



PARAMETRIC OPTIMIZATION OF MIG WELDING PROCESS TO IMPROVE ITS TENSILE STRENGTH

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ABSTRACT

Manufacturing process plays a very vital role in the product life management. The process parameters and its selection are important to achieve required outcomes. Welding is one of the critical manufacturing processes, which is affected by various process parameters involved. The outcomes of the welding process are measured in terms of strength, penetration, reinforcement, height and hardness. These outcomes are affected by different process input variables like current, voltage, welding speed, wire feed rate, etc. It is very important to set their value at a limit where work piece should not be overheated, residual stresses shall be at minimum level also it should not be so weak that fusion of two base metals will be less. In order to set their values different optimization techniques are used. Regression analysis is done in order to find out the relation between output and input variables. The values of weld current, arc voltage and wire feed rate are set by experimentation in terms of DOE. Results of the experimentation are discussed & interpreted in this paper.

KEYWORDS: TAGUCHI, L9 ARRAY, REGRESSION, ANOVA.

INTRODUCTION

MIG welding which is also called as GMAW. i.e. Gas metal arc welding is used to join the case of capacitor. In this type of welding a wire from reel is fed through a torch which is in contact with base metal & which supplies a current. The wire melts & converts into pool by arc. The welding arc is protected by shield gas. It is necessary to avoid oxidation of weld pool. Coating is given on electrode wire in order to produce a smoke which is also acts like a shield. Depending on the shielding gas process is divided into two types: i) MIG (Metal Inert gas) ii) MAG (Metal Active Gas). In Metal active gas welding a reactive gas like carbon dioxide (CO₂) is used to protect the weld. While MIG welding used an inert gas like argon. Generally MIG

welding is applied for aluminum, copper, stainless steel and high alloyed steel, metal transfer in the MIG welding is done by two methods: spray arc & short circuiting arc. In spray arc process an arc is introduced in between welding wire & work piece. The transfer of metal pool is in the form of continuous spray. The arc avoids spatters and it provides deep penetration in base material. In order to obtain spray arc, it is necessary to keep welding current above certain minimum value. The current level is depends on shielding gas, alloy, size of welding wire. So generally for wire having diameter greater than or equals to 0.8mm uses the current limit above 150 amperes. In short arc process no metal is transferred through an arc. It creates short circuits between wire and work piece, wire is fed again into arc. The arc produced in this method is having low

heat input. To obtain a better weld the arc voltage & arc length must be kept at constant value. This can be done by two ways: i) by adjusting the filler material feed speed to exactly the same as its melting. ii) By adjusting the ampere to exactly at the value required to melt the material. The basic elements of MIG welding equipment are

- i) Power source
- ii) Welding current switch
- iii) Power supply to wire feeder
- iv) Gas cylinder, Gas valve
- v) Gas regulator with flow adjustment
- vi) Wire feed motor with drive rolls.
- vii) Cable package including welding current cable, gas hose, control circuit cables and wire feed tube
- viii) Torch with contact tip for supplying current to the nozzle and control switch.

This study is focused on the GMAW welding process of AISI 1040 thin sheets of 3mm thickness. The filler material used in this case is ER 70S-6. The initial values or levels of process parameters are selected as per literature review and the actual work experience of the welder.

Process parameter	Level 1	Level 2	Level 3
Welding Current (Amp)	120	150	180
Arc Voltage (volts)	18	21	24
Wire Feed Rate (m/min)	2	3	4

Table1. Process level parameters.

In order to investigate the parameters to achieve maximum tensile strength, Design of experiment by Taguchi is used and it is followed by a regression analysis in order to find out optimized relationship between dependent and independent variables involved.

TAGUCHI DOE

Design of experiment basically found by R.A. Fisher in England in 1920's to study the effect different variables. Dr. Genechi Taguchi carried out required research in 1940 in the same field. He made techniques of experiments easier. Design of experiment is a tool used to plan, design analyze and interpreted the result. It avoids number of experiments to be carried out to achieve desired result. To do the experiment one need to find out objectives or output of the value to be obtained. After fixing the objectives, various factors which make changes in the output values are to be decided. If there are three output values of experiments then combined value for all three is given by,

$$V_0 = \left(\frac{V_1}{V_1 \text{ max}}\right) F_1 + \left(\frac{V_2}{V_2 \text{ max}}\right) F_2 + \left(\frac{V_3}{V_3 \text{ max}}\right) F_3$$

Where, V = Output values

Vmax = Maximum values of reading

F = Influence factor in percentage.

