded joint. Therefore, the optimal level of the process variables is the level with the greatest S/N ratio. The S/N response table for ultimate tensile strength is shown in above Table 4.

3.5. ANOVA Technique

ANOVA is a collection of statistical models used to analyze the difference between group means and their associated procedures (such as "variation" among and between groups), developed by R.A. Fisher. ANOVA is the statistical method used to interpret experimental data to make the necessary decisions. A better feel for the relative effect of the different welding parameters on the ultimate tensile strength was obtained by decomposition of variance, which is called analysis of variance. ANOVA helps in formally testing the significance of all main factors and their interactions by comparing the mean square against an estimate of experimental errors at specific confidence levels. Through ANOVA, the parameters can be categorized into significant and insignificant process parameters. A statistical analysis of variance is performed to see which process parameters are statistically significant at 95% confidence level.

The purpose of the analysis of variance (ANOVA) is to examine which design parameters significantly affect the quality characteristic. This is to accomplished by separating the total variability of the S/N ratios, which is measured by the sum of the squared deviations from the total mean S/N ratio, into contributions by each of the parameters and the error. First, the total sum of squared deviations SST from the total mean S/N ratio nm can be calculated as,

$$SS_T = \sum_{J=1}^{P} (\acute{\eta}_j - \acute{\eta}_m)$$

Table 5:- ANOVA Table for ultimate strength

Control factors	DOF	Seq SS	Adj SS	Adj MS	F	P	
A	2	1.4836	1.4836	0.7418	33.3	0.029	Significant
B	2	2.4578	2.4578	1.2289	55.1	0.018	Significant
C	2	0.0002	0.0002	0.0001	0.01	0.994	In significant
Error	2	0.0445	0.0445	0.0222			
Total	8	3.9862					

S = 0.149231   R-Sq = 98.88%   R-Sq(adj) = 95.53%

The P (Probability) value states that the values 0.029, 0.018 are significant. In this case welding current and welding voltage are significant parameter and travelling speed is non-significant parameter. The value of $P \leq 0.05$ indicates those models are significant. Where, f = Degree of Freedom, SS = Sum of Square, MS = Mean Sum of Square, F = F value or Variance ratio SS'= Pure Sum of Square, P = Percentage contribution, F (0.05) Tabulated = Tabulated F value at 95% Confidence level.

Table 6:- S/N Response Table for Ultimate Tensile Strength

Level	**A**	**B**	**C**
1	59.17	59.08	59.73
2	59.89	59.74	59.73
3	60.13	60.36	59.72
Delta	0.95	1.28	0.01
Rank	2	1	3

From Above table, the optimum levels are $A_3B_3C_1$ which is based on larger-the-better criterion. The ANOVA is a statistical tool used to determine the level of contribution of each process parameter to the overall improvement of the tensile strength of the welded joint.

4. RESULTS AND DISCUSSION

4.1 .Optimum parameter selection from S/N ratio for UTS

The observed value of Ultimate Tensile strength (UTS) and corresponding values of S/N ratio are listed in Table 6 and the response values for S/N ratio of UTS are listed in Table 4. The graphical plots for showing S/N ratio with each parameter are presented in figure. By analyzing these values, the optimize TIG parameters values for Maximizing the Ultimate Tensile strength of welding joint comes out are Welding current, Welding voltage, Travelling speed ($A_3B_3C_1$).

Main effect plots of Factor A (Current), Factor B (Voltage) and Factor C (Travelling speed) are shown in Fig 4(a), Fig 4(b).From Fig. 4(a) it can be seen that tensile strength of the weld increases, when welding current increases from 80 amp to 120 amp, This observation is also reported by Kumar, D et al [2]. Thus optimum setting for current is 120 amp (A_3). From Fig. 6(b) it is observed that the Tensile strength increases when the voltage is increased from 10V to 18V. It is because of the increase in granule size, the tensile strength increases. This is also supported by the studies of Kumar, D. et al [2]. The optimum setting of Factor B (Welding voltage) can be found at 18 V (B_3). From the above main effect plot Fig.4 (b) it is observed that the tensile strength increases when the travelling speed is decreased from 60 mm/min to 80 mm/min. It is due to change in grain size of microstructure

