Journal of Manufacturing Engineering, December, 2011, Vol. 6, Issue. 4, pp 195-203

TAGUCHI PARAMETRIC DESIGN FOR TIG WELDING OF HEAT TREATED Al-65032 ALLOY

Haragopal G[1], *Ravindra Reddy P V R[2], Chandra Mohan Reddy G[3] and Subrahmanyam J V[4]

[1, 2] Department of Mechanical Engineering, CBIT, Hyderabad, Andhra Pradesh- 500075, India
[3] Department of Mechanical Engineering, Mahatma Gandhi Institute of Technology, Hyderabad, Andhra Pradesh -500075, India
[4] Department of Mechanical Engineering, Vasavi College of Engineering, Hyderabad, Andhra Pradesh - 500031, India

Abstract

Al-65032 is an Aluminum alloy used for construction of aerospace structures such as wings. This alloy can be welded by TIG or MIG welding. Hence establishment of welding parameters and their optimization for good quality weld is utmost important factor. As it is a heat treatable alloy and is generally heat treated, the welding parameters are to be designed keeping in view of the properties obtained after heat treatment. In this work, Taguchi parameter design is used to design the process parameters that optimize the mechanical properties of weld specimen. The process parameters of the TIG welding setup considered are gas pressure, current, groove angle and pre-heat. Assigning the process parameters to L-9 orthogonal array, experiments are conducted and the optimization condition is obtained along with the identification of most influencing parameters using S/N analysis and mean response analysis. ANOVA is also carried out to reaffirm the same. A confirmation test is conducted to ascertain the optimized condition.

Key Words: *Al 65032, TIG, Taguchi, Orthogonal Arrays, S/N Analysis and ANOVA.*

1. Introduction

Aluminum and its alloys are difficult to weld materials. Al-65032 is a precipitation hardening aluminum alloy, containing magnesium and silicon as its major alloying elements. It has good mechanical properties and exhibits good weldability. It is one of the most common alloys of aluminum for general purpose use. It is commonly available in pre-tempered grades such as, 65032-O (solutionized), 65032-T6 (solutionized and artificially aged), 65032-T651 (solutionized, stress-relieved stretched and artificially aged).it has a density of 2.70 g/cm³ and the chemical composition of the alloy is shown in table 1.

Table 1: Chemical Composition of Al-65032 Alloy

Si	Fe	Cu	Mg	Cr	Zn	Ti	Oth ers	Al
0.4- 0.8	< 0.7	0.15- 0.4	< 0.15	0.04- 0.35	< 0.25	< 0.15	< 0.15	Ba l

Al-65032 is widely used for construction of aircraft structures, such as wings and fuselages. It is also used in yacht construction, including small utility boats, in the construction of bicycle frames and components, in automotive parts, such as wheel spacers, aluminum cans for the packaging of foodstuffs and beverages etc, where welding is predominately used. Hence its welding characteristics need to be studied.

Today, Tungsten Inert gas Welding (TIG) and Metal Inert Gas welding (MIG) are the two recommended options for welding aluminum and its alloys [1]. The parametric design of the alloy for as weld condition by TIG and MIG welding processes has been studied by the authors [2, 3]. But this alloy is mostly used in post weld heat treated (solutionised) condition, in this work the parametric design of the Al-65032 alloy with TIG welding is carried out for heat treated condition.

Tungsten inert gas (TIG) welding is a multi-objective and multi-factor metal fabrication technique and several process parameters interact in a complex manner resulting direct or indirect influence on weld bead geometry, mechanical properties and metallurgical features of the weldment as well as on the weld chemistry [4].

Studying the design parameters one at a time or by trial and error until a first feasible design is found is a common approach to design optimization [5].However, this leads either to a very long and expensive time span for completing the design or to a premature termination of the design process due to budget or schedule pressures [6]. Taguchi's approach to

**Corresponding Author - E- mail: ravindra_cbit@yahoo.com*

parameter design provides the design engineer with a systematic and efficient method for determining near optimum design parameters for performance and cost with an objective of selecting the best combination of control parameters so that the product or process is most robust with respect to noise factors. [7] i.e the aim of parametric design experiment is to identify and design the process parameters that optimize the chosen quality characteristic that are least sensitive to noise factors [8]. The method is applicable over a wide range of engineering fields that include processes that manufacture raw materials, sub systems, products for professional and consumer markets. The various steps for the parametric design are: determining the quality characteristic to be optimized, identifying the noise factors and test conditions, identifying the control parameters and their levels, selecting the suitable orthogonal array, conducting the experiments, analyze the data and determine the optimum levels and prediction of performance at these levels [9].

