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Parametric Optimization for Gas Metal Arc Welding Process of SS316L and AISI D2 Steels by Grey-Taguchi Method

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Authors' contributions

This work was carried out in collaboration between both authors. Author SVA designed the study, performed the statistical analysis and wrote the first draft of the manuscript. Author RRK managed the analyses of the study. Both authors read and approved the final manuscript.

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ABSTRACT

The current research work is to optimize the gas metal arc welding parameters on the impact strength, hardness and flexural strength of dissimilar weld joints of SS316L and AISI D2 steels by using Taguchi based grey relational method. The experiments were planned as per Taguchi L_8 orthogonal array by considering four input parameters like current (amps), voltage (volt), speed (cm/min) and root gap (mm). The experimental results shows that, the maximum impact strength of 4.36 J/mm^2, maximum hardness of 49.5 HRC and maximum flexural strength of 583.3 MPa was obtained for the weld joints fabricated under the optimum welding conditions of current 80 amps, voltage 15 volt, speed 45 cm/min and root gap 2.0 mm. Analysis of variance was used to determine the significant contribution of each welding parameter on the output characteristics. The percentage contribution graph shows that, root gap was the most significant parameter on multiple output responses that contributes P-54.64% followed by welding speed of P- 20.26% and voltage of P- 11.94%.

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Keywords: SS316L; AISI D2 steel; welding parameter; mechanical properties; Grey relational method; ANOVA.

1. INTRODUCTION

Austenitic stainless steels are considered to be easily weldable as compared to Ferritic, Martensitic and dual phase stainless steels because of their low alloy content [1]. Though they are easily weldable but careful consideration should be given on its welding parameters chosen when they material joining to itself or some other alloy steels. Defects associated with welding such as solidification crack, intermetallic formation and wider microstructure changes have higher tendency to occur in dissimilar material joining [2]. Coarse grain formation in the joining of austenitic stainless steel to tool steel leads to deteriorate the mechanical and corrosion properties of weldments [3]. There is also problem carbide formation in joining of dissimilar materials austenitic stainless steel to tool steel with austenitic stainless steel filler material. Carbide formation is a resultant factor due to high carbon content in the steel [4,5]. Similar and dissimilar material joining involves austenitic stainless steel are more susceptible to unpredicted phase growth. As a result of this phase growth, delta ferrite phase, sigma phase and grain boundary corrosion takes place at weld interface [6]. In order to avoid such effects higher welding speed is required [7]. Fusion zone micro segregation resulting in interdendritic regions enriched with Fe, Cr and C leads to degradation of mechanical and corrosion properties of the weldment. However this can be controlled by selection of welding process parameters [8,9]. Many researchers investigated welding of austenitic stainless steel with low carbon plain steel, ferritic stainless steel and tool steel etc., adopted by various welding methods [10]. Welding of austenitic stainless steel to tool steel in general ,and MIG welding of such dissimilar combination in specific, can be considered as quite interesting area where most research may conclude. The quality of the MIG welded joint greatly depends on the mechanical metallurgical characteristics of the weld and weld geometry features. These features are hardly influenced by various input parameters of the welding such as current, voltage, welding speed and gas flow rate etc [11-14]. Nabendu ghosh et al. revealed the effects of current, gas flow rate and nozzle to plate distance on the tensile properties of the MIG welded austenitic stainless steel 316L and also optimized the process parameter using grey-based Taguchi method [15]. Thus, the present work deals with multi response optimization of gas metal arc welding parameters using Taguchi based grey relational analysis. The main objective is to analyze the effect of welding parameters viz., current, voltage, speed and root gap on the mechanical properties such as impact strength, hardness and flexural strength during gas metal arc welding of SS316L and AISI D2 steels. Furthermore, ANOVA analysis was carried out to find out the significant contribution of each parameter on output responses.

2. EXPERIMENTAL DETAILS

In the present study, SS316L and AISI D2 steels were used as the test materials. The ER 316LSi filler wire was used to produce the weldments. The chemical composition of base steels and filler wire are given in Table 1. The test specimens having rectangular plate of 75 mm x 50 mm x 3mm were prepared for welding experiments. The schematic diagram of the specimen prepared for butt weld joints is shown in Fig. 1. Prior to the welding process, the square edge butt joints of the test specimen were prepared. Argon gas was used as a shielding gas in order to protect the welded area from the atmospheric gases such as nitrogen, oxygen and carbon dioxide. The welding specimens for before and after the welding process are shown in Fig. 2 (a) and (b).

