Grey-based Taguchi Method for Multi-Weld Quality Optimization of Gas Metal Arc Dissimilar Joining of Mild Steel and 316 Stainless Steel

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Abstract

Welding processes play a significant role in many fabrication and manufacturing industries. Among various welding processes that have been developed over the years, Gas Metal Arc Welding (GMAW) or Metal Inert Gas Welding (MIG) has received a lot of interest due to its ability to weld a variety of metallic materials, easy adaptation for automation, high deposition rate, high efficiency, and low capital requirement. This study focus on the optimization of the multi-performance characteristics of MIG welded butt joint of AISI 1008 mild steel and AISI 316 austenitic stainless steel by hybrid Grey based Taguchi method. L9 Taguchi orthogonal array was adopted for the optimization of the MIG welding current, voltage and gas flow rate. The weld joint integrity has been assessed in terms of the tensile strength, yield strength, percentage elongation and Vickers microhardness of the fusion zone. Welding current of 180 A, voltage of 14 V, and gas flow rate of 19 l/min were obtained as the optimal parameter setting for the MIG welding process. The tensile strength, yield strength, percentage elongation and hardness of 559.25 MPa, 382.22 MPa, 33.34 %, and 250.63 HV respectively were obtained at the optimal setting. Voltage was the most significant process parameter with 63.76 % contribution for the multi-performance of the weldments. The confirmatory test was performed to validate the optimization process which proved Grey based Taguchi method to be an easy but yet effective method for multi-performance characteristics optimization of welded joints.

Keywords: Welding; Taguchi optimization; Grey-relational analysis; multi-performance characteristics

1. Introduction

Welding is a well-known manufacturing process. It is a permanent joining similar or dissimilar materials usually by the application of heat. A filler material which may or may not be of the same material with the base materials is often used to facilitate the joining process [1]. Welding technology has evolved over the year's dues its numerous applications in industries. Among various welding processes developed over the years, gas metal arc welding (GMAW) has received wide interest due to its capability in welding of a wide range of materials such as nickel, carbon steel, stainless steel, low alloy steel, aluminium, copper and many others, high deposition rate, ability to be automated, high speed, lower cost and versatility [2,3]. In GMAW, welding is created by the heat of the arc generated between the continuously fed welding wire and the workpiece. Although welding of similar materials is less challenging due to differences in metallurgical, chemical and thermal properties in dissimilar welding of materials, so many advantages such as cost-saving and weight reduction among others make dissimilar welding very attractive in many industrial and manufacturing applications [1]. Dissimilar stainless steel and carbon steel welded components for instance is applied in petrochemical and power generation industries in the fabrication of boilers, pressure vessels, liquid metal reactors and heat exchangers [4]. Furthermore, in heavy industrial applications such as in automobile, aerospace and shipping industries call for solutions associated with dissimilar welding of metals. This is especially true as each metal component in dissimilar welded structure has its unique benefits.

Although solid-state welding such as friction stir welding offers some advantages over fusion welding such as reduced heat-affected zone, high strength, absence of solidification cracking, low residual stress and high efficiency in welding of stainless steel and carbon steel, their high equipment cost and technical demand limit their application [5]. As a result of this, fusion welding such as gas tungsten arc welding or tungsten inert gas welding (GTAW or TIG) and gas metal arc welding (GMAW or MIG) of stainless steel and carbon steel remains an active field of research for various applications. However, the performance of welded components depends greatly on the proper selection of the process parameters. Some of these parameters in fusion welding include the welding current, arc voltage, gas flow rate, electrode-to-workpiece distance, electrode diameter, working angle, edge preparation, preheating and vibration. Selection of these parameters can be done through trial and error method or from the welder's experience. However, this approach is time-consuming and can lead to waste of resources. The approach that researchers have adopted is the optimization of these process parameters to obtain an optimal setting that would give the best weld joint performance. Taguchi optimization method has been identified as a robust technique in welding process parameter optimization [6]. However, Taguchi method is only effective in single performance optimization. For multi-performance optimization, grey-relational analysis is commonly used [7,8]. Several efforts have been made by various researchers in the optimization of fusion welding process parameters which have been examined below.

