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Evaluation of Tensile Strength and Distortion Control in GTAW Weldment of AA 6061 by Taguchi and Grey Relational Approach

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Abstract: ***Tungsten inert gas welding (TIG) is also known as Gas tungsten arc welding (GTAW) in USA and Wolfram inert gas (WIG) in Germany. This welding process is widely used for producing high welding quality of a variety of materials, specially, for stainless steel, aluminium and titanium. This paper present the influence of a welding process parameters like welding current, gas flow rate, root gap and bevel angle on the output responses such as distortion and tensile strength of Aluminium alloy on AA6061 material. The experiment is conducted on AA6061 specimens of single V-groove butt joint of thickness 4mm and length 150 mm. In this paper an L9 orthogonal array of taguchi method is consider with nine experiment runs to optimize the process parameter. Analysis of variance (ANOVA) is used to find the percentage of contribution of each parameter on tensile strength and angular distortion and the purpose to use the analysis of variance is to find out which welding parameters significantly affect the quality characteristic. Analysis has been carried out by using, grey relational analysis, taguchi method, signal to noise ratio and analysis of variance. In Grey relational analysis, an optimised process parameter of TIG welding was obtained, by analysing grey relational grade we found the degree of influence of each parameter on quality target. Distortion measured is carried out with measuring device dial gauge and measuring of tensile strength is carried out with universal testing machine. Finally at the end, a confirmation test was done to compare the estimated value with the experimental value and a error is find which tell about the closeness of experimental value to the estimated value. The regression model were developed using Minitab software.***

Keyswords: TIG welding, Taguchi method, Grey Relational Analysis, ANOVA

1. Introduction

Gas tungsten arc welding process, consist of non-consumable tungsten electrode which is used to provide the arc for welding.Tungsten inert gas welding (TIG) is also known as Gas tungsten arc welding (GTAW) in USA and Wolfram inert gas (WIG) in Germany. This welding process is widely used for producing high welding quality of a variety of materials, specially, for stainless steel, aluminium and titanium. A separate filler metal with an inert shielding gas is used. Gas tungsten arc welding process welding set utilised suitable power source, a cylinder of argon gas, welding torch having connection of cable for current supply, tube for shielding gas supply and tube water for cooling torch.

The most commonly used gas for TIG welding is argon gas which can be used on all metals like Ferrous and non ferrous metal. Electrodes for TIG welding are Pure Tungsten or a Tungsten oxide, generally 2 % Thoriated tungsten are used for DC welding and 2 % Zirconiated tungsten are recommended for AC welding.

1.1 Welding of Aluminium Alloy

Tungsten inert gas welding is usedto weld thinner aluminium alloy. To achieved a best result a manual welding on thickness ranging from 0.030 inch - 3/8 inch. Mechanized welding is done on thickness ranging from 0.020 to 1 inch. Alternating current or direct current power source may be used, but the ac and dc current is provided for either welding mechanized or manual or mechanized. Pure or zirconium tungsten electrode is used for aluminium welding. Argon shielding gas usually used for both ferrous and non-ferrous metal.

1.2 Advantages and disadvantage of Aluminium TIG welding:

AC polarity for aluminium, high quality welds, all position welding, can be used on a variety of metals, excellent welding on very thin materials, fusion welding is possible, no slag, no Spatter. Disadvantages are as follows requires low deposition rates, clean base material, high operator skill needed, often slow.

1.3 Control of Weld Distortion:

Distortion is a re-occuring and costly problem resulting from most industrial fabrication working process the employ heat, such as cutting and welding. For these purpose, distortion is very apparent because of concentrated nature of heat source. Distortion in a weldment is the result of non-uniform expansion and contraction of the weld and surrounding base material caused by heating and cooling cycle of the welding or cutting process. Because of expansion and subsequent contraction of a yielded material is restrained by the surrounding colder material, tensile stress is build-up around the weld combined with simultaneously generated compressive stress in a result of plate.These stress caused the plate to distortion if they exceeded a certain level.As shown in Figure1, distortion causes change in shape and orthogonal reduction in length, shrinkage in both longitudinal and transverse direction. Fig. 1 shows front view of welded component shows the transverse distortion which is an angularmovement of the part about the weld point[1].

