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Abstract

Welding is one of the most popular methods of metal joining processes. The joining of the materials by welding provides a permanent joint of the components. The objective of this research is to determine the influence of various welding parameters on the weld bead of SS 304 welded joint. Welding technique of Gas Tungsten Arc Welding (GTAW) was involved in this research work and the influence of the welding speed, current, electrode, root gap on the strength of the material was analysed. The result showed that speed is most influencing factor to have highest bend strength and current that is to be used while welding is the most influencing factor to get higher tensile strength. Taguchi method is a powerful tool that uses a special design to study the parameter space with small number of experiments through orthogonal arrays. In a Taguchi grey relational analysis, it has been found that the optimal results occur when the cutting speed is 1.7mm/ sec, the current is 80 Ampere, and the electrode size is 1.6mm.

Keywords: Taguchi, GTAW, PMI, NDT, Grey Relational analysis

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1. Introduction

Welding is one of the fabrication processes that is used for joining the metals, by causing coalescence which replaces other joining processes like bolting, riveting. The acceptance of the welded samples is most important. In order to meet its requirements and standards, non-destructive evaluation of these materials is done in various stages to evaluate weld quality. Techniques used in non-Destructive evaluation by Radiographic Testing (RT). These tests can be done in a simpler way to find out the defects in the weldment. Now a day's welding is mostly used in fabrication of many components including critical shapes and structures (Cho, Boyce, and Dawson 2005).

Gas tungsten arc welding (GTAW) in which an arc is maintained between the base metal and the non-consumable tungsten electrode. The heat affected zone, tungsten electrode, molten metal is shielded by a blanket of inert gases fed through GTAW torch which protects atmospheric contamination. In GTAW welding inert gases like Argon is used which acts as shielded gases because they prevent atmospheric contamination of molten weld pool and also, they do not react with the base metal. This shielding gas acts as a blanket to the weldment and excludes active properties surrounded in the air. Welding method and suitable parameters are implemented in this research to identify the best welding methodology (Jamshidi Aval et al. 2009).

Taguchi method is a powerful tool that uses a special design to study the parameter space with small number of experiments through orthogonal arrays (Gopalsamy, Mondal, and Ghosh 2009; Angappan, Thangiah, and Subbarayan 2017). In the factorial design, the number of levels and factors increases the number of factors and levels increases exponentially. This technique provides an efficient, simple and systematic approach to optimize design for quality, performance and cost. Large number of experiments has to be done, when the factors and levels increases. To solve the problem, an orthogonal array is developed in Taguchi method to study entire parameters. These results are characterized into three categories. In this research larger-the-better is chosen to get the final strength that should be maximum. In order to optimize welding performance, grey relational analysis is employed (Kim et al. 2018).

Then a statistical analysis of the established variance is performed to check the statistical process parameters. Optimal combination of the parameters was concluded after analysis of all variances. This research studied the influence of various input parameters on the tensile strength of SS304L welded joint. The influence of speed, current, electrode size on the welding are identified (Jamshidi Aval et al. 2009; Lee and Jeng 2001).

