Parametric optimization of TIG process parameters using Taguchi and Grey Taguchi analysis

Dheeraj Singh[1], Vedansh Chaturvedi[2], JyotiVimal[3]
1, Research Scholar,9752138072.
2, Assistant Professor,8989273208.
3, Assistant Professor, 9479934701.
Department of Mechanical Engineering
Madhav Institute of Technology & Science Gwalior 474005

ABSTRACT

The object of this study is to investigate the optimum process parameters for Tungsten inert gas welding (TIG). The optimization of TIG welding operating Parameters are for stainless steel work piece using grey relation analysis method is done. Sixteen Experimental runs based on an orthogonal array Taguchi method were performed. Four parameters namely current, gas flow rate, welding speed and gun angle is taken as process variable. The objective function have been Chosen in relation to parameters of TIG welding bead geometry i.e. tensile load, area of Penetration, bead width, bead height and penetration for quality targets. An optimal Parameters combination of the TIG operation was obtained via grey relation analysis. By analysis the grey relation grade, coefficient of grey relation controllable process Factors onto individual quality characteristics targets additionally the analysis of variance (ANOVA) is also applied to identify the most significant factor gun angle is the most significant factor. The experiment results are proposed to illustrate the approach.

Keywords: TIG welding, grey relation analysis, Taguchi method (TM), analysis of variance (ANOVA).

1. INTRODUCTION

A non consumable tungsten rod is used as the electrode with inert gas shielding both the molten metallic pool and red hot filler wire tip. TIG welding also known as GTA (tungsten arc) in USA and WIG (wolfram inert gas) in Germany is a welding of process used of high quality welding. Argon or helium is used for shielding purpose. TIG welding can be done in almost all position metal thickness ranging 1 to 6 mm is generally joint by TIG process.[1] Gas tungsten arc welding produce the high quality welds most consistency. It can weld all metal in any configuration. But it is not economically competitive on heavy section. TIG welding is very strong process for improving quality characteristics of weld pool. There good quality product is welded this method and research and development field. [2-6]

The Taguchi method is used to optimize the bead geometry parameters like bead height, bead width, area of penetration, tensile load and penetration on particular welding machine. [14-15] Taguchi method is used statistical techniques in process parameters selection has been proved by many investigators to great effect.

2. SCHEME OF INVESTIGATION

In order to maximize the quality characteristic, the present investigation has been made in the following sequence.

- Selection of base material and filler material.
- Identify the important welding process parameters.
- Find the upper and lower limits of the identified process parameters.
- Selection of orthogonal array (design of matrix).
- Conduct the experiments as per the selected orthogonal array.
- Record quality characteristics (i. e. mechanical properties).
- Find the optimum condition for maximizing the mechanical properties.
- Conduct the confirmation test.
- Identify the significant factors.
- Check the adequacy of the developed models.

3. GREY RELATIONAL ANALYSIS

3.1. DATA PREPROCESSING

Grey data processing must be performed before Grey correlation coefficients can be calculated. A series of various units must be transformed to be dimensionless. Usually, each series is normalized by dividing the data in the original series by their average. Let the original reference sequence and sequence for comparison be represented as $x_o(k)$ and $x_i(k)$, i=1, 2, . . .,m; k=1, 2, . . ., n, respectively, where m is the total number of experiment to be considered, and n is the total number of observation data. Data preprocessing converts the original sequence to a comparable sequence. Several methodologies of preprocessing data can be used in Grey relation analysis, depending on the characteristics of the original sequence. If the target value of the original sequence is "the-larger-the-better", then the original sequence is normalized as follows.

$$x_i^*(k) = \frac{x_i^{(O)}(k) - \min.\ x_i^{(O)}(k)}{\max.x_i^{(O)}(k) - \min.x_i^{(O)}(k)} \tag{1}$$

If the purpose is "the-smaller-the-better", then the original sequence is normalized as follows

$$x_i^*(k) = \frac{\max.x_i^{(O)}(k) - x_i^{(O)}(k)}{\max.\ x_i^{(O)}(k) - \min.x_i^{(O)}(k)} \tag{2}$$

However, if there is "a specific target value" then the original sequence is normalized using.

$$x_i^*(k) = 1 - \frac{\left|x_i^{(O)}(k) - OB\right|}{\max.\ \left\{\max.x_i^{(O)}(k) - OB, OB - \min.\ x_i^{(O)}(k)\right\}} \tag{3}$$

Where OB is target value.

