IMPLEMENTATION OF TOPSIS TECHNIQUE FOR OPTIMIZE PROCESS PARAMETERS OF TUNGSTEN INERT GAS (TIG) WELDING OF STAINLESS STEEL 304L

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ABSTRACT

The production and manufacturing industries has taken advantage of TIG welding to join thin section of metals. Improved quality of weld for stainless steel and non-ferrous alloys are also obtained by TIG welding process. Due to shallow penetration, the TIG welding has lower productivity than Arc welding processes. Which results having application in only to join thin sections. Now-a-days in industries stainless steel 304L is commonly used because of its resistance to corrosion, higher tensile strength and better creep rupture strength. In this study welded joints have been made by using three levels of Current, Gas flow rate and Root gap. The design of experiment is prepared by using Taguchi method. Minitab 19.0 software is used for the preparation of design of experiment. The optimization of process parameters for higher Tensile strength, hardness and depth of penetration of joint is done by using TOPSIS optimization technique. For 110A of current, 7 lit/s of Gas flow rate and 2 mm of root gap gives the best optimum results of high tensile and hardness.

Keyword: - *TIG welding, Resistance to corrosion, Tensile strength, creep rupture strength, Taguchi method, TOPSIS optimization technique.*

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1. INTRODUCTION

The welding process is used to joining various like and dislike materials usually ferrous and non-ferrous. This is generally melting and adding the filler material to parent piece in order to form weld joints. Then it is cooled and the pressure application is done on it [3]. The TIG welding process uses an arc between work piece to be welded and non-consumable electrode under covering the arc with shielding gas is extremely important. It is popular welding technique used for high quality weld and the optimum welding operation [4]. Tungsten Inert Gas (TIG) Welding technique plays an important role in welding of steels, magnesium, aluminium alloys and copper alloys. The basic components of TIG welding machine contains power source, a welding torch, a shielding inert gas cylinder and supply of filler wire, etc. The electrodes having three types A pure tungsten, Thoriated tungsten and Zirconated tungsten electrodes [6]. Argon gas is widely used as shielding gas for stainless steel Welding process. The Welding torch is used for the holding the non-consumable electrode which conducts welding current to the arc. Holding torches are rated according to maximum Welding current that can be used without overheating. The one terminal coming from machine is connected to workpiece. The shielding gas is selected according to material which is to be welded [7]. The process parameters which are considered in TIG welding is welding current, Welding voltage, gas flow rate, welding speed, electrode gap and root gap etc. The response parameters in TIG welding are tensile strength, impact toughness, hardness, weld geometry and bending strength etc. (1-6). Ganesh mudaliyar et al.[10] investigated the depth of penetration achieved in 6mm thickness plate by using the silicon dioxide powder coating and optimized the result by using Taguchi optimization. Ananya prajapati et al. [11] studied the weld bead geometry of SS 304 with different levels of process parameters and optimized it by using genetic algorithm. D bahar [12] welded two dissimilar materials (SS 304 and MS 1018) by tungsten inert gas welding and optimized the process parameters by using Taguchi analysis. Anmoljeet Singh et al. [13] presents study of welding of dissimilar materials by using process parameters and analysis were done by using Taguchi analysis. Sreejith Nair [14] studied the TIG welding process at different values of process parameters and gives the effect of each parameters on Response parameters by response surface methodology. G N reddy et al.[15] used modern technique for joining two work pieces with high precision and response surface methodology is used for optimize the result. The main components of TIG welding is shown in figure 1.