By referring the literatures, there are many welding process parameters were highly influencing on the mechanical properties of the weld joints [16]. In this work, four welding parameters namely current, voltage, speed and root gap were selected as predominant parameters on the output response characteristics on gas metal arc welding process of steels [17]. The welding parameters and their levels are provided in Table 2. Taguchi method is one of the most powerful statistical techniques for analyzing the process parameters. It provides a simple, efficient and systematic approach to optimize parameters for performance and quality and cost [18]. According to Taguchi method, an L_8 orthogonal array was considered for the experiments. The experiments were carried out as per L_8 orthogonal array is depicted in Table 3. After the welds, they were subjected for different types of mechanical tests such as impact test, hardness test and flexural test. All the test samples were prepared as per the ASTM standards. Impact test was conducted by Izod method. The test specimens were prepared as per ASTM standards with dimensions of 75mm x 10mm x 3mm. Flexural test was carried out by using a 40KN universal testing machine (UTM). The test specimens were prepared as per ASTM standards having dimensions of 15mm x 10mm x 3mm. The hardness test of the weld joint was measured by using a Rockwell hardness machine. The evaluated output responses are provided in Table 3.

Table 1. Chemical composition of SS316L steel, AISI D2 steel and ER 316LSi filler wire

Base plate	Composition wt.%								
	C	Mn	Si	P	Cr	Mo	Ni	V	S	Fe
SS316L	0.03	2.0	0.75	0.045	18.0	3.0	14.0	-	-	Remain
AISI D2	1.50	0.35	0.30	0.03	12.0	0.80	-	0.90	0.03	Remain
ER 316LSi	0.006	1.6	0.8	0.025	18.5	2.6	12	-	0.025	Remain

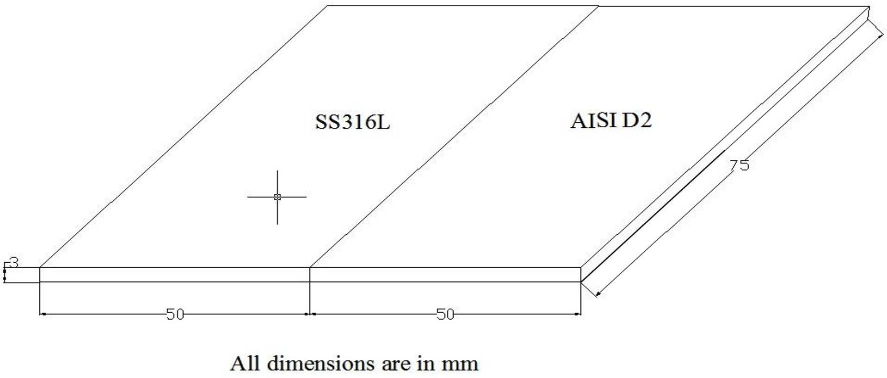

Fig. 1. Schematic diagram of the specimen for weld joint

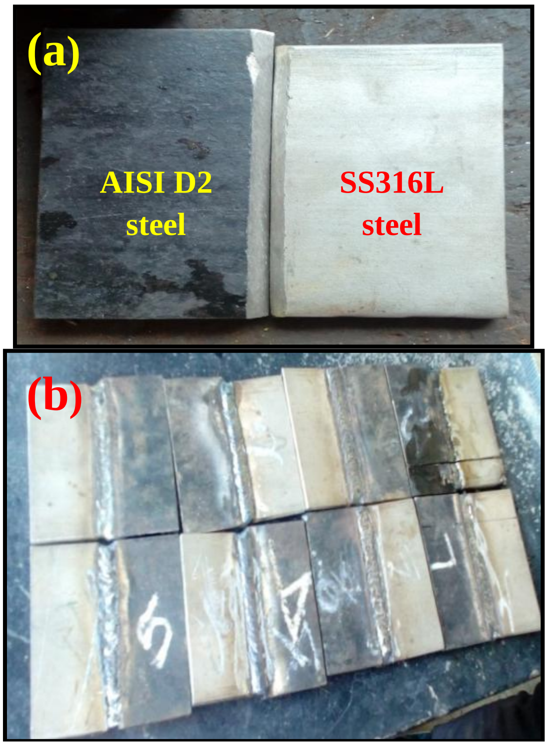

Fig. 2. Weld metals (a) (b) Before welding and (c) After welding

Table 2. Welding parameters and their levels

Symbol	Parameter	Unit	Level 1	Level 2
A	Current	amps	80	120
B	Voltage	volt	15	20
C	Speed	cm/min	35	45
D	Root gap	mm	1.5	2.0

