PARAMETRIC OPTIMIZATION OF SHIELDED METAL ARC WELDING (SMAW) PROCESS FOR PRESSURE VESSEL WELD USING SA 515 GR 60

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ABSTRACT

Concept of Optimization of Shielded Metal Arc Welding (SMAW) process parameters for SA 515 gr 60 pressure vessel weld as per ASME sec-IX is presented here. The any type of rupture in pressure vessels causes an explosion which is cause of loss of life and properties. This concept is capable to identify optimum parameter which can be used for welding of pressure vessel joint. Mechanical properties of weld joint affected with groove angle, welding current and electrode diameter. The experimental work was performed with Taguchi method with various ranges of welding current, groove angle and electrode diameter. The mechanical properties like tensile strength, hardness and microstructure of weld joint required to be testing. This study shows that improvement in welding quality of weld joint by improving the mechanical properties of weld joint. The optimum parameters can be achieved by optimization technique, which can be used in pressure vessel weld to achieve excellent weld quality.

Keyword: *SMAW, Taguchi method, Tensile strength, Hardness, Microstructure, Grey relational analysis*

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1. INTRODUCTION

SA 515 gr 60 Carbon steel material is widely used for manufacturing of pressure vessel. The pressure vessels are as the form of the cylinders or tanks which are used to store fluids under pressure. The any type of rupture in pressure vessels causes an explosion which is cause of loss of life and properties. The quality of pressure vessel is mainly depending on the welding. The Shielded Metal Arc Welding (SMAW) was used to manufacturing of pressure vessel. In which coalescence is produced by heating work piece with electric arc setup between electrode holder and work piece.

The experimental work was performed with Taguchi method in Minitab 17 software with various ranges of welding current, groove angle and electrode diameter. The mechanical properties like tensile strength, hardness and microstructure of weld joint required to be testing. The main objective of this research is to find out the optimum parameters for the welding of carbon steel material SA 515 gr 60 pressure vessel welds. Another objective is to improve weld quality means, prevention of failure by improving the mechanical properties of weld metal.

2. EXPERIMENTAL DETAILS

Shielded metal arc welding (SMAW) operation has been used for carbon steel plates of size 100×150×12 mm^3. The electrode E-6013 has been used as a filler metal in SMAW process. The shielded metal arc welding process has been carried out with various input parameters like groove angle, welding current and electrode diameter. The three level of each input parameter has been used in welding process. The three ranges of each input have been used for welding of carbon steel plates. The various ranges of groove angle are 45°, 60° and 75°. The ranges of welding current are (100, 120, and 140) Amp. The ranges of electrode diameter are (2.5, 3.2, and 4) mm.

A design of experiments (DOE) has been designed with Taguchi method. A set of nine experiments have been designed. The experiments have been arranged in three levels and three ranges of each input parameters. Taguchi design analysis has been used to determine the most affecting factor on response parameter. ANOVA (Analysis of variance) analysis has been carried out for validation of Taguchi design analysis. For parametric optimization Taguchi method and Grey relational analysis method have been used.