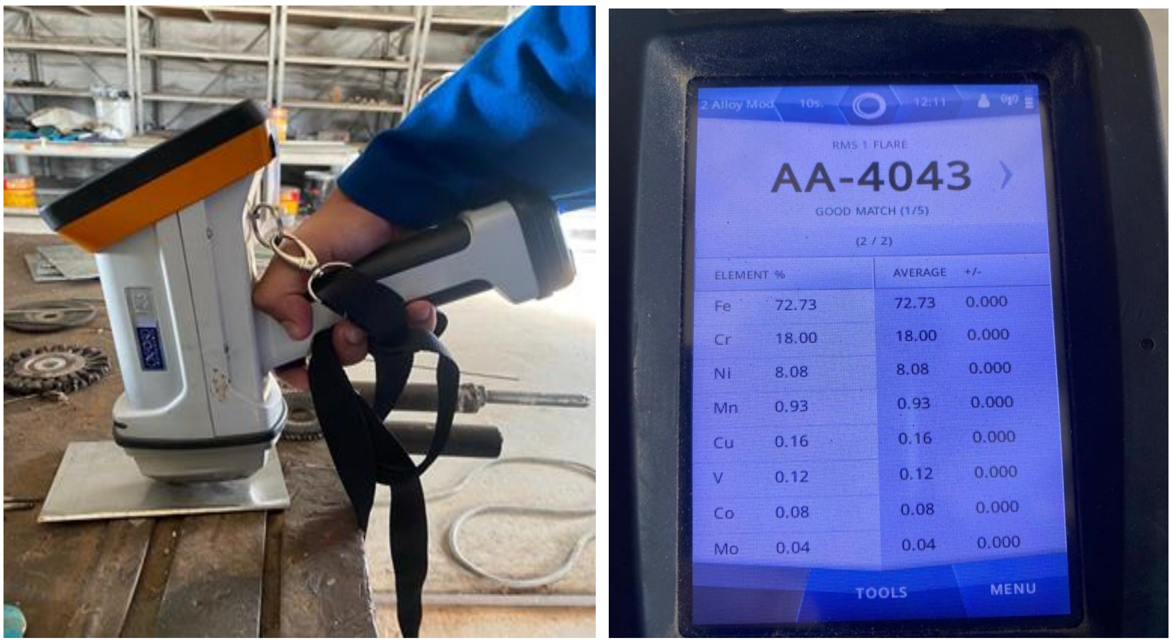
2. Experimental Methodology

In the first phase, material selection was performed. Stainless steel is widely used material for different type of equipment, machinery and structural construction. Mostly these are subjected to the corrosion and require resistance against corrosion. There are different types of stainless steels for different type of applications. The types of stainless steels are austenitic stainless steel, ferritic stainless steel, martensitic stainless steel and duplex stainless steel. Austenitic stainless steel, is most widely used material for different applications such as medical device industry, marine application, aerospace and automotive application. This type of Austenitic Stainless Steel is mostly identified as 300 series grades.

SS304, stainless steel is selected over other materials because of its distinct properties, cheaper cost and its availability in the market. SS 304 stainless steel used in pressure vessels. This grade has high corrosion resistance and can be operated at different temperature ranges. Chromium plays a vital role in this material for high resistance to corrosion. As per the mechanical properties, the minimum tensile strength is 75000 psi, minimum yield strength is 30000 psi. elongation 40%, and hardness 201 HBN. The chemical composition of SS304 measured by positive material identification (PMI) X-MET 7500 as shown in Figure 1 and Table 1. Positive Material Identification (PMI) is a fast and non-destructive testing (NDT) method for verifying the chemical composition of metals and alloys. Welding samples of thickness 3 mm, length 100 mm and width 150 mm were prepared from 304 stainless steel plate as shown in Figure 2.

Table 8. Chemical composition of stainless steel

Elements	Weight percentage	Elements	Weight percentage	Elements	Weight percentage
Ferrous	72.73	Copper	0.16	Chromium	18.0
Manganese	0.93	Silicon	0.75	Molybdenum	0.04
Vanadium	0.12	Nickel	8.08	Cobalt	0.08



(a) (b)

Figure 1. (a) Taking readings from the PMI (b) sample reading

Tensile studies were carried out on the weldments which were fabricated as per the dimensions reported in the ASTM E8/8M standards (Black and Kohser 2012; Öchsner 1983). Sheets were cut using the water jet machining setup as shown in the Figure 2. These samples were tested at a strain rate of 2 mm/min at room temperature.

Figure 2. Preparation of tensile test specimen using water jet machining

Figure 3. Welding setup and apparatus

3. Taguchi Method Analysis

Minitab was used for the implementation of Taguchi design. In Taguchi method first optimal parameters were determined by using L9 orthogonal array. L9 means that it will investigate for three levels and three different factors. Table 2 gives the factors and levels of welding which are employed for welding the samples. Table 3 gives the design of experiment data that is taken for analysis. Non-consumable tungsten electrode shall be used as electrode. Filler rod ER308 shall be used while welding. Below table listed shows the remaining parameters to be maintained in three different levels to way forward with Taguchi method. Table 4 shows the chemical composition of ER308 electrode.