4.2 Main Effect Plots for S/N Ratio for UTS

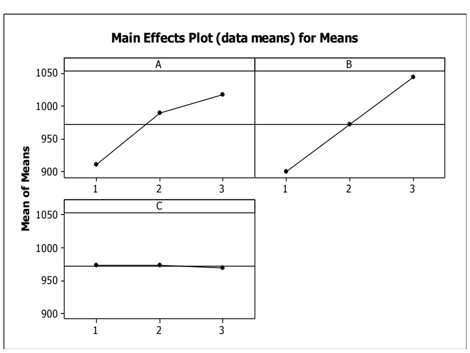


Fig 4 (a) S/N Ratio Graph

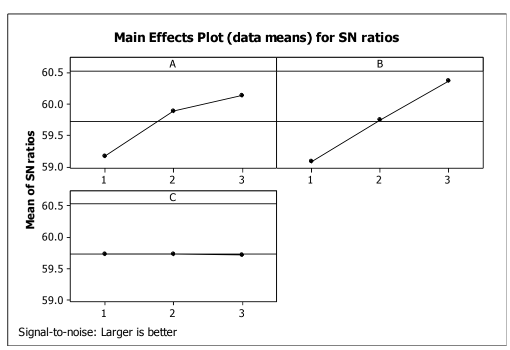
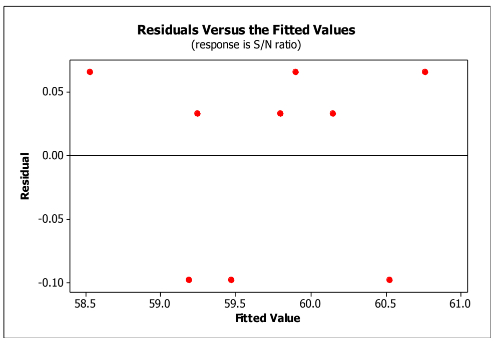


Fig 4 (b) Graph for Mean Values

The normal Probability plot of the residuals for fatigue life is shown in Fig 4.1 which reveals that the residuals are falling on the straight line which means the errors are distributed normally and the constant variance assumption can be checked with Residuals versus Fits plot of Figure 4.2. This plot should show a random pattern of residuals on both sides of 0, and should not show any recognizable patterns. A common pattern is that the residuals increase as the fitted values increase.



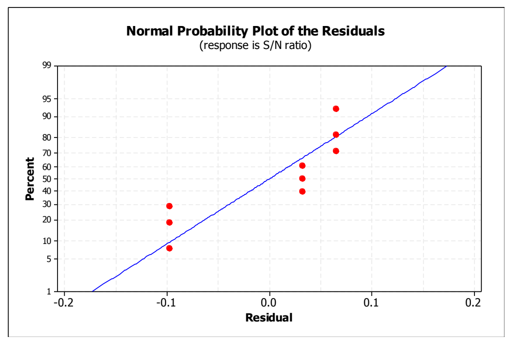


Fig 4.1 Normal Probability vs Residuals

Fig 4.2 -Residual vs Fitted values

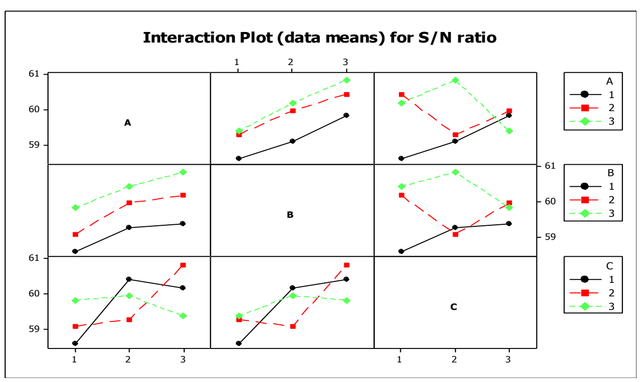


Fig 4.3:-Interaction plot for S/N ratio

4.3. Analysis of cruciform joint

Finite element analysis has been extensively used for analyzing fatigue life of mechanical components. In this study, the maximum stress is identified for different type of loads on cruciform welded joints.

Base plate is constrained in X and Y directions on one side and on the other side of the plate, it is constrained only in Y direction. Structural Ti 6 Al 4V plate dimensions are 100 x 16 x 6 mm and 100 x 16 x 6 mm for base plate and cross plate, respectively. 200 Mpa, 220Mpa and 300Mpa load are applied onto the top surface of the cross plate gradually. Load and boundary conditions and pressure application of the model is shown in figure 4.4(b) and figure 4.4(c), respectively. For fatigue analysis, constant amplitude load is applied fully reversed (vertical push and pull) and is shown in figure 4.4

When cruciform welded joint is subjected to tensile forces of 21 kN, 24kN, 28 kN the following stresses were observed at various points of specimen. Von-Misses equivalent stress distribution for Cruciform welded joint is shown.