3. RESULT AND DISCUSSION

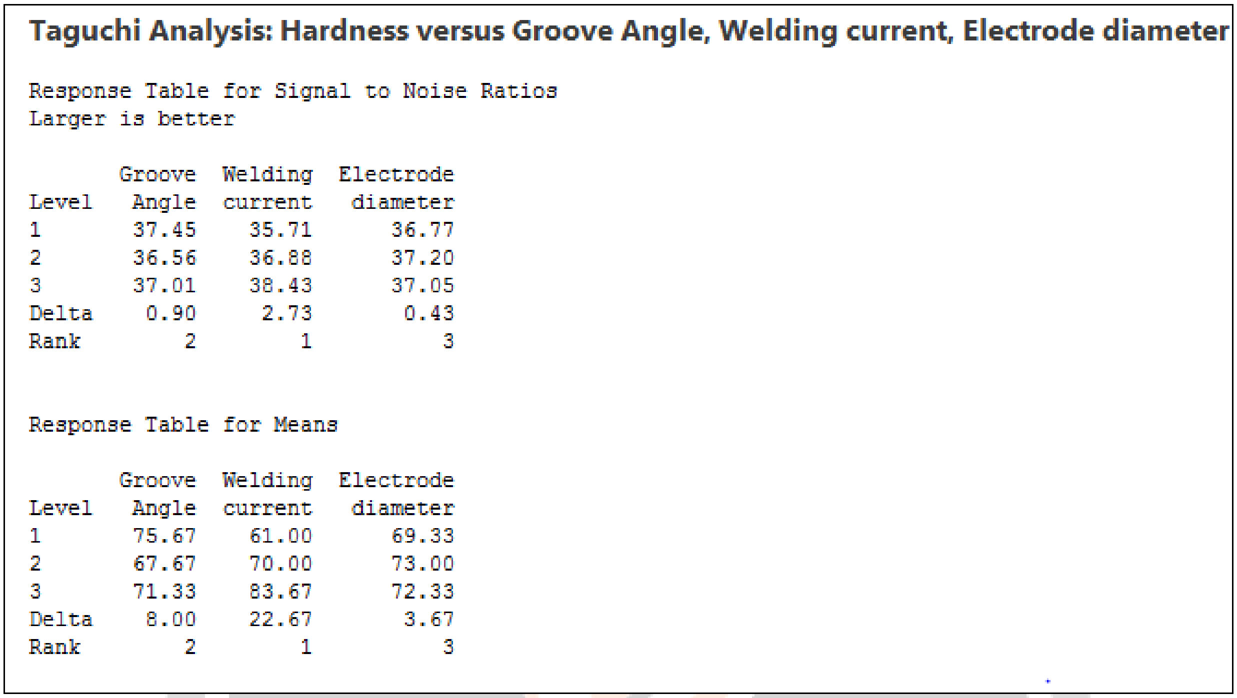
The welding experiments have been carried out with various ranges of groove angle, welding current and electrode diameter. The weld joints have been mechanically tested. The mechanical properties like hardness, tensile strength and microstructure have been tested. The hardness test carried out by Rockwell hardness test machine. The tensile test has been carried out by UTM (Universal testing machine). The microstructure has been carried out by optical microscope machine.

Table: 1 Result for welding experiments

Weld trials	Groove angle (Degree)	Welding current (Amp)	Electrode diameter (mm)	Hardness (HRBW)	Tensile strength (N/mm^2)
1	45	100	2.5	60	450.23
2	45	120	3.2	76	468.20
3	45	140	4.0	91	502.48
4	60	100	3.2	61	480.82
5	60	120	4.0	64	509.65
6	60	140	2.5	78	465.12
7	75	100	4.0	62	509.14
8	75	120	2.5	70	455.36
9	75	140	3.2	82	473.24

Now after the determination of result, the Taguchi analyze design has been done to identify how each input parameter affect the response parameter. The Taguchi analyze design shows the effect of input factor on the response parameter. In Taguchi analysis higher delta (difference between major and minor value) means higher rank for that parameter. Here, in figure1 welding current with 1^{st} rank represent that the welding current is most affecting parameter for hardness. Groove angle with 2^{nd} rank and then electrode diameter with 3^{rd} rank. The figure 2 shows

Taguchi's analysis for tensile strength. The electrode diameter is the most affecting parameter with 1st rank. Groove angle is 2nd most affecting parameter and last is welding current with 3rd rank.



Taguchi Analysis: Hardness versus Groove Angle, Welding current, Electrode diameter