Kanakavalli et al. [3], by Taguchi method and grey relational analysis, optimized the welding current, arc voltage, welding speed and bevel angle of MIG dissimilar welding of AISI 1010 and AISI 1018 for the butt joint ultimate tensile strength and hardness. The optimal setting was observed as welding current, arc voltage, welding speed and bevel angle of 150 A, 16 V, 0.94 m/min and 45 degrees respectively. Kumar and Singh [9], optimized the MIG process parameters by grey-based Taguchi method in terms of the ultimate tensile strength and percentage elongation of butt joint welded AISI 1018 mild steel. The preheating temperature was observed in the study as the most influential parameter in the determination of the ultimate tensile strength and percentage elongation of the welded joint. AISI 310 stainless steel is one of the most widely used metals in making boilers and pressure vessels. Hence, Sankar et al. [10], by grey-relational analysis obtained the optimal welding current, voltage and gas flow rate for MIG welding of AISI 310 stainless steel in butt joint configuration. The welding current was found to have the greatest effect on the ultimate tensile strength and hardness of the weld joint. Prajapati et al. [11], reported welding voltage as the most significant parameter in the optimization of MIG cladding of low alloy steel by grey-relational analysis coupled with Taguchi method and fuzzy interference system in term of the size of the heat-affected zone, bead width and depth of penetration. Kim et al. [12], improved the ultimate tensile strength, bead width and depth of penetration in hybrid laser-MIG welding of aluminium alloy for automobile application by grey-relational analysis of the welding process parameters. Bandhu et al. [13], by Taguchi method effectively regulated the rate of metal transfer in MIG welding of ASTM 387 low alloy steel. The study observed welding current, welding voltage and gas flow rate of 100 A, 16 V and 21 l/min respectively as the optimal setting for the depth of penetration and heat-affected zone. Mahmood and Alwan [14], obtained an improvement in the hardness and bending strength of MIG welded low carbon steel joint by Taguchi method optimization of the welding current, wire feed rate and gas pressure. Sivasakthivel and Sudhakaran [15], performed multi-objective optimization in MIG welding of AISI 202 stainless steel. The process parameters optimized in the study were the welding current, welding torch angle, gas flow rate, welding speed and wire feed speed all at five levels. The arc voltage, wire feed speed and gas flow rate of MIG welding of steel pipe used for high-temperature application were optimized by Sudhakar et al. [16] in terms of the penetration shape factor, reinforcement form factor and ultimate tensile strength. Several studies have investigated the optimization of TIG welding process parameters [17–22]. In all the cases, significant improvements were observed in the response variables.

From the literature review, appreciable research effort has been made towards optimization of MIG and TIG welding processes for various response variables. However, optimization of MIG dissimilar welding of stainless steel and mild steel is very limited. This calls for more research to be carried in this area of study. This current study, therefore, seeks to optimize the MIG welding process parameters in butt joint welding of AISI 316 stainless steel and AISI 1008 mild steel in terms of the ultimate tensile strength, yield strength, percentage elongation and hardness. AISI 316 is austenitic stainless steel used for applications requiring superior corrosion resistance and sufficient strength while AISI 1008 mild steel is used in shipbuilding, tanks and boilers [23].

2. Experimental Approach

2.1 Selection of material

The materials used in this study are 6 mm thick AISI 316 austenitic stainless steel and AISI 1008 mild steel plates for MIG welding in 2.5 mm groove butt joint. 1.6 mm thick ER309LSi austenitic stainless steel welding wire was used as the filler material. The presence of silicon in the welding wire improves the fluidity of the molten metal. Table 1 and Table 2 give respectively the chemical compositions of the base metals and their mechanical properties. A mixture of argon and CO_2 was used as the shielding gas.

Table 1: Chemical composition of AISI 316 and AISI 1008

Element (wt.%)	Cr	Ni	Mn	Mo	Si	N	C	P	S	Fe
AISI 316	16.4	11.4	2.00	2.6	O.74	0.2	0.07	0.055	0.040	Bal
AISI 1008	~	~	0.220	0.007	0.03	~	0.094	0.002	0.006	Bal

Table 2: Mechanical properties of AISI 316 and AISI 1008

Base metal	Tensile Strength (MPa)	Yield Strength (MPa)	Percentage Elongation (%)

AISI 316	638.14	498.57	59.68
AISI 1008	395.93	295.95	48.13

2.2 Selection welding process parameters

The process parameters and their levels were chosen based on previous studies [3,10,11]. Welding current, welding voltage and gas flow rate at three levels were chosen for L_9 Taguchi orthogonal array. The parameters and their levels are given in Table 3.

