

## PARAMETRIC OPTIMIZATION OF MIG PROCESS PARAMETERS USING TAGUCHI AND GREY TAGUCHI ANALYSIS

Dinesh Mohan Arya \*

Vedansh Chaturvedi \*\*

Jyoti Vimal \*\*

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### ABSTRACT

*The aim of this study is to investigate the optimization process parameters for Metal inert gas welding (MIG). The optimization of MIG welding operating parameters are for alloy steel work piece using grey relational analysis method. Sixteen experimental runs based on an orthogonal array Taguchi method were performed. This paper presents the influence of welding parameters like wire diameter, welding current, arc voltage, welding speed, and gas flow rate optimization based on bead geometry of welding joint. The objective function have been chosen in relation to parameters of MIG welding bead geometry Tensile strength, Bead width, Bead height, Penetration and Heat affected zone (HAZ) for quality target. Optimal parameters contribution of the MIG operation was obtained via grey relational analysis. By analysis the grey relational grade, preprocessed data, and grey relational coefficient of grey relational controllable process factor on the individual quality characteristic targets additionally the analysis of variance (ANOVA) is also applied to identify the welding current is the most significant factor. Experiment with the optimized parameter setting, which have been obtained from the analysis, are giving to validate the results.*

**Keywords:-**MIG Welding, Grey relational analysis, Taguchi orthogonal array, Analysis of variance (ANOVA).

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\*Research Scholar, Department of Mechanical Engineering, Madhav Institute of Technology & Science, Gwalior

\*\*Assistant Professor, Department of Mechanical Engineering, Madhav Institute of Technology & Science, Gwalior

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## 1. INTRODUCTION

MIG (Metal Inert Gas) welding, also known as MAG (Metal Active Gas) and in the USA as GMAW (Gas Metal Arc Welding), is a welding process that is now widely used for welding a variety of materials, ferrous and non ferrous.[1]

In gas shielded arc welding both the arc and the molten weld pool are shielded from the atmosphere by a stream of gas. The arc may be produced between a continuously fed wire and the work. The shielding gas can be both inert gas like argon and active gases like argon-oxygen mixture and carbon-di-oxide which are chemically reactive. It can be used on nearly all metals including carbon steel, stainless steel, alloy steel and aluminum. Arc travel speed is typically 30-38 cm/minute and weld metal deposition rate varies from 1.25 kg/hr when welding out of position to 5.5 kg/hr in flat position.[8]

Metal transfer across the arc, is short circuiting transfer, globular transfer, spray transfer, pulsed spray transfer. The made of weld metal transfer is determined by the following welding current, electrode size, electrode composition, electrode stick out, shielding gas. Joint type in MIG welding, the most commonly used joint type are the butt joint, corner joint, edge joint, lap joint and T-joint.[1] A metal inert gas welding process. Here, the arc is maintained between a consumable electrode and the work piece in an inert gas atmosphere. The coiled electrode wire is fed by drive rolls as it melts away at the tip. Except for aluminum, a DC source is used with the consumable electrode as the positive terminal. [7]

Arc welding process plays an important contribution in manufacturing. Metal inert gas (MIG) welding is one of the most important arcs welding Process. MIG welding is a highly complex, multi-variable system, in which the variables affecting weld quality are not clearly known. Thus developing a model for making to prophesy of weld bead geometry has turned out to be non-trivial and number of approaches has been to exhibit to tackle the problem. In the present work, the input variables and responses for the MIG welding process have been investigated and different planning using grey relational analysis have been applied to prophesy the weld bead geometry. [3]

The requirements for quality products has led to the rapid advancement of today`s automated manufacturing environments. The quality of a product can be defined as the ability to fulfill the reasonable expectation and need set by the consumer. [8]