In this work, the quality characteristics considered are mechanical properties such as UTS, 0.2% proof stress, percentage elongation and impact energy. Noise factors may include variations in environmental operating conditions. The control parameters identified are gas pressure, current, groove angle and preheat. Three levels are considered for the control parameters based on the preliminary tests. Since there are four parameters and three levels the orthogonal array L-9 can be selected for minimum number of experiments that is given by (L-1) F+ 1, where L and F are number of levels and the number of factors respectively [10].

2. Experimentation

Standard L-9 orthogonal array used for the analysis is shown in table 2.

Table 2: Standard L-9 Orthogonal Array

Run	1	2	3	4
1.	1	1	1	1
2.	1	2	2	2
3.	1	3	3	3
4.	2	1	2	3
5.	2	2	3	1
6.	2	3	1	2
7.	3	1	3	2
8.	3	2	1	3
9.	3	3	2	1

Preliminary tests were conducted to set the range of parameters. The range is selected based on no defect condition obtained from the radiography. For each parameter minimum value is taken as level-1(L1), maximum value is taken as level-3(L3) and approximately middle value is taken as level-2(L2). The levels selected for the input parameters are shown in table 3

Table 3: Levels Chosen for Input Parameters

S.No	Input Parameter	L1	L 2	L3
1.	Pressure (KPa)	90	104	125
2.	Current (Amps)	220	230	245
3.	Groove angle (Deg)	45	60	70
4.	Pre-heating (^{O}C)	125	150	175

The parameters listed in table 3 are assigned to columns of orthogonal array shown in table 2 sequentially and the orthogonal array after assignment is shown in table 4.

Welding test pieces with dimensions 150mm X 150mm X 6mm is carried out using square wave TIG 355 manufactured Lincon Electrical Company, USA and is shown in Fig 1.the welded specimens are heat treated by heating the pieces to a temperature of 823K for a time period of 1hour and then quenching it and again reheating the same at 450K for 8hours and then letting it cool in atmospheric conditions.

Table 4: Assigned L-9 Orthogonal Array

Run	Pressure (KPa)	Current (Amps)	Groove angle (Deg)	Pre-heating (^{O}C)
1.	90	220	45	125
2.	90	230	60	150
3.	90	245	70	175
4.	104	220	60	175
5.	104	230	70	125
6.	104	245	45	150
7.	125	220	75	150
8.	125	230	45	175
9.	125	245	60	125

Specimens for tensile test and impact test are prepared and tested. A sample of test weld specimen, a set of tensile test pieces and a set of impact test pieces are shown in Fig.2, Fig.3, and Fig.4 respectively.

Argon is the most commonly shielding gas for MIG and TIG welding of aluminum and other nonferrous materials as it provides good arc starting and stable metal transfer due to its low ionization potential, superior cleaning action, arc stability and control over voltage and weld appearance. Shielding gases must be of high purity for welding applications. The purity required is at a level of 99.995% [11]. The organ gas used for welding in the experiment contains the impurities as shown in Table 5.

Fig. 1 Square Wave TIG 355 Welding Power Source

Fig.2 A Sample of Weld Specimen

Fig. 3 Tensile Test Pieces

Fig. 4 Impact Test Pieces after the Test

Table 5: Impurities in the Shielding Gas as per Quality Certificate

O_2	H_2O	CO_2	CO	Oxides of N_2	H_2	HC	Cl
2 ppm	2 ppm	Nil	Nil	Nil	Nil	0.2 ppm	Nil

3. Results & Discussion

For each run the quality characteristics (UTS, proof stress and % elongation) are found from the stress-strain curves obtained. The signal to noise (S/N) ratio for each quality characteristic is calculated, the significant parameters are identified and the optimum input parameter for each quality characteristic is predicted from the S/N values and the mean response. ANOVA is also carried out to ascertain the significant parameters identified through S/N analysis. A confirmation test is conducted at optimum conditions to ensure the correctness of the analysis.