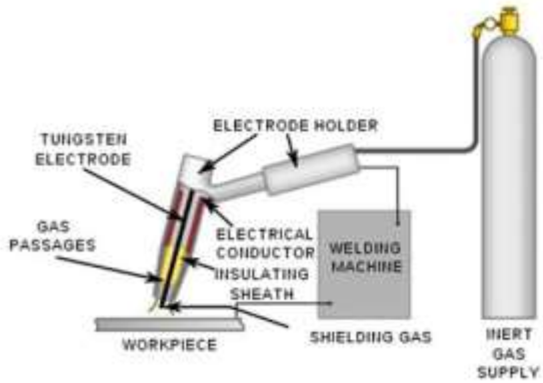


Fig -1: Principle components of TIG welding process

2. METHODOLOGY

2.1 **Experimental setup**

In this Experimental work MOGORA TIG 200 welding machine is used with polarity Direct Current Electrode Negative [DCEN]. The Austenitic Stainless Steel AISI 304L material used as workpiece. The figure 2 shows graphical abstract of this Experimental work. Figure 3 shows the experimental setup of TIG welding machine.

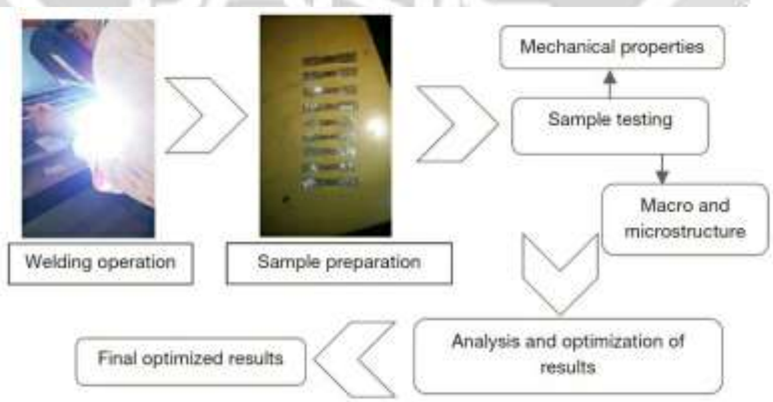


Fig -2: Graphical abstract of welding operation

Fig -3: Experimental setup of TIG Welding machine

The pure Argon was used as shielding gas for TIG welding operation. It gives the better weld geometry due to its continuous flow and good appearance of weld pool. For welding operation, the specimen was designed as per standard. The notch was prepared on one side of workpiece as per standard selected by using thickness of workpiece.

2.2 Experimental work

2.2.1 Parent metal (base metal)

The base metal used in this Experimental work was austenitic stainless steel 304L. The thickness of plate was 6 mm. The plate was cut into eighteen pieces of having size of 50×50×6 mm. For removing the dust and dirt on surface of workpieces, silicon carbide paper 400 grade and acetone were used. The filler material was used as SS 304 wire form and diameter of filler material was 1.6 mm. The chemical composition of SS 304L is shown in Table 1.

Alloy element	C	Si	Mn	P	S	Cr	Ni	Fe
SS 304L	0.06	0.42	1.89	0.032	0.014	18.67	8.53	Balance

Table -1: Chemical composition of austenitic stainless steel 304L

3.2.2 Taguchi design of experiment

The Taguchi design of experiment was used for experimental work. There were three process parameters with three different levels selected. The levels of process parameters are shown in Table 2.

Process parameters	Level l	Level 2	Level 3
Welding current (A)	90	110	130
Gas flow rate (L/min)	7	9	11
Root gap (mm)	1	2	3

Table -2: Levels of process parameters

In this Experimental work, L9 orthogonal array was used. In this array, the experiments used to handle 3 levels of process parameters to get influence of each parameter on response parameters. The Taguchi design of experiment was prepared by using Minitab 19 software. The experiments were conducted by using process parameters given in Table 3.

Welding Current (A)	Gas flow rate (lit/s)	Root gap (mm)
90	7	1
90	9	2
90	11	3
110	7	2
110	9	3
110	11	1
130	7	3
130	9	1
130	11	2

Table -3: Design of experiment (DOE) Taguchi

3.2.3 Experimentation as per DOE

According to Design of experiment (DOE) the experiments were conducted. The MOGORA TIG 200 welding machine was used for working operation. Nine specimens were welded with feasible process parameters having size of 50×100×6 mm. The single pass TIG welding operation was done on workpiece. The welding variables as follows:
Base metal - SS 304L

