Modelling And Optimization Of Process Parameters For Tig Welding Of Aluminium-65032 Using Response Surface Methodology

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Abstract

Tungsten inert gas welding is one of the widely used techniques for joining ferrous and non ferrous metals. TIG welding offers several advantages like joining of dissimilar metals, low heat affected zone, absence of slag etc. The aim of this paper is to investigate the effect of TIG welding process parameters on welding of Aluminium-65032. Response Surface Methodology was used to conduct the experiments. The parameters selected for controlling the process are welding speed, current and gas flow rate. Strength of welded joints were tested by a UTM. Percent elongation was also calculated to evaluate the ductility of the welded joint. From the results of the experiments, mathematical models have been developed to study the effect of process parameters on tensile strength and percent elongation. Optimization was done to find optimum welding conditions to maximize tensile strength and percent elongation of welded specimen. Confirmation tests were also conducted to validate the optimum parameter settings.

Keywords: TIG welding, Al-65032, Ultimate Tensile Strength, Response Surface Methodology.

1. INTRODUCTION

1.1 WELDING

Welding is a fabrication process that joins materials, usually metals or thermoplastics by causing coalescence. Gas tungsten arc welding, GTAW, also known as tungsten inert gas welding, is an arc welding process that uses a non consumable electrode to produce the weld. Weld area is protected from atmospheric contamination by a shielding gas (usually inert gas such as argon) and a filler material is normally used.GTAW is most commonly used to weld thin sections of stainless steel and non ferrous metals such as aluminium, magnesium and copper alloys.

Aluminium based alloys have been widely used in automobile structures due to their unique properties such as high strength to weight ratio.

1.2 Aluminium – 65032

Aluminium – 65032 is a precipitation hardening aluminium alloy [1], which has good mechanical properties, exhibits good weld ability and is one of the most common alloys of aluminium. Chemical composition [1] of Al-65032 is given in table 1

Table 1: Chemical composition of Aluminium – 65032

Al	Si	Fe	Cu	Mn	Cr	Zi	Ti
97.53	0.4-0.8	<0.7	0.15 –0.4	<0.15	0.04-0.35	<0.25	<0.15

Application of Al – 65032 alloy includes construction of aircraft structures, construction of boats, bicycle frames and components, automobile parts, cans for packing of food stuffs and beverages etc.

2. LITERATURE REVIEW

G.Haragopal et al. (2011) [1] used Taguchi method to study the effect of gas pressure,current,grooveangle and preheat on MIG welding of Aluminium alloy(Al-65032). They indicated that welding current has more effect ultimate tensile strength whereas gas pressure is the most significant parameter for proof stress, elongation and impact energy.

G.Padmanaban et al (2011) [2] studied the effect of optimization of pulsed current gas tungsten arc welding process parameters on tensile strength in AZ31B magnesium alloy. Result showed that maximum tensile strength of 188Mpa was obtained under the welding condition of peak current of 210 A, base current of 80A, pulse frequency of 6 Hz and pulse on time of 50%.

R.Satish et al. (2012) [3] studied weldability and process parameter optimization of dissimilar pipe joints using GTAW. Taguchi method was used to formulate the experimental layout to rank the welding input parameters which affects quality of weld. Results showed that lower heat input resulted in lower tensile strength and too high heat input also resulted in reduced tensile strength.

Dr.Kumar et al (2009) [4] investigated the effect of process parameters on GTAW for Al-7039 alloy. Taguchi method is used to formulate the experimental layout to analyze the effect of each process parameters on bead geometry.

Narongchai Sathavornvichit et al, (2006) [5] determined the optimal factors of Flux cored arc welding process for steel ST37.Experiments were conducted by central composite design,They found that optimum conditions were 300ampere of current,30volt of voltage,45mm of stickout and 60 degrees of angle.

Ugur esme et al.(2009) [6] investigated the multi response optimization of tungsten inert gas welding for an optimal parametric combination to yield favorable bead geometry of welded joints using grey relational analysis and Taguchi method. The significance of factors on overall quality characteristics of the weldment has also been evaluated quantitatively by the analysis of variance method.

M.Balasubramanian et al (2009) [7] studied the weld pool geometry of pulsed current gas tungsten arc welded titanium alloy using central composite design. Mathematical models were developed. Lexicographic method was used to optimize process parameters.