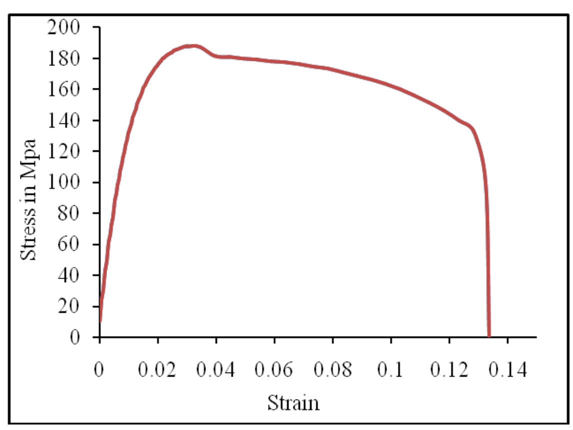

Fig. 5 Sample Stress-Strain Curve (Run-1)

3.1 S/N Analysis

The S/N ratio developed by Taguchi is a performance measure to choose control levels that best cope with noise [12]. The S/N ratio takes both the mean and the variability into account. In its simplest form, it is the ratio of the mean to the standard deviation [13]. The S/N equation depends on the criterion for the quality characteristic to be optimized. Generally three cases may arise: lower the better, nominal the best and higher the better. In the present work the criterion is higher the better for whose the S/N ratio is calculated using the following formula.

$$S/N_i = -10\log\left[\frac{1}{n}\sum_{j=1}^{n}\frac{1}{Y_{ij}^2}\right]$$

Where Y_{ij} is the measured value of quality characteristic of i[th] trial and j[th] experiment and and n is the number experiments in a trial. The UTS values obtained for the three sample for each run are shown in table 6 and the signal to noise ratio (S/N) values are calculated and presented in the same table.

Table 6: UTS Values and S/N Value for Each Run

Run	UTS			S/N
1	187.35	185.03	186.12	45.3977
2	181.37	183.79	181.26	45.2076
3	177.45	178.01	175.74	44.9623
4	186.17	184.68	184.59	45.3501
5	181.92	180.53	179.27	45.1326
6	182.58	184.37	183.74	45.2755
7	186.29	185.53	189.36	45.4386
8	181.02	178.24	178.14	45.0628
9	179.58	181.81	180.45	45.1347

The average S/N values for each parameter at three levels are calculated and presented in table 7. The range (Δ) for each parameter is computed. Higher value of Δ indicates higher the relative effect of parameter on the quality characteristic.

Table 7: Average S/N Ratio of Process Parameters for the UTS

Levels	Pressure	Current	Angle	Preheat
1	45.1892	45.3955	45.2217	45.2217
2	45.2527	45.1343	45.2308	45.3072
3	45.212	45.1242	45.1779	45.1251
Δ	0.06354	0.2713	0.05293	0.18214

From the table 7, it is evident that the most significant parameter that effect UTS of the alloy is current followed by preheat.

The average S/N values for the process parameters at three levels are plotted and presented in Fig 6. Fig 6 indicates that the optimum condition for the maximum UTS is Pressure-2, current-1, Angle-2 and preheat-2, where 1, 2, 3 refer the levels. Mean response of UTS is plotted in Fig 7. It also shows the same optimum conditions for the maximization of UTS. The mean response is the average value of the quality characteristic to be studied.