Electrode - 2.4 mm with 2% thorium tungsten electrode

Welding current - 90-130 A

Shielding gas - pure Argon

Filler diameter - 1.6 mm dia. SS 304 wire

Root gap - 1-3 mm

Joint design - single butt weld joint

The welded specimen of dimensions 50×100×6 mm is shown in figure 4. After the welding process the specimens were prepared for testing. The testing was carried out on universal testing machine (UTM) for tensile strength and micro-hardness tester for hardness test. For measurement of depth of penetration, the microscope with 5X magnification was used. The preparation for tensile strength was according to ASTM standards. The ASTM standard design for Experimental work specimen is shown in figure 5. Prepared ASTM specimen for tensile test is shown in figure 6.

Fig -4: Welded specimen of size 50×100×6 mm

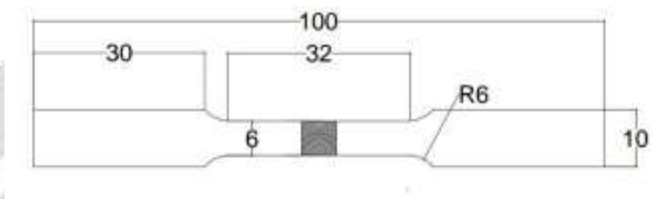


Fig -5: ASTM standard design for Experimental work

Fig -6: Prepared specimen for tensile test

3. RESULTS AND DISCUSSION

Tensile test is performed and results were calculated after testing it on universal testing machine (UTM) having 1000N capacity. All specimen was failed at welding section because that section was weaker than base metal. In this Experimental work, the tensile strength, hardness and depth of penetration having more response, so "higher is better" characteristics used for analysis the results. The result consists of 3 process parameters i.e. Welding current, gas flow rate and root gap effect on responses i.e. Tensile strength, harness and depth of penetration. These are mentioned in Table 4.

Welding Current (A)	Gas flow rate (L/min)	Root gap (mm)	Tensile strength (MPa)	Hardness (HV)	Depth of penetration (mm)
90	7	1	329.75	250.66	3.26
90	9	2	401.59	270.51	3.69
90	11	3	682.25	345.92	4.05
110	7	2	598.23	240.30	3.96

110	9	3	630.45	310.89	4.32
110	11	1	343.00	270.57	4.19
130	7	3	542.08	280.64	5.23
130	9	1	268.13	295.35	5.02
130	11	2	554.31	300.63	4.87

Table -4: Results of response parameters

4.1 Signal to noise ratio (S/N ratio)

4.1.1 S/N ratio for tensile strength

The S/N ratio is defined as ratio of mean to standard deviation. It always depends on the quality of process. Larger signal to noise ratio shows that better signal is obtained at lesser noise. The mean response and S/N ratio for tensile strength is arranged in table 5 and the figure 7, shows main effect plot for means.

Level	Current	GFR	Root gap
1	471.2	490.0	313.6
2	523.9	433.4	518.0
3	454.8	526.5	618.3
Delta	69.1	93.1	304.6
Rank	3	2	1

Level	Current	GFR	Root gap
1	53.4	53.53	49.88
2	54.08	52.21	54.16
3	52.71	54.09	55.78
Delta	1.37	1.87	5.91
Rank	3	2	1

Table -5: Mean response and mean S/N ratio for Tensile strength

Figure -7: Main effect plot for means (Tensile strength)

From this information, it is clear that root gap has first rank in response. Hence, the effect of root gap is most for tensile strength.

4.1.2 S/N ratio for hardness

The mean response and S/N ratio for hardness is arranged in table 6, and the figure 8, shows main effect plot for means.

