Optimization of MIG welding process parameters for hardness and strength of welding joint using Grey relational analysis

D.Bahar[1], Md. Nawaz Sharif[2], K. Shravan Kumar[3] and D. Reddy[4]

[1, 2, 3 & 4] *Department of Mechanical Engineering, Rajiv Gandhi University of knowledge technologies Basar, Nirmal (TS)-504107*
Email: *dilbahar_me_iitd@rgukt.ac.in*[1]

Abstract- Aim of this communication is to investigate the process parameters of Metal inert gas (MIG) welding to optimize the hardness and ultimate tensile strength (UTS) of a weld bead formed between dissimilar materials: mild steel (MS 1020) and stainless steel (SS 316) using Taguchi technique and Grey relational analysis. By inducing 4 levels of process parameters: arc voltage, welding speed, gas flow rate and wire feed rate 16 experiments are conducted and consequently L 16 orthogonal array is constructed. Subsequently MINITAB software is employed to analyze and optimize the experiments. Through analysis of variance (ANOVA) contribution and effect of individual parameter is also investigated.

Index Terms: MIG welding, Taguchi, Grey Relational analysis, ANOVA, S/N ratio, UTS, MS 1020, SS 316

1. INTRODUCTION

Metal Inert Gas (MIG) welding is one of the arc welding process, also known as Metal Active Gas (MAG) and Gas Metal Arc Welding (GMAW) broadly used for welding a variety of ferrous and non ferrous materials. In MIG welding source of heat for melting the plates is produced by maintaining the arc between the plates those are to be welded and consumable electrode which is to be continuously fed through the spool and the rollers. The weld pool is protected by externally supplied shielding gas. The variety of shielding gases used in mig welding are carbon-di-oxide, argon and mixture of argon and helium are used. There is no requirement of additional filler metal in MIG electrode itself acts as the filler metal. MIG welding process takes place in three steps heating, melting and solidification of plates including melting and solidification of electrode, which forms the bond between the plates. A photographic view of an automatic MIG welding machine is shown in Fig. 1 on which experiments are performed.

Figure 1: Automatic MIG welding machine

1.1 Working principle

In MIG welding the electrode in the form of coil continuously feed towards the workpiece during the process. At the same time inert gas (e.g. argon, helium or CO2) is

International Journal of Research in Advent Technology, Vol.6, No.5, May 2018
E-ISSN: 2321-9637
Available online at www.ijrat.org

passed around electrode from the same torch. Usually argon, helium, or a suitable mixture of these is used as a inert gas to protect the weld pool from atmosphere. When gas is supplied, it gets ionized and an arc is initiated in between electrode and work piece results in to production of heat. Electrode melts due to the heat and molten filler metal falls on the heated joint. Continuous welding with coiled wire results in high metal depositions rate and high welding speed. In general, filler wire is connected to the positive terminal of DC source forming one of the electrodes and workpiece is connected to the negative terminal. The power source could be constant voltage DC power source with electrode positive which yields a stable arc and smooth metal transfer with less spatter for the entire current range. The gas shield around it does not ionized, which prevents weld against atmospheric contamination and surface oxidation.

1.2 Effecting Parameters in MIG welding

Weld quality and deposition rates are affected by the following welding parameters:

- Electrode size, Welding current, Arc voltage
- Arc travel speed, welding position
- Gas Flow rate, Shielding Gas composition
- Electrode extension