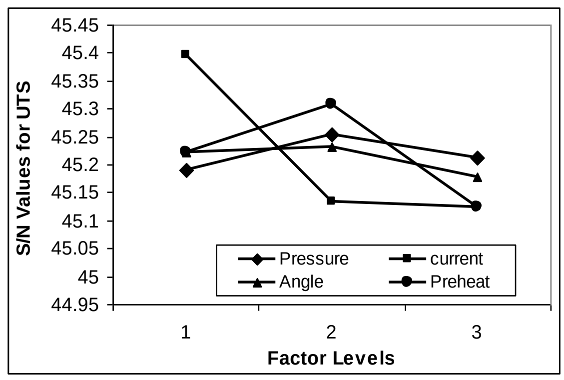

Fig. 6 Effect of Process Parameters on Average S/N Ratio for UTS

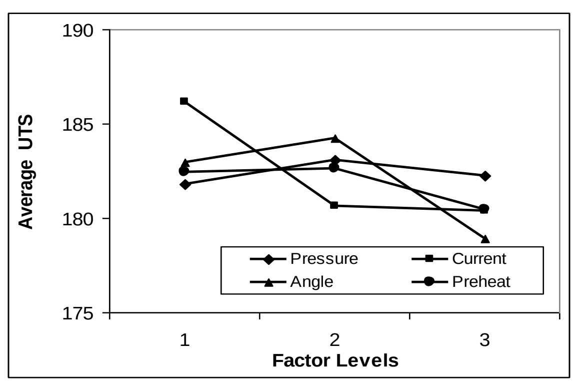

Fig. 7 Mean Response Plot for UTS

Similarly the analysis is carried out for proof stress and presented in table 8 and table 9. From table 9 it is evident that the most influencing parameter that affects proof stress is also current followed by preheating

The average S/N values of 0.2 % proof stress is plotted in Fig 8 and the Mean response of proof stress is presented in Fig 9.

Table 8: S/N Values for Proof Stress

Run	0.2% Proof Stress			S/N
1	98.14	96.37	96.79	39.7436
2	95.53	96.59	94.98	39.6176
3	100.34	96.47	97.68	39.8355
4	109.21	111.36	109.89	40.8391
5	104.33	106.19	105.23	40.4438
6	103.64	102.25	100.32	40.1756
7	101.87	104.24	103.45	40.2713
8	110.45	109.51	107.62	40.7624
9	94.34	96.23	94.53	39.5565

Table 9: Average S/N Ratio of Process Parameters for the Proof Stress

levels	Pressure	Current	Angle	Preheat
1	39.7322	40.2847	39.9146	39.9146
2	40.4862	40.2746	40.0044	40.0215
3	40.1967	39.8559	40.1835	40.479
Δ	0.75393	0.42879	0.26889	0.56438

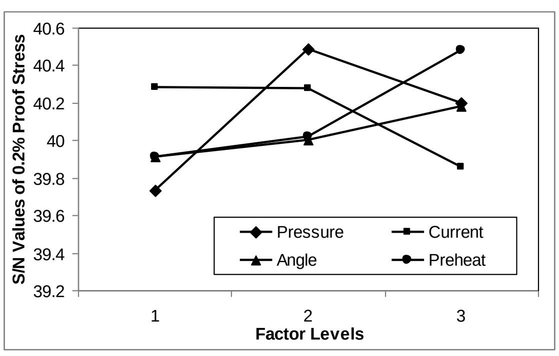

Fig. 8 Effect of Process Parameters on Average S/N Ratio for Proof Stress

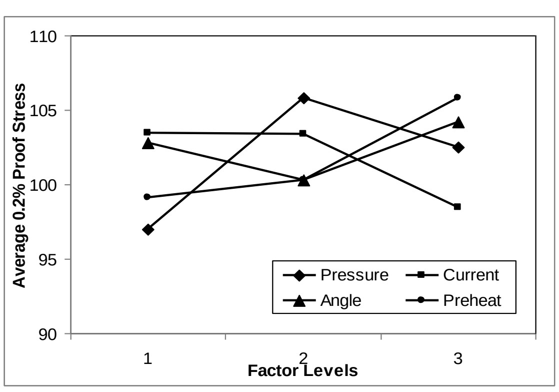

Fig. 9 Mean Response Plot for Proof Stress

From Fig 8 and Fig 9, it is observed that the optimum conditions for the maximization of the proof stress are Pressure-2, Current-1, angle-3 and preheat-3. S/N values for percentage elongation and average S/N ratio of the process parameters for the percentage elongation are presented in table 10 and table 11 respectively.

Table 10: S/N Values for Percentage Elongation

Run	Percentage Elongation			S/N
1	13.53	12.66	14.71	22.6431
2	14.82	13.12	13.78	22.832
3	10.16	11.01	9.23	20.0473
4	12.62	11.97	12.42	21.8175
5	13.97	13.37	14.23	22.8242
6	14.28	14.86	13.95	23.1363
7	15.14	15.89	14.97	23.7041
8	16.23	17.34	15.72	24.2911
9	15.34	14.87	15.13	23.5851

Table 11: Average S/N Ratio of Process Parameters for Percentage Elongation

levels	Pressure	Current	Angle	Preheat
1	21.8408	22.7216	23.0175	23.0175
2	22.5927	23.3158	22.7449	23.2241
3	23.8601	22.2562	22.1919	22.052
Δ	1.26742	0.46536	0.82562	1.1721

From the table 11, it is evident that the pressure followed by preheat is the most influencing parameter for the percentage elongation. The average S/N values and the mean response of percentage elongation are shown in Fig 10 and Fig 11 respectively.