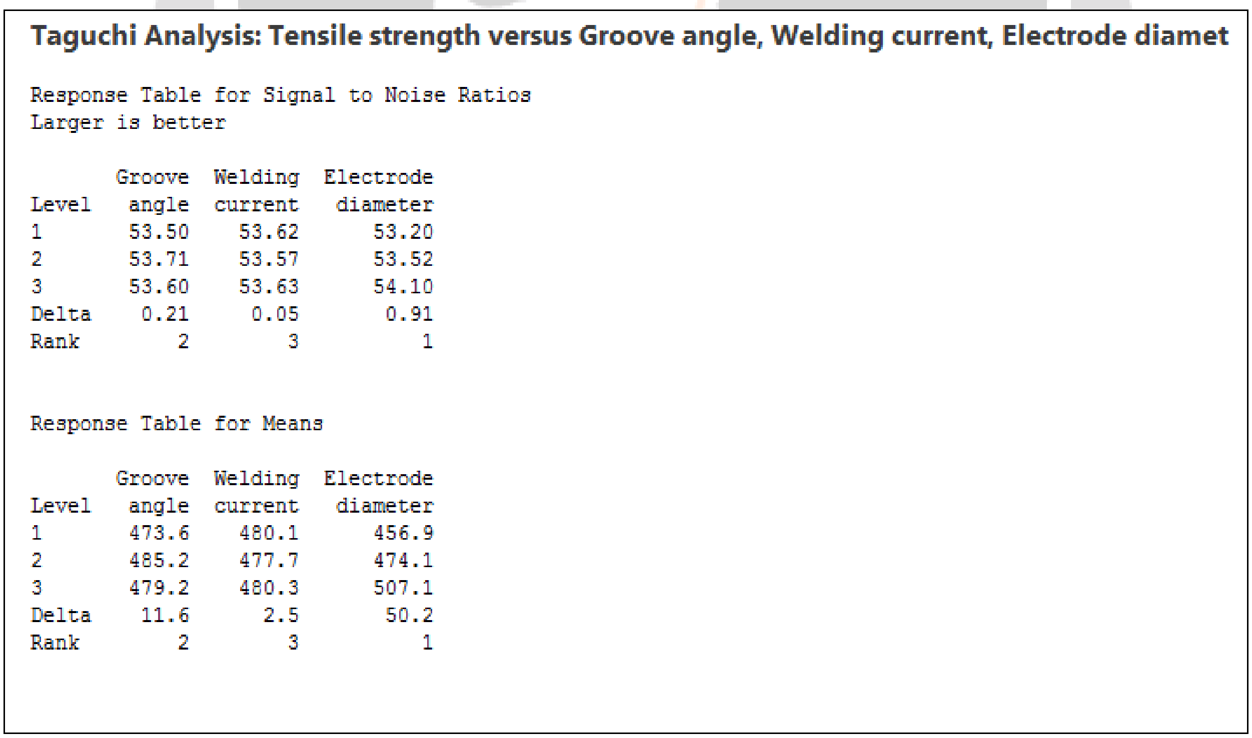
Response Table for Signal to Noise Ratios
Larger is better

Level	Groove Angle	Welding current	Electrode diameter
1	37.45	35.71	36.77
2	36.56	36.88	37.20
3	37.01	38.43	37.05
Delta	0.90	2.73	0.43
Rank	2	1	3

Response Table for Means

Level	Groove Angle	Welding current	Electrode diameter
1	75.67	61.00	69.33
2	67.67	70.00	73.00
3	71.33	83.67	72.33
Delta	8.00	22.67	3.67
Rank	2	1	3

Figure: 1 Taguchi's analysis for hardness



Taguchi Analysis: Tensile strength versus Groove angle, Welding current, Electrode diamet

Response Table for Signal to Noise Ratios
Larger is better

Level	Groove angle	Welding current	Electrode diameter
1	53.50	53.62	53.20
2	53.71	53.57	53.52
3	53.60	53.63	54.10
Delta	0.21	0.05	0.91
Rank	2	3	1

Response Table for Means

Level	Groove angle	Welding current	Electrode diameter
1	473.6	480.1	456.9
2	485.2	477.7	474.1
3	479.2	480.3	507.1
Delta	11.6	2.5	50.2
Rank	2	3	1