Table 9. Factors and levels of welding

Levels	**1**	**2**	**3**
Speed (mm/sec)	1.4	1.7	2.0
Current (Amps)	60	80	100
Electrode size (mm)	1.2	1.6	2.0

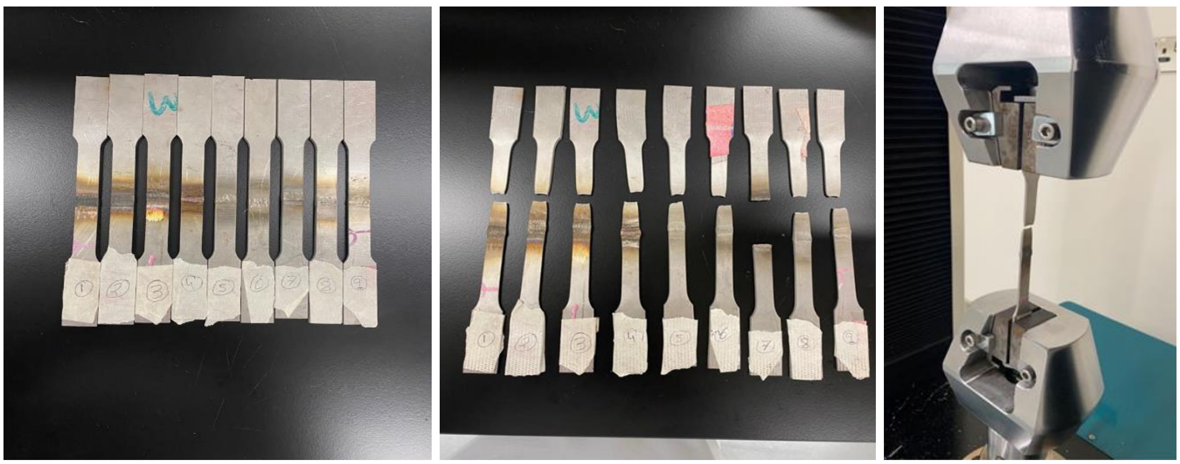
Table 10. Design of experiment

Sample Number	**Electrode**	**Speed (mm/s)**	**Current (AMPS)**	**Electrode size (mm)**
1	ER308	1.4	60	1.2
2	ER308	1.7	80	1.2
3	ER308	2.0	100	1.2
4	ER308	1.4	60	1.6
5	ER308	1.7	80	1.6
6	ER308	2.0	100	1.6
7	ER308	1.4	60	2.0
8	ER308	1.7	80	2.0
9	ER308	2.0	100	2.0

Table 11. Electrode (ER308) chemical composition

Elements	**Weight Percentage**
Carbon	0.08
Manganese	1.00 - 2.50
Phosphorous	0.030
Sulphur	0.030

Silicon	0.30 – 0.65
Chromium	19.5 – 22.0
Nickel	9.0 - 11.0
Molybdenum	0.750
Copper	0.750



(a) (b) (c)

Figure 4. (a) Samples before (b) Sample after the tensile test (c) Sample in the tensile tester

GTAW is an arc welding process that uses an arc between a non-consumable tungsten electrode and the weld pool. The process is commonly referred to as TIG (tungsten inert gas) or heliarc welding, and is used with a shielding gas and without the application of pressure. GTAW can be used with or without the addition of filler metal. The constant current (CC) type power supply can be either dc or ac, and depends largely on the metal to be welded. Direct current welding is typically performed with the electrode negative (DCEN) polarity. DCEN welding offers the advantages of deeper penetration and faster welding speeds. Alternating current provides a cathodic cleaning (sputtering) that removes refractory oxides from the surfaces of the weld joint, which is necessary for welding aluminum and magnesium. The cleaning action occurs during the portion of the ac wave, when the electrode is positive with respect to the work piece. Radiography testing is a nondestructive testing method where X-rays or gamma rays are passed through the manufactured components to check the irregularities in side. It is mainly used to observe cracks, flaws and cavities inside material.