Erdal Karadeniz et al (2007) [8] studied the effects of various welding parameters on welding penetration in ERD emir 6842 steel having 2.5mm thickness welded by robotic gas metal arc welding. welding current ,welding speed and arc voltage were chosen as process parameters. The depth of penetration were measured for each specimen and effect of these parameters on penetration were researched. From the study, it is found that increasing welding current increased the depth of penetration.

D.S.Nagesh et al (2002) [9] studied that bead geometry and penetration are important physical characteristic of a weldament. It was observed that high arc travel rate or low arc power normally produce poor fusion. A neural network was developed for estimating weld bead and penetration geometric parameters.

From the literatures, it is observed that only few works have been reported on the study of TIG welding process parameters for welding of Aluminium-65032. Therefore the aim of the present study is to investigate the effect of TIG welding process parameters on the welding of Al-65032.The experiments were conducted using a statistical technique called Design of Experiments (DOE).

3. METHODOLOGY OF INVESTIGATION

3.1 Response Surface Methodology (RSM)

Response Surface Methodology (RSM) is a collection of statistical and mathematical techniques useful for developing, improving, and optimizing processes [2, 10-11]. With this technique, the effect of two or more factors on quality criteria can be investigated and optimum values are obtained. In RSM design there should be at least three levels for each factor.

Table 2: Factors & Levels

Factors	Notation	Levels		
		-1	**0**	**+ 1**
Welding speed (mm / min)	S	150	175	200
Welder current (Amps)	I	100	110	120
Gas flow rate (LPM)	L	10	11	12

RSM also quantifies relationships among one or more measured responses and the vital input factors. The version 14 of the MINITAB software was used to develop the experimental plan for RSM.

3.2 Central Composite Design (CCD)

The first requirement for RSM involves the design of experiments to achieve adequate and reliable measurement of the response of interest. To meet this requirement, an appropriate experimental design technique has to be employed. The experimental design techniques commonly used for process analysis and modelling are the full factorial, partial factorial and central composite designs. A full factorial design requires at least three levels per variable to estimate the coefficients of the quadratic terms in the response model A partial factorial design requires fewer experiments than the full factorial design However, the former is particularly useful if certain variables are already known to show no interaction. An effective alternative to factorial design is central composite design (CCD), [5, 13-14] requires many fewer tests than the full factorial design and has been shown to be sufficient to describe the majority of steady-state process responses. Hence in this study, it was decided to use CCD to design the experiments. Hence the total number of tests required for the three independent variables is 2^3 + (2x3 + 6 = 20. Once the desired ranges of values of the variables are defined, they are coded to lie at ±1 for the factorial points, 0 for the center points and ±p for the axial points.

3.4 Factors and Levels

In this study three parameters have been chosen for analysis. They are welding speed, welding current and gas flow rate [3-4, 12]. Several trial runs were conducted to determine the range of parameters. The levels for parameters finally chosen are shown in table 2.

Table 3: central Composite Design Matrix

Exp No.	Welding speed (mm / min)	Welding current (A)	Gas flow rate (LPM)
1.	-1	-1	-1
2.	1	-1	-1
3.	-1	1	-1
4.	1	1	-1
5.	-1	-1	1
6.	1	-1	1
7.	-1	1	1
8.	1	1	1
9.	-1	0	0
10.	1	0	0
11.	0	-1	0
12.	0	1	0
13.	0	0	-1
14.	0	0	1
15.	0	0	0
16.	0	0	0
17.	0	0	0
18.	0	0	0
19.	0	0	0
20.	0	0	0

Table 4: Experimental Design Variables

Exp No.	Welding speed (mm / min)	Welding current (A)	Gas flow rate (LPM)
1.	150	100	10
2.	200	100	10
3.	150	120	10
4.	200	120	10
5.	150	100	12
6.	200	100	12
7.	150	120	12
8.	200	120	12
9.	150	110	11
10.	200	110	11
11.	175	100	11
12.	175	120	11
13.	175	110	10
14.	175	110	12
15.	175	110	11
16.	175	110	11
17.	175	110	11
18.	175	110	11
19.	175	110	11
20.	175	110	11

4. EXPERIMENTAL WORK

4.1 Experimental Procedure

Welding specimen has been prepared to fabricate TIG welded joints. Aluminium alloy 65032 specimen (75mm x 75mm x 3mm) in the specified dimension was considered for welding of square butt joints.

Welding process has been carried out in TIG welding machine. Experiments were conducted based on central composite design matrix [5] which is given in Table 4.