Table 3. L8 orthogonal array design and corresponding output results

Ex. No	Input parameters				Output responses		
	Current (amps)	Voltage (volt)	Speed (cm/min)	Root gap (mm)	Impact Strength (J/mm^2)	Hardness (HRC)	Flexural Strength (MPa)
1	80	15	35	1.5	3.46	61.0	300.0
2	80	15	45	2.0	4.36	49.5	583.3
3	80	20	35	2.0	4.26	60.5	280.0
4	80	20	45	1.5	4.30	51.0	383.3
5	120	15	35	2.0	4.41	31.0	545.0
6	120	15	45	1.5	4.40	51.0	421.0
7	120	20	35	1.5	4.20	25.0	278.0
8	120	20	45	2.0	4.40	53.0	387.0

3. RESULTS AND DISCUSSION

3.1 Grey Relational Analysis

In this method, a multi objective optimization process used to determine the optimum combination of the input parameters on the multi response characteristics [19]. The following steps are carried out during the grey relational analysis:

Step 1(S/N ratio): Taguchi technique was used to calculate the S/N ratio. In general, three types of S/N ratio available such as larger-the-better, the smaller-the-better, and nominal-the-best. Since, the responses are selected as a larger-the-better S/N ratio and it was calculated by using equation (1) [19].

S/N ratio $= -10\log_{10}(1/n)\sum_{k=1}^{n}\frac{1}{Y_{ij}^{2}}$ (1)

Where n – number of replications, Y_{ij} – observed responses value where i = 1, 2, 3…..n; j = 1, 2, 3…….k.

Step 2 (Normalized S/N ratio): It is essential to normalize the data sequence for the experimental results within 0 and 1. Here, the target value is “larger-is-better", then the original sequence is normalized by using equation (2). [19]

$$x_i^*(k) = \frac{x_i^{(0)}(k) - \min x_i^{(0)}(k)}{\max x_i^{(0)}(k) - \min x_i^{(0)}(k)} \quad (2)$$

Where $x_i^*(k)$ - is the sequence after the data processing or compatibility sequence, $x_i^{(0)}(k)$ - is the original sequence of the target value for *i* = 1, 2, 3…., *m* and *k* = 1, 2,…., *n*. m- is total number of experiments and n- is total number of process responses.. The calculated S/N ratio and normalized S/N ratio values are presented in Table 4.

Step 3 (Grey relational coefficient): During this step, grey relational coefficient value is calculated from the normalized S/N ratio values by using equation (3) [19]

$$\gamma\left(x_0^*(k)\cdot x_i^*(k)\right) = \frac{\Delta\min + \zeta\cdot\Delta\max}{\Delta_{0i}(k) + \zeta\cdot\Delta\max} \quad (3)$$

Where,

$\gamma\left(x_0^*(k)\cdot x_i^*(k)\right)$- is the grey relational coefficient, $\Delta_{0i}(k)$ - is the deviation coefficient, $\Delta_{0i}(k) = \left|x_0^*(k) - x_i^*(k)\right|$ is the absolute value of the difference between reference sequence and compatibility sequence, $x_0^*(k)$ -is reference sequence or ideal sequence, $\Delta \min$ & $\Delta \max$ - is a minimum and maximum value of $\Delta_{0i}(k)$ and ζ - is distinguishing coefficient (0.5).

Step 4 (Grey relational grade): The grey relational grade for combined multi objectives can be obtained from the grey relational coefficient of all the output responses and it can be calculated using equation (4).

$$\gamma\left(x_0^* \cdot x_i^*\right) = \frac{1}{n}\sum_{k=1}^{n}\gamma\left(x_0^*(k)\cdot x_i^*(k)\right) \tag{4}$$

The grey relational grades are than sequenced in descending order. The highest value of grey relational grade represents the optimal level combination of welding parameters for the desired multiple responses. The calculated grey relational coefficient and grey relational grade are provided in Table 5.