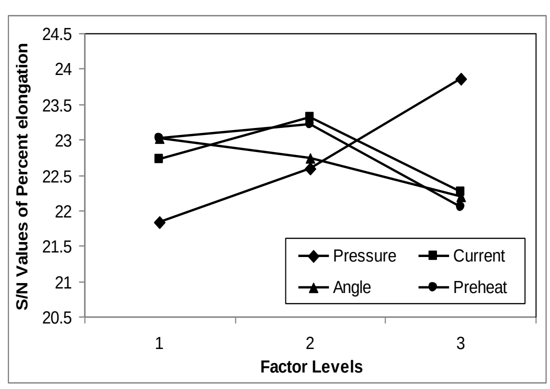

Fig. 10 Effect of Process Parameters on Average S/N Ratio of % Elongation

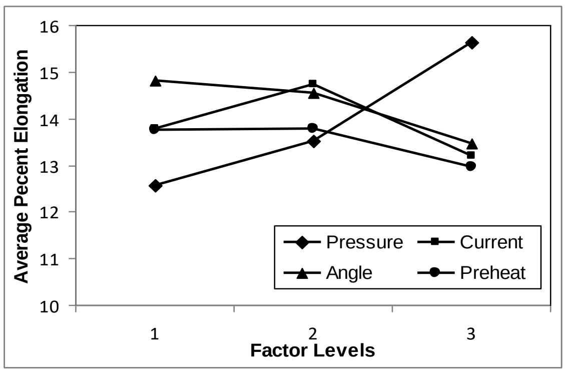

Fig. 11 Mean Response Plot for Percentage Elongation

From Fig 10 and Fig 11, it is observed that the optimum conditions for the maximization of the percentage elongation are Pressure-3, Current-2, angle-1 and preheat-2.

The S/N values for impact energy are computed and shown in table 12. Their average values at various levels are presented in table 13. From table 13, it is clear that preheat has maximum influence on the impact energy followed by groove angle.

Table 12: S/N Values for Impact Energy

Run	Impact Energy J			S/N
1	5.9	6.2	6.1	15.6534
2	5.1	4.9	5	13.9759
3	3.8	3.9	4.2	11.9453
4	4.1	4.2	3.8	12.0894
5	8.9	9.2	8.7	19.0134
6	4.8	5.3	4.9	13.9559
7	5	5.1	4.9	13.9759
8	3.8	3.9	4.2	11.9453
9	4.1	4	3.8	11.9554

Table 13: Average S/N Ratio of Parameters for Impact Energy

levels	Pressure	Current	Angle	Preheat
1	13.8582	13.9063	15.5408	15.5408
2	15.0196	14.9782	12.6736	13.9692
3	12.6255	12.6189	14.9782	11.9933
Δ	2.39403	2.35936	2.86717	3.54744

Effect of process parameters on average S/n values and the mean response for impact energy are plotted in Fig 12 and Fig 13 respectively.

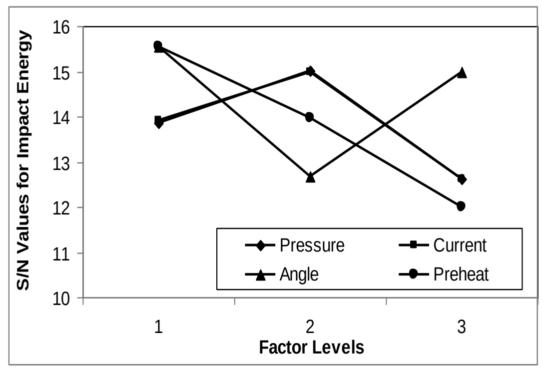

Fig. 12 Effect of Process Parameters on S/N Values Impact Energy

.