Electrode diameter influences the weld bead configuration, the depth of penetration, bead width and welding speed. As a general rule, for the same welding current and wire feed speed setting the arc becomes more penetrating as the electrode diameter decreases. Commonly used electrode sizes are (mm): 0.8, 1.0, 1.2,1.6 and 2.4. The level of welding current used in MIG has the highest effect on the deposition rate, the weld bead size, shape and penetration. In MIG welding, metals are usually welded with direct current electrode positive (DCEP), opposite to TIG welding because it facilitates the maximum heat input to the electrode results in to high deposition rate. Keeping all the other welding parameters constant, increase in current will increase the depth and the width of the weld penetration as well as the size of the weld bead. The arc voltage is one of the most crucial parameter in MIG welding. When all other variables: electrode composition and sizes, the type of shielding gas and the welding technique are same, arc length is directly related to the arc voltage. Excessively high and low voltage causes an unstable arc. On one hand excessive voltage causes the formation of excessive spatter and porosity. On the other hand low voltage causes porosity and overlapping at the edges of the weld bead. Value of arc voltage to be used, depends on base metal thickness, type of joint, electrode composition and size, shielding gas composition, welding position, type of weld etc. The main function of shielding gas is to protect the arc and molten weld pool from atmosphere gases (oxygen and nitrogen). If weld pool not protected properly then formation of oxides and nitrites will take place which are responsible for weld deficiencies such

as porosity, slag inclusion and weld embrittlement. Therefore shielding gas and its flow rate have a significant effect on Arc characteristics, penetration, Mode of metal transfer and weld bead profile, cleaning action of weld bead, speed of welding, weld metal mechanical properties. Generally Argon, helium and argon-helium mixtures are used in wider applications for welding of non-ferrous metals and alloys. CO_2 and Argon are used in Carbon steel. The welding speed is the rate at which arc travels along the work- piece. For a constant given current, slower welding speed proportionally provides larger bead and higher heat input to the base metal owing to longer heating time. The welding speed is a crucial parameter in MIG welding should be decided by the operator in accordance with the joint fit-up, thickness of the metal being welded and welding position.

1.3 Optimization

Taguchi Technique

Taguchi technique is a statistical tool designed by Taguchi and Konishi. Taguchi technique identifies proper control factors to obtain the optimum results of the process. Orthogonal Arrays (OA) are employed to perform a set of experiments to analyze the data.

Analysis of S/N ratio:

In Taguchi technique, the term 'signal' represents the desirable value for the output characteristic and the term 'noise' represents the undesirable value for the output characteristic. S/N ratios for different conditions are:

1. Nominal is the best characteristic

$$S / N = 10 \log_{10}\left(\frac{\bar{y}}{s_y^2}\right) \text{...(1)}$$

2. Smaller is the best characteristic

$$S / N = - 10 \log_{10}\left(\frac{\sum y^2}{n}\right) \text{...(2)}$$

3. Larger the better characteristics

$$S / N = -10 \log_{10}\left(\frac{1}{n}\sum \frac{1}{y^2}\right) \text{...(3)}$$

Where; n is the number experiments performed and y is the output response obtained by the experiment.

Analysis of Variance:

The purpose of ANOVA is to investigate which parameter significantly affects the performance characteristics. And also calculates the percentage of influence of each parameter on different responses.

Grey Relational Analysis:

This technique converts the multiple performance characterictics into single performance characteristics and simplifies the optimization process.

International Journal of Research in Advent Technology, Vol.6, No.5, May 2018
E-ISSN: 2321-9637
Available online at www.ijrat.org

Grey relational analysis and data preprocessing:

In Grey Relational analysis, the first step is data pre-processing to avoid the problem of different scales, units and targets. The following steps are followed in GRA

- Experimental data are normalized in the range between zero and one.
- On the basis of normalized experimental data grey relational coefficients are calculated.
- The Grey relational grades are computed by averaging the weighted grey relational coefficients corresponding to each performance characteristic.
- Then optimal levels of process parameters are selected.

Normalization:

In the analysis of grey relation for 'higher is better' response normalization done by equation (4) and when the response is 'lower is better', normalization done by equation (5).

$$X_i^*(k) = \frac{X_i(k) - X_i \min(k)}{X_i \max(k) - X_i \min(k)} \dots (4)$$

$$X_i^*(k) = \frac{X_i \max(k) - X_i(k)}{X_i \max(k) - X_i \min(k)} \dots (5)$$

Where;

$X_i^*(k)$ and $X_i(k)$ are the normalized data and observed data, respectively, for i^{th} experiment using K^{th} response. The smallest and largest values $X_i(k)$ in the Kth response are $X_i \min(k)$ and $X_i \max(k)$, respectively.

