

Optimal Tensile Strength by Submerged Arc Welding

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Abstract: To contend the market in the existent state, cost efficacy is vastly desired. For that, productivity improvement technique is among the many ways [1]. Submerged Arc Welding (SAW) is used as a productivity improvement method in the present paper where manufacturing process of fabricated parts are not only curtail by tumbling the process time, moreover by strengthening the weld quality too. Efforts are initiated to improve the productivity of the fabrication department of one of the industrial set up under study is taken by achieving the tensile strength of the weld bead in single pass only. In this process, conventional flux is supplemented by alloying in variations to achieve the optimal tensile strength, which are further verified by one of the optimisation method. The effect of input parameters are analysed over the output response and observed that one parameter has more substantial effect on the tensile strength than the other remaining parameters.

Keywords: Industrial unit, Optimization, Submerged Arc Welding (SAW), Tensile strength.

I. INTRODUCTION

Submerged arc welding is one of the non pressure electric arc welding processes, where continuously fed consumable solid electrode is provided. The molten weld and the arc zone are protected from atmosphere under a blanket of granular flux. Under molten state, flux exaggerates the current path between electrode and base metal. Submerged arc welding process is used in both automatic and semi-automatic mode. Also, more than one wire can be fed simultaneously to increase the deposition rate or welding speed [2, 3].

Whereas, Mercado *et al.* [4] were studied the effect of flux composition for tensile properties of submerged-arc weld beads. Kanjilal *et al.* [5] had examined the combined effect of flux mixture and welding parameters on SAW metal chemical composition and mechanical properties. Shen *et al.* [6] had observed that reinforcement, bead width, penetration,

deposition and HAZ size increased with increasing heat input, but the contact angle decreased with it. Datta *et al.* [7] had exercised the Taguchi philosophy for parametric optimization of bead geometry and HAZ width in SAW by using slag as a recycling process along with a mixture of fresh flux and fused flux and to study the influence on weld quality.

Kumanan *et al.* [8] had also used Taguchi method and Regression analysis for determining the process parameters of submerged arc welding. Beidokhti *et al.* [9] had explained the effect of titanium fixed flux on the microstructure and inclusion formation in submerged arc welded pipeline steel. Shahid *et al.* [10] had reviewed that problem occurs with dissimilar welding which affect the properties and efficiency of the weld joint and weld intermediate layers at the interface can improve the strength of dissimilar metals welding. Moshi *et al.* [11] had concluded that SAW process is recommended for high quality weld producon for applications more than 4% ferrite in the weld deposits.

II. EXPERIMENT SET UP AND MATERIALS USED

In the experimental process set up over SAW, automatic mode was used by automatically fed wire electrode and automatically controlled arc length; whereas flux was fed mechanically.

Materials used in experiment are:

- Base Metal
- Electrode
- Flux

A. Base Metal

The percentage composition of base metal used in the experiment is given in the Table I; with dimension of each piece is 260×130×10mm.

TABLE I: PERCENTAGE COMPOSITION OF BASE METAL

C	Mn	Si	P	S
0.1624	0.9917	0.1095	0.01426	0.00752

B. Electrode

Mild Steel electrode wire (EH-14) is used in this experiment. The diameter of the electrode wire is 3.2mm and its composition is given in the Table II.

TABLE II: PERCENTAGE COMPOSITION OF ELECTRODE

C	Mn	Si	P	S	Ti	Nb	V
0.2	1.8	0.1	0.03	0.03	0.002	0.007	0.002

C. Flux

Three types of flux are used in this experiment. 1st type of the flux is AUTOMELT B31, whereas 2nd and 3rd are 10% and 20% nickel powder addition in 1st type of flux. Percentage composition of AUTOMELT B31 is given in the Table III.

TABLE III: PERCENTAGE COMPOSITION OF FLUX

SiO ₂ +TiO ₂	CaO+MgO	Al ₂ O ₃ +MnO	CaF ₂
15	20	30	35

III. WELDING PARAMETERS AND THEIR LEVELS

Parameters and their level selected are given in the Table IV.