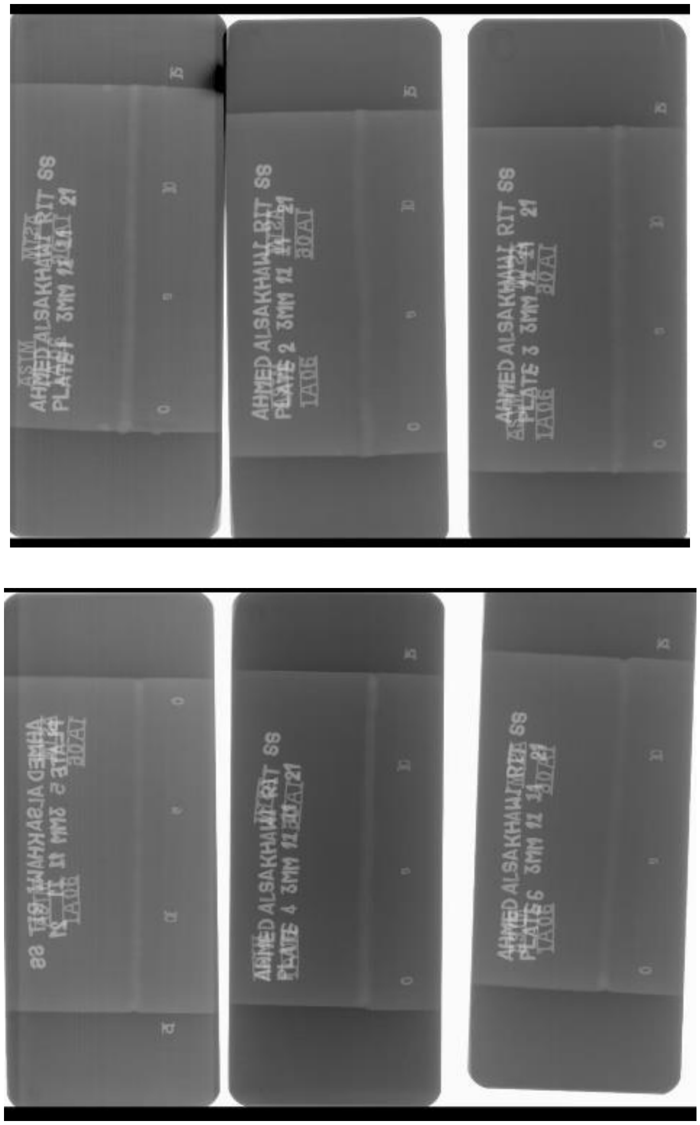


Figure 5. Samples tested under radiography non-destructive testing method

Table 12. Experimental design using L9 orthogonal array and performance result

Sr. No.	Current (amps)	Speed (mm/s)	Electrode size (mm)	Yield strength (MPa)	UTS (MPa)	Modulus (GPa)	Resilience (MPa)	Toughness (MPa)	RT
1	60	1.4	1.2	316	653.38	5.04	981.327	1165.743	0.785
2	80	1.7	1.2	338.45	663	3.78	1390.377	205236.1	0.964
3	100	2.0	1.2	280.795	580.59	4.68	560.89	60041.2	0.983
4	60	1.7	1.6	343.71	656.35	4	1981.529	122409.6	0.966
5	80	2.0	1.6	308.872	662.59	3.01	761.8	119351	0.98

6	100	1.4	1.6	322.3	660.82	3.71	1250.353	117366.2	0.764
7	60	2.0	2.0	311	652.69	4.01	653	72746.03	0.784
8	80	1.4	2.0	338.3	666.5	4.41	1143.383	58027.71	0.956
9	100	1.7	2.0	329.872	650.59	3	1403.467	56378.90	0.866

4. Grey relational analysis (GRA)

The transformation of S–N ratio values from the original response values was the initial step. For that the equation (1) of 'larger the better' was used. Subsequent analysis was carried out on the basis of these S/N ratio values.

$$S/N_L = -10 * \log(1/y^2) \qquad (1)$$

In GRA, initially the experimental data are normalized. By using this normalized data, grey relational coefficient was evaluated, the grey relational grade was obtained by averaging the GRC values related to selected experimental results.

Table 13. S-N ratio for the responses

Sr. No.	S-N ratio Yield strength	S-N ratio for UTS	S-N ratio of Modulus	S-N ratio Resilience	S-N ratio of Toughness	S-N ratio RT
1	49.994	56.303	14.049	59.836	61.332	-2.103
2	50.590	56.430	11.550	62.863	106.245	-0.315
3	48.968	55.277	13.405	54.978	95.569	-0.146
4	50.724	56.343	12.041	65.940	101.756	-0.295
5	49.796	56.425	9.571	57.637	101.537	-0.175
6	50.165	56.402	11.387	61.941	101.391	-2.338
7	49.855	56.294	12.063	56.298	97.236	-2.114
8	50.586	56.476	12.889	61.164	95.273	-0.391
9	50.367	56.266	9.542	62.944	95.022	-1.243