## 2 SCHEME OF INVESTIGATION

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

- Selection of base material.
- Identify the importance MIG welding process parameters.
- Find the upper and lower limits (i.e. range) of the identified process parameters.
- Select the orthogonal array (design of matrix).
- Conduct the experiments as per the selected orthogonal array.
- Record the quality characteristics (i.e. material 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  $x_i(k)$ ,  $i=1, 2, \dots, m$ ;  $k=1, 2, \dots, n$ , 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.[2]

$$x_i^*(k) = \frac{x_i^{(0)}(k) - \min. x_i^{(0)}(k)}{\max. x_i^{(0)}(k) - \min. x_i^{(0)}(k)} \quad (1)$$

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

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

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

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

Where OB is the 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,  $x_i^{(O)}(1)$ .

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

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.

$$\gamma(x_0^*(k), x_i^*(k)) = \frac{\Delta_{\min} + \zeta \Delta_{\max}}{\Delta_{0i}(k) + \zeta \Delta_{\max}} \quad (5)$$

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

$$\Delta_{0i}(k) = |x_0^*(k) - x_i^*(k)|, \quad \Delta_{\max} = \max_{j \in i} \max_k |x_0^*(k) - x_j^*(k)|,$$

$$\Delta_{\min} = \min_{j \in i} \min_k |x_0^*(k) - x_j^*(k)|,$$

$\zeta$  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.

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

$$\sum_{k=1}^n \beta_k = 1$$

(6)

Here, the Grey relational grade  $\gamma(x_0^*, x_i^*)$  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 ANALYSIS OF VARIANCE (ANOVA)

Analysis of variance (ANOVA) and F-test (standard analysis) are used to analysis the experimental data as given follows. [7]

#### 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 ( $Y = A, B, C, D, E$ )

$N_{Y1}, N_{Y2}, N_{Y3}, N_{Y4}$  = 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

$CF = T^2/n$

$S_T = \sum_{i=1 \text{ to } 16} X_i^2 - CF$

$S_Y = (X_{Y1}^2/N_{Y1} + X_{Y2}^2/N_{Y2} + X_{Y3}^2/N_{Y3} + X_{Y4}^2/N_{Y4}) - CF$

$f_Y = (\text{number of levels of parameter Y}) - 1$

$f_T = (\text{total number of results}) - 1$

$f_e = f_T - \sum f_Y$

$V_Y = S_Y/f_Y$

$S_e = S_T - \sum S_Y$

$V_e = S_e/f_e$

$F_Y = V_Y/V_e$

$S_Y' = S_Y - (V_e * f_z)$

$P_z = S_Y'/S_T * 100\%$

$P_e = (1 - \sum P_Y) * 100\%$

## 4. EXPERIMENTAL PROCEDURES

### 4.1 EXPERIMENTAL SETUP

Experiments were conducted MIG welding machine equipment which is shown in fig 1.

The MIG welding L&T, ZUPER ARC machine setup consist of machining base ,the equipments DC output source, Wire feed unit, Torch, Work return welding lead, Shielding gas supply, (normally from cylinder).power source have a Main supply line, on/off switch, Transformer,

Rectifier, Welding regulator. Most modern wire feed units control the wire feed speed via a DC motor and thruster control PCB to provide continuous control of Armature volts and hence RPM of motor. The MIG torch can be air cooled or water cooled and most modern air cooled torches have a single cable in which the welding wire slides through a liner. Gas flows around the outside of this liner and around the tube the liner sits in the power braid and trigger wires. MIG torch combination have a gas nozzle, contact tip, contact tip holder, liner, swan neck, trigger, and gun plug, trigger cables, current cable, gas hose. The shielding gas should also have a pronounced effect on the following aspects of the welding operation and the resultant weld. Arc characteristics, Mode of Metal Transfer, Penetration and Weld Head profile, Speed of Welding, Undercutting Tendency, and Cleaning Action Weld Metal Mechanical Properties. A basic position or starting point would be Aluminum – Argon, Magnesium – Helium, Copper Alloys – Argon – Helium Mix, Steel – Carbon dioxide not commonly used, Today, Argon-Carbon dioxide mix is preferred.