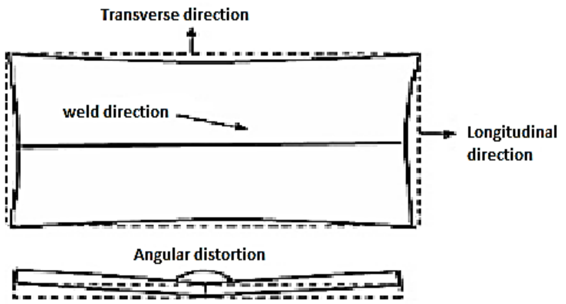


Figure 1: Distortion caused by welding

In the present study, transverse distortion is measured and expressed in angular distortion in unit degree. Following are factor affecting distortion to cause in material is parent material properties, restraint, joint design, part fit-up, welding procedure. By following prevention we can minimised the distortion are do not over weld, use intermittent welding, uses as few weld passes as possible, minimised welding time, plan welding process etc.

2. Literature Review

S. Akella, B. Ramesh kumar [1] this paper investigate that ANOVA is applied for optimization of TIG welding parameters. L8 orthogonal array was selected for exp. From the exp it is found that root gap has major contribution of 43% and welding current has 36% on angular distortion.Ugur Esme, Melih Bayramoglu, Yugut Kazancoglu, Sueda Ozgun [2] investigate that ANOVA for grey relational grade indicate that welding speed has 52.41% contribution and is the most significant parameter. L16 orthogonal array is used.R. Satish, B. Naveen, P. Nijanthan, K. Arun Vasatha Geethan, Vaddi Seshagiri Rao [3] investigate that lower the heat input result in lower the tensile strength and higher the heat input will also result in reduced tensile strength. The factor were selected is current, bevel angle, gas flow rate.L9 orthogonal array is used. Carbon steel pipe and stainless steel pipe is of size 7.11mm thick and 150mm length.

Reddy Sreenivashul, DR. Ch.Srinivasarao [4] in this paper the effect of drilling parameter on surface roundness and roughness error were investigated in drilling of 6061 AA with HSS twist drill. L18 orthogonal array were used in this paper. At 25.13 m/min cutting speed and 0.3 mm/rev feed rate, 10mm drill dia, 110 degree point angle, 12% cutting fluid mixture ratio were min surface roundness and roughness error were found.

Raghuraman S, Thirupathi K, Panneerselvam T, Santosh [5] the optimal parameter combination was determined at pulse current 26 amp, pulse ON time at 55 micro sec, and pulse OFF time at 5 micro sec.Ravendra Singh, Vedansh Chaturvedi, Jyoti Vimal [6] investigate that carburisation temp is most significant factor for carburization process by ANOVA. L9 orthogonal array is used with 9 experiments run.Ahmed Khalid Hussain, Abdul Lateef, Mohd Javed, Pramesh. T. [7] investigate that depth of penetration of weld bead decrease with increase in bevel height of V butt joint, the heat effected zone, strength increase with decrease input.Mukesh, Sanjeev Sharma [8] use L9 orthogonal array, material used is austenitic stainless steel 202 grade. Current has the max influence on the output characteristic.

Deepak Malik, Sachin Kumar, Mandeep Saini [11] investigate angular distortion is due to the non-uniform transverse shrinkage along the depth of plate weld. Butt weld design is used. Matlab 16 is used to developed a source code. L9 orthogonal array is selected for design. Angular distortion has +ve effect with increase in diameter of electrode and increase in length, and –ve effect with increase in current and time gap between passes.

3. Optimization Using Taguchi's Method

A Taguchi method has now a days become a powerful optimization techniques for improving productivity during research and development, to produce high quality of the product can be produced at low cost and also quickly. The complex caused affect relationships between design parameters and performance is reveal systematically by taguchi method. These in leads to building quality performance into process and products before actual production begin. The first objective of Taguchi methods is to reducing the variability in a quality. A key premise of Taguchi is that society incurs a loss any time a product whose performance is not on target get shipped to customer.