TABLE IV: WELDING PARAMETERS AND THEIR LEVELS

Parameters	Notation	Level 1	Level 2	Level 3
Voltage	A	26	30	34
Travel Speed	B	10	12	14
Flux	C	1	2	3

IV. TAGUCHI METHOD

Taguchi method is very efficient for the design of high quality manufacturing systems to provide much-reduced variance for the experiment with optimum setting of process control parameters. In the process, an orthogonal array provides a set of well balanced (minimum experimental runs) experiments and Taguchi’s signal-to-noise ratios, which is logarithmic functions of desired output; serve as objective functions for optimization. This helps in data analysis and prediction of optimum results. The S/N ratio is the ratio of the mean (signal) to the

standard deviation (noise). The ratio depends on the quality characteristics of the product / process to be optimized. This helps in data analysis and prediction of optimum results [12].

A. Orthogonal Arrays

An orthogonal array provides a set of well balanced (minimum experimental runs) experiments. In this experimental study, three factors are varied to three levels each in the orthogonal array L₉, which is given in the Table V.

TABLE V: L₉ ORTHOGONAL ARRAY

Experiment no.	Voltage (Volts)	Travel Speed (m/hr)	Flux
1.	26	10	1
2.	26	12	2
3.	26	14	3
4.	30	10	2
5.	30	12	3
6.	30	14	1
7.	34	10	3
8.	34	12	1
9.	34	14	2

B. Signal-to-Noise Ratio (S/N Ratio)

The S/N ratio developed by Dr. Taguchi is a performance measure to select control levels that best cope with noise. The S/N ratio takes both the mean and the variability into account. The S/N ratio is the ratio of the mean (signal) to the standard deviation (noise). The ratio depends on the quality characteristics of the product / process to be optimized. The standard S/N ratios generally used are as follows: nominal-is-best (NB), lower-the-better (LB), and higher-the-better (HB).

Larger is better:

$$\left(\frac{S}{N}\right)_{HB} = -10 \log(\text{MSD}_{HB}) \text{ Where } \text{MSD}_{HB} = \frac{1}{R} \sum_{j=1}^R (1/y_j^2)$$

Nominal is best:

$$\left(\frac{S}{N}\right)_{NB} = 10 \log_{10} (\text{MSD}_{NB})$$

$$\text{Where } \text{MSD}_{NB} = \frac{1}{R} \sum_{j=1}^R (y_j - y_o)^2$$

Lower is better:

$$\left(\frac{S}{N}\right)_{LB} = -10 \log(\text{MSD}_{LB}) \text{ Where } \text{MSD}_{LB} = \frac{1}{R} \sum_{j=1}^R (y_j^2)$$

V. TENSILE TEST

The testing is carried on Computerized Universal Testing Machine (UTM). Table VI shows the result of tensile strength and it's mean which is also shown in the Fig. 1.

TABLE VI: RESULT OF TENSILE STRENGTH

Run	Voltage	Travel Speed	Flux	Tensile strength, t_1 in MPa	Tensile strength t_2 in MPa	Mean (t_1+t_2)	S/N Ratio
						2	
1	26	10	1	465	477	471	53.4583
2	26	12	2	502	478	490	53.7961
3	26	14	3	496	506	501	53.9955
4	30	10	2	517	539	528	54.4470
5	30	12	3	544	536	540	54.6472
6	30	14	1	477	473	475	53.5336
7	34	10	3	573	587	580	55.2667
8	34	12	1	542	534	538	54.6149
9	34	14	2	528	536	532	54.5175