Figure 1: MIG welding machine setup

#### 4.2 SELECTION OF MATERIAL

In this study two alloy steel plate of length 250 mm width 40 mm 1.2 mm thickness and height is equivalent to plate thickness made of Alloy steel which is a high carbon alloy steel with high degree of hardness and which rises the temperature of the tool tip to visible red heat. Ordinary high carbon and low alloys tool steels do not withstand the heating effect and readily lose hardness. But high speed steels have the property to withstand this heating effect without losing

hardness. So called high speed steels are of composition that have good wear resistance and retain their hardness of high temperature. A superior brand of high speed steel has the following composition as per ISS Carbon (0.70%), Tungsten (18.00%), Chromium (4.00%), and Vanadium (1.00%).

#### 4.3 RECORD OF QUALITY CHARACTERISTICS

To evaluate the quality of MIG welds measurement of weld pool geometry are performed. In this study the bead width, bead height, penetration and heat affected zone (HAZ) of weld pool are used to describe the weld pool geometry measured by Bridge cam gauge (BCG). These parameters measured accurately and one time measured by (BCG).

Tensile specimen of necessary dimension as per ASTM E8M were separated out from welding coupon plates and test were measured on 400 KN computer control universal testing machine. The specimen loaded at the rate of 1.5 KN/min as per ASTM specification. So that tensile specimen under goes deformation. The specimen finally fails after necking and load vs displacement was recorded. The tensile property higher the better quality characteristic.

#### 4.4 SELECTION OF THE MIG WELDING PARAMETERS AND THEIR LEVELS

In this study, the experimental plan has five variables, namely, Wire diameter, Welding current, Arc voltage, Welding speed, and Gas flow rate. On the basis of preliminary experiment conducted by using one variable at a time approach, the feasible range for the welding parameters was defined by the Wire diameter (0.8-1.2mm), Welding current (80-110amp), Arc voltage (18-19.5VOLT), Welding speed (45-55cm/min), Gas flow rate (10-15ltr/min). In the MIG welding parameters were selected, shown in Table-1.

Table 1: Parameters and their levels

Notation	Process Parameter	Level 1	Level 2	Level 3	Level 4
A	Wire diameter (mm)	0.8	0.9	1.0	1.2
B	Welding current (amp)	80	90	100	110
C	Arc voltage (volt)	18	18.5	19	19.5
D	Welding speed (cm/mm)	45	48	51	55
E	Gas flow rate (let/min)	10	13	14	15

### 5. EXPERIMENTAL DESIGN



The application of design-of-experiments (DOE) to demand as of right anxious planning, best ground-plan of the experiment and table shown. The choose design matrix based on Taguchi L16 ( $4^5$ ) orthogonal array consist 16 set of code condition and the experimental result for the response Tensile strength, Bead width, Bead height, penetration, and heat affected zone (HAZ) in process parameter. In the present study there 12 degree of freedom owing to the four level welding parameters. While the reciprocal action between the parameters is neglected. Once the DOF are known the next step is choose an appropriate orthogonal array. The DOF for the orthogonal array should be greater than or at least equal to those process parameters. In this study an L16 orthogonal array is used because it has 15 degree of freedom in the welding parameters. The experiment output for the process parameter is shown in Table 2.