Level	Current	GFR	Root gap
1	289.0	257.2	272.1
2	273.9	292.2	270.5
3	292.2	305.7	312.4
Delta	18.3	48.5	42.0
Rank	3	1	2

Level	Current	GFR	Root gap
1	49.13	48.19	48.68
2	48.70	49.30	48.61
3	49.31	49.66	49.86
Delta	0.61	1.48	1.26
Rank	3	1	2

Table -6: Mean response and mean S/N ratio for hardness

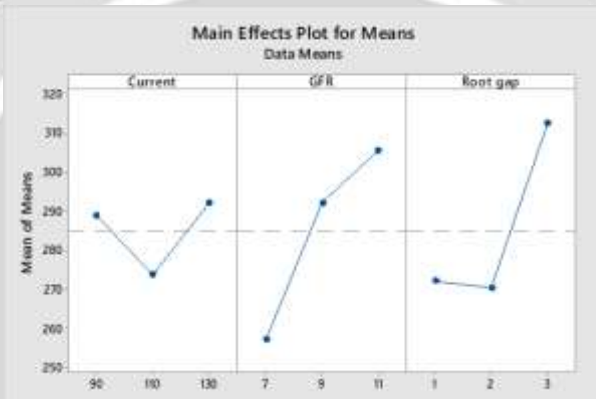


Figure -8: Main effect plot for means and S/N ratio (hardness)

From this information, it is clear that gas flow rate has first rank in response. Hence, the effect of gas flow rate is most for hardness.

4.1.3 S/N ratio for depth of penetration

The mean response and S/N ratio for depth of penetration is arranged in table 7, and the figure 9, shows main effect plot for means and S/N ratio.

Level	Current	GFR	Root gap
1	3.667	4.150	4.157
2	4.157	4.343	4.173
3	5.040	4.370	4.533
Delta	1.373	0.220	0.377
Rank	1	3	2

Level	Current	GFR	Root gap
1	11.25	12.20	12.24
2	12.37	12.69	12.35
3	14.04	12.78	13.08
Delta	2.79	0.59	0.84
Rank	1	3	2

Table -7: Mean response and mean S/N ratio for depth of penetration

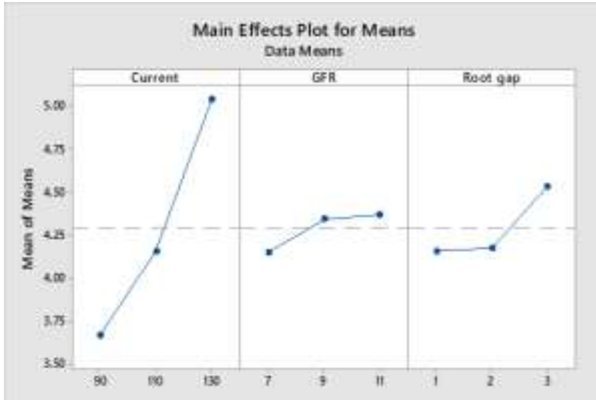


Figure -9: Main effect plot for means and S/N ratio (depth of penetration)

From this information, it is clear that current first rank in response. Hence, the effect of current is most for depth of penetration.

4.2 Analysis of variance

The analysis of variance (ANOVA) is used for to find the effect of process parameters on the tensile strength, hardness and depth of penetration. It gives the contribution of each process parameters that affect the response parameters. In this study, ANOVA is calculated at 95% confidence level. The regression equation gives the effect of each process parameters at different levels.

4.2.1 ANOVA for tensile strength, hardness and depth of penetration

The results of TIG welding process are analyzed and analysis of variance is generated using MINITAB 19 software. The main effect plots are also generated which provides an idea about the optimum process parameters and their levels. The ANOVA table for tensile strength, harness and depth of penetration is as mentioned in table 8, 9 and 10 respectively.

Source	DF	Adj SS	Adj MS	F-value	P-value
Current	2	7813	3907	0.58	0.634
GRF	2	13213	6607	0.98	0.506
Root gap	2	144630	72315	10.70	0.085
Error	2	13522	6761		
Total	8	179179			