Determination of grey relation coefficient:

After pre-processing the data, the grey relation coefficient (GRC) $\zeta_i(k)$ for the Kth response characteristics in the ith experiment can be expressed as following:

$$\zeta_i(k) = \frac{\Delta \min + \zeta \Delta \max}{\Delta_i(k) + \zeta \Delta \max} \dots (6)$$

where;

$X_0^i(k)$ = denotes reference sequence , $X_j^*(k)$ = denotes the comparability sequence

$\varsigma \in [0,1]$, is the distinguishing factor; 0.5 is widely accepted.

$\Delta_i = |X_0^*(k) - X_j^*(k)|$ = differnece in absolute value between $X_0^*(k)$ and $X_j^*(k)$

$\Delta_{min} = \min_{(j \in i)} \min_{(k)} |X_0^*(k) - X_j^*(k)|$ = smallest value of Δ_i.

$\Delta_{max} = \max_{(j \in i)} \max_{(k)} |X_0^*(k) - X_j^*(k)|$ = largest value of Δ_i.

Calculation of grey relational grade:

After calculating GRC, the grey relational grade (GRG) is obtained as:

$$\gamma_i = \left(\frac{\sum w \times \zeta_i(k)}{m} \right) \dots (7)$$

Here γ_i is the Grey Relational Grade, n is the number of responses, m is the number of run and w is the weight factor. Amount of influence of a response can be controlled in deciding the optimum machining parameters varying the

value of w keeping in mind $\sum_1^n w$ should be equal to 1.

Singh and Dhami [1] analysed the defects in metal inert gas welding Of A312tp316l stainless steel pipe using Taguchi technique by considering current, voltage and welding speed and observed that voltage contributes major proportion for the quality of weld bead.

Mishra , Panda and Mohanta [2] Optimized the process parameters in MIG welding for high depth of penetration on the basis of process parameters: welding current, welding voltage and welding speed.

Sheik and Achwal [3] studied the effect of MIG welding process parameters on weldability of Galvenize steel. welding current ,welding voltage, welding speed were considered as input parameters and out put responses were penetration,bead width and heat generation.

Arya and Chaturvedi [4] studied the influence of welding parameters like wire diameter, welding current, arc voltage, welding speed, and gas flow rate. 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

Rizvi and Tewari [5] performed experiments for parametric optimization of welding parameters such as arc voltage, wire feed speed and shielding gas flow rate for IS 2062 structural steel using Taguchi method and Grey relational analysis for tensile strength, Micro hardness, toughness, and Micro structure.

Pal and Handuja [6] observed the effect of different welding parameters: welding voltage, filler wire rate and v-angle etc. on the strength of the weld joint and elongation produced during the tensile test. They found that that the most significant parameter which affects UTS value of welding joint is V- butt angle and the least significant is wire feed rate

Chavda et al. [7] Observed the influence of welding parameters like welding current, welding voltage, Gas flow rate, wire feed rate, etc. on weld strength, weld pool geometry of Medium Carbon Steel material during welding.

Patel and Chaudhary [8] made review on optimization of mechanical properties and found that various parameters affect the hardness and ultimate tensile strength of AISI 1020.

Kumar and Brar [9] investigated to find the best process parameters: welding current, voltage, welding speed and number of passes for hardness and residual stresses.

Gangadhar et al. [10] performed MIG welding on mild steel pieces to optimize the hardness and tensile strength of the joint. It was found that that Increase in current and weld speed increases the ultimate tensile strength and hardness of welded joint.