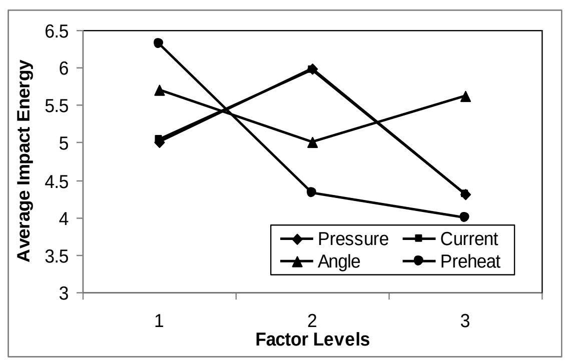

Fig. 13 Mean Response Plot for Impact Energy

From Fig 12 and Fig 13, it is observed that the optimum conditions for the maximization of impact energy are Pressure-2, Current-2, angle-1 and preheat-1.

3.2 ANOVA

ANOVA (Analysis of variance) is also carried out to find out the relative significance of each parameter on the mechanical properties. ANOVA is a statistically based objective decision making tool for detecting any differences in average performance of the groups of items tested taking the variation into account rather than using pure judgment [14]. The ANOVA table for UTS is presented in table 14

From Table 14, it is seen that the current is significant in affecting UTS with 99% confidence level ($F_{0.01,2,18}$ = 6.01) and preheat with 95% confidence level ($F_{0.05,2,18}$ = 3.55). Current has maximum contribution in affecting UTS. This is same as the result obtained from the S/N test.

Table 14: ANOVA Table for UTS

Source	SS	dof	MS	F	P
Pressure	18.49	2	9.2	0.22	0.47
Current	2640.9	2	1320.4	32.03	68.02
Angle	156.0	2	78.0	1.89	4.01
Pre-heat	324.7	2	162.3	3.93	8.36
SSR	3140.1	8	392.5		
SST	3882.1	26	149.3		
SSE	742.02	18	41.2		

ANOVA table for proof stress is presented in table 15. From table 15, it is evident that the preheat, pressure (at 99% confidence level) and current (at 95% confidence level) are the significant parameter in affecting the proof stress with a contribution of 31.5%, 21% and 17.9% respectively. S/N analysis has also given the similar result

Table 15: ANOVA Table for 0.2% Proof Stress

Source	SS	dof	MS	F	P
Pressure	2435.4	2	1217.7	6.5	21.07
Current	2072.0	2	1036.0	5.5	17.93
Angle	27.9	2	13.9	0.07	0.24
Pre-heat	3645.7	2	1822.8	9.73	31.55
SSR	8181.2	8	1022.6		
SST	11553.3	26	444.3		
SSE	3372.1	18	187.3		

ANOVA test for percentage elongation (Table 16) reveals that pressure is the most significant parameter that effects the percentage elongation at 99% confidence level with a contribution of 58.9%. This is also in line with the S/N analysis.

Table 16: ANOVA Table for Percentage Elongation

Source	SS	dof	MS	F	P
Pressure	762.3	2	381.1	46.7	58.9
Current	25.8	2	12.9	1.5	1.9
Angle	234.3	2	117.1	14.3	18.1
Pre-heat	123.4	2	61.7	7.5	9.5
SSR	1145.9	8	143.2		
SST	1292.6	26	49.7		
SSE	146.7	18	8.1		4

Table 17: ANOVA Table for Impact Energy

Source	SS	dof	MS	F	P
Pressure	39.6	2	19.8	3.5	5.6
Current	42.2	2	21.1	3.7	6.0
Angle	73.9	2	36.9	6.6	10.6
Pre-heat	441	2	220.5	39.3	63.2
SSR	596.9	8	74.6		
SST	697.6	26	26.8		
SSE	100.7	18	5.5		

ANOVA of Impact energy (Table 17) says pressure is the major contributor for the variation in impact energy (At 99% confidence level with 63.2% contribution) and the prediction is found to be same as S/N analysis.