Figure 2 :Work piece of steel alloy

Table 2. Experimental layout using L16 orthogonal array

Experiment No.	A	B	C	D	E
1	1	1	1	1	1
2	1	2	2	2	2
3	1	3	3	3	3
4	1	4	4	4	4
5	2	1	2	3	4
6	2	2	1	4	3
7	2	3	4	1	2
8	2	4	3	2	1
9	3	1	3	4	2
10	3	2	4	3	1

11	3	3	1	2	4
12	3	4	2	1	3
13	4	1	4	2	3
14	4	2	3	1	4
15	4	3	2	4	1
16	4	4	1	3	2

### 5.1 EXPERIMENTAL RESULTS

Table 3. Experimental results for steel alloy

Experiment No.	Tensile strength (N/mm <sup>2</sup> ) Larger is better	Bead width (mm) Smaller is better	Bead height (mm) Smaller is better	Penetration (mm) Larger is better	HAZ (mm) Smaller is better
1	260.12	8.10	0.251	1.263	5.621
2	262.17	8.19	0.259	1.264	5.720
3	271.16	8.61	0.273	1.277	5.800
4	269.27	8.50	0.260	1.278	5.770
5	265.71	8.43	0.251	1.273	5.765
6	272.18	8.65	0.275	1.288	5.806
7	252.17	7.19	0.203	0.985	3.868
8	272.00	8.61	0.281	1.291	5.996
9	257.19	7.21	0.210	1.05	4.380
10	262.11	8.10	0.235	1.212	5.720
11	281.16	8.91	0.294	1.306	6.127
12	277.91	8.77	0.288	1.298	6.099
13	261.33	8.05	0.231	1.239	5.712
14	271.16	8.51	0.271	1.281	5.937
15	255.34	7.05	0.210	0.998	4.367
16	267.14	8.43	0.255	1.235	5.766

Table 4. Preprocessed data results for steel alloy

Experiment No.	Tensile strength	Bead width	Bead height	Penetration	HAZ
1	0.274	0.435	0.225	0.866	0.223
2	0.344	0.387	0.183	0.869	0.180
3	0.655	0.161	0.109	0.909	0.144
4	0.589	0.220	0.178	0.912	0.158
5	0.467	0.258	0.225	0.897	0.160
6	0.690	0.139	0.099	0.943	0.142
7	0	0.924	1	0	1
8	0.684	0.161	0.068	0.953	0.057
9	0.173	0.913	0.439	0.202	0.773
10	0.342	0.435	0.308	0.707	0.180
11	1	0	0	1	0
12	0.887	0.075	0.031	0.975	0.012
13	0.315	0.462	0.329	0.791	0.183
14	0.655	0.215	0.120	0.922	0.084
15	0.109	1	0.439	0.040	0.779
16	0.516	0.258	0.204	0.778	0.159

Table 5. Grey relational coefficient for steel alloy

Experiment No	Tensile strength	Bead width	Bead height	Penetration	HAZ
1	0.645	0.534	0.689	0.366	0.691
2	0.592	0.563	0.732	0.365	0.735
3	0.432	0.756	0.821	0.354	0.776
4	0.459	0.694	0.737	0.354	0.759
5	0.517	0.659	0.689	0.357	0.757
6	0.420	0.782	0.834	0.346	0.778

7	1	0.351	0.333	1	0.333
8	0.422	0.756	0.880	0.344	0.897
9	0.742	0.353	0.532	0.712	0.892
10	0.593	0.534	0.618	0.414	0.735
11	0.333	1	1	0.333	1
12	0.360	0.869	0.941	0.338	0.976
13	0.613	0.519	0.603	0.387	0.732
14	0.432	0.699	0.806	0.351	0.856
15	0.821	0.333	0.532	0.925	0.390
16	0.492	0.659	0.710	0.391	0.758

Table 6. Grey relational grade for steel alloy

Experiment No.	A	B	C	D	E	Grey relational grade
1	1	1	1	1	1	0.585
2	1	2	2	2	2	0.597
3	1	3	3	3	3	0.627
4	1	4	4	4	4	0.600
5	2	1	2	3	4	0.595
6	2	2	1	4	3	0.632
7	2	3	4	1	2	0.603
8	2	4	3	2	1	0.659
9	3	1	3	4	2	0.546
10	3	2	4	3	1	0.578
11	3	3	1	2	4	0.733
12	3	4	2	1	3	0.696
13	4	1	4	2	3	0.570
14	4	2	3	1	4	0.628
15	4	3	2	4	1	0.600