The loss function is used to measure this loss, a quantity dependent on the deviation of the product performance from its target performance. Using Loss function directly to determining the tolerance limit. The objective of the Taguchi method is to delivering a robust design. However, some factor present in the environment on which the user of a product has some or no control. The robust design procedures adjust the design feature of the product such that the performance of the product remains unaffected by these factors. For a process, the robust design optimized the process parameters such that the quality of the product that the process deliver, stay on target, and is unaffected by factor beyond control. Statistically designed experiments using orthogonal array and signal-noise ratio constitute the core of core of robust design procedure or steps. There are three Signal-to-Noise ratio of common interest for optimization:

(i) Smaller-The-Better:

n= -10 Log_{10} [mean of squares of measured data] (1)

(ii) Larger-The-Better:

n= -10 Log_{10} [mean of square of the reciprocal of measured data] (2)

(iii) Nominal-The-Best:

n= 10 Log_{10} [square of mean/variance] (3)

3.1 Work Material:

4mm thick aluminium alloy (AA 6061) were used in this study. The dimension of work piece is 28mm in width & 150mm in length. The welding experiment is done with TIG welding machine, polarity: alternating current high frequency (ACHF), 99.99% pure argon gas is used as a shielding gas for this exp. Filler metal used is ER4043 of 2.5mm in diameter. Electrode of diameter 3mm is used. The tensile test is carried out with universal testing machine: UTM-40, Fie ichalkaranji, model no:8/83594, capacity is 0-400 KN. The angular distortion is measured with the help of Dial indicator.

Table 1: Chemical composition (%) of AA6061 work piece.

Si	0.43
Fe	0.24
Cu	0.19
Mn	0.086
Mg	0.98
Cr	0.099
Zn	0.011
Ti	0.023
Tl	0.072
Al	Remainder

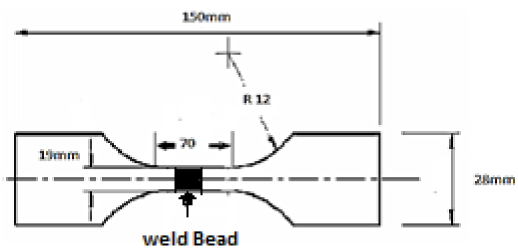


Figure 2: Tensile testing welded specimen

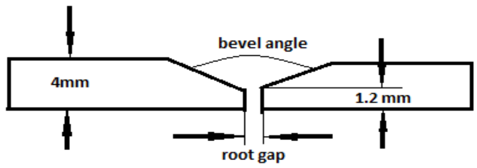


Figure 3: Sample specimen of work piece

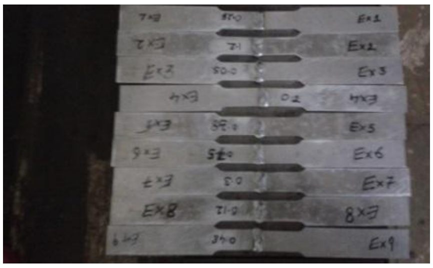


Figure 4: welded sample

Figure 5: Dial indicator use for measuring distortion

3.2 Formation of L9 Orthogonal Array by Taguchi Method:

Orthogonal array are special experimental designs that require only a small no.of experimental run to help discover main factor effects. Orthogonal array are fractional factorial design and a symmetrical subsets of all combination. In these study L9 orthogonal array is used with 3 level and 4 parameter and responses to be measure are ultimate tensile strength and angular distortion are as follows.

Table 2: Process parameters and their level

Parameters	Level 1	Level 2	Level 3
Current (Amps)	110	125	140
Gas flow rate(G.F.R) (LPM)	9	12	15
Root gap (mm)	1	1.5	2
Bevel angle(degrees)	30	40	50

Table 3: L9 Orthogonal array with experiments results

Run	Current	Gas flow rate	Root gap	Bevel angle	UTS N/mm^2	Dis. degree
1	110	9	1	30	44.09	0.095
2	110	12	1.5	40	127.58	0.450
3	110	15	2	50	79.34	0.019
4	125	9	1.5	50	81.94	0.076
5	125	12	2	30	110.68	0.145
6	125	15	1	40	117.51	0.286
7	140	9	2	40	144.81	0.114
8	140	12	1	50	117.35	0.045
9	140	15	1.5	30	61.82	0.183

3.3 Analysis of S/N ratio:

The term "signal" represents the desirable value (mean) and the term "noise" represents the undesirable value (standard deviation) for output characteristic in Taguchi method. Therefore S/N ratio used to measure the quality characteristic deviating from the desirable value.