Table 3: Welding process parameters and their levels

Symbol	Parameter	Units	Level 1	Level 2	Level 3
C	Current	Ampere (A)	120	150	180
V	Voltage	Voltage (V)	10	12	14
G	Gas flow rate	Litre/minute (l/min)	15	17	19

2.3 Welding of the material

The double-sided MIG dissimilar welding of the metal plates in butt joint was done with Miller XMT 400 Series MIG welding machine as shown in **Fig.1**.

Fig.1 MIG welding machine

2.4 Mechanical properties of the welded specimen

The output responses considered in this study for multi-performance optimization are the welded joints' ultimate tensile strength, yield strength, percentage elongation and hardness of the weld zone. The tensile properties were determined by 250 KN Zwick/Roell Z250 tensile testing machine (**Fig.2**). The ASTM-E8 tensile test specimens were cut-off from the welded samples by waterjet machining. The tensile test was repeated three times and the average is taken for each line of the Taguchi orthogonal array. The tensile test specimen is shown in Fig. 3. All dimensions are in mm. The fractured samples after the tensile test are shown in **Fig.4**.

Fig.2 Zwick/Roell Z250 tensile testing machine

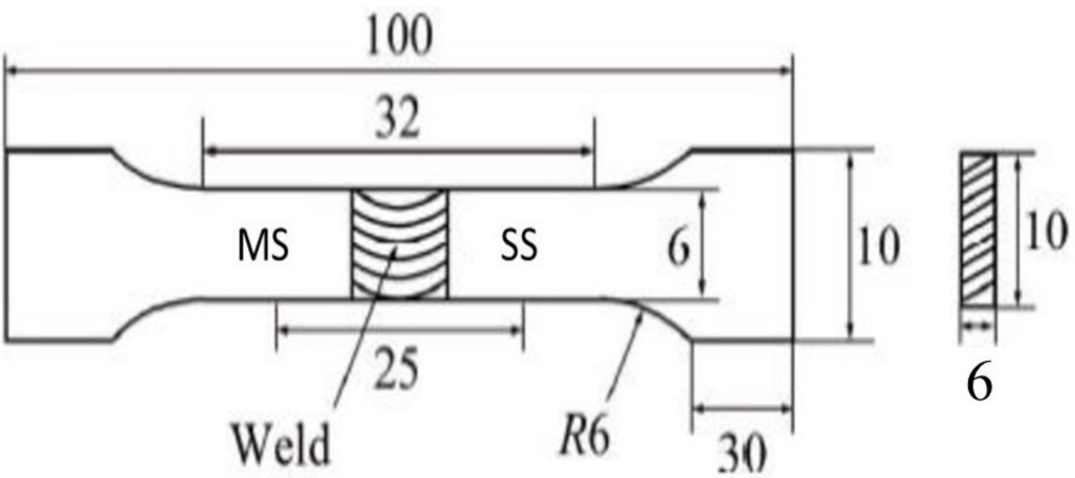

Fig.3 ASTM-E8 tensile test specimen

Fig.4 The fractured tensile specimens

The Vickers microhardness hardness of the weld zone was determined following ASTM standard E384 with a sample size of 20 x 10 mm by hardness testing machine shown in **Fig.5**. Standard metallographic sample preparation was followed to obtain a plain surface for the hardness test. This involved mechanical grinding with abrasive silicon carbide papers of 200-4000 grit size until the surfaces of the became plain. The samples were hot mounted on polyfast resin in such a way as to expose the transverse section of the weld bead for easy handling. An indentation force, dwell time and spacing between indentation of 500 gf, 10 s and 1 mm respectively were chosen for the hardness test. Many indentations were done on the weld zone for each line of the experiment and the average taken as the hardness value.

Fig.5 Microhardness testing machine

3. Optimization techniques

3.1 Taguchi Method

The Taguchi method was named after Japanese quality manager who is also an engineer and statistician [3]. Since its development, various fields of study have applied it in the optimization of countless processes. This method involves maximizing the ratio of the process parameters that can be controlled known as the signal to those that cannot be controlled known as the noise (signal-to-noise ratio). There are three standard signal-to-ratios (S/N ratios) generally adopted depending on the desired output response as shown in equations (1-3) [24]. By this approach, the optimal setting of the input process parameters is achieved with a minimum number of experiments known as the Taguchi standard orthogonal array. As a minimum number of the experiment is conducted to achieve the optimal setting that would give the best-desired outcome instead of trying out all the possible combinations of the input process parameters as is the case in the classical design of experiment both time and cost is saved [21]. The number of experiments to be conducted in the Taguchi method is denoted as $La(X^n)$. Where a is the number of runs of the experiment, X is the number of level of the input process parameters and n is the number of the input process parameters [25-29].