16	4	4	1	3	2	0.602
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Table7. Response Table for grey relational for steel alloy

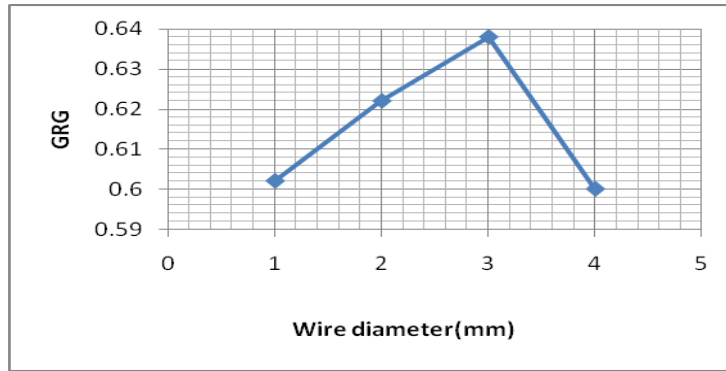
Levels	Factors				
	A	B	C	D	E
1	0.620	0.574	0.638	0.628	0.605
2	0.622	0.608	0.622	0.639	0.587
3	0.638	0.640	0.615	0.600	0.631
4	0.6	0.639	0.587	0.594	0.639

## 5.2 ANALYSIS OF VARIANCE (ANOVA)

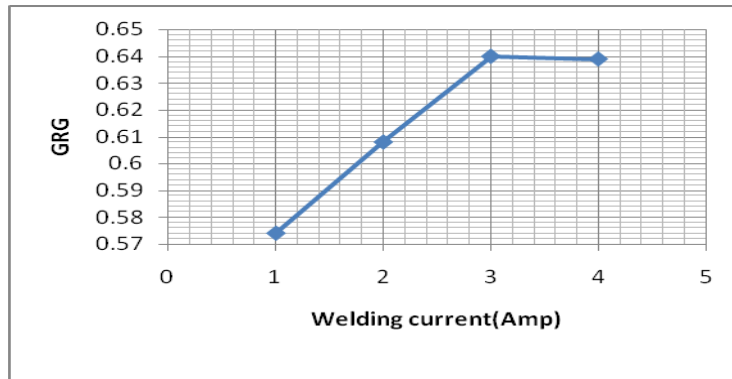
Analysis of variance (ANOVA) was introduced by Sir Ronald Fisher. The purpose of the analysis of variance (ANOVA) is to investigate which design parameters significantly affect the quality characteristic.

Table 8. Analysis of variance (ANOVA) and F-test for steel alloy

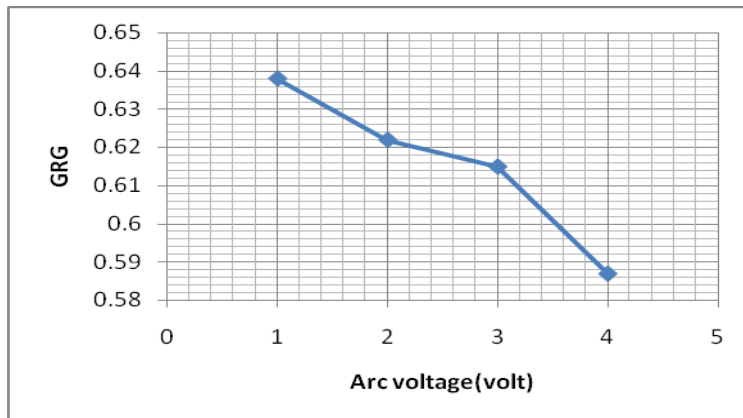
Factor	DOF	Sum of squares	Mean variance	F-ratio	Sz	Contribution (%)
A	3	0.002	0.00066	0.00066	0.002	6.896
B	3	0.01	0.0033	0.0033	0.01	34.483
C	3	0.003	0.001	0.001	0.003	10.345
D	3	0.004	0.0013	0.0013	0.004	13.793
E	3	0.005	0.0016	0.0016	0.005	17.241
Error	0	0.005				17.242
Total	15	0.029	0.0078			100.00