Alternatively, the original sequence can be normalized the simplest methodology that is the values of the original sequence can be divided by the first value of the sequence, $x_i^{(O)}(1)$.

$$x_i^*(k) = \frac{x_i^{(O)}(k)}{x_i^{(O)}(1)} \tag{4}$$

Where $x_i^{(O)}(k)$ is the original sequence, $x_i^*(k)$ the sequence after the data preprocessing, max. $x_i^{(O)}(k)$ The largest value of $x_i^{(O)}(k)$, min $x_i^{(O)}(k)$: the smallest value of $x_i^{(O)}(k)$.

3.2 CALCULATION OF GREY RELATIONAL COEFFICIENT AND GREY RELATIONAL GRADES:

Following the data preprocessing, a Grey relational coefficient can be calculated using the preprocessed sequences. The Grey relational coefficient is defined as follows.

$$\gamma\left(x_0^*(k), x_i^*(k)\right) = \frac{\Delta_{\min.} + \zeta\,\Delta_{\max.}}{\Delta_{0i}(k) + \zeta\,\Delta_{\max.}}$$

$$0 < \gamma\left(x_0^*(k), x_i^*(k)\right) \leqq 1 \qquad (5)$$

Where $\Delta_{0i}(k)$ is the deviation sequence of reference sequence $x_0^*(k)$ and comparability sequence $x_i^*(k)$, namely.

$$\Delta_{0i}(k) = \left|x_0^*(k) - x_i^*(k)\right|, \qquad \Delta_{\max.} = \underset{\forall j \in i}{\max.}\ \underset{\forall k}{\max.} \left|x_0^*(k) - x_j^*(k)\right|,$$

$$\Delta_{\min.} = \underset{\forall j \in i}{\min.}\ \underset{\forall k}{\min.} \left|x_0^*(k) - x_j^*(k)\right|,$$

ζ is the distinguishing coefficient, $\zeta \in [0,1]$

A Grey relational grade is a weighted sum of the Grey relational coefficients, and is defined as follows.

$$\gamma\left(x_0^*, x_i^*\right) = \sum_{k=1}^{n} \beta_k \gamma\left(x_0^*(k), x_i^*(k)\right)$$

$$\sum_{k=1}^{n} \beta_k = 1 \qquad (6)$$

Here, the Grey relational grade $\gamma\left(x_0^*, x_i^*\right)$ represents the level of correlation between the reference and comparability sequences. If the two sequences are identical, then the value of the Grey relational grade equals to one. The Grey relational grade also indicates the degree of influence exerted by the comparability sequence on the reference sequence.

Consequently, if a particular comparability sequence is more important to the reference sequence than other comparability sequences, the Grey relational grade for that comparability sequence and the reference sequence will exceed that for other Grey relational grades. The Grey relational analysis is actually a measurement of the absolute value of data difference between the sequences, and can be used to approximate the correlation between the sequences

3.3 ANALYISI OF VARIANCE (ANOVA)

Analysis of variance (ANOVA) and F-test (standard analysis) are used to analysis the experimental data as given follows

Notation:

