International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Impact Factor (2012): 3.358

Parametric Optimization of Metal Inert Gas Welding and Tungsten Inert Gas Welding By Using Analysis of Variance and Grey Relational Analysis

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Abstract: ***Metal Inert Gas (MIG) welding and Tungsten Inert Gas (TIG) are one of the widely used techniques for joining ferrous and non-ferrous metals. In this experiment Design of Experiment method was used. For this work with use of the experimental data, optimization done by the grey relational analysis (GRA) technique, in which input parameters for MIG welding are welding current, gas flow and wire feed rate and the output parameter is tensile strength. Also the input parameters for TIG welding are welding current, gas flow and the output parameter is tensile strength. Aluminum used as base material for welding. For Experimental design full factorial method was used ($L=m^n$) to find out number of readings. To find out percentage contribution of each input parameters for obtaining optimal conditions, Analysis of variance (ANOVA) method was used. The grey relational grade obtained with use of grey relational analysis technique. By analyzing the Grey relational grade the optimum parameters were evaluated.***

Keywords: ANOVA, Grey relational analysis, Tensile Strength, MIG Welding, TIG Welding

1. Introduction and Literature Survey

The American Welding Society (AWS) defines weld as "A localized coalescence of metals or non-metals produced either by heating the materials to suitable temperatures, with or without application of pressure, or by pressure alone, and with or without the use of filler material." Indian Standard IS: 812-1957 defines the weld as "A union between two pieces of a metal at faces rendered plastic or liquid by heat or by pressure, or both. Filler metal may be used to affect the union". International Organization for Standards (ISO) defines welding as "An operation by which two or more parts are united, by means of heat or pressure, or both, in such a way that there is continuity of the nature of the material between these parts. A filler material, the melting temperature of which is of the same order as that of the parent material, may or may not be used."

Gas metal arc welding (GMAW), sometimes referred by its subtype metal inert gas (MIG) welding or metal active gas (MAG) welding is a welding process in which an electric arc forms between a consumable wire electrode and the work piece metals, which heats the work piece metals, causing them to melt and join. Along with the wire electrode, a shielding gas feed through the welding gun, which shields the process from contamination in the air. The process can be semi-automatic or automatic.

Gas tungsten arc welding (GTAW), also known as tungsten inert gas (TIG) welding, is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. The weld area is protected from atmospheric contamination by an inert shielding gas (argon or helium), and a filler metal is normally used, though some welds, known as autogenous welds, do not require it.

Salawadagi Sushant S., Kumbhar S. [1] researched the effect of MIG welding parameters like welding speed, weld current, weld plate angle. The ANOVA and GRA method used with output parameter as residual stress.

Rati Saluja, K M Moeed [2] researched the effect of MIG welding parameters like welding current, voltage stick out distance of electrode and welding speed on aluminium measuring bead geometry and weld penetration using response surface methodology in. As per this experiment the increase of welding current the better bead geometry and weld penetration can be obtained up to the specific value of current.

S.R. Meshram and N.S. Pohokar [3] researched the effect of MIG welding parameters like voltage, wire feed rate, welding speed, nozzle to plate distance and gas flow. With use of ANOVA methodology. Penetration and UTS measured as confirmation test. As result, it obvious that increasing the parameter value of welding current, increased the value of depth of penetration and UTS. Other than that, arc voltage and welding speed is another factor that influenced the value of UTS.

Bhargav Patel, Jaivesh Gandhi [4] studied the effect of MIG welding parameters like welding current, welding speed, flow of shielding gas arc voltage as input parameters and ANOVA methodology used. Tensile strength measured as output parameter. It is obvious that increasing welding current increased the UTS. In addition, arc voltage is another parameter in incrimination of UTS. However, its effect is not as much as current.

Palani.P.K, Saju.M [5] researched the effect of TIG welding process parameters on welding of Aluminium-65032. Response Surface Methodology was used to conduct the experiments. The parameters selected for controlling the process are welding speed, current and gas flow rate. Strength of welded joints were tested by a UTM.

G.Haragopal, P.V.R.Ravindra reddy [6] researched Taguchi method to study the effect of gas pressure, current, groove angle and preheat on MIG welding of Aluminium alloy (Al-65032). They indicated that welding current has more effect ultimate tensile strength whereas gas pressure is the most

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significant parameter for proof stress, elongation and impact energy.