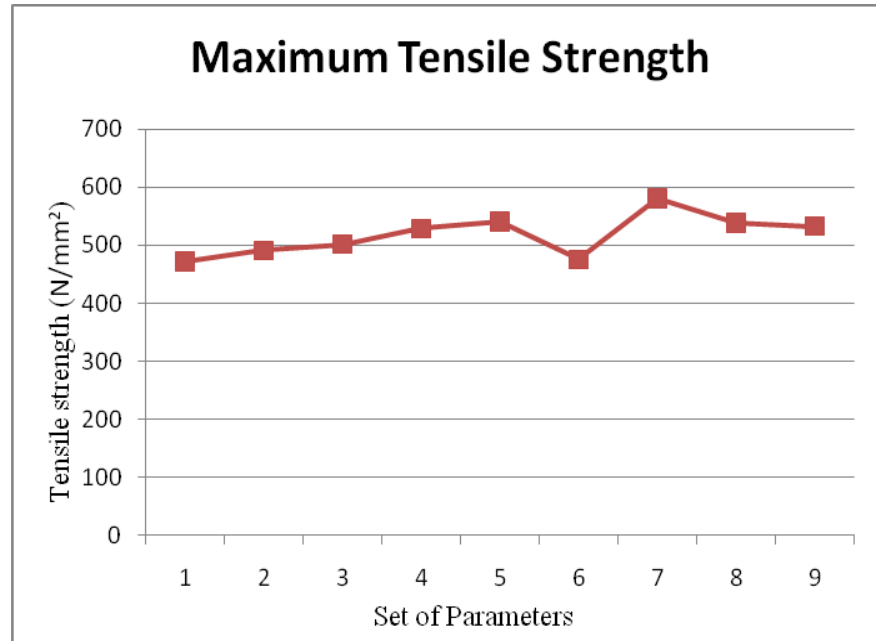


Fig. 1: Maximum Tensile Strength

A. ANOVA for Tensile Strength

The analysis of variance is carried out at 95% confidence level. The main purpose of analysis of variance is to investigate the influence of the design parameters on tensile strength. In this experimentation work, results are generated for mean of tensile strength. This method separates the total variability of the response (sum of squared deviations about the grand mean) into contributions rendered by each of the parameter/ factor and the error. Thus

$$SS_T = SS_F + SS_E$$

$$\text{Where } SS_T = \sum_{j=1}^P (\gamma_j - \gamma_m)^2$$

Where SS_T = Total sum of squared deviations about the mean.

γ_j = Mean response for j^{th} experiment.

γ_m = Grand mean of the response.

SS_F = Sum of squared deviations due to each factor.

SS_E = Sum of squared deviations due to error.

In the ANOVA Table, mean square deviation is given by:

$$MS \text{ (Mean Square)} = \frac{SS}{DF}$$

Where, SS is sum of square division

DF is degree of freedom

F-value of Fisher’s F ratio (Variance ratio) is given by:

$$F = \frac{MS \text{ for a term}}{MS \text{ for an error term}}$$

If the P-value appears less than 0.05, then it can be concluded that the corresponding factor has significantly influence on the selected response, at 95% confidence level.

The analysis of variance is carried out at 95% confidence level. The main purpose of analysis of variance is to investigate the influence of the design parameters on tensile strength by indicating that which parameters is significantly affected the quality characteristics. It uses the P-value, termed as probability of significance. If the P-value appears less than 0.05, then it can be concluded that the corresponding factor has significantly influence on the selected response, at 95% confidence level. At minimum value of P the F (Fisher value) should be maximum. From Table VII, it is concluded that voltage and flux have significant effect on the tensile strength with contribution of 58.40% and 30.84%, whereas travel speed has insignificant affected the tensile strength with contribution of 9.59%. Fig. 2 also shows the percentage contribution of parameters.

TABLE VII: ANALYSIS OF VARIANCE FOR MEAN

Source	DF	Seq SS	Adj SS	Adj MS	F	P	%age Contribution
Voltage	2	5928.2	5928.2	2964.11	50.14	0.02	58.40
Travel Speed	2	973.6	973.6	486.78	8.23	0.11	9.59
Flux	2	3129.6	3129.6	1564.78	26.47	0.036	30.84
Residual Error	2	118.2	118.2	59.11			1.16
Total	8	10149.6					

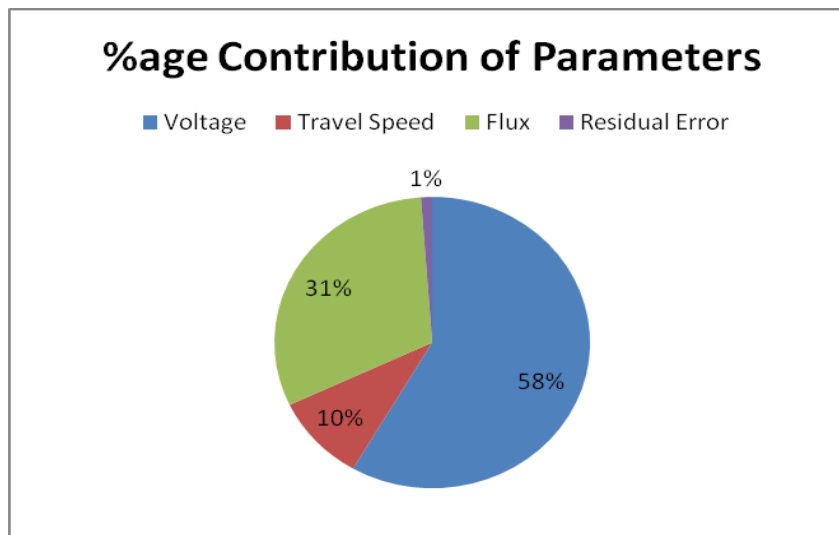


Fig. 2: Percentage Contribution of Parameters

The response Table VIII shows the average of each response characteristic for each level of each factor. The table includes

rank based on delta statistics, which compare the relative magnitude of effects.