Table 4. Calculated S/N Ratio and Normalized S/N ratio

Ex. No	Impact Strength		Hardness		Flexural Strength	
	S/N Ratio	Normalized S/N Ratio	S/N Ratio	Normalized S/N Ratio	S/N Ratio	Normalized S/N Ratio
1	10.7815	0.0000	35.7066	1.0000	49.5424	0.0720
2	12.7897	0.9473	33.8921	0.6805	55.3178	1.0000
3	12.5882	0.8421	35.6351	0.9862	48.9432	0.4389
4	12.6694	0.8842	34.1514	0.7223	51.6708	0.3449
5	12.8888	1.0000	29.8272	0.1666	54.7279	0.8745
6	12.8691	0.9894	34.1514	0.7222	52.4856	0.4683
7	12.4650	0.7789	27.9588	0.0000	48.8809	0.0000
8	12.8691	0.9894	34.4855	0.7777	51.7542	0.3570

Table 5. Evaluated grey relational coefficients and grade value

Ex. No	Grey relational coefficient			Grey relational grade
	Impact strength	Hardness	Flexural strength	
1	0.3333	1.0000	0.3501	0.5611
2	0.9046	0.6101	1.0000	0.8382
3	0.7599	0.9731	0.4712	0.7347
4	0.8119	0.6429	0.4328	0.6292
5	1.0000	0.3749	0.7993	0.7247
6	0.9792	0.6428	0.4846	0.7022
7	0.6933	0.3333	0.3333	0.4533
8	0.9792	0.6922	0.4374	0.7029

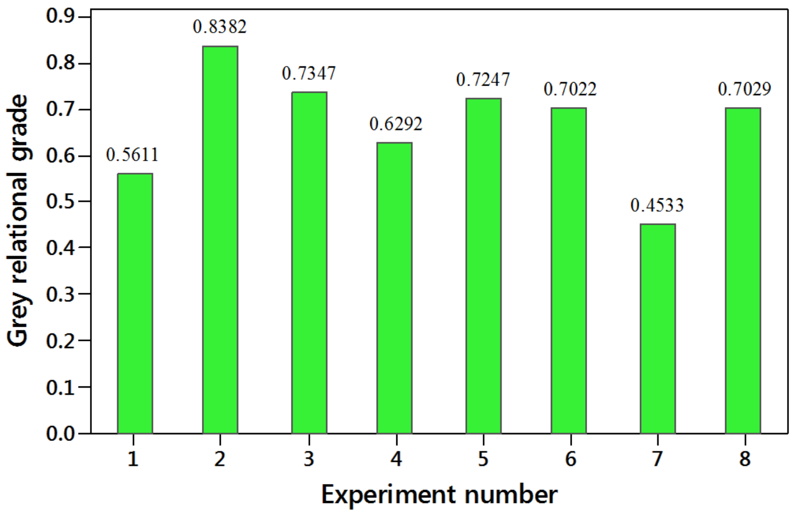

Fig. 3. Rank plot for GRG

Fig. 3 shows the GRG for all the experiments conducted during welding process. From Fig. 3, it can be proved that experiment number 2 has a higher grey relational grade (0.8382), which identifies the better combination of optimal process parameters (current - 80 amps, voltage – 15 volts, speed – 45 cm/min and root gap – 2.0 mm) for best multiple response characteristics with an objective to maximize the impact strength, hardness and flexural strength for the gas metal arc welding process of dissimilar weld joints of SS316L and AISI D2 steels. Saadat Ali Rizvi et al. [20] were observed the similar observations during GMA welding of SS304H welded steel.

3.2 Analysis of Welding Parameters on GRG

Table 6 depicts the mean grey relational grade for each level of the welding parameters and the average mean grey relational grade. From the Table, the order of influencing welding parameters is observed by the difference between the maximum and minimum value of mean grey relational grade. The higher values indicate the predominant influencing parameter on the output response characteristics that is assigned in rank 1. From Table 6, it can be noticed that the root gap was the most predominant factor for affecting the combined multi-response characteristics such as impact strength, hardness and flexural strength of weld joints, followed by speed and voltage. Fig. 4 shows the main effect plot of welding parameters such as current, voltage, speed and root gap on the mean grey relational grade. From the plot, the dotted line indicates the average value of grey relational grade and the higher value denotes the required multi- response characteristics. It was reveals that the optimum level of parameter combinations are $A_1B_1C_2D_2$, which indicates that the current at level 1 (80 amps), voltage at level 1 (15 volt), speed at level 2 (45 cm/min) and root gap at level 2 (2.0 mm).