S	R-sq.	R-sq(adj)
82.2247	92.45%	69.81%

Table -8: ANOVA for tensile strength

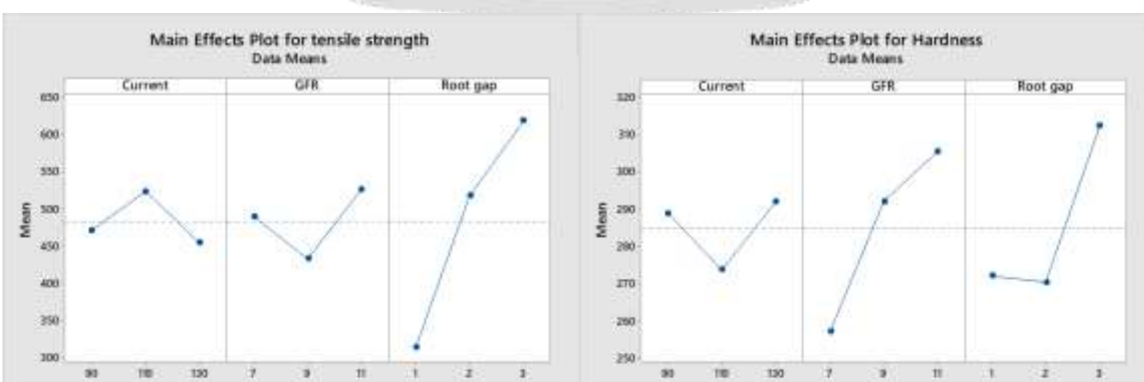
Source	DF	Adj SS	Adj MS	F-value	P-value
Current	2	573.9	287.0	0.92	0.520
GFR	2	3760.9	1880.5	6.04	0.142
Root gap	2	3388.1	1694.0	5.44	0.155
Error	2	622.3	311.1		
Total	8	8345.2			
S		R-sq		R-sq(adj)	
17.6390		92.54%		70.17%	

Table -9: ANOVA for hardness

Source	DF	Adj SS	Adj MS	F-value	P-value
Current	2	2.9064	1.4531	33.60	0.029
GFR	2	0.08649	0.04324	1.00	0.500
Root gap	2	0.27176	0.13588	3.14	0.241
Error	2	0.08649	0.04324		
Total	8	3.3512			
S		R-sq		R-sq(adj)	
0.2079		97.42%		89.68%	

Table -10: ANOVA for depth of penetration

From the analysis of variance, it is clear that current and gas flow rate are the most significant parameters. While root gap has high significance that means it will significantly affect the response parameters than current and gas flow rate.The value of R-square for tensile strength, hardness and depth of penetration is 92.45%, 92.54% and 97.42% respectively which proves that the process parameters considered for experimentation are significant. The main effect plots for the responses are as shown in figure 10.



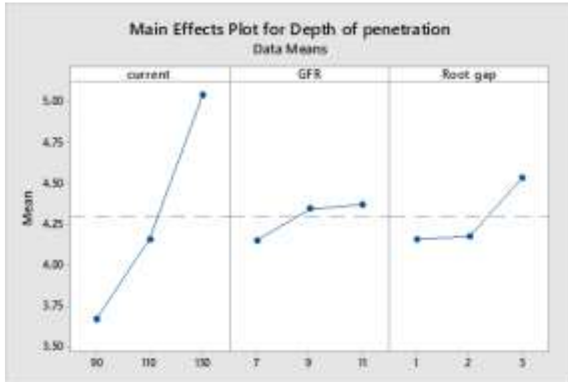


Figure -10: Main effect plot for tensile strength, hardness and Depth of penetration

From the main effect plot, it is clear that tensile strength is higher at 110A current, 11L/min gas flow rate with 3mm root gap. Hardness is higher at 130A current, 11L/min of gas flow rate with 3mm root gap. Whereas, depth of penetration is higher at 130A current, 11L/min of gas flow rate with 3mm of root gap.

4.3 Regression equations for 3 Response parameters

Regression analysis generates an equation to conclude statistical relationship between process parameters and response parameters and to determine new readings. The given equation is used for the tensile strength calculation from any random value of current, gas flow rate and Root gap.