Table 4: S/N ratio for tensile strength and distortion

Run .no	Tensile Strength (N/mm2)	S/N Ratio (dB)	Distortion (degree)	S/N Ratio (dB
1	44.09	32.88	0.095	20.44
2	127.58	42.11	0.450	6.93
3	79.34	37.98	0.019	34.42
4	81.94	38.26	0.076	22.38
5	110.68	40.88	0.145	16.77
6	117.51	41.40	0.286	10.87
7	144.81	43.21	0.114	18.87
8	117.35	41.38	0.045	26.93
9	61.82	35.82	0.183	14.75

From the table 4, the S/N ratio based on larger-the-better criterion for tensile strength and S/N ratio based on smaller-the-better criterion for distortion is taken for larger the better:

$$\frac{S}{N} = -10 \log \{(\frac{1}{n}) \sum_{i=1}^{n} \frac{1}{{yi}^2}\} \quad (4)$$

For smaller the better:

$$\frac{S}{N} = -10 \log \{(\frac{1}{n}) \sum_{i=1}^{n} {yi}^2\} (5)$$

Where n is the number of measurement, and y_i is the value of response

Regardless of the category of the quality characteristic, a greater S/N ratio corresponds to better the quality characteristics. Therefore optimal level of the process parameter for TIG welding is level with greater S/N ratio.experiment no. 7 show, for max strength the optimal parameter is $\mathbf{A_3B_1C_3D_2}$and experiment no. 3show, for min distortion the optimal parameter $\mathbf{A_1B_3C_3D_3}$.

3.4 Analysis of Variance (ANOVA):

The purpose of ANOVA is to investigate which TIG welding parameters significantly affect the quality characteristic or responses. This is accomplished by separating the total variability of the signal-to-noise ratios, is measured by the sum of the squared deviations from the total mean S/N ratio, into contributions by each of the welding parameters and the error. The % contribution by each of the TIG welding parameter can be used to evaluate the importance of the process parameter change on the quality characteristic.

Table 5: Analysis of variance for tensile strength

Factors	S.S	D.O.F	M.S.S	% Contribution
Current	1001.290	2	500.645	11.37
Gas flow rate	1859.047	2	929.523	21.11
Root gap	801.274	2	400.637	9.10
Bevel angle	5140.703	2	2570.35	58.40
Error	0	0		
Total	8802.315	8	4401.15	100

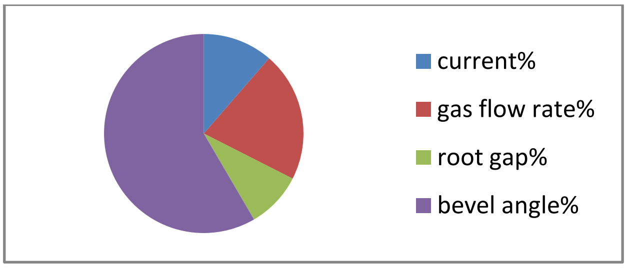


Fig 6: Pie chart for % contribution of different parameters for tensile strength.

Table 5 shows the result of analysis of variance for tensile strength. By use of analysis of variance the % contribution of current is 11.37%, gas flow rate is 21.11%, root gap is 9.10%& bevel angle is 58.40%. It is clear from ANOVA table 5 that bevel angle is the most significant factor for tensile strength and current is least significant factor for tensile strength.

Table 6: Analysis of variance for distortion

Factors	S.S	D.O.F	M.S.S	% Contribution
Current	0.00886	2	0.00443	6.02
Gas flow rate	0.02114	2	0.01057	14.37
Root gap	0.031972	2	0.01598	21.72
Bevel angle	0.085168	2	0.042584	57.87
Error	0	0		
Total	0.147151	8	0.073575	100

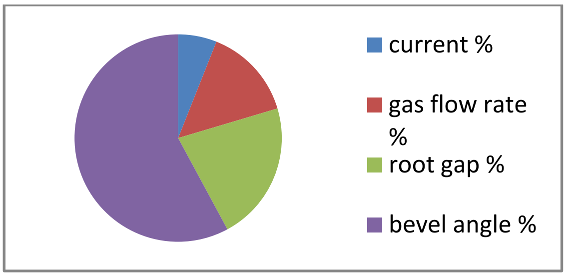


Fig 7: Pie chart for % contribution of different parameters for Distortion

Table 6 shows the result of analysis of variance for distortion. By use of analysis of variance the % contribution of current is 6.02%, gas flow rate is 14.37%, root gap 21.72% & bevel angle is 57.87%. It is clear from ANOVA table 6 that bevel angle is the most significant factor for distortion and current is least significant factor for distortion.