Following Notation are used for calculation of ANOVA method
C.F. = Correction factor
T = Total of all result
n = Total no. of experiments
S_T = Total sum of squares to total variation.
X_i = Value of results of each experiments (i = 1 to 16)
S_Y = Sum of the squares of due to parameter Y (Y = A, B, C, D)
$N_{Y1}, N_{Y2}, N_{Y3}, N_{Y4}$ = Repeating number of each level (1, 2, 3, 4) of parameter Y
$X_{Y1}, X_{Y2}, X_{Y3}, X_{Y4}$ = Values of result of each level (1, 2, 3, 4) of parameter Y
F_Y= Degree of freedom (D.O.F.) of parameter of Y
f_T = Total degree of freedom (D.O.F.)
f_e = Degree of freedom (D.O.F.) of error terms
V_Y = Variance of parameter Y
S_e = Sum of square of error terms
V_e = Variance of error terms
F_Y = F-ratio of parameter of Y
S_Y' = Pure sum of square
C_Y= Percentage of contribution of parameter Y
C_e = Percentage of contribution of error terms
$CF = T^2/n$
$S_T = \sum_{i=1 \text{ to } 16} X_i^2 - CF$
$S_Y = (X_{Y1}^2/N_{Y1} + X_{Y2}^2/N_{Y2} + X_{Y3}^2/N_{Y3} + X_{Y4}^2/N_{Y4}) - CF$
f_Y = (number of levels of parameter Y) – 1
f_T = (total number of results)-1

$f_e = f_T - \sum f_Y$
$V_Y = S_Y/f_Y$
$S_e = S_T - \sum S_Y$
$V_e = S_e/f_e$
$F_Y = V_Y/V_e$
$S_Y' = S_Y - (V_e * f_z)$
$P_z = S_Y'/S_T * 100\%$
$P_e = (1 - \sum P_Y) * 100\%$

4. EXPERIMENTAL PROCEDURES

4.1 EXPERIMENTAL SETUP

Experiments were conducted on TIG welding Lincoln Invertec 350V pro machine.TIG welding machine setup consist of machining base, DC or AC power source, TIG torch, work return welding lead, shielding gas cylinder, foot control and filler rod. The experiment performed and constructed to control the electrode arc and linear displacement of torch along the weld pool pad centre. The tungsten electrode as cathode and work piece as anode is taken. TIG process employs on electrode made high melting point metal usually a type of tungsten which is not melt because of it is melting point 3500 ^{0}C. The electrode and molten pool is shielded from the atmosphere by stream of inert gas which flows around electrode and is directed onto the work piece by nozzle which surrounds the weld pool. In TIG welding the primary function of the arc is to supply heat to melt the work piece and any filler materials which may be necessary. The process parameters like current, gas flow rate, welding speed and gun angle maintain the control panel.

Figure 1: TIG welding machine setup

4.2 SELECTION OF MATERIAL

In this study weld pool joint to join 1.2 mm AISI304 this stainless steel plate (30x250) which is used in many steel parts. The material composition of the work piece is given Table: 1

C	Mn	P	S	Si	Cr	Mo	Ni	Cu
0.08	2.00	0.04	0.03	1.00	19	0.20	10.5	0.02

The electrode tungsten alloy and tungsten oxides is taken (zirconium or thorium). 2% thoriated for DC and 2% zirconiated for AC welding is recommended.

4.3 RECORD OF QUALITY CHARACTERISTICS

To find out the quality of TIG welding measurement of the weld bead geometry are performed. In this study the bead height, bead width, penetration and area of penetration of weld bead are used to describe the weld geometry and measured by bridge cam gauge. These parameters are measured accurately together by bridge cam gauge (BCG).

Tensile specimen of required dimension as per ASTM E8M was separated out from weld coupon plates and test were measured on400 KN computer controlled universal testing machine. The specimen was loaded at the rate of 1.5 KN/ min as per ASTM specification, so that the tensile specimen undergoes deformation. The specimen finally fails after necking and load vs displacement was recorded. The tensile properties have a higher the better quality characteristic.