TABLE VIII: RESPONSE TABLE FOR MEAN OF TENSILE STRENGTH

Level	Voltage	Travel Speed	Flux
1	487.3	526.3	494.7
2	514.3	522.7	516.7
3	550.0	502.7	540.3
Delta	62.7	23.7	45.7
Rank	1	3	2

The Delta statistic is the highest minus the lowest average for each factor. Minitab assigns ranks based on Delta values, rank 1 to the highest Delta value, rank 2 to the second highest, and so on. Use the level averages in the response tables to determine which level of each factor provides the best result.

B. Parameters Optimum Combinations

On the basis of above results, tensile strength of base metal will be maximum when voltage is 34 V, travel speed 10 m/h and flux is 3. So these are the optimum welding parameters on which

highest tensile strength is attained and also given in the Table IX.

TABLE IX: OPTIMUM COMBINATIONS OF PARAMETERS

Voltage	Level 3	34V
Travel speed	Level 1	10 m/hr
Flux	Level 3	3

ANOVA has been performed in the statistical software package MINITAB. Main Effect Plot for Tensile Test also generated by this software and shown in the Fig. 3.

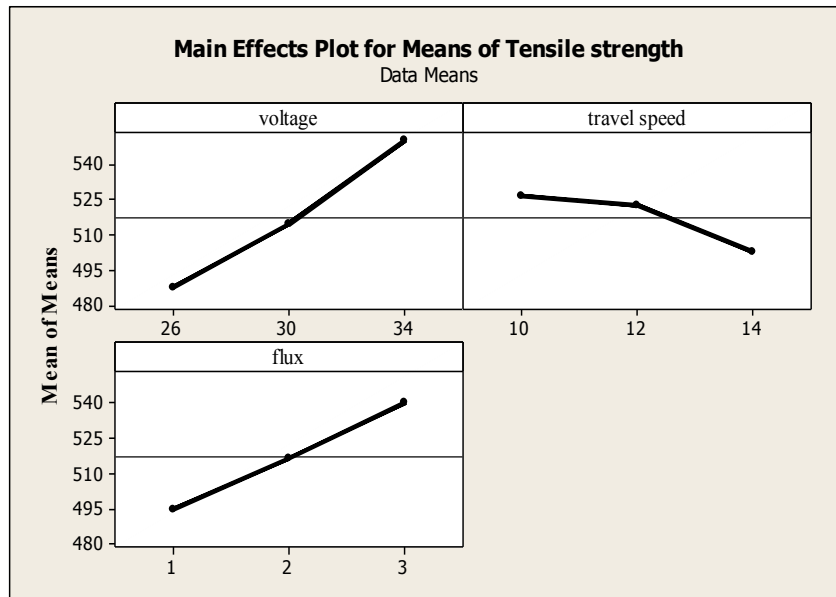


Fig. 3: Main Effect Plot for Tensile Test

After ANOVA we can conclude that welding voltage and flux is significantly affects the Tensile strength, and travel speed insignificantly affects the Tensile strength.

C. Signal-to-Noise Ratio

Taguchi has created a transformation of the repetition data to another value called the signal-to-noise (S/N) ratio. The control factors that may contribute to reduce the process variation can also be quickly identified by analyzing the S/N ratio. The larger the S/N ratio, the more desirable it is. The S/N ratio, which condenses the multiple data points within a trial, depends on the type of characteristic being evaluated. The equations for calculating the S/N ratios for LB (lower-the-better), NB

(nominal the best), and HB (higher-the-better) characteristics are different.

The response parameter, tensile strength is a ‘Higher the better’ (HB) case and S/N_{HB} was calculated using equation (1).

- Larger is better:

$$\left(\frac{S}{N}\right)_{HB} = -10 \log(MSD_{HB})$$

$$\text{Where } MSD_{HB} = \frac{1}{R} \sum_{j=1}^R (1/y_j^2) \tag{1}$$

Where MSD signifies mean square deviation, y_j is the response value under each trial, and R is the number of repetitions. The S/N ratio calculated for each trial is shown in Table X.