(a) Signal-to-noise ratio for 'nominal is best'

$$\eta = 10 \log \frac{1}{n} \sum_{i=1}^{n} \frac{\mu^2}{\sigma^2} \tag{1}$$

(b) Signal-to-noise ratio for 'smaller the better'

$$\eta = -10 \log \frac{1}{n} \sum_{i=1}^{n} {y_i}^2 \tag{2}$$

(c) Signal-to-noise ratio for 'larger the better'

$$\eta = -10 \log \frac{1}{n} \sum_{i=1}^{n} \frac{1}{{y_i}^2} \tag{3}$$

Where η is the signal-to-noise ratio, n is the number of experiments, μ is the mean of the signal-to-noise ratio, σ is the standard deviation, and y_i is the output response. The combination of the parameters that give the highest signal-to-noise ratio is taken as the optimal combination.

The steps taken for Taguchi optimization include determination of the process performance/characteristics to be maximized or minimized or maintained, determining the factors that control the performance, choosing of the appropriate orthogonal array, carrying out the experimental trials to obtain the output responses, analysing the output response values to determine the optimal setting and then finally confirmation of the optimal setting [3]. In the current study, three levels for the welding current, voltage and gas flow rate are to be optimized against multi-performance characteristics of the dissimilar butt joint namely the tensile strength (TS), the yield strength (YS), the percentage elongation (PE) and hardness (H). The Taguchi analysis was performed with Minitab 17 software for the L9 orthogonal array. The orthogonal array is presented in Table 4.

Table 4: L_9 Taguchi orthogonal array

Run No	Current (A)	Voltage (V)	Gas flow rate (l/min)
1	120	10	15
2	120	12	17
3	120	14	19
4	150	10	17
5	150	12	19
6	150	14	15
7	180	10	19
8	180	12	15
9	180	14	17

3.2 Grey-relational analysis

There is rarely a real-life situation where process performance is measured only by one single objective/characteristics. Unfortunately, classical Taguchi method can only be effectively utilized for single performance characteristic. This has led researchers to explore other alternatives to meet this need. Grey-relational analysis has received numerous interest since its development because of its suitability for multi-performance characteristics optimization. Although there is always a unique optimum setting for each of the performance characteristics, grey-relational analysis is capable of converting many performance characteristics of a process into a single grey-relational grade (GRG) [25]. This process is known as the grey-relational generation. The steps involved grey-relational analysis include: determination of the process performance/characteristics to be maximized or minimized or maintained, finding the factors that control the performance, choosing of the appropriate orthogonal array, carrying out the experimental trials to obtain the output response values, normalization of the output response values depending on the signal-to-noise ratio criterion, calculation of the deviation sequence, calculation of the grey-relational coefficient, calculation of the grey-relational grade, ranking of the grey-relational grade to determine the optimal setting and then finally confirmation of the optimal setting [3].

3.3 The proposed hybrid method

The proposed hybrid method in this study is the combination of the Taguchi method and the grey-relational analysis. This is popularly known as the Grey based Taguchi method. After the calculation of the S/N ratios of the output response values, the following steps were followed [25]:

(1) Normalization

The S/N ratios obtained from the Taguchi analysis are normalized from 0-1. This step is followed to avoid error due to differences in the units of performance characteristics. The aim of the current research is the maximize the tensile strength, the yield strength, the percentage elongation, and the hardness. So, S/N ratio of larger the better was chosen. The equations for normalization of smaller the better and larger the better are shown in equations (4-5).

(a) Smaller the better criterion

This criterion is chosen where the aim is to reduce the value of output response as much as possible. The normalization equation for this is as follows-

$$R_{ij} = \frac{P_{ijmax} - P_{ij}}{P_{ijmax} - P_{ijmin}} \tag{4}$$

(b) Larger the better criterion
This criterion is selected when the aim is to increase the value of the output response. The equation for this criterion is-

$$R_{ij} = \frac{P_{ij} - P_{ijmin}}{P_{ijmax} - P_{ijmin}} \tag{v}$$

Where R_{ij} is the normalized signal-to-noise ratio, P_{ij} is the S/N ratio obtained from the Taguchi method, P_{ijmax} and P_{ijmin} are the maximum and the minimum Taguchi S/N ratios respectively.