4.1. Grey Relational Generation (GRG)

GRG can be categorized into three types namely smaller the better, larger the better or nominal is a better (NB) criterion. The preferred quality characteristics for ultimate tensile strength, yield strength and impact toughness are larger the better criterion; then it is expressed by using equation (2):

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

Where i=1,…..m; k=1,2,3,…n; m= no of experimental data, n= number of factor, yi(k)=original sequence, yi*(k) after gray relation generation; min yi(k) and max yi(k) are the minimum and maximum value of yi(k),respectively. The normalized value is shown in Table 7.

Table 14. Sequences of each performance characteristic after data processing normalization

Sr. No.	Yield Strength (MPa)	UTS (MPa)	Modulus (MPa)	Resilience (MPa)	Toughness (MPa)	RT
1	0.584	0.856	0.411	0.443	0.000	0.107
2	0.924	0.962	0.555	0.719	1.000	0.923
3	0.000	0.000	0.143	0.000	0.762	1.000
4	1.000	0.889	0.445	1.000	0.900	0.932
5	0.471	0.957	0.994	0.243	0.895	0.987
6	0.682	0.938	0.591	0.635	0.892	0.000
7	0.505	0.848	0.441	0.120	0.799	0.102
8	0.922	1.000	0.257	0.564	0.756	0.888
9	0.922	1.000	0.257	0.564	0.756	0.888

Table 15. Deviation sequences

Sr. No.	Yield Strength (MPa)	UTS (MPa)	Modulus (MPa)	Resilience (MPa)	Toughness (MPa)	RT
1	0.416	0.144	0.589	0.557	1.000	0.893
2	0.076	0.038	0.445	0.281	0.000	0.077
3	1.000	1.000	0.857	1.000	0.238	0.000
4	0.000	0.111	0.555	0.000	0.100	0.068
5	0.529	0.043	0.006	0.757	0.105	0.013
6	0.318	0.062	0.409	0.365	0.108	1.000
7	0.495	0.152	0.559	0.880	0.201	0.898
8	0.078	0.000	0.743	0.436	0.244	0.112
9	0.203	0.175	0.000	0.273	0.250	0.500

4.2. *Grey relational coefficient (GRC)*

The calculation for grey relation coefficient was done using equation (3). GRC is referred as $\varepsilon_i(k)$, can be calculated as equation 3 below. In the current study, distinguishing coefficient (ψ) was used as 0.5 similar to the available metal cutting literature (Jozić, Bajić, and Celent 2015).

$$\varepsilon_i(k) = \frac{\Delta_{min} + \psi\Delta_{max}}{\Delta_{ij} + \psi\Delta_{max}} \quad (3)$$

4.3. *Grey relation grade*

The grey relational grades (GRG) are determined by taking average of the Grey Relational Coefficient related to every observation as presented in equation (4)

$$\gamma_i = \frac{1}{n}\sum_{i=1}^{n} \varepsilon_i(k) \quad (4)$$

Where γ_i shows the GRG calculated for ith experiment, and n is count of process response.

Sr. No.	Gray Relation coefficient						Grade	Rank
	Yield Strength (MPa)	UTS (MPa)	Modulus (MPa)	Resilience (MPa)	Toughness (MPa)	RT		
1	0.546	0.776	0.459	0.473	0.333	0.359	0.518	8
2	0.868	0.929	0.529	0.640	1.000	0.867	0.793	2
3	0.333	0.333	0.368	0.333	0.678	1.000	0.409	5
4	1.000	0.818	0.474	1.000	0.833	0.880	0.825	1
5	0.486	0.921	0.987	0.398	0.827	0.974	0.724	4
6	0.611	0.890	0.550	0.578	0.822	0.333	0.690	6
7	0.503	0.767	0.472	0.362	0.714	0.358	0.564	7
8	0.864	1.000	0.402	0.534	0.672	0.818	0.695	5
9	0.711	0.741	1.000	0.647	0.667	0.500	0.753	3