4. Optimization Using Grey Relational Analysis

As we know that for optimizing the process parameters taguchi method has been extensively adopted in welding process to improve processes with single performance characteristic.However, traditional Taguchi method cannot solve multi-objective optimization problem. To overcome this problem Taguchi method coupled with the grey relational method Grey relational analysis was performed to combine the multiple responses into single responses, known as grey relational grades. Rank these grey relation grades, and determine the optimal TIG welding parameter settings. In grey relational analysis when range of sequence is so large that, the function of factor is neglected. To overcome this problem one has to one has to pre-process the data which are related to a group of sequences, known as grey relational generation. So the experimental result are normalized in the range of 0 to 1. The normalization can be done form three different approaches.

If the expectancy is the "**smaller-the better**", then the original sequence should be normalized as follows.

$$x_i(k) = \frac{\max\ y_i(k) - y_i(k)}{\max\ y_i(k) - \min\ y_i(k)} \quad (6)$$

If the target value of original sequence is infinite, then it has a characteristic of the "**larger-the–better**". The original sequence can be normalized as follows.

$$x_i(k) = \frac{y_i(k) - \text{Min}\ y_i\ (k)}{\max\ y_i(k) - \min\ y_i(k)} \quad (7)$$

However, if there is a definite target value to be achieved, the original sequence will be normalized in the form.

$$x_i(k) = 1 - \frac{|\ y_i(k) - y|}{\max y_i\ (k) - y_i} \quad (8)$$

Where $x_i(k)$ is the value after the Grey relational generation,min $y_i(k)$ is the smallest value of $y_i(k)$ for the k^{th}response, and max $y_i(k)$ is the largest value of $y_i(k)$ for the k^{th} response. An ideal sequence is $x_0(k)$ (k = 1, 2, 3,...,9) for the responses. The definition of Grey relational grade in the course of Grey relational analysis is to reveal the degree of relation between the 9 sequences [$x_0(k)$ and $x_i(k)$,i= 1, 2, 3, ...,9] [2].

In Grey relational generation, tensile strength should follow tothe larger-the-better (LB) criterion and distortion corresponding to the smaller-the-better (SB) criterion and their normalized value given in table 8 :

Table 7: Grey relational generation of each performance characteristics

Experiment no.	Tensile strength (larger-the-better)	Distortion (smaller-the-better)
1	0.0000	0.8236
2	0.8289	0.0000
3	0.3499	1.0000
4	0.3757	0.8677
5	0.6611	0.7076
6	0.7289	0.3805
7	1.0000	0.7795
8	0.7273	0.9396
9	0.1760	0.6194

Following data pre-processing, a grey relational coefficient is calculated to express the relationship between the ideal and actual normalized experimental results. The grey relational coefficient can be expressed as follows:

$$\xi_i(k) = \frac{\Delta_{min} + \psi\Delta_{max}}{\Delta_{oi}(k) + \psi\Delta_{max}} \quad (9)$$

Where $\Delta_{0i} = || x_0(k) - x_i(k) ||$ difference of the absolute value $x_0(k)$ and $x_i(k)$; ψ is the distinguishing coefficient $0 \le \psi \le 1$;ψ=0.5 generally used,$\Delta_{min} = \forall j^{min} \in i \forall k^{min} || x_0(k) - x_i(k) ||$ = the smallest value of Δ_{0i}; and $\Delta_{max} = \forall j^{max} \in i \forall k^{max} || x_0(k) - x_i(k) ||$ = largest value of Δ_{0i}. Grey relational coefficient is calculated shown in table 8.

Table8: Grey relational coefficient of each performance characteristics

Experiment no.	Tensile strength	Distortion
1	0.3333	0.7392
2	0.7450	0.3333
3	0.4347	1.0000
4	0.4447	0.7907
5	0.5960	0.6309
6	0.6484	0.4466
7	1.0000	0.6939
8	0.6470	0.8922
9	0.3776	0.5677

After obtaining the grey relational coefficient, normally we take the average of the grey relational coefficient as the grey relational grade. The grey relational grade is defined as follows.