4.4 SELECTION OF TIG WELDING PARAMETERS AND THEIR LEVELS

In this study the experimental plan has four variables namely current, gas flow rate, welding speed and gun angle on the basis of preliminary experiments conducted by using one variable at time approach the feasible range for the machining parameters was defined. By varying current (40-85A), gas flow rate (5-20 lit./ min), welding speed (8-14m/min) and gun angle (50^0-80^0). In the machining parameter design four levels of the weld parameters were selected shown in Table: 2

Table 2: Parameters and their levels

Notation	Process parameters	Level 1	Level 2	Level 3	Level 4
A	Current(A)	40	55	70	85
B	Gas flow rate (ltr./min)	5	10	15	20
C	Welding speed (m/min)	8	10	12	14
D	Gun angle	50	60	70	80

5. EXPERIMENTAL DESIGN

The application of design of experiment (DOE) careful planning, good layout of the experiment and table shown The chose design matrix based on Taguchi L16 (4^4) orthogonal array consist 16 set of code condition and the experimental results for the response TL, AP, BW, BH and P in process parameters. In the present study there 12 degree of freedom owing to the four level polishing parameters is applied. While the between parameters is neglected. Once the degree of freedom are known the next step is chose an appropriate orthogonal array. The degree of freedom for the orthogonal array should be greater than or at least equal to those process parameters. In this study an L16 orthogonal array which 15 degree of freedom was applied.

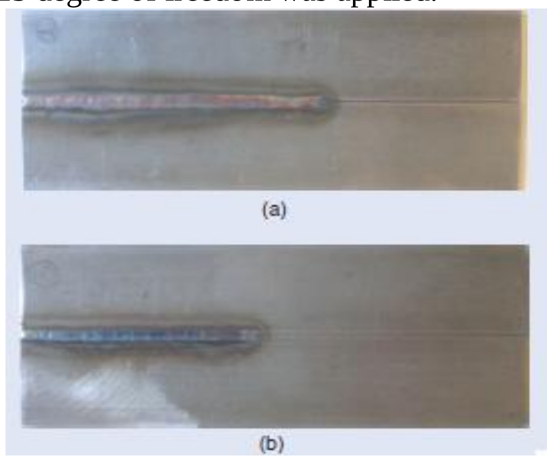


Figure 2. work piece of stainless steel

Table 3: Experimental layout using L16 orthogonal array

Experiment No.	Current A	Gas flow rate B	Welding speed C	Gun angle D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	4	4	4
5	2	1	2	3
6	2	2	1	4
7	2	3	4	1
8	2	4	3	2
9	3	1	3	4
10	3	2	4	3
11	3	3	1	1
12	3	4	2	2
13	4	1	4	2
14	4	2	3	1
15	4	3	2	4
16	4	4	1	3

5.2 EXPERIMENTAL RESULT

Table 4: Experimental results for stainless steel

Experiment No.	**Tensile load (Mpa)** Larger is better	**Area of penetration (mm^2)** Larger is better	**Bead width (mm)** Smaller is better	**Bead height (mm)** Smaller is better	**Penetration (mm)** Larger is better
1	250.2	8.67	6.98	0.195	1.128
2	289.6	11.96	9.88	0.267	1.123
3	266.7	9.81	7.51	0.168	0.998
4	293.1	12.05	9.98	0.312	1.215
5	278.8	10.29	8.19	0.251	1.125
6	263.1	9.26	7.12	0.257	1.181
7	288.8	11.89	9.71	0.301	1.212
8	243.1	7.22	6.22	0.155	0.857
9	223.3	7.12	6.25	0.157	0.997
10	263.8	9.16	7.25	0.198	1.125
11	277.3	10.12	8.14	0.205	1.177
12	279.6	10.89	8.56	0.261	1.189
13	281.3	11.26	9.22	0.267	1.123
14	287.3	11.88	9.78	0.299	1.210
15	279.1	11.26	9.26	0.271	1.205
16	277.2	10.15	8.12	0.212	1.180