Table 16. Grey relational coefficient, grey relational grade and their rank

The GRG represents level of relationship among the reference or ideal sequence and the comparative sequence. If larger GRG is obtained for the equivalent set of process parameters compared to other sets, it is considered to be the most favorable optimal setting. The GTAW dissimilar welding process on SS 304 Stainless steel plate was performed accordingto L9 orthogonal array to investigate the effect of the welding process parameters, namely, welding current, Electrode diameter and welding speed on the output responses, ultimate tensile strength and Radiography testing. An effort has been taken to determine the best possible set of welding parametersfor SS 304 Stainless steel plate effectively and efficiently. By using

GRA complicated optimization, problem can be solved effectively. The higher grey relational grade will have better multi response characteristics. Below table shows the grey relational grade for all experiments. Hence, it is clear that experiment 4 has the optimal parameters setting for best multi-response characteristics, such as ultimate tensile strength and radiography.

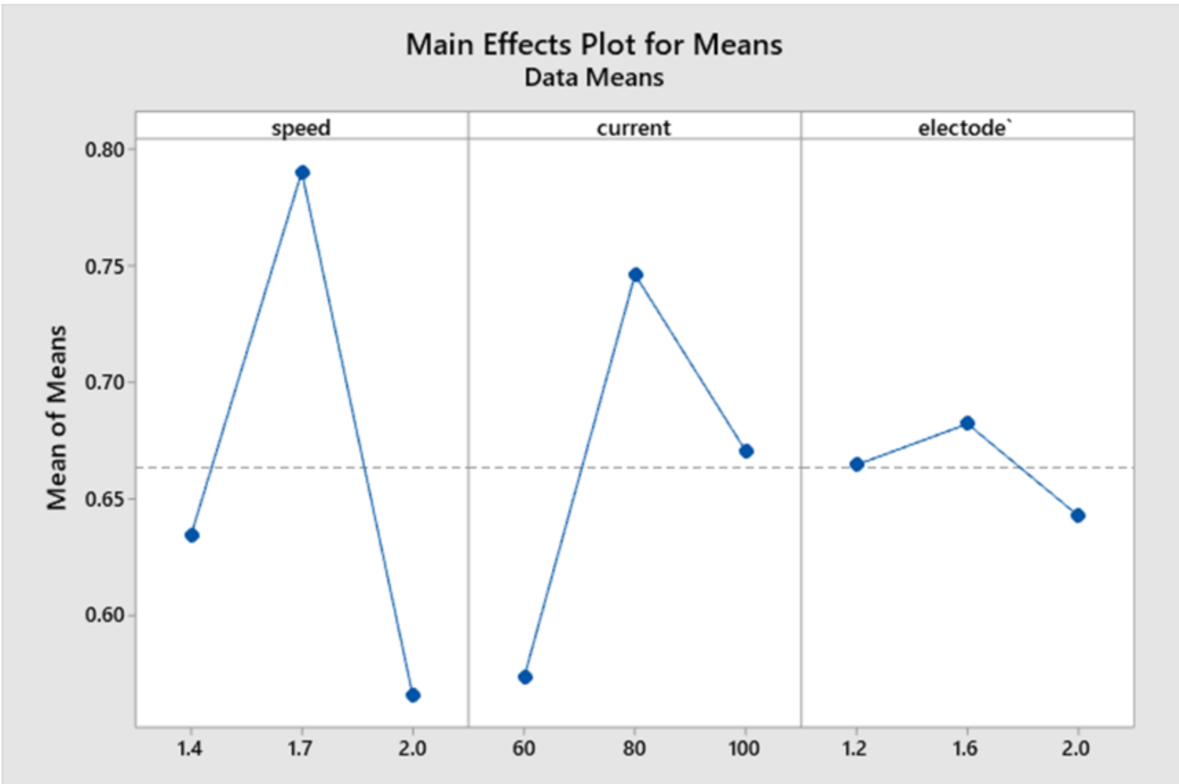


Figure 6. Mean of mean of different input variables

5. Conclusions

- In this study, Taguchi L9 array with grey relational analysis has been used to optimize the multiple performance characteristics such as ultimate tensile strength and radiography testing.
- An optimum combination of three set of test parameters of grey relational grade for

quality weld joints was found to be welding current of 60 A, Electrode size of 1.6mm and welding speed of 1.4 mm/s.

- Based on the results of GRG, it was observed that the welding current exerted a significant influence on multiple responses followed by welding speed and diameter of electrode.

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