Table 6. Response table for mean GRG

Parameters	Grey relational grade			
	Level 1	**Level 2**	**Max-Min**	**Rank**
Current (amps)	0.6908	0.6458	0.0450	4
Voltage (volt)	0.7066	0.6300	0.0765	3
Speed (cm/min)	0.6185	0.7181	0.0997	2
Root gap (mm)	0.5865	0.7501	0.1637	1
Average grey relational grade = 0.6682				

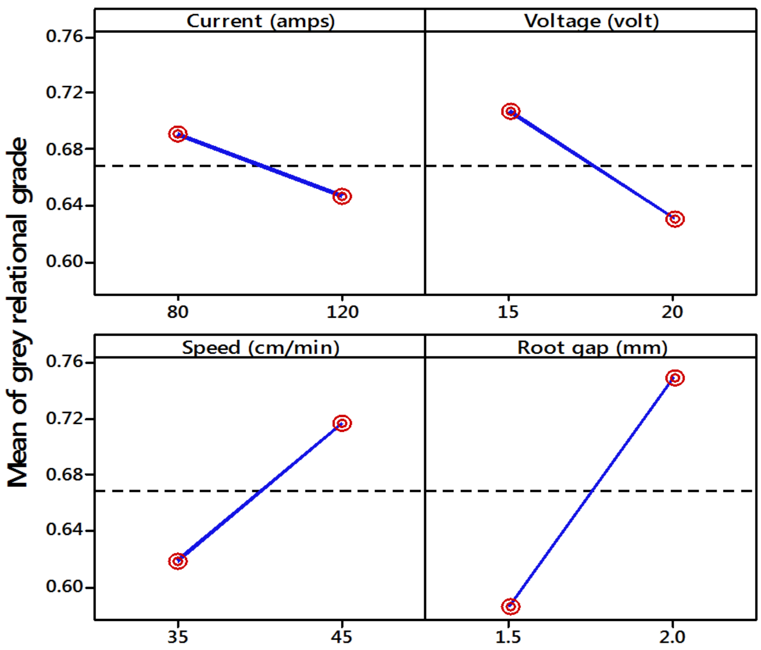

Fig. 4. Main effect plot for GRG

3.3 Analysis of Variance

ANOVA is a statistical method to identify the influence of parameters and also find the percentage contribution of those parameters on output response characteristics under investigation [18]. Table 7 shows the ANOVA results for mean grey relational grade. From the table, it can be understood that all the calculated F-ratio values were greater than tabulated $F_{0.05}$ = 4.46, which confirms the statistical and physical influence of all the welding parameters simultaneously affecting the multi-response characteristics. Fig. 5 shows the percentage contribution graph of each welding parameter on multi-response characteristics (GRG). From the figure, it is also confirmed that root gap was the most influencing parameter on the multi-response characteristics that contributes (P = 54.64%) followed by speed (P = 20.26%), voltage (P = 11.94%) and current (P = 4.13%). The R-sq value is 90.99% of GRG which indicates that the model is able to predict the multi-response with high accuracy. Nabendu Ghosh et al. [21] reported similar observations during the gas metal arc welding process of AISI 409 ferritic stainless steel, where an increase in the welding current improved the mechanical properties [21].