Figure: 2 Taguchi's analysis for tensile strength

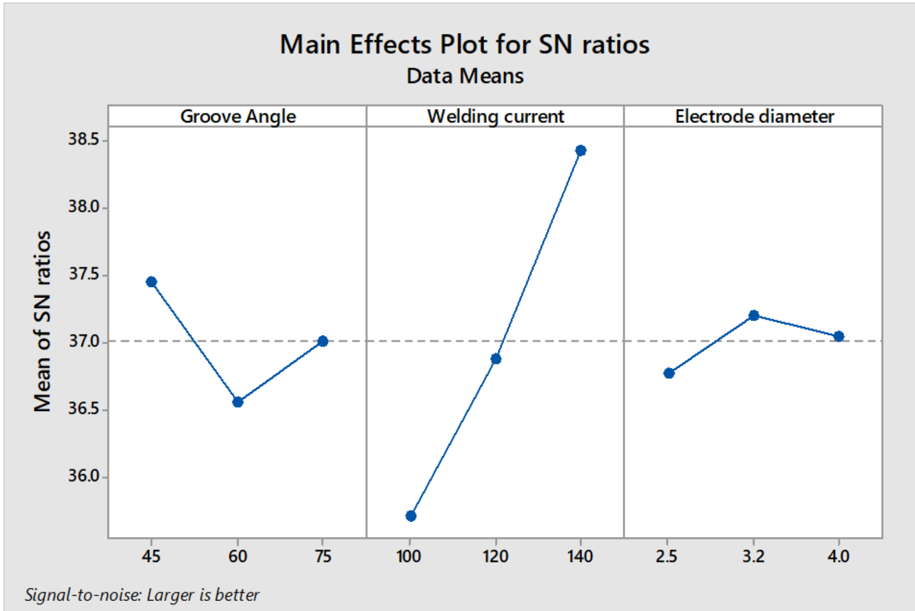


Figure: 3 Main effects plot for S/N ratio of hardness

The figure 3 shows main effect plot for S/N ration of hardness. The aim of this investigation is to maximize the response value, so larger is better criteria selected.

The S/N ratio represent significant factor for response value. The figure shows that hardness is higher when groove angle is 45°, welding current at 140 Amp and electrode diameter is 3.2 mm.

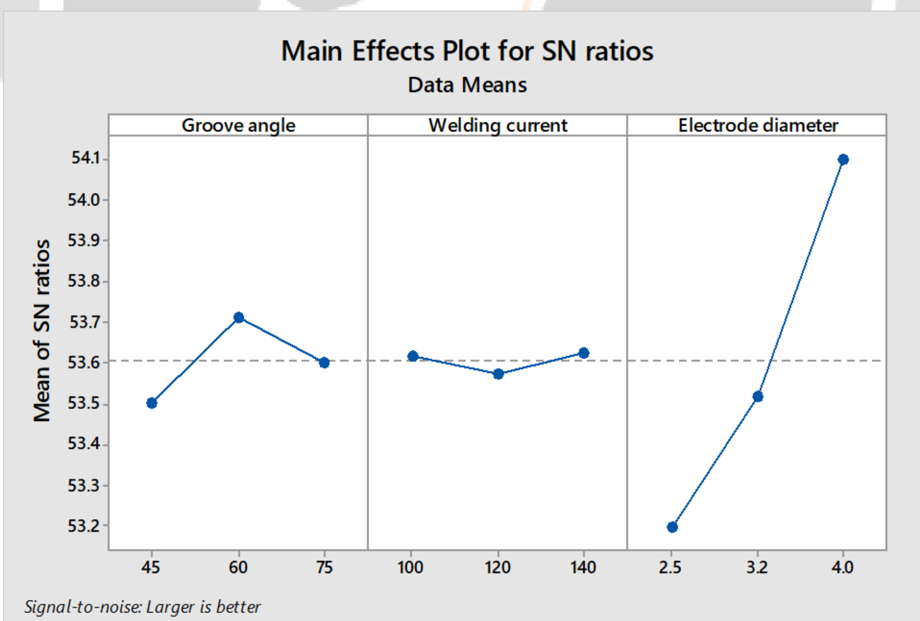


Figure: 4 Main effects plot for S/N ratio of tensile strength

The figure 4 shows that tensile strength of weld joint is higher when groove angle is 60°, welding current at 140 Amp and electrode diameter is 4 mm.

4. ANOVA ANALYSIS OF VARIANCE

ANOVA analysis has been carried out for the validation of DOE model by the value of (R-Sq). The value of R-sq should be nearer to 1. The ANOVA analysis has been carried out by statistical software Minitab 17 software, which is help to determine the significance input parameter for response parameter.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Groove Angle	2	96.22	48.11	10.53	0.041
Welding current	2	781.56	390.78	17.94	0.039
Electrode diameter	2	22.89	11.44	2.53	0.656
Error	2	43.56	21.78		
Total	8	944.22			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
4.66667	89.10%	81.55%	76.59%

Figure: 5 ANOVA for hardness

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Groove angle	2	200.51	100.25	18.81	0.038
Welding current	2	11.93	5.96	8.81	0.248
Electrode diameter	2	3903.19	1951.59	26.39	0.024
Error	2	14.71	7.35		
Total	8	4130.33			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
2.71178	87.64%	81.58%	71.79%

Figure: 6 ANOVA for tensile strength

The ANOVA gives the significant parameter for response variable by the value of "*F*". Higher the *F* value means factor is more significant to response parameter. The hardness ANOVA shows the *F* value for welding current (17.94), groove angle (10.53) and electrode diameter (2.53).