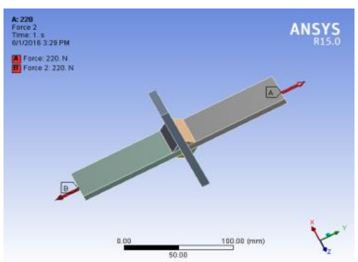


Fig 4.4 a

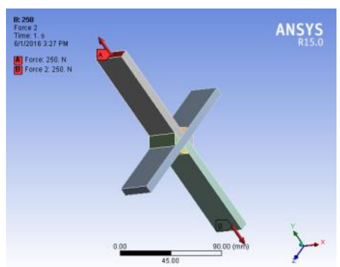


Fig 4.4 b

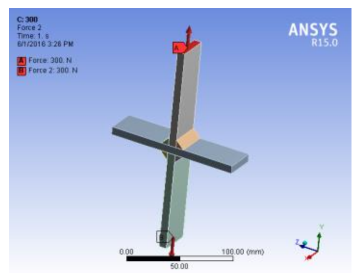


Fig 4.4 c

Fig 4.4 (a),(b),(c)Modeling of Cruciform welded joint and application of loads (21,24,28 kN) on cross plate respectively.

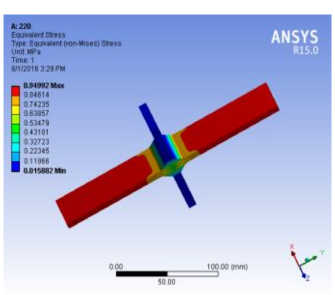


Fig 4.5 a

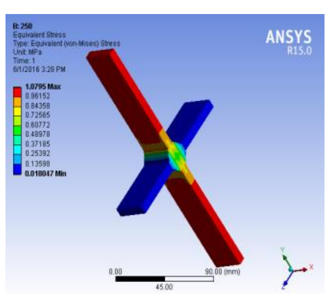


Fig 4.5 b

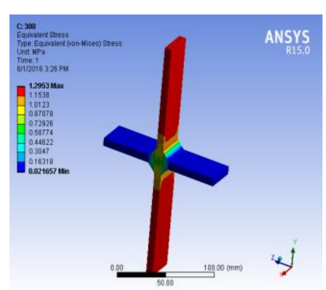


Fig 4.6 c

Fig 4.5 (a), (b), (c) Maximum stress obtained for above loads are 949 Mpa,1079 Mpa and 1295 Mpa respectively.

4.4. Confirmatory test

Once the optimal level of design parameters has been selected, the final step is to predict and verify the improvement of the quality characteristic using the optimal level of design parameters. The estimated S/N ratio using the optimal level of the design parameters can be calculated as

$$\acute{\eta} = \eta_m + \sum_{i=1}^{n} (\acute{\eta}_i - \acute{\eta}_m)$$

Where $\acute{\eta}_m$ is the total mean of S\N ratio, $\acute{\eta}_i$ is the mean S\N ratio at the optimum level, and the n is the number of welding parameter that significantly affect the performance. Confirmation experiment is done at optimal process level and actual ultimate tensile strength found to be 1040 N/mm^2. The comparison of the predicted strength with actual strength using the optimal parameters is shown in Table 7. Good agreement between the predicted and actual penetration being observed.

Table 7: Result of conformation experiment

	Initial process parameters	Optimal process parameters		Improvement in S/N Ratio
		Predicted	Actual	
Level	$A_3B_3C_2$	$A_3B_3C_1$	$A_3B_3C_1$	0.957
Ultimate Tensile Strength (N/mm^2)	1120	1020	1040	
S/N ratio	60.8279	60.15	59.87	

CONCLUSION

1. In this research work, the Taguchi orthogonal array and ANOVAs method were used for parameter optimization of TIG welding for Single responses i.e. Ultimate tensile strength.
2. This research can be found very useful for obtaining best combination of parameters for both output responses individually; results variation will be small from desired value.
3. The study found that the control factors had varying effects on the Tensile strength, welding voltage and welding current having the highest effects, The level of influence of the welding parameters on the weld strength is determined by using ANOVA. Confirmation experiment was also conducted and the effectiveness of Taguchi optimization method was verified. The experimental value of ultimate tensile strength that is observed from optimal level of welding parameters is 1040 $N/mm^{2.}$ The improvement in S/N ratio is 0.957.
4. Welding parameters like current and voltage are considerably significant on tensile strength whereas travel speed as insignificant effect. Taguchi optimization method was successfully applied to find the optimal level of TIG welding parameters for improving weld strength of Ti 6Al 4V Cruciform weld shape.

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