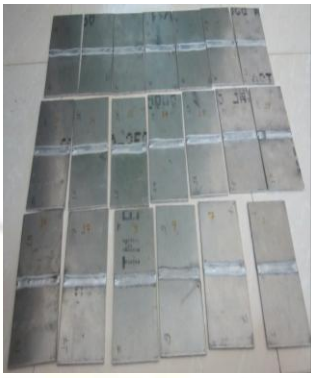

Fig. 1 Photos of Welded Specimen

4.2 Tensile Testing

The ultimate tensile strength of the machined specimen were tested in the calibrated universal tensile testing machine. Percent elongation was also calculated. Tensile test carried out according to ASTM standards, using specimen prepared as shown in Fig.2

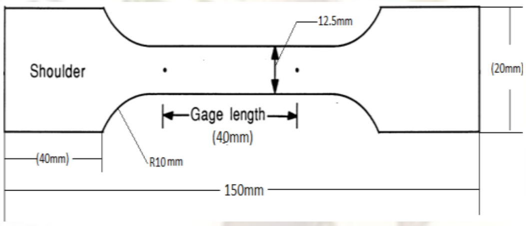

Fig.2 Dimensions of tensile test specimen

4.2.1 Test Specimen

Welded joints were machined for conducting tensile test. Test specimen prepared according to ASTM Standards is shown in Fig 3.

Fig.3 Test Specimen

The Tensile test was carried out in the servo controlled universal testing machine with 1000 KN load capacity. The specimen is loaded at the rate of 0.1KN/Min. Due to the pulling effect of machine, tensile specimen undergoes deformation. Twenty specimens were tested at each condition, ultimate tensile strength and percent elongation were calculated

Fig.4 Specimen after tensile test

Table 5:. Tensile strength and % Elongation values

Exp. No	Welding Speed (Mm/Min)	Welding Current (Amps)	Gas Flow Rate (Lpm)	Tensile Strength (Mpa)	% Elongation
1	150	100	10	112.7	6.12
2	200	100	10	98.6	5.8
3	150	120	10	109.3	6.1
4	200	120	10	88	5.55
5	150	100	12	122.6	6.25
6	200	100	12	95.7	5.6
7	150	120	12	112	6.15
8	200	120	12	93.3	5.7
9	150	110	11	117.3	6.20
10	200	110	11	100.8	5.9
11	175	100	11	93.3	5.65
12	175	120	11	98.6	5.85
13	175	110	10	104	5.95
14	175	110	12	93.6	5.65
15	175	110	11	96	5.75
16	175	110	11	96	5.75
17	175	110	11	93	5.6
18	175	110	11	96	5.7
19	175	110	11	90.6	5.55
20	175	110	11	96	5.75

5. RESULTS AND DISCUSSION

5.1 Analysis of variance

Analysis of variance (ANOVA) is similar to regression in that it is used to investigate and model the relationship between a response variable and one or more independent variables.

In this study general linear model is used to determine the influence of welding speed, current and gas flow rate on ultimate tensile strength and % Elongation.

5.2 Analysis of variance for UTS

Table 6: ANOVA For UTS

S = 4.986, R-sq = 85.5% R-sq (adj) = 75.1%

Source	DF	SS	MS	F	P	Contribution (%)
Regression Model	9	1465.6	1465.6	6.55	0.004	85.49
Linear	3	999.83	999.83	13.40	0.001	58
Square	3	452.52	452.52	6.07	0.013	26.39
Interaction	3	13.25	13.25	0.18	0.909	0.77
Residual Error	10	248.64	248.64	-	-	-
Lack of Fit	5	222.24	222.24	8.42	0.018	12.96
Pure Error	5	26.4	26.4			-
Total	**19**	**1714.24**	-			**100**

5.3 Model coefficients for UTS.

Table 7

Term	Coef	Term	Coef	Term	Coef
Constant	96.138	Welding speed*welding speed	10.6045	Welding speed*welding current	0.1250
Welding speed	-9.75	Welding current*welding current	-2.4955	Welding speed*gas flow rate	-1.2750
Welding current	-2.17	Gas flow rate *gas flow rate	0.3545	Welding current*gas flow rate	0.1250
Gas flow rate	0.46	-	-	-	-

Table 6 shows ANOVA table corresponding to ultimate tensile strength. Linear has great percentage of contribution on UTS and Interaction has less percentage of contribution on UTS.

Table 7 shows estimated model coefficients for ultimate tensile strength.

5.4 Estimated regression Model for UTS

From Regression analysis, a mathematical model for predicting UTS in terms of welding speed, current and gas flow rate is developed and is given below.