3.3 Prediction of optimum conditions for the characteristics

From the analysis of S/N ratio and mean response characteristic, it is seen that Pressure -2 gives better UTS, proof stress and impact energy and pressure 3 gives better percentage elongation. As the contribution of pressure to elongation (58.97%) is more than double that of the sum of UTS (0.47%), proof stress (21%) and impact energy (5.69%), pressure-3 is taken as optimum condition. Current-1 gives better UTS and proof stress and current-2 gives better percentage elongation and impact energy. Since the contribution of current for UTS (68%) and proof stress (17.9%) much higher than that of percentage elongation (2%) and impact energy (6%), current-1 is considered to be optimum for better mechanical properties. Even though, Grove angle 2 and 3 give better UTS and proof stress respectively, angle-1 is taken as the optimum condition because it is better for percent elongation and impact energy for which the contribution of grove angle is much higher than that of UTS and proof stress. Preheat-2 is better for UTS and percent elongation. Preheat-3 is better for proof stress and preheat-1 is better for impact energy. But, as the contribution of preheat is more for impact energy, preheat-1 is considered to be the required optimum. Hence the optimum condition for better mechanical properties is pressure-3, Current-1, Angle-1 and preheat-1.

The predicted mean for the quality characteristic can be computed using the formula [12]

$$S_{mp} = \overline{Y} + \sum\left(P_i - \overline{Y}\right)$$

Where $\overline{Y}$ is the grand average of performance characteristic. P is the average value of quality characteristic for the input parameter and 'i' is the level corresponding to optimum value. The above equation for the current problem yields

$$S_{mp} = \overline{Y} + \left(P_3 - \overline{Y}\right) + (C_1 - \overline{Y}) + (A_1 - \overline{Y}) + (Ph_1 - \overline{Y})$$

Where P is pressure, C is current, A is groove angle and Ph is preheat. The predicted values of quality characteristic at the optimum condition are computed and presented in table 18.

Table 18: Predicted Values of Quality Characteristics at the Optimum Condition

Quality Characteristic	$\overline{Y}$	Pressure -3	Current -1	Angle-1	Preheat-1	S_{mp}
UTS	182.	182	186	182	182	186.6
Proof Stress	101	102	103	102	99	102.5
Elongation	13.9	15.6	13.7	14.8	13.7	16.26
Impact Energy	5.1	4.3	5.03	5.7	6.32	6.056

The confidence interval (CI) of predicted mean of optimum quality characteristic on confirmation test is estimated using the formula [8]

$$CI = \sqrt{F(\alpha, v_1, v_2) v_2 \left[\frac{1}{N_{eff}} + \frac{1}{R} \right]}$$

Where $N_{eff} = \frac{N}{1 + T_{DOF}}$, F(α, v_1, v_2) is the standard value of F for 100(1- α) confidence level, v_1 is the degrees of freedom of the factor and v_2 is the degrees of freedom of the error, R is the number of replications of the confirmation experiment, N is the total number of experiments. T_{DOF} is degrees of freedom of mean.

Substituting v_2 = 18, N= 27, R=3, T_{DOF} = 8 and F (0.01, 2, 18) = 6.01(for 99% confidence level), the confidence interval is found out to be ± 8.5.

Taking 3 samples the confirmation test is carried out at the optimum condition i.e with pressure 125 KPa, current 225 amps, groove angle 45^0 and preheating 125^0 C. Mechanical properties obtained at the optimum condition are UTS = 184.62 MPa, proof stress =103.14 MPa, elongation = 15.93% and impact energy = 6.2 J. The properties obtained from the confirmation test are with the tolerance limits (± 8.5) of predicted properties.

3.4 Microstructure examination

Microstructure examination is also carried for the parent metal and the welded specimens. It is observed that there is wide variation of grain size ranging from 100-120 microns to 300-400 microns with the variation of parameters (Avg. grain size of parent metal is. 70-80 microns). Microstructure of for parent metal and one of the weld specimens is presented in Fig 14(a) and Fig 14(b) respectively as a sample. It also seen from the micro structures that the parent metal contains equiaxial grains and epitaxial grains are observed at the interface of the weld bead

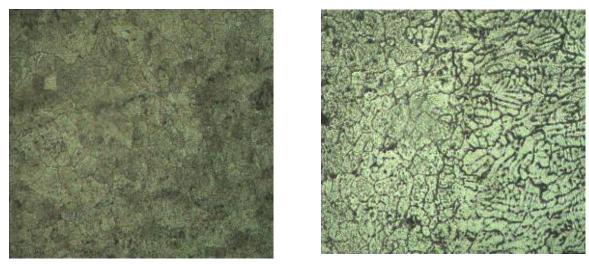

Fig. 14 Microstructures x100 (a) Parent Metal (b) near Weld Bead

4. Conclusion

In this work, the authors found out the most significant parameters that affects the mechanical properties of TIG welding weldments of Al 65032 alloy after heat treatment using S/N analysis and mean response analysis. ANOVA is carried out to ensure the result obtained from the above analyses. The analysis reveals following findings.