Table 5: Preprocessed data results for stainless steel

Experiment No.	T L	A P	B W	B H	P
1	0.242	0.314	0.798	0.754	0.768
2	0.949	0.982	0.027	0.287	0.754
3	0.622	0.546	0.657	0.917	0.399
4	1.000	1.000	0.000	0.000	1.014
5	0.795	0.643	0.476	0.389	0.759
6	0.570	0.434	0.761	0.350	0.918
7	0.938	0.968	0.712	0.070	1.005
8	0.284	0.020	1.000	1.000	0.000
9	0.000	0.000	0.992	0.987	0.397
10	0.580	0.414	0.726	0.726	0.759
11	0.774	0.609	0.489	0.682	0.907
12	0.806	0.765	0.378	0.325	0.941
13	0.830	0.839	0.202	0.287	0.754
14	0.916	0.967	0.053	0.083	1.000
15	0.799	0.833	0.191	0.261	0.986
16	0.772	0.615	0.495	0.637	0.915

Table 6. Grey relational coefficient for stainless steel

Experiment No.	T L	A P	B W	B H	P
1	0.674	0.614	0.385	0.402	0.394
2	0.345	0.337	0.949	0.635	0.399
3	0.446	0.478	0.437	0.353	0.556
4	0.333	0.333	1.000	1.000	0.330
5	0.386	0.437	0.512	0.562	0.397
6	0.467	0.535	0.397	0.588	0.353
7	0.348	0.340	0.413	0.877	0.332
8	0.638	0.962	0.333	0.333	1.000
9	1.000	1.000	0.335	0.336	0.557
10	0.463	0.547	0.408	0.408	0.397
11	0.392	0.451	0.506	0.423	0.355
12	0.383	0.395	0.569	0.606	0.345
13	0.376	0.373	0.712	0.653	0.399
14	0.353	0.340	0.904	0.858	0.333
15	0.385	0.373	0.724	0.657	0.336
16	0.393	0.448	0.503	0.439	0.353

Table 7: Grey relational grade for stainless steel

Experiment No.	A	B	C	D	For stainless steel
1	1	1	1	1	0.494
2	1	2	2	2	0.533
3	1	3	3	3	0.454
4	1	4	4	4	0.599
5	2	1	2	3	0.459
6	2	2	1	4	0.468
7	2	3	4	1	0.462
8	2	4	3	2	0.473
9	3	1	3	4	0.646
10	3	2	4	3	0.445
11	3	3	1	1	0.425
12	3	4	2	2	0.459
13	4	1	4	2	0.503
14	4	2	3	1	0.558
15	4	3	2	4	0.495
16	4	4	1	3	0.427

Table 8. Response table for grey relational for stainless steel

Levels	Factors			
	A	B	C	D
1	0.520	0.525	0.453	0.485
2	0.465	0.501	0.487	0.492
3	0.494	0.459	0.533	0.446
4	0.495	0.489	0.502	0.552

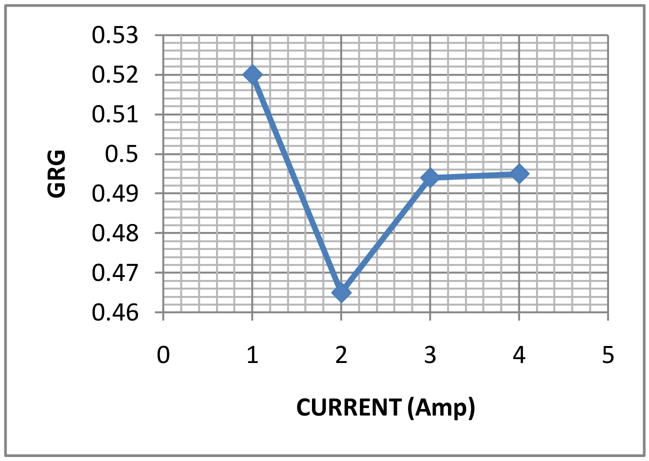
5.3 ANALYSIS OF VARIANCE (ANOVA)

Analysis of variance (ANOVA) was introduced by Sir Ronald Fisher. The purpose of the analysis of variance (ANOVA) is to investigate which design parameters significantly affect the quality characteristic.