$UTS = 96.138 - 9.75 \times S - 2.17 \times I + 0.46 \times L + 10.6045 \times S^2 - 2.4955 \times I^2 + 0.3545 \times L^2 + 0.1250 \times S \times I - 1.2750 \times S \times L + 0.1250 \times A \times L.$

5.5 Analysis of variance for % Elongation

Table 8: ANOVA For %Elongation

S = 0.1397, R-sq = 80.0% R-sq (adj) = 75.21%

Source	DF	SS	MS	F	P	Contribution (%)
Regression Model	9	0.77857	0.86508	4.43	0.015	80.4
Linear	3	0.51867	0.1728	8.86	0.004	52.37
Square	3	0.24406	0.081	4.17	0.037	24.74
Interaction	3	0.01584	0.0052	0.27	0.845	0.0162
Residual Error	10	0.19509	0.019	-	-	-
Lack of Fit	5	0.15675	0.031	4.09	0.047	-
Pure Error	5	0.03833	0.007	-	-	-
Total	**19**	**0.97366**	**-**	**-**		**100**

5.6 Model Coefficients For Percent Elongation.
Table 9

Term	Coef	Term	Coef	Term	Coef
Constant	5.730	Welding speed*welding speed	0.2486	Welding speed*welding current	-0.00375
Welding speed	-0.227	Welding current*welding current	-0.05136	Welding speed*gas flow rate	-0.2875
Welding current	-0.017	Gas flow rate-*gas flow rate	0.00136	Welding current*gas flow rate	0.03375
Gas flow	0.007				

Table 8 shows the ANOVA table corresponding to % Elongation. This table shows that main effects of welding speed, current and gas flow rate are all significant with respect to percent elongation. Table 9 shows estimated model coefficients for percent elongation.

5.7 Estimated Regression model for % Elongation

%Elongation = 5.730 – 0.227 x S - 0.017 x I – 0.007 x L + 0.2486 x S^2 - 0.05136 x I^2 - 0.00136 x L^2 - 0.00375 x S x I – 0.2875 x S xL + 0.03375 x I x L.

5.8 Optimization of process Parameters

One of the most important aims of experiments related to welding is to achieve high value of tensile strength and Elongation. The response surface optimization is a technique for determining best welding parameter combination[6-7,13]. Here the goal is to maximize UTS and % Elongation. RSM optimization result for UTS and % Elongation is shown in Fig 5. Optimum parameters obtained are shown in table 1

Table 10: Response optimization for process parameter

Parameters	Goal	Optimum Combination			Lower	Target	Upper	Predicted Response
		Welding speed	Current	Gas flow rate				
Tensile strength	Max	150	108.385	11.99	88	122.6	122.6	119.1298
% Elongation	Max	150	108.385	11.99	5.55	6.25	6.25	6.21

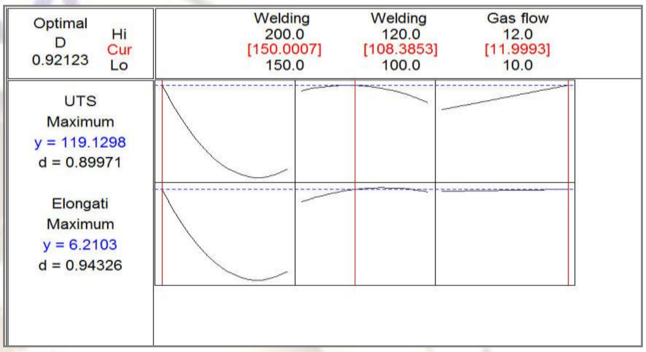

Fig 5. Optimization using MINITAB VI4 Software

5.9 Effect of process parameters on UTS

The main effects of the plot, for UTS with the process parameter of welding speed, current and gas flow rate were shown in Fig.5.2. Graph shows that UTS decreases from 115 MPa to 95 MPa. when welding speed increases from 150mm/min to 200 mm/min,because of less penetration depth. UTS decreases from 105 MPa to 101MPa when current changes from 100 Amps to 120 Amps, due to the result of increased input heat associated with the use of higher current. As gas flow rate changes from 10 LPM to 12 LPM,UTS increases from 103Mpa to 104Mpa,due to decrease in the porosity level of weld metal. Fig 7 is contour plot, is a graphic representation of the relationship among three numeric variables in two dimensions