The value of *P* should be lesser than 0.05 (consider confidence level 95%). *P* value for welding current is 0.039 which is less than 0.05, for groove angle 0.041 which is also less than 0.05 that means welding current is most significant parameter then groove angle.

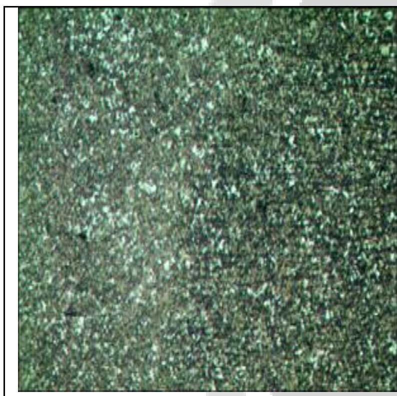
The value of *F* for electrode diameter is 26.39 which is highest compare to others so, electrode diameter is the most significant factor for the tensile strength. After then groove angle with *F* value 18.81 second most affecting parameter. The welding current with *F* value 8.81 not affecting too much.

Table: 2 Concluded results of Taguchi analysis and ANOVA

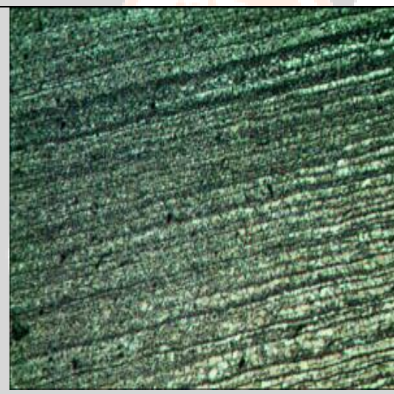
Response/Input Parameter	Groove angle (Degree)	Welding current (Amp)	Electrode diameter (mm)	ANOVA result (significant factor)
Hardness	45	140	3.2	Welding current (F=17.94)
Tensile strength	60	140	4.0	Electrode diameter (F=26.39)

5. MICROSTRUCTURE

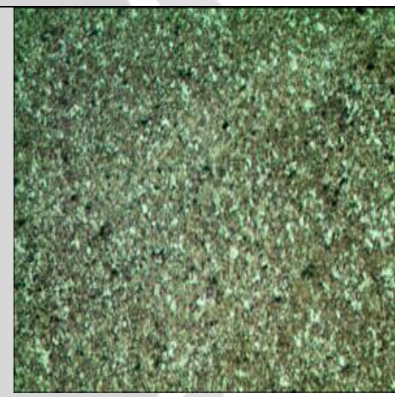
The microstructure tests were carried out by Optical Microscope Model: NIM 1000X. The microstructure test determines grain boundaries of weld metal (WM). The microstructure of weld metal (WM) observed at 100X by Optical Microscope.



