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

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Abstract:
Welding is a manufacturing process, which is carried out for joining of metals by Metal Inert Gas (MIG) welding and Tungsten Inert Gas (TIG) Welding. All welds will be prepared by MIG and TIG welding technique. I have studied Design of Experiment method (Full factorial method) for this work and by use of the experimental data have optimized by grey relational analysis (GRA) optimization technique. In which input parameters for MIG welding are welding current, wire diameter and wire feed rate and the output parameter is hardness. Also the input parameters for TIG welding are welding current, wire diameter and the output parameter is hardness. We were used AISI 1020 or C20 material for welding. It is a plain carbon steel and also known as "soft" or mild steel. Small scale trial welding experiments, in the light of field joint of plate have been planned to perform on 5 mm plate thicknesses of low alloy steel AISI 1020 or C20 and double V-groove joint is used. For Experimental design we were used full factorial method ($L=m^n$) to find out number of readings. To find out percentage contribution of each input parameter for obtaining optimal conditions, we were used analysis of variance (ANOVA) method. We take a grey relational analysis (GRA) optimization technique for optimization of different values. A grey relational grade obtained from the grey relational analysis is used to optimize the process parameters. By analyzing the Grey relational grade we find the optimum parameters.

Keywords: *ANOVA, Grey relational analysis, Hardness, MIG Welding, TIG Welding*

1. Introduction

Welding is used as a fabrication process in every industry large or small. It is a principal means of fabricating and repairing metal products. The process is efficient, economical and dependable as a means of joining metals. This is the only process which has been tried in the space. The process finds its applications in air, underwater and in space. Why welding is used, because it is suitable for thicknesses ranging from fractions of a millimeter to a third of a meter and Versatile, being applicable to a wide range of component shapes and sizes. Uger esme, Mehim bayramoglu (2009) have used AISI 304 Stainless steel plate. TIG welding machine is used. The input parameters are travel speed, current, nozzle plate distance. The output parameters are bead penetration and tensile load. He is used ANOVA and GRA method. Ehsan Gharibshahiyan (2011) has investigated the effect of welding parameters and heat input on the HAZ and grain growth, the role of grain size on hardness and toughness of low carbon steel has also been studied, it was observed that, at high heat input, coarse grains appear in the HAZ which results in lower hardness values in this zone. For example raising the voltage from 20 to 30 V decreased the grain size number from 12.4 to 9.8 and hardness decreased from 160 to 148 HBN. High heat input and low cooling rates produced fine austenite grains, resulting in the formation of fine grained polygonal ferrites at ambient temperature. Abdul Ghalib (2012) has investigated, As a result, it obvious that increasing the parameters value of welding current increased the value of depth of penetration. Other than that, arc voltage and welding speed is another factor that influenced the value of depth of penetration. The microstructure has shown the different grain boundaries of each parameter that affected of the welding parameters. Erdal Karadeniz (2007) has investigated, As a result of this study; it was obvious that increasing welding current increased the depth of penetration. In addition, arc voltage is another parameter in incrimination of penetration. However, its effect is not as much as current. The highest penetration was observed in 60 cm/min welding current.

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 factorial design, and used **full factorial design**. For a full factorial design, if the numbers of levels are same then the possible design N is

$$N = L^m \quad \dots (1)$$

Where, L = number of levels for each factor, and m= number of factors.