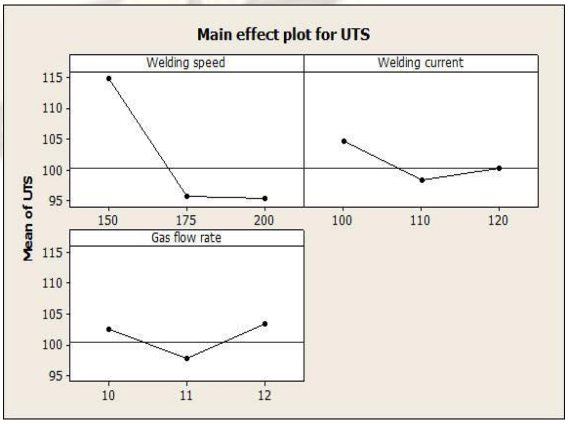

Fig.6 Main effect plot for UTS

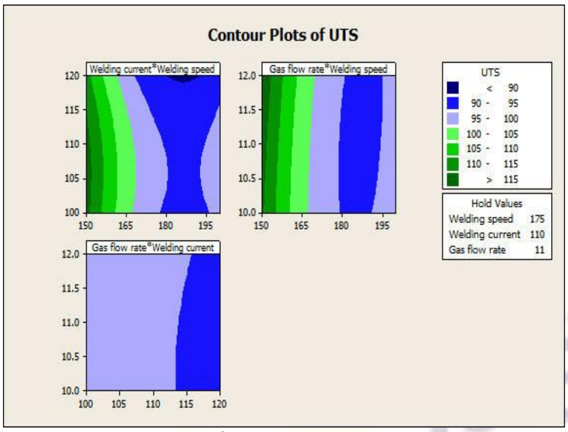

Fig.7 Contour plot for UTS

5.10 Effect of Process parameters on Percent Elongation

The main effect plot shows that value of percent elongation decreases as welding speed increases from 150mm/min to 200mm/min. it is due to the fact that orientation of the grains has the predominant effect on the decreased ductility with increasing travel speed. As current changes from 100A to 120 Amps, percent elongation decreases due to high heat input. When gas flow rate increases from 10 LPM to 12 LPM,percent elongation decreases. Fig. 9 shows the contour plot for percent Elongation at Constant welding speed, current and gas flow rate.

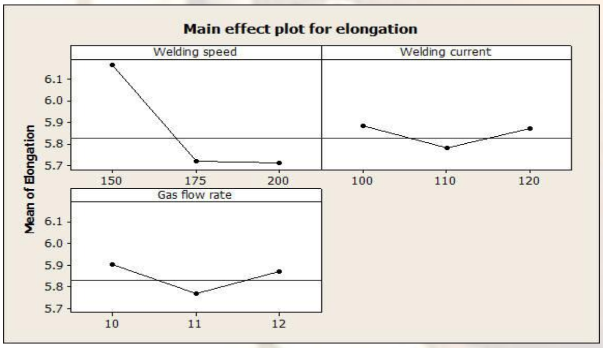

Fig. 8 Main effects plot for percent elongation

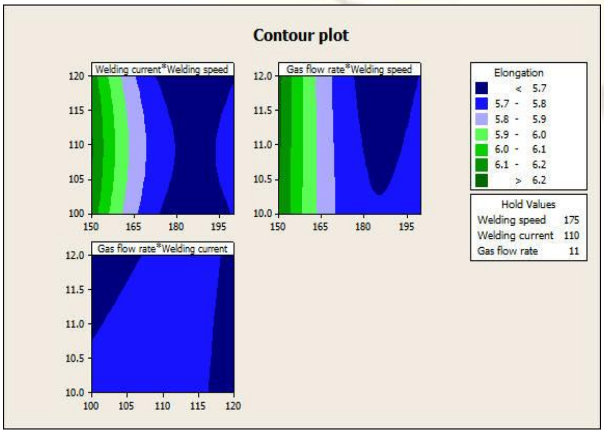

Fig 9. Contour plot for % Elongation

6. CONCLUSION

The effect of TIG welding parameters like welding speed, current and gas flow rate on ultimate tensile strength and percent elongation in welding of Al-65032 has been studied. Experiments were conducted using central composite design matrix and mathematical models have been developed. From the study it was observed that welding speed has the most significant effect on both UTS and percent Elongation followed by welding current. However gas flow rate has least significant influence on both UTS and percent elongation.
Optimization was done to maximize UTS and percent elongation. Predicted properties at optimum condition are verified with a confirmation test and are found within the limits.

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