2. MATERIALS AND METHODS

Step-I: 16 pieces of SS 316 and MS 1020 having same and

International Journal of Research in Advent Technology, Vol.6, No.5, May 2018
E-ISSN: 2321-9637
Available online at www.ijrat.org

proper dimensions are prepared. Chemical composition of SS 316 and MS 1020 is given in Table 1

Table 1: Chemical composition of used materials

SS 316		MS 1020	
Element	Content	Element	Content
Carbon,C	<0.03%	Carbon,C	0.17-
Iron,Fe	16-18%		0.230%
Nickel,Ni	20-14%	Iron,Fe	99.08-
Molybdynum, Mo	2-3%		99.53%
Manganeese, Mn	<2%	Manganese,Mn	0.30-
Silicon,Si	<1%		0.60%
Phosphorous,P		Phosphorous,P	<0.05%
<0.045%		Sulfur,S	<0.06%
Sulfur,S	<0.03%		

Step II: In welding operation some parameters kept constant and some of the parameters are varied (in 4 leveles) as given in Table 2

Fixed parameters:
      a) Welding current (varied accordingly voltage 120-270 amp)
      b) Electrode diameter (1.2mm)
      c) Arc length (1.2-1.5 cm)

Step III: Hardness and Tensile tests are conducted on the welded pieces (shown in Fig. 2) to know the ultimate tensile strength (UTS) and hardness of welded joints. Results of UTS and hardness (RHC) are tabulated in Table 3.

Table 2: varied parameters with their levels

Varied parameters	Level	Level	Level	Level

	1	2	3	4
Welding speed, S (mm/min)	100	200	300	400
Arc voltage, V (V)	20	25	30	35
Gas flow rate, GFR (mm^3/min)	12	15	18	21
Wire feed rate, WFR (m/min)	3	4	5	6

Table 3: L 16 Orthogonal array along with results

Exp.	V	GFR	WFR	S	U.T.S (MPa)	RHC
1	20	12	3	100	164.96	55
2	20	15	4	200	66.02	50
3	20	18	5	300	97.7	67
4	20	21	6	400	135.29	51
5	25	12	4	300	224.4	50
6	25	15	3	400	201.5	55
7	25	18	6	100	163.31	54
8	25	21	5	200	163.31	53
9	30	12	5	400	232.66	46
10	30	15	6	300	202.85	40
11	30	18	3	200	135.85	56
12	30	21	4	100	163.36	57
13	35	12	6	200	233.21	38
14	35	15	5	100	203.13	47
15	35	18	4	400	165.25	57
16	35	21	3	300	97.88	50

International Journal of Research in Advent Technology, Vol.6, No.5, May 2018
E-ISSN: 2321-9637
Available online at www.ijrat.org

Figure 2: Based upon L 16 orthogonal array 16 welding experiments are performed

3. RESULTS AND DISCUSSION

From Table 3, values are employed in MINITAB software to analyze the main effect of S/N ratios and optimal conditions. Fig. 3 shows the main effect plot for S/N ratios and Table 4 presents the analysis of variance of hardness.
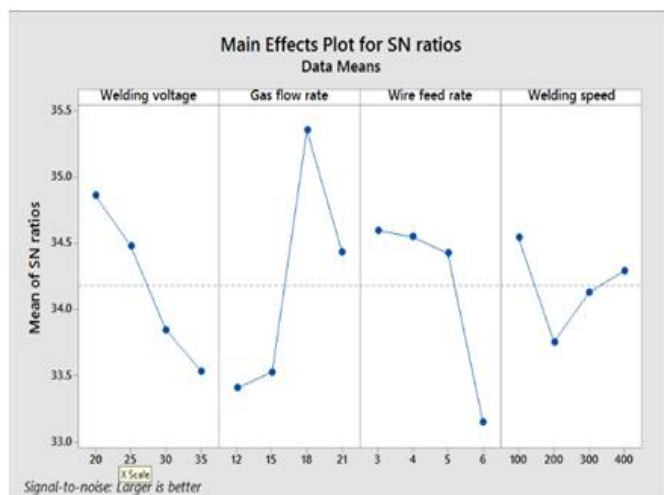