G.Padmanaban V.Balasubramanian [7] researched the effect of optimization of pulsed current gas tungsten arc welding process parameters on tensile strength in AZ31B magnesium alloy. Result showed that maximum tensile strength of 188Mpa was obtained under the welding condition of peak current of 210 A, base current of 80A, pulse frequency of 6 Hz and pulse on time of 50%.

R.Satish, B.Naveen [8] researched the weldability and process parameter optimization of dissimilar pipe joints using GTAW. Taguchi method was used to formulate the experimental layout to rank the welding input parameters which affects quality of weld. Results showed that lower heat input resulted in lower tensile strength and too high heat input also resulted in reduced tensile strength.

2. Design of Experiment

Design of experiments was developed in the early 1920s by Sir Ronald Fisher at the Rothamsted Agriculture field Research Station in London, England. His initial experiments were concerned with determining the effect of various fertilizers on different plots of land. The final condition of the crop was not only dependent on the fertilizer but also on the number of other factors (such as underlying soil condition, moisture content of the soil, etc.) of each of the respective plots. Fishers used DOE which could differentiate the effect of fertilizer and the effect of other factors. Since that time the DOE has been widely accepted in agricultural as well as Engineering Science. Design of experiments has become an important methodology that maximizes the knowledge gained from experimental data by using a smart positioning of points in the space. This methodology provides a strong tool to design and analyze experiments; it eliminates redundant observations and reduces the time and resources to make experiments. We have used full factorial design, if the numbers of levels and numbers of factors known then the possible design N is

$$L = M^{n} \ldots \quad (1)$$

Where, M = number of levels for each factor, and n= number of factors.

2.1 DOE for MIG welding:

Table 1: Factors and their levels in MIG welding

Process Parameters	Level 1	Level 2	Level 3
Electric current	135	145	155
Feed rate	9	10	11
Gas flow	15	20	25

2.2 DOE for TIG welding

Table 2: Factors and their levels in TIG welding

Process Parameters	Level 1	Level 2	Level 3
Electric current	210	225	240
Gas flow	6	7	8

3. Data obtained from experimental work for UTS (MIG)

Table 3: UTS Data obtained in MIG welding

Electric current(Am)	Feed rate(mm)	Gas flow (lit/min)	UTS(MPa)
135	9	15	69.21
135	9	20	72.29
135	9	25	78.36
135	10	15	72.81
135	10	20	75.46
135	10	25	78.11
135	11	15	70.23
135	11	20	74.34
135	11	25	78.63
145	9	15	70.46
145	9	20	74.53
145	9	25	79.72
145	10	15	72.67
145	10	20	74.42
145	10	25	78.12
145	11	15	70.17
145	11	20	77.81
145	11	25	78.32
155	9	15	79.91
155	9	20	79.11
155	9	25	75.04
155	10	15	79.12
155	10	20	78.89
155	10	25	84.96
155	11	15	81.54
155	11	20	84.67
155	11	25	87.34

4. Data obtained from experimental work for UTS (TIG)

Table 4: UTS Data obtained in TIG welding

Electric current(Amp)	Gas flow(lit/min)	UTS(MPa)
210	6	64.29
210	7	60.19
210	8	69.74
225	6	87.48
225	7	79.79
225	8	78.53
240	6	79.28
240	7	76.73
240	8	77.48

5. Work Piece Material and Dimension

1xxx Series: Pure aluminum (> 99.5% Al) with only trace elements. This material is soft with low mechanical strength, but high conductivity.
Type of joint: Butt Joint with Complete Penetration Groove
Thickness: 10mm
Length: 125mm
Width: 50.8mm

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Figure 1: Aluminum Work Pieces