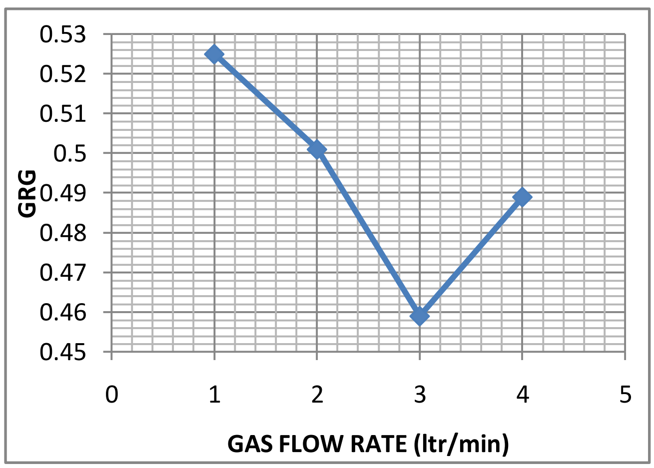
Table 9. Analysis of variance (ANOVA) and F-test for stainless steel

Factor	DOF	Sum of squares	Mean variance	F-ratio	Sz	Contribution (%)
A	3	0.006	0.002	3.333	0.0042	8.076
B	3	0.009	0.003	5.000	0.0072	13.846
C	3	0.013	0.004	6.666	0.0112	21.538
D	3	0.022	0.007	11.666	0.0202	38.846
error	3	0.002	0.0006			17.694
Total	15	0.052				100.000

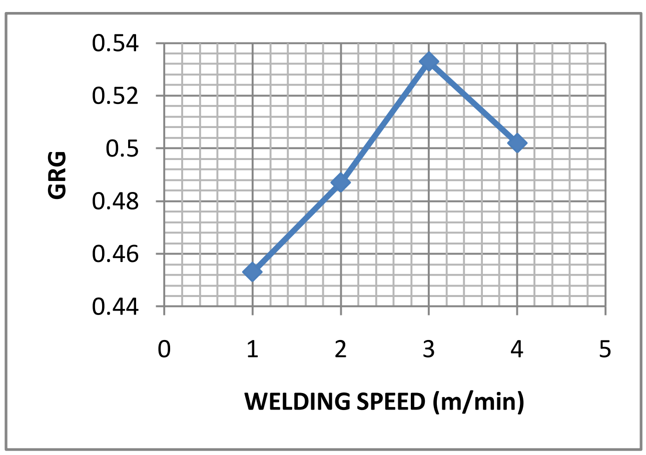
Table 4 shows the experimental results for stainless steel obtained, Table 5 shows the pre-processed data results. The grey relation coefficients of each performance characteristic are calculated in Table 6. Table 7 shows the grey relational grade. Table 9 shows the analysis of variance and F- test results which identifies the most significant factor.



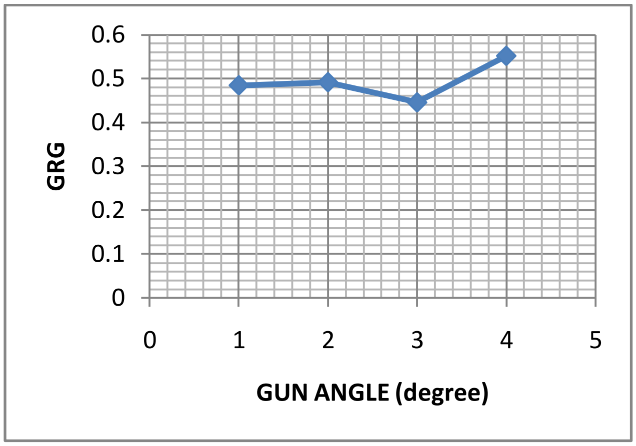
Graph between GRG and CURRENT (Amp)



Graph between GRG and Gas flow rate (ltr/min)



Graph between GRG and Welding speed (m/min)



Graph between GRG and Gun angle (degree)

Figure 3: Influence Of Process Parameters On Multiple Performance For Stainless Steel

RESULT AND CONFIRMATION TEST

After identifying the predicted optimal parameter setting, the final phase is to verify the optimal result by conducting the confirmation experiments. The A1B1C3D4 is an optimal parameter combination for stainless steel of the TIG welding process via the Grey relational analysis. Therefore, the condition A1B1C3D4 of the optimal parameter combination of the TIG welding process was treated as a confirmation test. If the optimal setting for steel with a current 40 A, gas flow rate 5 ltr/min, welding speed 12 m/min and gun angle 80^0, for stainless steel, the final work piece give the Tensile load (294.1Mpa), Area of penetration (13.05 mm^2), penetration (2.215 mm) maximum Bead width (5.22 mm) and Bead height (0.055 mm) are minimum.