(2) Calculation of the deviation sequence (DS)
This step entails the determination of the absolute difference from the normalized S/N ratios. This is given by equation (6)[26, 27, 28] as-

$$\triangle_{ij} = |P_{ijmax} - P_{ij}| \tag{6}$$

Where $\triangle_{ij}$ is the deviation sequence, P_{ijmax} is the maximum value of the deviation sequence and P_{ij} is the corresponding reference deviation sequence.

(3) Finding the grey-relational coefficient (GRC)
This step helps to determine the relationship between the ideal and comparable sequence. This is determined using the formula in equation (7)-

$$\lambda_{ij} = \frac{\triangle_{min} + \delta.\triangle_{max}}{\triangle_{ij} + \delta.\triangle_{max}} \tag{7}$$

Where λ_{ij} is the grey-relational coefficient, $\triangle_{ij}$ is the reference deviation sequence, δ is the distinguishing coefficient whose value is taken as 0.5, $\triangle_{min}$ and $\triangle_{max}$ are the minimum and maximum deviation sequence.

(4) Calculation of the grey-relational grade (GRG)
The GRG is obtained by taking the average of the grey-relational coefficients. The formula for GRG is given in equation (8). The obtained is ranked to find the experimental run with the optimum setting. The higher the value of GRG the closer the corresponding parameter setting is to the optimum setting.

$$\xi_{ij} = \frac{1}{n}\sum_{l=1}^{n} \lambda_{ij} \tag{8}$$

Where ξ_{ij} is the grey-relational grade, n is the number of output performance characteristics of the process being studied and λ_{ij} is the grey-relational coefficient.

(5) In this final step, the GRG is used as the output response in the Taguchi analysis to determine the optimal setting from the main effect plots of the GRG against the input process parameters.

4. Results and discussion

4.1 Experimental results

Table 5 shows the tensile strength (TS), yield strength (YS), percentage elongation (PE), and hardness results of the experimental design which shows maximum tensile strength and hardness of 520. 63 MPa and 363.25 MPa respectively at the welding current of 120 A, voltage of 14 V and gas flow rate of 19 l/min, maximum percentage elongation of 32.53 % at the welding of 180 A, the voltage of 10 V and gas flow rate of 19 l/min and maximum hardness of 244.65 HV at the welding current of 180 A, voltage of 14 V and gas flow rate at 17 l/min. Table 6 presents the signal-to-noise ratios of the experimental results using larger the better criterion. The main effect plots for each of the output responses are shown in **Fig.6**. In can be observed that for the tensile strength and percentage elongation, the optimum setting is current, voltage and gas flow rate all at level 3 (C3V3G3). That is welding current, voltage and gas flow rate of 180 A, 14 V and 19 l/min respectively. The optimal setting for the yield strength and hardness is similar to the optimal setting for the tensile strength and percentage elongation except for the gas flow rate. The optimal setting for yield strength is the welding current of 180 A, the voltage of 14 and gas flow rate of 15 l/min ((C3V3G1) while for the hardness, the optimum is welding current of 180 A, voltage of 14 V and gas flow rate of 17 l/min (C3V3G2). Furthermore, the input process parameters show both increasing and decreasing effect on the output responses except for the tensile strength and the yield strength which increased as the voltage increased and percentage elongation which increases with an increase in the welding current.

The impact of process parameters on the mechanical properties such as Tensile Strength, Yield strength and elongation percentage are depicted in main effects plots as seen in Figure 6. As the welding current increases from 120 A to 150 A, there was decrease in the tensile strength and later increased significantly at 180 A. But the influence of the welding voltage took an increasing turn on the tensile strength as the welding voltage increases. While the influence of the gas flow rate on the tensile strength showed similar trend to welding current. In addendum, the influence of the process parameters on the yield strength is similar to the trend on tensile strength as seen in main effect plots in Figure 6. The interactions between the three process parameters show that welding current of 180 A, welding voltage of 14 V and gas flow rate of 19 l/min had given better tensile strength property. While welding current of 180 A, welding voltage of 14 V and gas flow rate of 15 l/min had given better yield strength property.