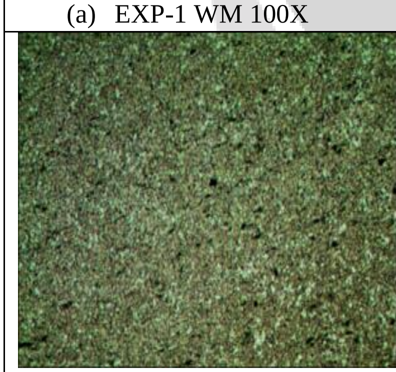
(a) EXP-1 WM 100X



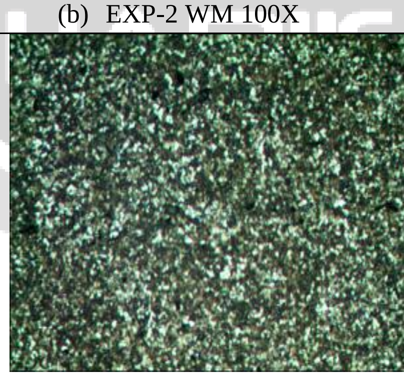
(b) EXP-2 WM 100X



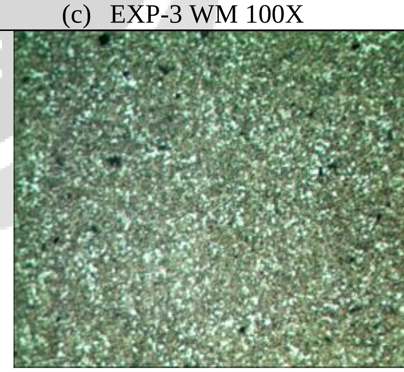
(c) EXP-3 WM 100X



(d) EXP-4 WM 100X



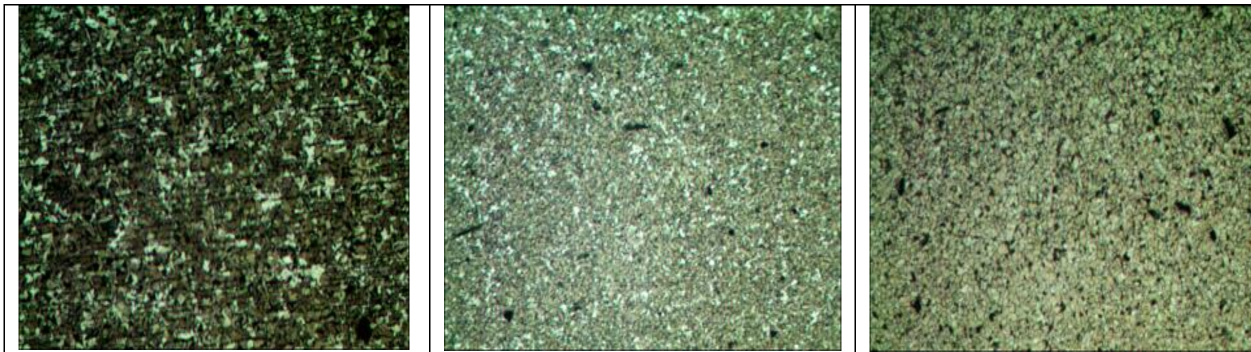
(e) EXP-5 WM 100X



(f) EXP-6 WM 100X

Figure: 7 Microstructure for welding experiments 1-6

The microstructure test shows the ferrite (white constituents) and pearlite (dark constituents). The ferrite is interstitial solid solution of carbon and pearlite is combination of ferrite and cementite.



(g) EXP-7 WM 100X (h) EXP-8 WM 100X (i) EXP-9 WM 100X

Figure: 8 Microstructure for welding experiments 7-9

The heat input and pearlite (dark constituents) are inversely proportional to each other. It means as increase in heat input amount of pearlite decreases. It affects that poor the mechanical properties. As increase in groove angle more heat deposited so that the cooling rate of metal increases.

Due to increase in cooling rate coarse microstructure generated, which means poor mechanical properties. With 3rd experiment, 45° groove angle, 140 Amp welding current and 4 mm electrode diameter, we can achieve good mechanical properties. So that the microstructure of weld metal in third experiment consists fine grains compare to other.

6. GREY RELATIONAL ANALYSIS (GRA) FOR OPTIMIZATION

The optimization of process parameter means to find out best parameter at which we can achieve our best output or desire output. In this study grey relational analysis method has been used for optimization. In grey relational analysis (GRA) method for optimization, first step is to perform normalize raw data for analysis. It's called "normalization".

In this study, normalization of experimental results performs between ranges of 0 to 1. It's called grey relational generating. Here larger-the-better attributes taken for the response variables like hardness and tensile strength. The grey relational generating calculated by following equation:

$$Xij = \frac{Yij - Min\,\{Yij, i=1,2,\ldots\ldots,m\}}{Max\,\{Yij, i=1,2,\ldots\ldots,m\} - Min\{Yij, i=1,2,\ldots\ldots,m\}} \quad \text{for } i = 1, 2.....m \text{ and } j = 1, 2.....n$$

Where, Yij = Performance value of attributes

Grey relational coefficient can be calculated by following equation.

$$Y\,(xoj, xij) = \frac{\Delta \min + \xi\, \Delta max}{\Delta ij + \xi\, \Delta max} \quad \text{for } i = 1, 2\ldots m,\ j = 1, 2 \ldots n$$

$$\Delta ij = |\ xoj - xij\ |$$

$$\Delta min = Min\{\Delta ij, i = 1,2, \ldots\ldots, m; j = 1,2, \ldots\ldots n\}$$

$$\Delta max = Max\{\Delta ij, i = 1,2, \ldots\ldots, m; j = 1,2, \ldots\ldots n\}$$

ξ is the distinguishing coefficient, $\xi \in [0,1]$ & ξ is assumed as 0.5

Table: 3 Grey relational generations

Trial No.	Hardness (HRBW)	Tensile strength (Mpa)
1	0.0000	0.0000
2	0.5161	0.3059
3	1.0000	0.8798
4	0.0323	0.5151
5	0.1290	1.0000
6	0.5806	0.2509
7	0.0645	0.9906
8	0.3226	0.0863
9	0.7097	0.3870

The grey relational calculation consist the average of grey relational coefficient for each experiment. Higher the grey relational grade means higher the rank. Higher the rank means that parameters are best for response variables. Higher the rank means better product quality of product or better value of response variable.