CONCLUSION

The paper presented the optimization of the TIG welding process of stainless steel work piece by the grey relational analysis. The optimal process parameters that have been identified the best combination of process variables for stainless steel are current at 40 A, gas flow rate (ltr/min), welding speed at 12 m/min and gun angle 80^0. As a result, the target performance characteristics, i.e. Tensile load, area of penetration, and penetration can be maximized and the Bead width, Bead height can be minimized through this method. The effectiveness of this approach is verified by experiment and analysis of variance. After identify the predicted optimal parameter setting with the help of (ANOVA) the most significant factor also found in this case gun angle is having maximum percentage contribution. So it is most significant factor in this result.

REFERENCES

[1] Pawan Kumar1, Kishor Purushottamrao Kolhe2, Sashikant Janardan Morey3, " Process Parameters Optimization of an Aluminium Alloy with Pulsed Gas Tungsten Arc Welding (GTAW) Using Gas Mixtures", (2011), 2, 215-257.

[2] Ugur Esme1, Melih Bayramoglu2,Yugut Kazancoglu3, Sueda Ozgun4 "optimization of Weld bead geometry im TIG welding process using grey relation analysis and Taguchi Method", 43 (2009) 3,143-149.

[3] A. Kumar1 , S. Sundarrajan2, "Optimization of pulsed TIG welding process parameters On mechanical properties of AA 5456 Aluminium alloy weldments" , 30 (2009), 1288-1297.

[4] M. Balasubramanian1, V. Jayabalan2, and V. Balasubramanian3 Process Parameters Optimization of Pulsed Current Argon Tungsten Arc Welding of Titanium Alloy" , (2008), 24,3,423.

[5] S. Datta, A. Bandyopadhyay, P.K. Pal, Int J Adv Manuf Technol., 39 (2008), 1136-1143.

[6] Kumar A, Shailesh P, Sundarrajan S. Optimization of magnetic arc oscillation process Parameters on mechanical properties of AA 5456 Aluminium alloy weldments. J Mater 29 (10), (2008), 1904-1913.

[7] Kumar A, Nageshwar Rao GVS, Sundarrajan S. Modelling and simulation of pulsed TIG welding process of an aluminium alloy. 1 (1-2), (2007), 85- 94.

[8] T. Senthikumar, V. Balasubramanian and M. Y. S. Babu, " Effect of pulsed Current GTAW Parameters on Fusion Zone Microstructure of AA6061" , 13, 4, (2007), 33-37.

[9] D.C. Chen, C.F. Chen, J Mater Process Technol.,190 (2007), 130-137.

[10] A. Kumar and S. Sundarrajan," Selection of welding Process Parameters for Optimum but Joint Strength of an Aluminium Alloy", 21, 8, (2006), 789-793.

[11] V. M. Radhakrishnan, " Welding Technology & Design" (second edition 2005), New Age International publishers New Delhi.

[12] S.C. Juang, Y.S. Tarng " Process parameters selection for optimizing the weld pool Geometry in the TIG welding of stainless steel,122 (2002) 33-37.

[13] Ranjit K. Roy, " Design of Experiments Using the Taguchi Approach", John Wiley & Sons, New York, 2001.

[14] G.S. Peac, Taguchi Methods : A Hand on Approach, Addison-Wesely, Readung, MA (1993).

[15] G. Taguchi, Introduction to Quality Engineering, Asian Productivity Organization ,Tokyo, 1990.