Table 5: Welding parameters and the experimental values

Run No	Current (A)	Voltage (V)	Gas flow rate (l/min)	TS (MPa)	YS (MPa)	PE (%)	H (HV)
1	120	10	15	398.11	315.90	25.89	179.13
2	120	12	17	418.91	323.81	27.56	177.50
3	120	14	19	520.63	363.25	31.21	163.12
4	150	10	17	359.36	265.58	26.97	170.95
5	150	12	19	437.23	324.35	27.27	173.65

6	150	14	15	479.36	342.31	32.25	173.22
7	180	10	19	429.65	315.21	32.53	208.10
8	180	12	15	490.98	354.23	29.89	175.73
9	180	14	17	513.51	361.98	30.24	244.65

Table 6: Welding parameters and the signal-to-ratios of the experimental values

Run No	Current	Voltage	Gas flow rate	TS	YS	PE	H
1	120	10	15	51.97814	49.98815	28.25553	45.06337
2	120	12	17	52.46312	50.20303	28.80600	44.98397
3	120	14	19	54.31388	51.19941	29.85858	44.25014
4	150	10	17	51.10826	48.48075	28.61508	44.65738
5	150	12	19	52.81016	50.21233	28.64915	44.79350
6	150	14	15	53.57692	50.68594	30.16600	44.77196
7	180	10	19	52.66203	49.97182	30.24019	46.36544
8	180	12	15	53.80363	50.98325	29.50680	44.89692
9	180	14	17	54.19399	51.17137	29.55414	47.77090