Figure 3: Main effect plot for S/N ratios of hardness

Table 4: ANOVA for Hardness

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Welding voltage	3	0.000000	20.61%	0.000000	0.000000	65.24	0.003
Gas flow rate	3	0.000000	39.09%	0.000000	0.000000	123.75	0.001
Wire feed rate	3	0.000000	31.84%	0.000000	0.000000	100.80	0.002
Welding speed	3	0.000000	8.16%	0.000000	0.000000	25.82	0.012
Error	3	0.000000	0.32%	0.000000	0.000000		
Total	15	0.000000	100.00%				

In this study lager value of hardness is desirable and higher S/N ratios indicate optimal condition. Therefore optimal process parameters for hardness are evaluated and presented in Table 5. From Table 4, it is also clear that contribution of gas flow rate is higher (39.09%) and of welding speed is lower (8.16%). Error contribution is only 0.32% which vindicates a robust design of experiment.

Table 5: Optimal setting of Process parameters for hardness

Parameter	Levels	values
Welding voltage(v)	1	20
Gas flow rate(lit/min)	3	18

International Journal of Research in Advent Technology, Vol.6, No.5, May 2018
E-ISSN: 2321-9637
Available online at www.ijrat.org

Wire feed rate(m/min)	1	3
Welding speed(mm/min)	1	100

From Table 5 it can be inferred that except gas flow rate all other parameters should be low for optimum hardness. Like for hardness, similar analysis is performed for ultimate tensile strength (UTS). Fig. 4 shows the main effect plot for S/N ratios and Table 6 presents the analysis of variance of hardness.
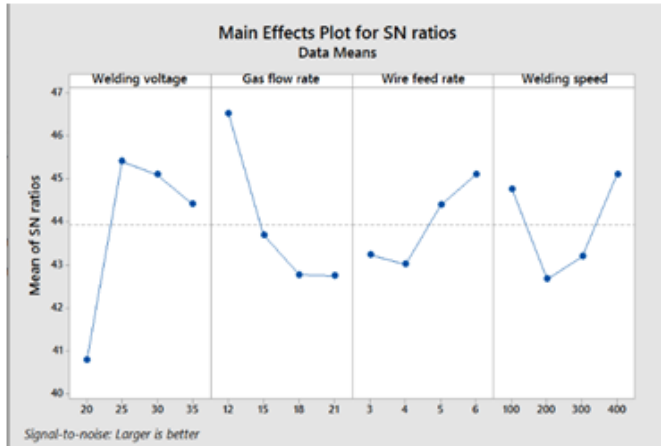

Figure 4: Main effect plot for S/N ratios of UTS

Table 6: ANOVA for UTS

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Welding voltage	3	12798	27.97%	12798	4265.9	7.55	0.065
Gas flow rate	3	25612	55.98%	25612	8537.2	15.11	0.026
Wire feed rate	3	3988	8.72%	3988	1329.4	2.35	0.250
Welding speed	3	1660	3.63%	1660	553.2	0.98	0.507
Error	3	1695	3.70%	1695	564.9		
Total	15	45752	100.00%				

In this study lager value of UTS is desirable and higher S/N ratios indicate optimal condition. Therefore optimal process parameters for toughness are evaluated and presented in Table 7. From Table 6, it is also clear that contribution of gas flow rate is higher (55.98%) and of welding speed is lower (3.63%). Error contribution is about 3.70% which vindicates a robust design of experiment.

Table 7: Optimal setting of Process parameters for UTS

Parameter	Levels	values
Welding voltage(v)	1	20
Gas flow rate(lit/min)	1	12
Wire feed rate(m/min)	4	6
Welding speed(mm/min)	4	400

From Table 5 it can be inferred that welding voltage & gas flow rate should be low for optimum UTS while wire feed rate and welding speed should be higher.

3.1 Multi response optimization

In order to optimize hardness as well as UTS, multi response optimization i.e Grey relational analysis is employed for which grey relational coefficients (GRC), grey relational grades (GRG) and ranks are calculated and presented in Table 8.