TABLE X: ANALYSIS OF VARIANCE FOR S/N RATIO

Source	DF	Seq SS	Adj SS	Adj MS	F	P	%age Contribution
Voltage	2	1.66152	1.66152	0.83076	37.20	0.026	58.38
Travel Speed	2	0.25587	0.25587	0.12793	5.73	0.149	8.99
Flux	2	0.88352	0.88352	0.44176	19.78	0.048	31.05
Residual Error	2	0.04466	0.04466	0.02233			1.57
Total	8	2.84557					

The ANOVA results for S/N ratio of tensile strength, given in Table X, shows two factors as most significant i.e. welding voltage and flux. Since the S/N ratio is to be maximized for optimal results for the responses, least variability would be

observed if the welding voltage was set at 34 Volts and flux 3 is used. The main effect plot for S/N values for the experiment is shown in Fig. 4 and 5, which gives a graphical representation of the above discussion.

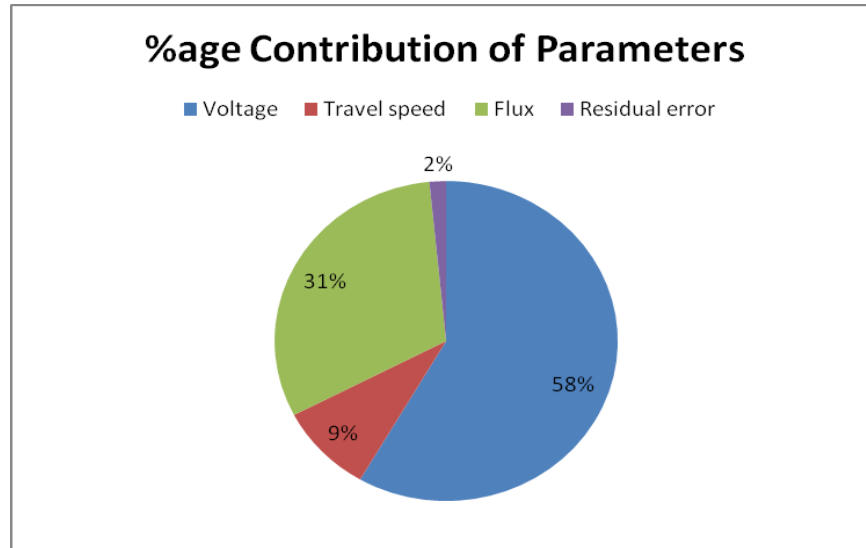


Fig. 4: Percentage Contribution of Parameters

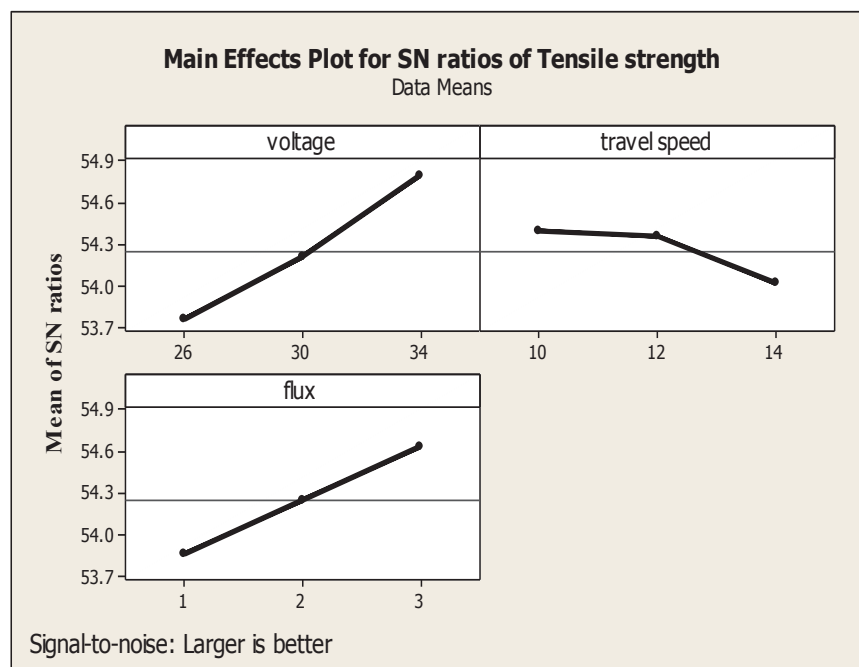


Fig. 5: Main Effect Plot for S/N Ratio of Tensile Test

D. Estimated Tensile Strength

Voltage has the significant effect the tensile strength. Higher tensile strength is the desired response parameter. For optimization of response 3rd level of voltage and flux has been chosen for optimal design. Mean value of tensile strength is given by:

$$\mu_{A_3C_3} = A_3 + C_3 - T \text{ (value of significant factor in response table - mean value of mean)}$$

$$= 550 + 540.3 - 517.22 = 573.08 \text{ N/mm}^2$$

Confidence Interval (CI) around the estimated mean for tensile strength:

$$C.I = \sqrt{\frac{F_{\alpha} : v_1 : v_2 \times V_e}{\eta_{\text{eff}}}}$$

α = Risk factor = 0.05

V_1 = D.O.F. for mean (Which is always equal to 1)

V_2 = D.O.F. for error = Total D.O.F. – D.O. F. of significant factors = 8-4 = 4

Now $F_{\alpha} : v_1 : v_2 = F_{0.05:1:4} = 7.7086$ (This value find out with the help of P chart with 95% confidence level)

$$V_e = \frac{\text{SS of e pooled}}{\text{D.O.F. of e pooled}}$$

V_e = Error variance

SS of e pooled = It is the total SS values – SS value of significant factor.

$$= 10149.6 - (5928.2 + 3129.6) = 1091.8$$

D.O.F. of e pooled = Total D.O.F. – D.O. F. of significant factors = 8-4 = 4

$$V_e = \frac{1091.8}{4} = 272.95$$

$$\eta_{\text{eff}} = \frac{9}{1 + \text{D.O.F. of } A_3 \times C_3} = \frac{9}{1 + (2 \times 2)} = 1.8$$

$$\text{So, } C.I = \sqrt{\frac{F_{\alpha} : v_1 : v_2 \times V_e}{\eta_{\text{eff}}}} = \sqrt{\frac{7.7086 \times 272.95}{1.8}} = 34.19$$

So the confidence interval around the estimated tensile strength is $573.08 \pm 34.19 \text{ N/mm}^2$.

E. Discussion on Tensile Strength

Voltage and flux have significant effect on the tensile strength with contribution of 58.40% and 30.84%, whereas travel speed has insignificant effected the tensile strength with contribution of 9.59%. Tensile strength is maximum ($A_3B_1C_3$ 580 N/mm^2) at voltage 34V, travel speed 10 m/hr and flux 3. The confidence interval is $573.08 \pm 34.19 \text{ N/mm}^2$.

VI. VERIFICATION OF TAGUCHI'S OPTIMAL RESULT

After evaluating the optimal parameter settings, the next step of the Taguchi approach is to predict and verify the enhancement of quality characteristics using the optimal parametric combination. The estimated S/N ratio using the optimal level of the design parameters can be calculated as [8]:

$$\hat{\eta} = \eta_m + \sum_{i=1}^o (\bar{\eta}_i - \eta_m)$$

Where η_m is the total mean S/N ratio, $\bar{\eta}_i$ is the mean S/N ratio at the optimal level, and o is the number of the main design parameters that affect the quality characteristic. Table XI represents the comparison of the predicted tensile strength with the actual parameters by using the optimal welding conditions; good agreement between the two has been observed. This

proves the utility of the Taguchi approach in relation to product / process optimization.

TABLE XI: RESULTS OF THE CONFIRMATORY TEST FOR TENSILE STRENGTH

	Initial Welding Parameters	Optimal Welding Parameters	
		Prediction	Experiment
Level	$A_2B_2C_2$	$A_3B_1C_3$	$A_3B_1C_3$
Tensile strength	530	573	580
S/N ratio (dB)	54.4855	55.1631	55.2667
Improvement in S/N ratio = 0.7812			

VII. CONCLUSION

Taguchi optimization method was applied to find the optimal process parameters for Tensile Strength when the nickel powder was added in flux, in different concentrations. After complete study it was conclusion that we can conclude that voltage and flux are significantly affects the Tensile strength, and travel speed insignificantly affects the Tensile strength. The conformation test also provides the satisfactory result.

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