2.1 DOE for MIG welding

2.1.1 Factors and their levels in MIG welding:

Table 1 Factors and their levels in MIG welding

Process parameter	Process designation	Level 1	Level 2	Level 3
Welding current (Amp)	A	100	140	180
Wire diameter (mm)	B	0.8	1	1.2
Wire feed rate (m/min)	C	2	3	4

In machining process, Surface finish is one of the most significant technical requirements of the customer. A reasonably good surface finish is desired to improve the tribological properties, fatigue strength, corrosion resistance and aesthetic appeal of the product. Nowadays, manufacturing industries specially concerned to dimensional accuracy and surface finish. H. Yanda, et al, (2010) has investigated, optimum Ra and MRR are obtained at highest level of cutting speed, whereas the optimum value of a given control factor tool life is lower level of cutting speed. Anyway, the optimum condition for MRR is resulted at cutting speed of 360 m/min, feed rate of 0.5 mm/rev. The optimum surface roughness is resulted at cutting speed of 360 m/min, feed rate of 0.2 mm/rev, and for the optimum tool life is resulted at cutting speed of 220 m/min, feed rate of 0.2 mm/rev. M. Naga Phani Sastry and. K. Devaki Devi (2011) has found that feed and depth of cut have more significant effect while speed has less significant effect on MRR and feed and depth of cut has equal significance on surface roughness (Ra). M. Kaladhar, et al (2012) observed that feed plays an important role in both minimization of surface roughness and maximization of MRR. The ANOVA and F-test revealed that the feed is the dominant parameter followed by nose radius for surface roughness. In case of MRR response, the depth of cut is the dominant one followed by the feed.

The aim of this experimental investigation is to evaluate the effects of the process parameters on AISI 316 austenitic stainless steel work piece surface roughness and material removal rate by employing design of experiment using L_{27} array and Analysis of Variance (ANOVA) using PVD coated Cermets tool on CNC lathe under dry environment. The AISI 316 austenitic stainless steel is the most widely used grade among the other grades of austenitic stainless steel. It is used for aerospace components and chemical processing equipment, for food, dairy, and beverage industries, for heat exchangers, and for the milder chemicals.

2.2 DOE for TIG welding

2.2.1 Factors and their levels in TIG welding:

Table 2 Factors and their levels in TIG welding

Process parameter	Process designation	Level 1	Level 2	Level 3
Welding current (Amp)	A	85	100	115
Wire diameter (mm)	B	0.8	1	1.2

From the above table according to design of experiments with full factorial design total numbers of experiments to be performed are 27.

Table 3 Data obtained from experimental work for hardness (MIG)

Welding current (Amp)	Wire diameter (mm)	Wire feed rate (m/min)	Hardness (BHN)
100	0.8	02	109
100	1	02	109
100	1.2	02	111
100	0.8	03	120
100	1	03	110
100	1.2	03	108
100	0.8	04	112
100	1	04	111
100	1.2	04	113
140	0.8	02	132
140	1	02	133
140	1.2	02	135
140	0.8	03	124
140	1	03	131
140	1.2	03	130

Welding current (Amp)	Wire diameter (mm)	Wire feed rate (m/min)	Hardness (BHN)
140	0.8	04	126
140	1	04	132
140	1.2	04	133
180	0.8	02	136
180	1	02	138
180	1.2	02	142
180	0.8	03	139
180	1	03	143
180	1.2	03	140
180	0.8	04	139
180	1	04	140
180	1.2	04	142

Table 4 Data obtained from experimental work for hardness (TIG)

Welding current (Amp)	Wire diameter (mm)	Hardness (BHN)
85	0.8	118
85	1	120
85	1.2	124
100	0.8	122
100	1	126
100	1.2	131
115	0.8	129
115	1	137
115	1.2	138

3. Experimental Set Up

In order to achieve the goal of this experimental work the welding were carried out in an INMIG-250i welding machine. Curent-50-250 Amp DCEP, ER 70 S-6 electrode, Volatge-17-27 volts. For TIG welding Saviour 150H welding machine is used. Voltage - 230 V AC, Curent-100-350 Amp, Electrode-Tungsten.

3.1 Work piece material

- Plain carbon steel AISI 1020 or C20
- Material thickness is 5 mm.

Table 5 Chemical compositions

Elements	C	Mn	S	P	Si	Al	Ni
Wt.%	0.123	0.9	0.008	0.013	0.013	0.045	0.004

3.2 Selection of weld joint

For 5 mm double V-groove weld joint design is selected.