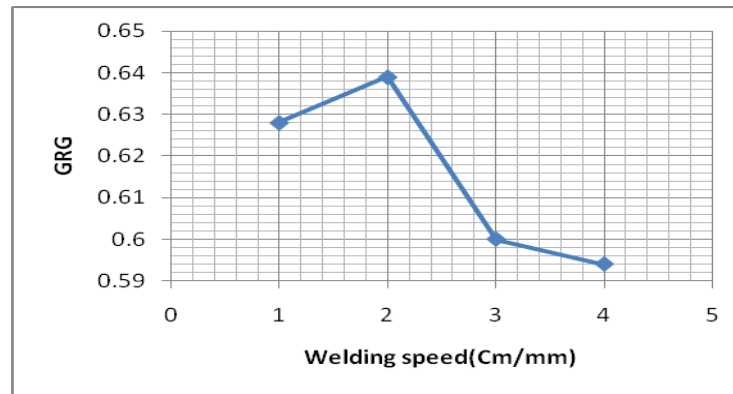
Graph between GRG and wire diameter



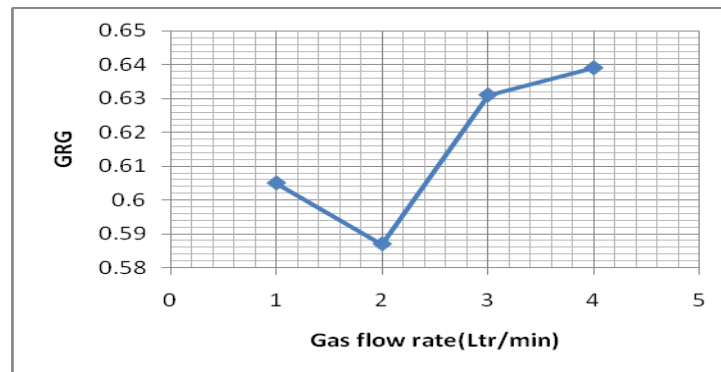
Graph between GRG and welding current



Graph between GRG and Arc voltage



Graph between GRG and welding speed



Graph between GRG and Gas flow rate

Figure 3: Influence Performances For Steel Alloy Of Process Parameters On Multiple

## RESULT AND DISCUSSION

After identifying the most influential parameters, the final phase is to verify the Tensile strength, Bead width, Bead height, Penetration and Heat affected zone by conducting the confirmation experiments. The *A3B3C1D2E4* is an optimal parameter combination for steel alloy of the MIG welding process via the Grey relational analysis. Therefore, the condition *A3B3C1D2E4* of the optimal parameter combination of the MIG welding process was treated as a confirmation test. If the optimal setting for steel alloy with a Wire diameter 1mm, Welding current 100 A, Arc voltage 18 V, Welding speed 48 cm/min, and Gas flow rate 15 ltr/min is used, the final work piece gives the Bead width (6.05mm), Bead height (0.103mm) and HAZ (2.868mm) minimum, Tensile strength (282.16N/mm<sup>2</sup>) and Penetration (2.306mm) is maximum.

## CONCLUSION

In the present study, Taguchi optimization technique pair with grey relational analysis has been adopted for evaluating parametric complex to carry out acceptable Tensile strength and Penetration higher is better. Bead width, Bead height and Heat affected zone (HAZ) lower is better of the alloy steel element to acquired by using Metal inert gas welding. After identify the predict optimal parameter setting with the help of (ANOVA) the most significant factor also found in this case welding current is having maximum percentage contribution. So it is most significant factor in this result.

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