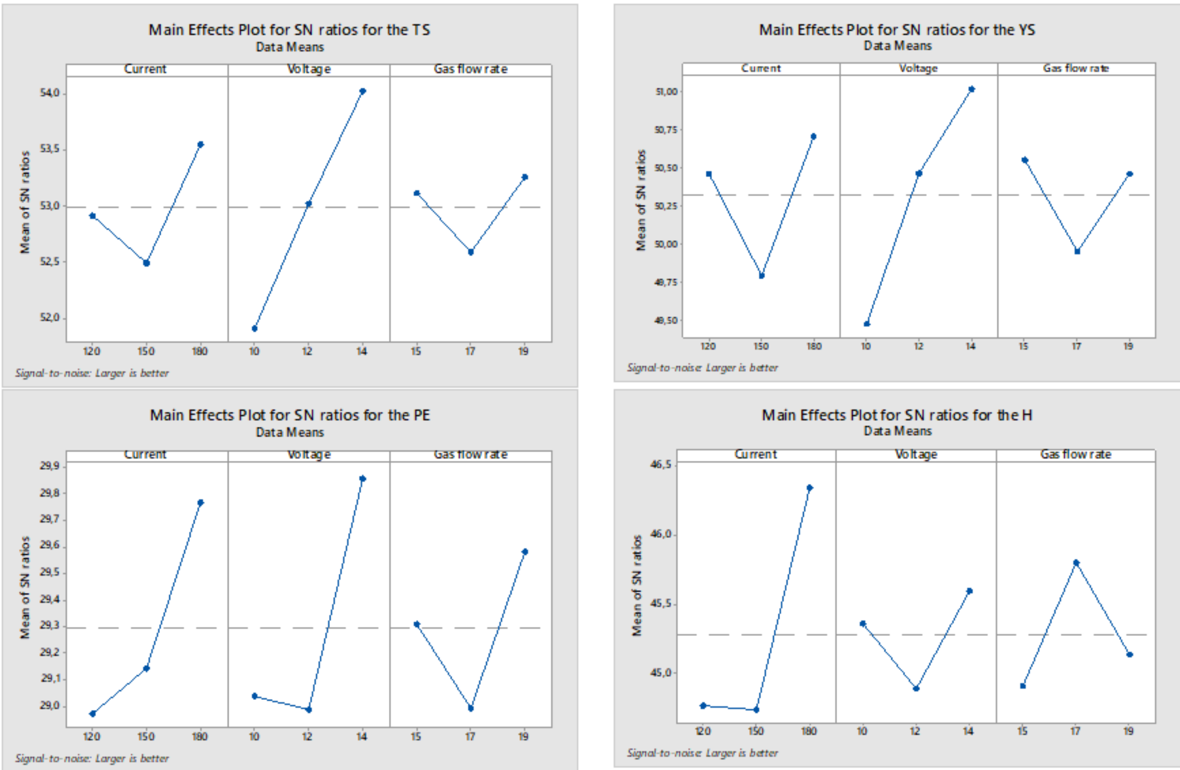

Fig. 6 Main effect plots of the output responses

4.2 Results of the grey-based Taguchi Method

The normalized S/N ratios, deviation sequences, grey-relational coefficient and grey-relational grades and rank are presented in Table 7, Table 8, Table 9, and Table 10 respectively. Table 10 shows that the maximum grey-relational grade is 0.87536 at experiment run no. 9. The welding parameters at this is welding current, voltage and gas flow rate of 180 A, 14 V, and 17 l/min respectively. **Fig.7** represents the main effect plot of the grey-relational grade against the input process parameters. It is seen that the optimal setting for the multi-performance characteristics (tensile strength, yield strength, percentage elongation and hardness) of the MIG dissimilar butt joint is C3V3G3. That is welding current at level 3 (180 A), the voltage at level 3 (14 V), and gas flow rate at level 3 (19 l/min). To determine the most significant parameter for the multi-performance characteristics, analysis of variance (ANOVA) at 95 % confidence level was performed as shown in Table 11. The ANOVA results show that all the process parameters were significant as can be seen from their p-values which are all lower than 0.05 %. Judging by p-value test, voltage with a p-value of 0.001 and 63.76 % contribution was the most significant process parameter followed by the welding current and gas flow rate with p-values of 0.002 and 0.021respectively.

Table 7: Normalized S/N ratios of the output responses

Run No	Current	Voltage	Gas flow rate	TS	YS	PE	H
1	120	10	15	0.27136	0.55446	0	0.23097
2	120	12	17	0.42265	0.63350	0.27736	0.20842
3	120	14	19	1	1	0.80772	0
4	150	10	17	0	0	0.18116	0.11566
5	150	12	19	0.53091	0.63692	0.19833	0.15432
6	150	14	15	0.77010	0.81113	0.96262	0.14821
7	180	10	19	0.48470	0.54845	1	0.60080
8	180	12	15	0.84082	0.92049	0.63047	0.18370
9	180	14	17	0.96259	0.98968	0.65432	1

Table 8: Deviation sequences of the normalized S/N ratios of the output responses

Run No	Current	Voltage	Gas flow rate	TS	YS	PE	H
1	120	10	15	0.72864	0.44553	1	0.76902
2	120	12	17	0.57735	0.36650	0.72264	0.79157
3	120	14	19	0	0	0.19228	1
4	150	10	17	1	1	0.81884	0.88433
5	150	12	19	0.46909	0.36308	0.80167	0.84567
6	150	14	15	0.22990	0.18887	0.03738	0.85179
7	180	10	19	0.51530	0.45154	0	0.39919
8	180	12	15	0.15918	0.07951	0.36953	0.81630
9	180	14	17	0.03740	0.01031	0.34567	0

Table 9: The GRC of the normalized S/N ratios of the output responses

Run No	Current	Voltage	Gas flow rate	TS	YS	PE	H
1	120	10	15	0.40696	0.52880	0.33333	0.39400
2	120	12	17	0.46410	0.57704	0.40895	0.38713
3	120	14	19	1	1	0.72226	0.33333
4	150	10	17	0.33333	0.33333	0.37912	0.36119
5	150	12	19	0.51595	0.57932	0.38412	0.37156
6	150	14	15	0.68503	0.72583	0.93044	0.36988
7	180	10	19	0.49247	0.52546	1	0.55605
8	180	12	15	0.75852	0.86280	0.57502	0.37985
9	180	14	17	0.93040	0.97979	0.59125	1

Table 10: The GRG and ranking of the output responses

Run No	Current (A)	Voltage (V)	Gas flow rate (l/min)	GRG	Rank
1	120	10	15	0.41577	8
2	120	12	17	0.45930	7
3	120	14	19	0.76390	2
4	150	10	17	0.35174	9
5	150	12	19	0.46274	6
6	150	14	15	0.67779	3
7	180	10	19	0.64350	5
8	180	12	15	0.64405	4
9	180	14	17	0.87536	1