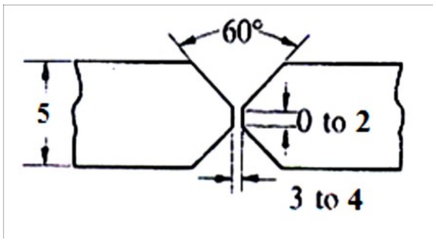

Fig. 1 Weld joint configurations for experiments

4. ANOVA Analysis

Table 6 ANOVA analysis of MIG welding

Parameter	Process Parameter	Variance	Test F	% of Contribution
A	Welding current	1895.44	169.039	94.01
B	Wire diameter	8.105	0.723	0.40
C	Wire feed rate	0.325	0.029	0.016
Error		11.213	1	5.56

Table 7 ANOVA analysis of TIG welding

Parameter	Process Parameter	Variance	Test F	%of Contribution
A	Welding current	148.775	53.51	73.36
B	Wire diameter	48.445	17.42	23.90
Error		2.78	1	2.74

5. Main effect plots for ANOVA

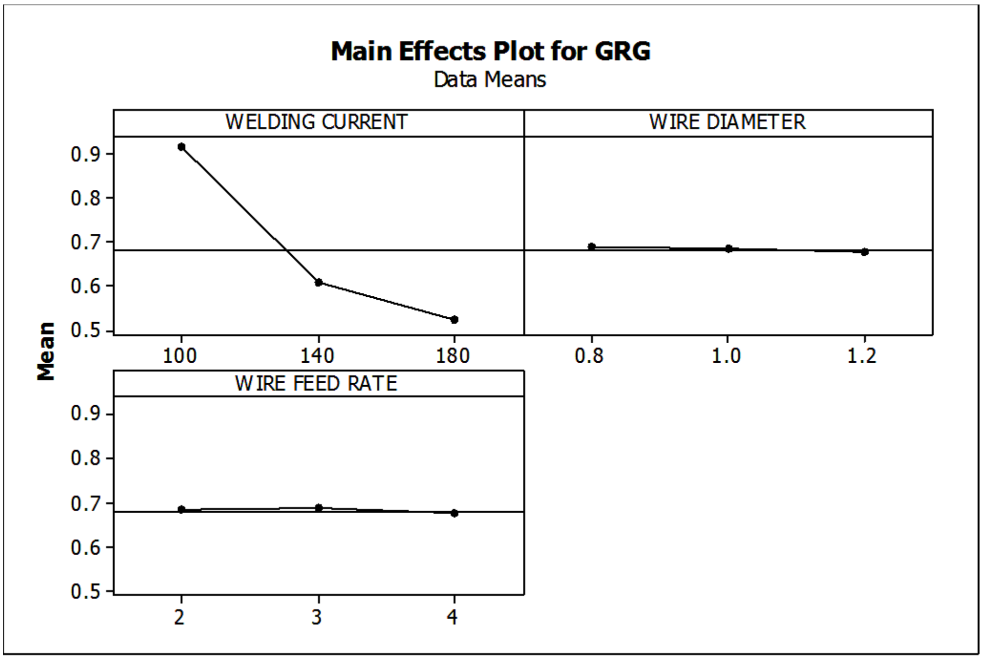

Fig. 2 Main effect plot of GRG for MIG welding

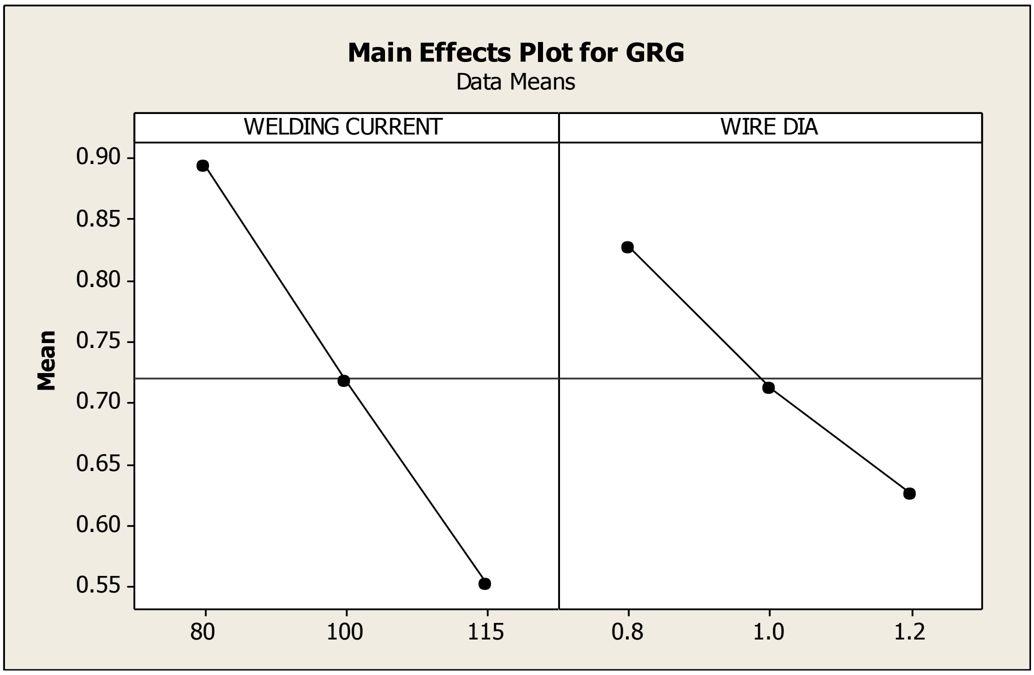

Fig. 3 Main effect plot of GRG for TIG welding

6. Grey Relational Analysis

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

$$Xi(k) = \frac{\max yi\,(k) - yi(k)}{\max yi(k) - \min yi(k)} \qquad \text{... (2)}$$

For Higher-the-Better (HB) criterion, the normalized data can be expressed as:

$$Xi(k) = \frac{yi(k) - \min yi\,(k)}{\max yi(k) - \min yi(k)} \qquad \text{… (3)}$$

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.

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 $\xi i(k)$is defined as follows

$$\xi i(k) = \frac{\min\Delta + \theta\max\Delta}{\Delta i\ (k) + \theta\max\Delta}; \quad 0 \le \xi i(k) \le 1 \qquad \text{... (4)}$$

Where Δi=$|x0(k) - xi(k)|$ =difference of the absolute value x0 (k) and xi (k); θ is the distinguishing coefficient 0 ≤ θ ≤ 1; $min\Delta$= ∀j $min\epsilon$i ∀k $min|x0(k) - xj(k)|$=the smallest value of Δ0i; and $max\Delta$= ∀j $max\epsilon$i ∀k max= largest value of Δ0i. After averaging the grey relational coefficients, the grey relational grade γi can be computed as:

$$yi = \frac{1}{n}\sum_{k=1}^{n} \xi i\ (k) \qquad \text{... (5)}$$

Where n = number of process responses. The higher value of grey relational grade corresponds to intense relational degree between the reference sequence x0 (k) and the given sequence xi (k).

The reference sequence x0 (k) represents the best process sequence. Therefore, higher grey relational grade means that the corresponding parameter combination is closer to the optimal.