Table 8: Grey relational coefficients, grades and ranks

Exp. No	GRC (HRC)	GRC (U.T.S)	GRG	Rank
1	0.59	0.64	0.52	10
2	0.497	0.33	0.42	12
3	1	0.42	0.70	3
4	0.51	0.53	0.48	11
5	0.49	0.92	0.62	4
6	0.56	0.80	0.57	6
7	0.57	0.63	0.55	7
8	0.54	0.63	0.54	8
9	0.43	0.98	0.60	5
10	0.35	0.80	0.71	2
11	0.51	0.53	0.48	11
12	0.64	0.63	0.57	6
13	0.33	1	0.57	6
14	0.44	0.81	0.74	**1**
15	0.64	0.64	0.53	9
16	0.49	0.42	0.53	9

Grey relational grades from Table 8 are analyzed in MINTAB for multi response optimization. Fig. 5 shows the main effect plot for S/N ratios and Table 9 presents the analysis of variance.
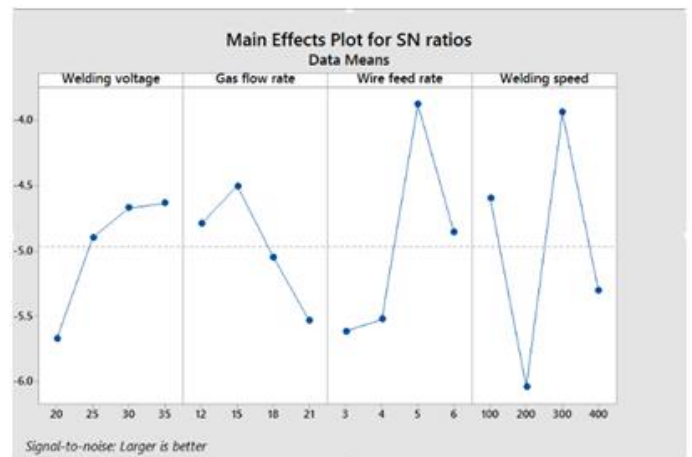

Figure 5: Main effect plot for S/N ratios for multi response

International Journal of Research in Advent Technology, Vol.6, No.5, May 2018
E-ISSN: 2321-9637
Available online at www.ijrat.org

Table 9: ANOVA for multi response

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Welding voltage	3	0.01002	8.75%	0.01002	0.003340	0.78	0.578
Gas flow rate	3	0.01312	11.46%	0.01312	0.004373	1.02	0.493
Wire feed rate	3	0.03572	31.20%	0.03572	0.011906	2.79	0.211
Welding speed	3	0.04282	37.40%	0.04282	0.014273	3.34	0.174
Error	3	0.01282	11.20%	0.01282	0.004273		
Total	15	0.11449	100.00%				

Since higher values of S/N ratios indicates optimality therefore corresponding optimal process parameters for multi response are presented in Table 10. From Table 9, it is also clear that contribution of welding speed is higher (37.40%) and of welding voltage is lower (8.75%).

Table 10: Optimal setting of Process parameters for UTS

Parameter	Levels	values
Welding voltage(V)	4	35
Gas flow rate(lit/min)	2	15
Wire feed rate(m/min)	3	5
Welding speed(mm/min)	3	300

From Table 10 it can be inferred that welding voltage should be higher for optimum UTS as well as hardness.

4. CONCLUSIONS

Following conclusions can be drawn from this study:
1. In optimization of hardness of the welding joint, contribution of gas flow rate is higher and apart from gas flow rate other parameters should be low.
2. Like for hardness, in optimization of UTS contribution of gas flow rate is higher. it is also observed that welding voltage and gas flow rate should be lower but wire feed rate and welding speed should be higher to optimize UTS.
3. In multi response optimization i.e optimization of hardness as well as UTS contribution of welding speed is higher and welding voltage should be high.

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