Figure 2: Machined Aluminum Work Piece

6. ANOVA Analysis

6.1 ANOVA Analysis of MIG Welding:

Table 5: Result of MIG Welding

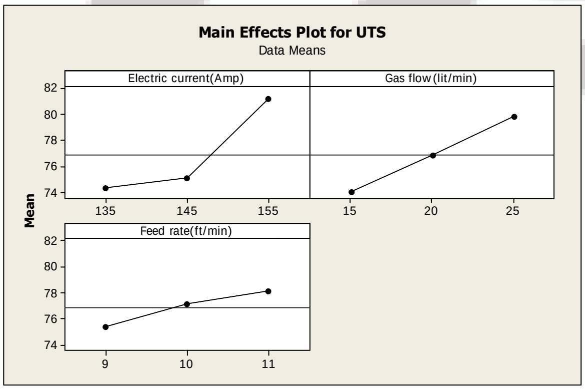
Parameters	*%contribution*
Electric Current	43.9565
Gas Flow	26.9715
Feed Rate	6.0172
Error	23.0548

6.2 ANOVA Analysis of TIG Welding

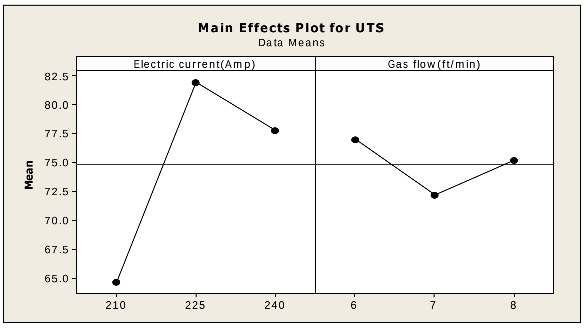
Table 6: Result of TIG Welding

Parameters	%contribution
Electric current	83.40%
Gas flow	9.76%
Error	6.80%

7. Main Effects Plot for ANOVA



Graph 1: ANOVA for MIG



Graph 2: ANOVA for TIG

8. Grey Relational Analysis

In grey relational generation, the normalized data corresponding to Lower-the-Better (LB) Criterion can be expressed as:

$$Xi\,(k) = \frac{\max\ yi\,(k) - yi\,(k)}{\max\ yi\,(k) - \min\ yi\,(k)}$$

For Higher-The-Better (Hb) Criterion, The Normalized Data Can Be Expressed As:

$$Xi(k) = \frac{yi(k) - \min yi(k)}{\max yi(k) - \min yi(k)}$$

Where xi (k) is the value after the grey relational generation, min $yi\ (k)$ is the smallest value of $yi\ (k)$ for the k_{th} response, and max $yi\ (k)$ is the largest value of $yi\ (k)$ for the k_{th} response. An ideal sequence is x_0 (k) for the responses. However, if there is ''a specific target value'', then the original sequence is normalized using,

$$Xi\ (k) = 1 - \frac{|yi\ (k) - OB|}{\max\{\max yi\ (k) - OB, OB - \min yi\ (k)\}}$$

The purpose of Grey relational grade is to reveal the degrees of relation between the sequences say, [x0 (k) and xi (k), i = 1, 2, 3…, n]. The Grey relational coefficient can be calculated using the preprocessed sequences. The Grey relational coefficient is defined as follows

$$\xi i(k) = \frac{\min\ \Delta + \theta \max\ \Delta}{\Delta i(k) + \theta \max\ \Delta}; 0 \leq \xi i(k)$$

The Grey relational grade γi can be computed as

$$\gamma i = \frac{1}{n} \sum_{k=1}^{n} \xi i(k)$$

8.1 Grey relational analysis for MIG welding

Table 7: NM Value and Grey relational coefficient

Experiment no	Normalize value of UTS	GRC of UTS	GRG No.
1	0	0.333333	27
2	0.169884	0.375907	23
3	0.504688	0.502355	11
4	0.198566	0.384192	21
5	0.344732	0.4328	16
6	0.490899	0.495491	14
7	0.05626	0.346323	25
8	0.282956	0.410832	20
9	0.519581	0.509986	10
10	0.068946	0.349393	24
11	0.293436	0.4144	18
12	0.579702	0.543302	6

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13	0.190844	0.381925	22
14	0.287369	0.412327	19
15	0.491451	0.495762	13
16	0.052951	0.345531	26
17	0.474352	0.487497	15
18	0.502482	0.501244	12
19	0.590182	0.54956	5
20	0.546056	0.52414	8
21	0.321566	0.424292	17
22	0.546608	0.524443	7
23	0.533922	0.517556	9
24	0.868726	0.792049	2
25	0.680088	0.609822	4
26	0.85273	0.772476	3
27	1	1	1