Table 6 Grey relational analysis for MIG welding

Experiment No.	Normalize value of Hardness	GRC of Hardness	GRG No.
1	0.971	0.971	02
2	0.971	0.971	02
3	0.914	0.920	04
4	0.657	0.744	07
5	0.942	0.945	03
6	01	01	01
7	0.885	0.896	05
8	0.914	0.920	04
9	0.857	0.874	06
10	0.314	0.593	12
11	0.285	0.583	13
12	0.228	0.564	14
13	0.542	0.658	08
14	0.342	0.603	11
15	0.371	0.613	10
16	0.485	0.660	09
17	0.314	0.593	12
18	0.285	0.583	13
19	0.200	0.555	15
20	0.142	0.538	16
21	0.0285	0.507	19
22	0.114	0.550	17
23	00	0.500	20
24	0.085	0.522	18
25	0.114	0.530	17
26	0.085	0.522	18
27	0.0285	0.507	19

Table 7 Grey relational analysis for TIG welding

Experiment No.	Normalize value of Hardness	GRC of Hardness	GRG No.
1	01	01	01
2	0.9	0.909	02
3	0.7	0.769	04
4	0.8	0.833	03
5	0.6	0.714	05
6	0.35	0.606	07
7	0.45	0.645	06
8	0.05	0.512	08
9	00	0.500	09

Table 8 ANOVA of Grey relational grade of MIG welding

Source	Degree of freedom DF	Sum of Square SS	Adj SS	Adj MS	Variance ratio F	P
Welding current	2	0.76620	0.76620	0.38310	129.44	0.000
Wire diameter	2	0.00076	0.00076	0.00038	0.13	0.880
Wire feed rate	2	0.00047	0.00047	0.00024	0.08	0.923
Error	20	0.05919	0.5919	0.00296		
Total	26	0.82663				
R-Sq = 92.84%					R-Sq(adj) = 90.69%	

Table. 9 ANOVA of Grey Relational Grade of TIG Welding.

Source	Degree of freedom DF	Sum of Square SS	Adj SS	Adj MS	Variance ratio F	P
Welding current	02	0.173787	0.173787	0.086893	71.91	0.001
Wire diameter	02	0.060984	0.060984	0.30492	25.23	0.005
Error	04	0.004834	0.004834	0.001208		
Total	08	0.239605				
R-Sq = 97.98%					R-Sq(adj) = 95.97%	

7. Regression Analysis Equations

By use of MINITAB 16 software I found the regression analysis equation.

Regression analysis of hardness for MIG welding

REGRESSION EQUATION:

HARDNESS = 73.8889 + 0.355556 WELDING CURRENT + 0.833333 WIRE DIAMETER + 0.944444 WIRE FEED RATE.

Regression analysis of GRG for MIG welding

REGRESSION EQUATION:

GRG = 1.41378 - 0.00490278 WELDING CURRENT - 0.0325 WIRE DIAMETER - 0.00411111 WIRE FEED RATE.

Regression analysis of hardness for TIG welding

REGRESSION EQUATION:

HARDNESS = 68.509 + 0.393694 WELDING CURRENT + 20 WIRE DIAMETER.

Regression analysis of GRG for TIG welding

REGRESSION EQUATION:

GRG = 2.17439 - 0.00967117 WELDING CURRENT - 0.5025 WIRE DIAMETER.

8. Result and Conclusion

In this dissertation work, various cutting parameters like, welding current, wire diameter and wire feed rate have been evaluated to investigate their influence for MIG welding and TIG welding. 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 94.01 %, wire diameter of 0.402 % and wire feed rate of 0.016 % and the error is of 5.56 %. 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 73.36 % and wire diameter of 23.90 % and the error is of 2.74 %. 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 MIG and TIG welding.
- Welding current is found to have effect on hardness. Increase in welding current, the value of hardness is increase in both welding.
- By use of GRA optimization technique the optimal parameter combination is meeting at experiment 6 and its parameter value is 100 Amp welding current, 1.2 mm wire diameter and 3 m/min wire feed rate for MIG welding.
- By use of GRA optimization technique the optimal parameter combination is meeting at experiment 1 and its parameter value is 80 Amp welding current and 0.8 mm wire diameter for TIG welding.

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