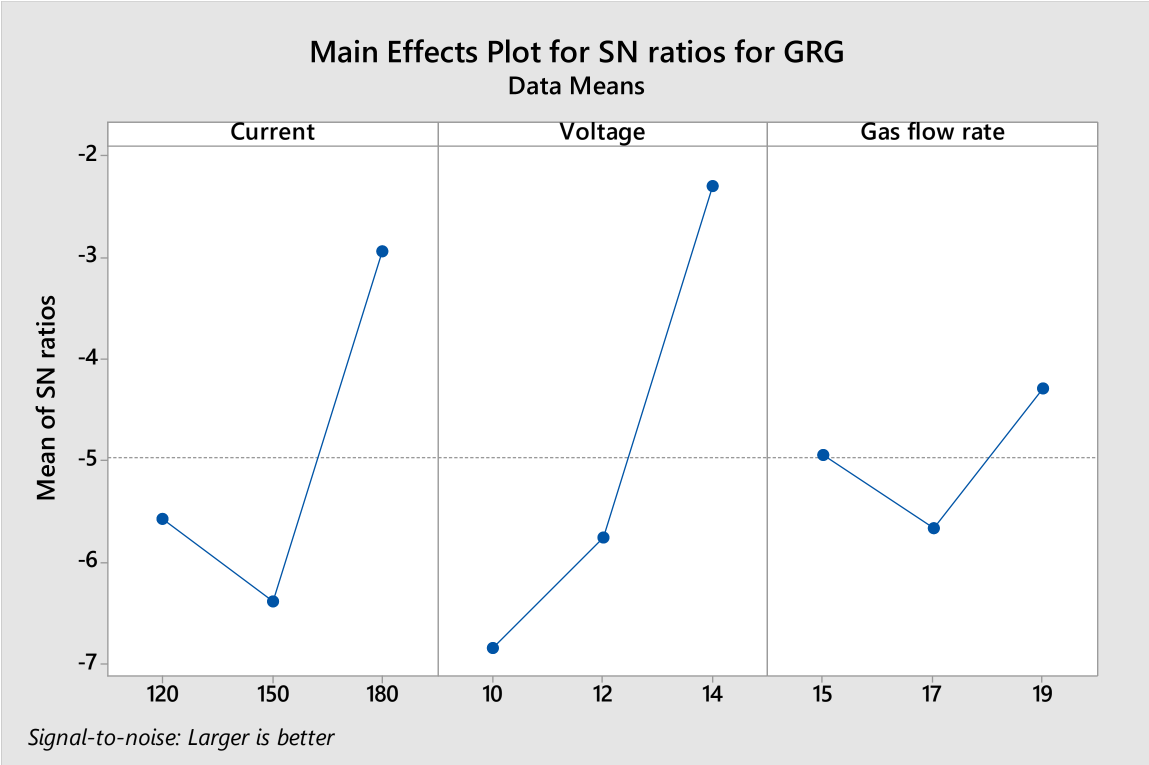

Fig.7 Main effect plot of the grey-relational grade vs the input process parameters

Table 11: ANOVA result of GRG

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Current	2	0.082863	33.75%	0.082863	0.041432	629.44	0.002
Voltage	2	0.156544	63.76%	0.156544	0.078272	1189.13	0.001
Gas flow rate	2	0.005993	2.44%	0.005993	0.002996	45.52	0.021
Error	2	0.000132	0.05%	0.000132	0.000066		
Total	8	0.245531	100.00%				

5.Confirmatory test

The confirmatory test has been conducted with the optimal setting obtained from the grey-based Taguchi method to validate the optimization of the multi-performance characteristics. With the optimal setting of the welding input process parameters (current of 180 A, the voltage of 14 V, and gas flow rate of 19 l/min), tensile strength, yield strength, percentage elongation and hardness of 559.25 MPa, 382.22 MPa, 33.34 %, and 250.63 HV respectively were obtained. These values are all higher than what was obtained from the initial setting of the parameters which, validates the grey-based Taguchi multi-performance characteristics optimization of the MIG welding process.

6. Conclusions

Successful multi-performance characteristics optimization has been performed in this work and the optimal setting of the MIG welding process was achieved. The following conclusions have been drawn in relation to the optimization of the MIG dissimilar welding of AISI 1008 and AISI 316:

- Welding current of 180 A, voltage of 14 V, and gas flow rate of 19 l/min is the optimal setting for the MIG dissimilar welding of AISI 1008 and AISI 316 by grey-based Taguchi multi-performance characteristics optimization method.
- Tensile strength, yield strength, percentage elongation and hardness of 559.25 MPa, 382.22 MPa, 33.34 %, and 250.63 HV respectively were obtained at the optimal setting.
- Out of the process parameters considered, voltage is the most significant process parameter with 63.76 % contribution.
- The tensile strength and yield strength of the welds increase as the voltage increases.
- The results of the confirmatory test validate the optimization process.

Declarations

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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