Regression equation for Tensile strength =

483.3 - 12.1 Current_90 + 40.6 Current_110 - 28.5 Current_130 +6.7 GFR_7- 49.9 GFR_9 + 43.2 GFR_11 - 169.7 Root gap_1 + 34.7 Root gap_2+ 135.0 Root gap_3 .. (1)

Regression equation for Hardness =

285.01 + 3.99 Current_90 - 11.14 Current_110 + 7.16 Current_130 - 27.84 GFR_7+ 7.19 GFR_9 + 20.66 GFR_11 - 12.88 Root gap_1 - 14.54 Root gap_2+ 27.42 Root gap_3 .. (2)

Regression equation for depth of penetration =

4.2878 - 0.6211 Current_90 - 0.1311 Current_110 + 0.7522 Current_130 - 0.1378 GFR_7 + 0.0556 GFR_9 + 0.0822 GFR_11 - 0.1311 Root gap_1 .. (3)

4. **OPTIMIZATION TECHNIQUE**

Technique for order preference by similarity to ideal solution (TOPSIS) is a simple and effective Multi Criteria Decision Making (MCDM) tool used in many applications like process parameter selection in manufacturing etc., TOPSIS is one of the multi criteria decision making methods (MCDM) used to solve multi objective problems. The following stages have been employed in this approach:

5.1 Making a matrix

This matrix has a number of attributes and b number of alternatives. In this experimental work, there are 3 response variable and 09 ways. Hence, the matrix is [9,3].

5.2 calculate normalized matrix

The calculation of normalized matrix is done in this step. The equation for normalized matrix calculation is mentioned equation below,

$$\overline{X_{xy}} = X_{ij} \Big/ \left(\sqrt{\sum_{j=1}^{n} X_{ij}^2}\right) \quad .. (4)$$

5.3 calculation of weighted normalized matrix (V_{ij})

The weightage for each response is given in this step. For this experimental work the weightage of both the response parameters are 0.5 because they have equally important. The equation for calculate weighted normalized matrix is,

$$V_{ij} = \bar{X}_{ij} \times W_i \quad .. (5)$$

5.4 calculation of ideal positive (V_j^+) and ideal negative (V_j^-) solution

In this step, the weighted normalized matrix is analyzed and then ideal positive and ideal negative solution is calculated for both the response parameters.

5.5 Calculation of L^2 distance

L^2 distance between alternative i and ideal negative solution

$$S^- = \sqrt{\sum_{j=1}^{n} \left(V_{ij} - V_j^-\right)^2} \quad .. (6)$$

L^2 distance between alternative i and ideal positive solution

$$S^+ = \sqrt{\sum_{j=1}^{n} \left(V_{ij} - V_j^+\right)^2} \quad .. (7)$$

5.6 calculate performance score and rank

In this last step, the performance score is calculated. The rank is inversely proportional to the performance score. The equation which calculates performance score is given below,

$$P_i = S_i^- \Big/ \left(S_i^+ + S_i^-\right) \quad .. (8)$$

The TOPSIS optimization table for Tungsten Inert gas welding process is mentioned in table 11.

Run Order	Pi	Rank
1	0.4558914	7
2	0.4757553	6
3	0.677555	2
4	0.7746661	1
5	0.6746521	3
6	0.3525309	8
7	0.511652	5

8	0.1628173	9
9	0.5411233	4

Table -11. TOPSIS optimization table for TIG welding process

The optimum condition for TIG welding of SS 304L is at run no. 4 which is having current of 110 A, gas flow rate of 7 lit/s and root gap of 2 mm.

5. CONCLUSIONS

1. The Taguchi method is successfully used for the making design of experiments in TIG welding of SS 304L.
2. Investigation of process parameters such as welding Current, Gas flow rate and Root gap on the Tensile strength and Hardness has been studied. All parameters which are taken into consideration has effect on response parameters.
3. From ANOVA table, it is clear that Root gap has most significant process parameter.
4. Regression equations generated is useful in calculating the tensile strength and Hardness for any random value for welding current, gas flow rate and Root gap.
5. From the TOPSIS optimization technique, it is clear that the optimum solution for response parameter is at 110 A current, 7 lit/s Gas flow rate and 2 mm Root gap.

7. ACKNOWLEDGMENT

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