8.2 Grey relational analysis for TIG welding

Table 8: NM Value and Grey relational coefficient

Experiment no	Normalize value of UTS	GRC of UTS	GRG No.
1	0.150238	0.370436	9
2	0	0.333333	8
3	0.349945	0.434762	7
4	1	1	1
5	0.718212	0.639559	2
6	0.672041	0.603895	4
7	0.699524	0.624628	3
8	0.606083	0.559336	6
9	0.633565	0.577078	5

8.3 Analysis of Variance for Grey Relational Grade

As we know that Analysis of variance (ANOVA) is a statistical model which can be used for find out effect of independent parameter on single dependent parameter and also it can be useful to find out the significant machining parameters and the percentage contribution of each parameter. This method is applied to analyze grey relational grade for find out effect of each parameter on multi objective optimization. By use of Minitab 16 statistical software the analyzed value of ANOVA analysis for multi objective optimization for MIG and TIG shown in Table 5 and Table 6

Table 9: Multi Objective Optimization For MIG

Source	Degree of freedom	Sum of Square	Adj SS	AdjMS	Variance ratio	P
Current	2	249.545	249.545	124.773	19.07	0.00
Feed	2	34.160	34.160	17.080	2.61	0.098
gas flow	2	153.120	153.120	76.560	11.70	0.00
Error	20	130.664	130.664	6.544		
	26	567.709				
S = 2.55816 R-Sq = 76.95% R-Sq(adj) = 70.03%						

Table 10: Multi Objective Optimization For TIG

Source	Degree of freedom	Sum of Square	Adj SS	AdjMS	Variance ratio	P
Current	2	693.32	693.32	346.66	26.46	0.005
Gas flow	2	17.75	17.75	8.87	0.68	0.558
Error	4	52.40	52.40	13.10		
Total	8	763.47				
S = 3.61949 R-Sq = 93.14% R-Sq(adj) = 86.27%						

9. Regression Analysis Equation By use of MINITAB 16 software

The regression equation For MIG
UTS = **2.4 + 0.340 Electric Current + 1.36 Feed Rate + 0.583 Gas Flow**

The regression equation For TIG
UTS = **- 17.2 + 0.436 Current - 0.88 Gas Flow**

10. Result and Conclusion

In this dissertation work, various cutting parameters like welding current, gas flow and wire feed rate have been evaluated to investigate their influence on MIG welding and TIG welding process. Based on the result obtained, it can be concluded as follows:

By use of ANOVA analysis the percentage contribution of MIG welding for welding current is **43.9565%**, gas flow of **26.9715%** and wire feed rate of **6.0172%** and the error is of **23.0548%**. This error is due to human ineffectiveness and machine vibration. By use of ANOVA analysis the percentage contribution of TIG welding for welding current is **83.4019%** and gas flow of **9.7966 %** and the error is of **6.8015%**. This error is due to human ineffectiveness and machine vibration. From the ANOVA it is conclude that the welding current is most significant parameter for both MIG and TIG welding. Welding current is found to have effect on UTS. Increase in welding current, the value of UTS is increase in both welding. By use of GRA optimization technique the optimal parameter combination is meeting at experiment 27 for MIG welding. By use of GRA optimization technique the optimal parameter combination is meeting at experiment 7 for TIG welding and the combinations for MIG Welding Current (155 Amp), Feed rate (11 ft/min),Flow Of Shielding gas (25 lit/min) and For TIG Welding Current (225 Amp), Flow Of Shielding gas (6 lit/min).

11. Future Scope

As is known, there is always some future scope of any research work. For the present work, the futuristic proposal of work to be included is summarized as under.

- In the present work only three process parameters were used. However, Voltage and welding Speed was not included in this model used for optimization. It is proposed to develop a model which correlates the Ultimate tensile strength (UTS) with the process parameters namely – Current, Gas Flow Rate, Feed rate, voltage.
- In the present work, the welding has been carried out on Aluminum. As a futuristic scope of this work, it is proposed to go for any other base material.

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