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k) \quad (10)$$

where n is the number of process responses. The higher value of Grey relational grade corresponds to intense relational degree between the reference sequence $x_0(k)$ and the given sequence $x_i(k)$. The reference sequence $x_0(k)$ represents the best process sequence; therefore, higher Grey relational grade means that the corresponding parameter combination is closer to the optimal [2].

Table 9: Grey relational grade

Exp. no	Tensile strength	Distortion	Grey relational grades	Rank
1	0.3333	0.7392	0.5361	8
2	0.7450	0.3333	0.5391	7
3	0.4347	1.0000	0.7173	3
4	0.4447	0.7907	0.6177	4
5	0.5960	0.6309	0.6134	5
6	0.6484	0.4466	0.5475	6
7	1.0000	0.6939	0.8469	**1**
8	0.6470	0.8922	0.7695	2
9	0.3776	0.5677	0.4726	9

According to the performed experiment design it is clearly observed from table 9 that the TIG process parameter setting of experiment no.7 has the highest grey relational grade. Thus the experiment no7 gives the best multi-performance characteristics among the 9 experiments with optimal parameter $A_3B_1C_3D_2$.

The mean of the grey relational grade for each level of the welding parameters shown in Table 10.After identifying the optimal level of process parameters the final step is predict and verify the improvement in the responses using the optimal process parameters. The parameter $A_3B_1C_3D_3$ is an optimal process parameter. As shown in table 11 of responses table of avg. grey relational grade, the greater the value of avg. grey relational grades give min distortion and max strength. It is found that largest value of grey relational grade for current is 140, gas flow rate is 9, root gap is 2 and bevel angle is 50. It is recommended level of controllable parameter for process of TIG welding to minimization of distortion ad maximization of tensile strength.

Table 10: Response table for the mean grey relational analysis

Level	Parameter			
	current	Gas flow rate (G.F.R)	Root gap	Bevel angle
1	0.5975	**0.6669**	0.6177	0.5407
2	0.5928	0.6406	0.5431	0.6445
3	**0.6963**	0.5791	**0.7258**	**0.7015**
Max-Min	0.0988	0.0263	0.1081	0.057

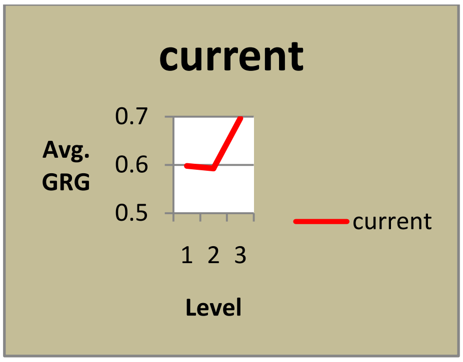
Table 11 shows the S/N ratio for overall grey relational grades. S/N ratio is based on **larger-the-better** criterion.

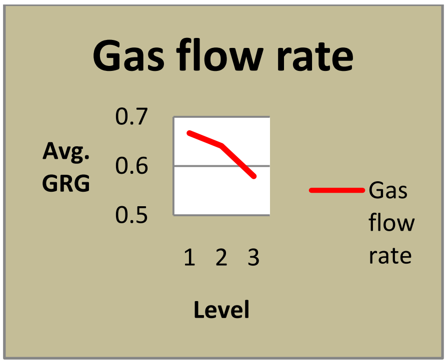
$$S/N = -10\log\left\{\frac{1}{n}\sum_{i=1}^{n}\frac{1}{yi^2}\right\} \quad (11)$$

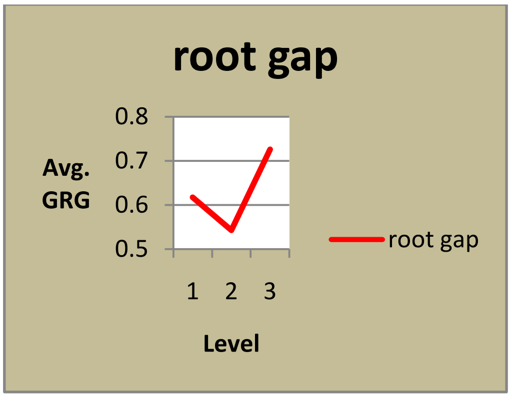
Table 11: S/N ratio for overall Grey relational grade