Current is the most influencing parameter on UTS with 68% contribution at 99% confidence level. Preheat and is the most significant parameters for proof stress and impact energy with contributions 31.5% and 63.2% respectively. Pressure is the most influencing parameter for proof stress with 58.97% contribution. Optimum condition for the maximization of mechanical properties is found out using S/N analysis and mean response analysis and the mechanical properties at the optimum condition are predicted. The optimum condition found out is 125 KPa pressure, 220 amps current, 45^0 groove angle and 125^0C preheat. The mechanical properties predicted at optimum condition are 186.64 MPa UTS, 102.58 MPa proof stress, 16.26% elongation and 6.056 J impact energy. The predicted properties at optimum condition are verified with a confirmation test and are found that the values are with in the limits.

References

1. *John L Campbell (1999), "Welding Aluminum Different, but not Difficult", Fabricator, Vol. 40(3), 1-4.*

2. *Haragopal G, Ravindra Reddy P V R, Chandramohan Reddy, Satyanarayana V V and Subrahmanyam J V (2010), "Parameter Design for TIG Welding of Al-65032 Alloy Using Taguchi Technique", Manufacturing Technology Today, CMTI, Vol. 9, 3-12.*

3. *Haragopal G, Ravindra Reddy P V R, Chandramohan Reddy G and Subrahmanyam J V (2011), "Parameter Design for MIG Welding of Al-65032 Alloy Using Taguchi Technique", Journal of Scientific and Industrial Research, Vol. 70, 844-850.*

4. *Ugur Esme, Melih Bayramoglu, Yugut Kazancoglu and Sueda Ozgun (2009), "Optimization of Weld Bead Geometry In TIG Welding Process Using Grey Relation Analysis and Taguchi Method", Materials and Technology, Vol. 43, 143–149.*

5. *Phadke S M (1989), "Quality Engineering Using Robust Design", Prentice Hall, Englewood Cliffs.*

6. *Resit Unal, Edwin B and Dea (1991), "Taguchi Approach To Design Optimization For Quality And Cost: An Overview", Annual Conference of the International Society of Parametric Analysts, 1-10.*

7. *Kackar and Raghu (1985), "Off-Line Quality Control, Parameter Design, and the Taguchi Method" Journal of Quality Technology, Vol. 17(4), 176-188.*

8. *Prabir Kumar Chaulia and Reeta Das (2008), "Process Parameter Optimization for Fly Ash Brick by Taguchi Method", Materials Research, Vol. 11 (2), 159-164.*

9. *Dalgobind Mahto and Anjani Kumar (2008), "Optimization of Process Parameters in Vertical CNC Mill Machines Using Taguchi's Design of Experiments", ARISER, Vol. 4(2), 61-75.*

10. *Gaitonda V N, Karnik S R, Achyutha B T and Siddeswarappa B (2006), "Taguchi Approach with Multiple Performance Charectaristics for Burr Size Minimization in Drilling", Journal of Scientific and Industrial Research, Vol. 65(12), 977-981.*

11. *TIG Hand Book (2010), 'Miller Electric Mfg Co'.*

12. *Bryne D M and Taguchi S (1986), "The Taguchi Approach to Parameter Design" ASQC Quality Congress Transactions, Anaheim, CA, 168.*

13. *Bharat Chandra Routara, Sauma Darshan Mohanti, Saurav Dutta, Ashsis Bandyopadhay and Sibasankar Mahapatra (2010), "Combined quality loss concept in WPCA Based Taguchi Philosophy for Optimization of Multiple Surface Quality Characteristics of 6061-T4 Aluminum in Cylindrical Grinding" Manufacturing Technology Today, Vol. 9(1), 13-21.*

14. *Phillip J Rose (1996), "Taguchi Techniques for Quality Engineering", McGraw-Hill International.*

Acknowledgement

The authors are thankful to SVAMEE Industries for providing the material and facilities for conducting the experiments and MSME testing station, ministry of small and medium enterprises, Hyderabad for providing the testing facilities.