Table: 4 Calculated grey relational coefficient and grade values

Trial No.	Grey relational coefficient		Grey relational grade	Rank
	Hardness (HRBW)	Tensile Strength (Mpa)		
1	0.3333	0.3333	0.3333	9
2	0.5082	0.4187	0.4635	6
3	1.0000	0.8061	0.9031	1
4	0.3407	0.5077	0.4242	7
5	0.3647	1.0000	0.6824	2
6	0.5439	0.4003	0.4721	5
7	0.3483	0.9815	0.6649	3
8	0.4247	0.3537	0.3892	8
9	0.6327	0.4492	0.5409	4

The above table shows the calculated values of grey relational coefficient and grey relational grade. The grey relational grade is the average value of grey relational coefficient. Higher the grey relational grade represents higher rank. Higher grey relational grade represents better quality. The third experiment has higher grey relational grade 0.9031. So our optimal parameters are 45º groove angle, 140 Amp welding current and 4 mm electrode diameter.

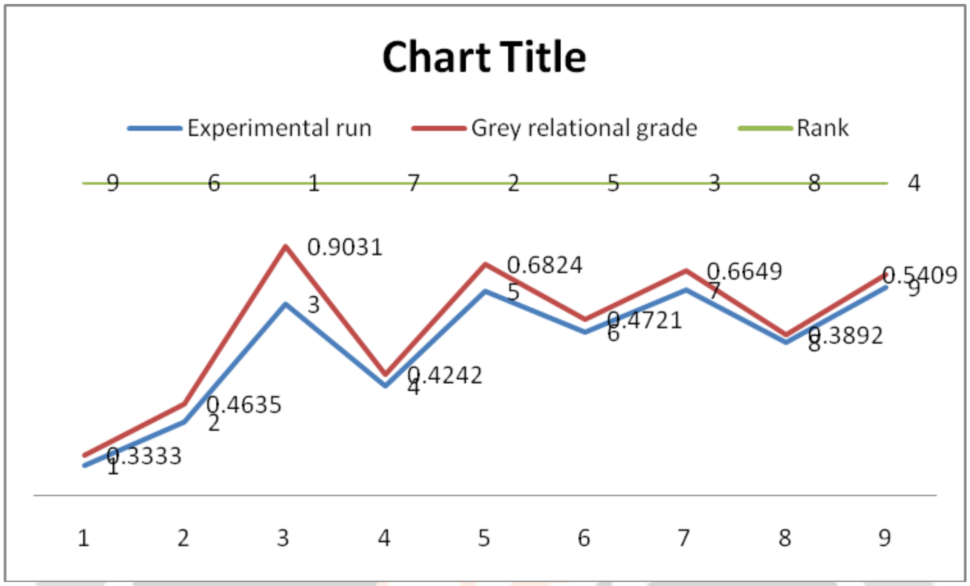


Figure: 9 Grey Relational Grade graph

The figure 8 shows the grey relational grade graph. In which, we can show that the experimental run, grey relational grade and rank. The figure show that the experiment with 0.9031 grey relational grade lies at rank 1. So, higher the grey relational grade consist higher rank. Experiment 3 has the higher grey relational grade value with first rank. So our optimize parameters are third experiments parameters. Optimum parameters are 45 groove angle, 140 Amp welding current and 4 mm electrode diameter.

7. CONCLUSION

In this study we have optimize the process parameters for the SA 515 Gr 60 carbon steel material. In this study three input parameters were selected with three levels. The set nine of experiments have been performed by Taguchi's method. The S/N ratio of hardness and tensile strength shows the input parameters at which we got better quality. The parameter optimize with grey relational analysis method. The optimize parameters are 45º groove angle, 140 Amp welding current & 4 mm electrode diameter.

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