Experiment no.	Grey relational grades	S/N ratio
1	0.5361	-5.41
2	0.5391	-5.36
3	0.7173	-2.88
4	0.6177	-4.18
5	0.6134	-4.24
6	0.5475	-5.23
7	0.8469	-1.44
8	0.7695	-2.27
9	0.4726	-6.51

Average grey relation grade graph for TIG parameter are shown below:







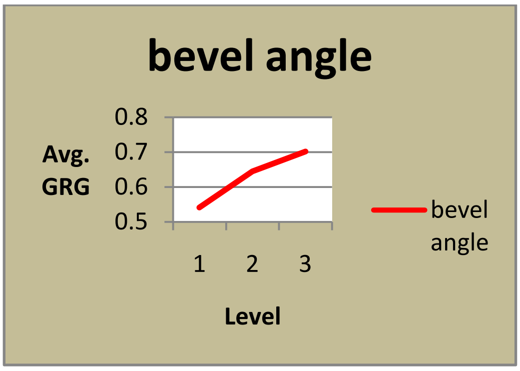


Fig 8: Graph plotted for level of optimal factor vs Avg. grey relational grades

Table 12: ANOVA of grey relational grade

Factors	S.S	D.O.F	M.S.S	% Contribution
Current	0.02049	2	0.01024	16.63
Gas flow rate	0.01217	2	0.00608	9.88
Root gap	0.05065	2	0.02532	41.11
Bevel angle	0.03988	2	0.01994	32.36
Error	0	0		
Total	0.12320	8	0.06160	100

From above table 12 shows, root gap is most significant factor for TIG process Al 6061 with 41.11% contribution. Along with current 16.63%, gas flow rate 9.88% and bevel angle 32.46% of contribution, if max of tensile strength and min of distortion are considered simultaneously.

5. Regression Analysis

In order to establish a correlation between the parameters regression model was used. The regressions were developed using **Minitab 17**.

The regression equation for tensile strength,

Tensile strength = -64 + 0.81current – 0.68 g.f.r +18.68 root gap + 1.03 bevel(12)

Distortion = 0.593 – 0.0024 current + 0.0113 g.f.r
- 0.049root gap – 0.00472 bevel (13)

6. Result and Confirmation Test

Table 13: Result of confirmation test

For Optimal parameter ($A_3B_1C_3D_3$)	Regression Estimate value	Experiment value	% Error
Tensile strength	132.14	129.68	1.8
Distortion	0.025	0.026	4

After identifying the predicted optimal parameter setting, the final phase is to verify the optimal result by conducting the confirmation experiments. The $A_3B_1C_3D_3$ is an optimal parameter combination for AA 6061 of the TIG welding process from the grey relational analysis. Therefore, the condition $A_3B_1C_3D_3$ of the optimal parameter combination of the TIG welding process was treated as a confirmation test. If the optimal setting for 6061 with a current 140 A, gas flow rate 9 ltr/min, root gap2 mm and bevel angle 50^0, for AA 6061, the final work piece give the Tensile strength 129.68 N/mm^2 and distortion 0.026^0which is closed to the estimated value

7. Conclusion

In present work, by using four different welding parameters like current, gas flow rate, root gap, bevel angle have been evaluated to investigate their influence for TIG welding process. In this taguchi method and grey relational method both were used to find the optimal process parameter for max tensile strength and min angular distortion. ANOVA is used to find the % contribution of each parameter for TIG process. S/N ratio is used to find the optimal parameter.

1. From avg. GRG table 10 largest value of avg. grey relational grades is current 140 amp, gas flow rate is 9 LPM, root gap is 2 mm and bevel angle is 50 degree. Therefore we can say that this level is a recommended level of the controllable parameter for TIG welding. From table 9 and 10 we can say that exp no 7 will give best optimal parameter for TIG welding from the nine exp.
2. From the taguchi method we find that exp. no 7 with optimal parameter $A_3B_1C_3D_2$ will give max tensile strength and exp. no 3 with optimal parameter $A_1B_3C_3D_3$ will give min distortion.

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