Table 7. ANOVA table for mean GRG

Parameters	DF	Seq.SS	Adj.MS	F-ratio	P (%)
Current (A)	1	0.004055	0.004055	1.38	4.13
Voltage (B)	1	0.011712	0.011712	3.98	11.94
Speed (C)	1	0.019870	0.019870	6.75	20.26
Root gap (D)	1	0.053579	0.053579	18.20	54.64
Error	3	0.008832	0.002944		8.96
Total	7	0.098048			
S = 0.0542589 R-Sq = 90.99% R-Sq(adj) = 78.98%					

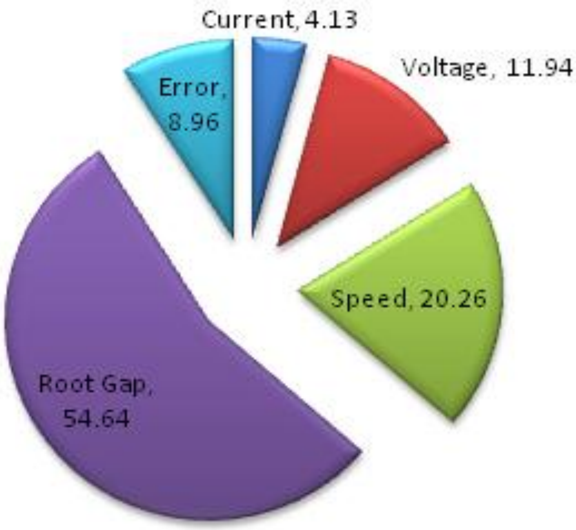

Fig. 5. Percentage contribution of welding parameters on GRG

Table 8. Results of confirmation experiment

Response parameters	Optimal welding parameter	
	Predicted	Experimental
Setting level	$A_1B_1C_2D_2$	$A_1B_1C_2D_2$
Impact strength (J/mm^2)	4.34	4.36
Hardness (HRC)	50.2	49.5
Flexural strength (MPa)	587.4	583.3
Grey relational grade	0.8610	0.8382

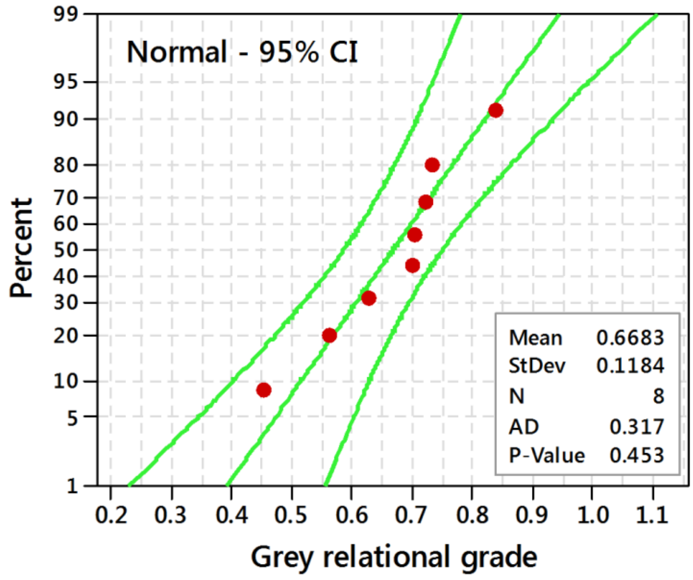

Fig. 6. Normal probability plot for GRG

3.4 Confirmation Test

The confirmation test was carried out to validate the experimental results. During the test, the optimum level parameters were considered to verify the output response characteristics for gas metal arc welding of dissimilar weld joints of SS316L and AISI D2 steels. The predicted value of grey relational grade was determined by using equation (5). [19]

$$\eta_{preticted} = \eta_m + \sum_{k=1}^{n} (\eta_i - \eta_m) \qquad (5)$$

Where, η_m- represents the total means grey relational grade and η_i- denotes the mean value of the grey relational grade at the optimum level and k- is the number of welding parameters. The predicted and experimental results are shown in Table 8. The normal probability plot for grey relational grade is shown in Fig. 6 and it is evident the all the residuals are found to be normally distributed along the straight line at 95% CI.

4. CONCLUSIONS

1. In this research work, SS316L and AISI D2 steels were successfully welded by using gas metal arc welding process.
2. The maximum impact strength of 4.36J/mm^2, flexural strength of 583.3MPa and hardness of 49.5HRC was achieved at the welded joints under the following conditions: current 80amps, voltage 45volts, speed 45cm/min and root gap 2.0mm.
3. ANOVA results exposed that the root gap was the most significant parameter on the impact strength, flexural strength and hardness followed by welding speed and voltage.
4. The confirmation test was carried out by the optimum parameters and the predicted values are very close to experimental results.
5. Taguchi coupled grey relational analysis is very efficient method to optimize the gas metal arc welding parameters on multi response characteristics.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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