There must be some levels for the factors and it is to be decided at the start. The size of experiment will be small to have cost effective experiments. The term array size is used to decide number of factors and their corresponding levels. There are three types of array available for DOE which are as follows:

Two level array: L4, L8, L12, L16, L32 and L 64

Three level array: L9, L18, and L27

Four level arrays: L16, L32 out of which suitable array for our requirement is L9 array.

Design of L9 array

Experiment	welding current (amp)	arc voltage (voltage)	wire feed rate (M/min)
1	120	18	2
2	120	21	3
3	120	24	4
4	150	18	3
5	150	21	4
6	150	24	2
7	180	18	4
8	180	21	2
9	180	24	3

Table 2 Design of experiment table.

So this is the required set of experiments to be carried out.

EXPERIMENTATION

Cutting of sheets and welding of the samples are as shown in the figure 1.

Welding machine: OTG MIG welding machine

Material used: AISI 1020 (EN8) 3mm thickness

Filler wire: ER-70S-6 (1.2mm diameter)

Torch travel speed: 350mm / min

Throat thickness: 5mm

Sample size: 150mm x 12mm x 3mm

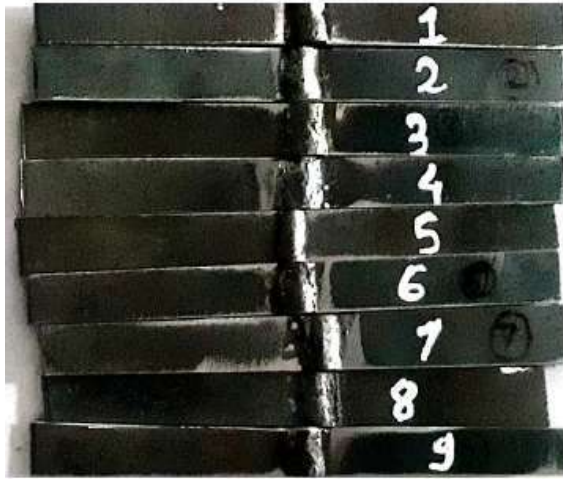


Fig 1 Cutting & welding of samples

Following samples are tested for tensile testing on universal testing machine with gradually applied tensile load. Test is carried out as per IS 1608 standard on UTM machine.

Make: F.I.E made Universal Testing Machine

Model: YTE 40

Specification / capacity: 400KN

Following are the results of tensile testing

welding current (amp)	arc voltage (voltage)	wire feed rate (M/min)	Y	S/N
120	18	2	255.5	48.1478
120	21	3	269.32	48.6038
120	24	4	375.13	51.4836
150	18	3	358	51.0777
150	21	4	395.75	51.9484
150	24	2	455.25	53.165
180	18	4	218.875	46.8039
180	21	2	363.625	51.2131
180	24	3	470.74	52.0145

Table3 Result of tensile test

Taguchi Analysis: It mainly uses three terminologies in order to analyze the design of experiment which are Mean value, standard deviation and signal to noise ratio. Main response is given by the equation:

$$\bar{Y} = \frac{1}{n} \sum_{i=1}^n Y_i$$

While standard deviation is given by the equation:

$$S = \sqrt{\frac{\sum_{i=1}^n (Y_i - \bar{Y})^2}{n - 1}}$$

The parameters which are preferred are selected based on signal to noise ratio response. It is defined as the ratio of mean to the standard deviation. Its value or formula is derived for different cases as follows:

i) Smaller the better: When we need to select the parameters which are affected by the types of error then we need to select the S/N ratio as small as possible. For this case S/N ratio is given by:

$$\frac{S}{N} = -10 \log \left(\frac{1}{n} \sum_{i=1}^n Y_i^2 \right)$$

ii) Nominal is the best: When analysis is to be carried out is for a diameter of shaft at its targeted value then we need to reduce the overall variation and to select the nominal the best. For this case S/N ratio is given by:

$$\frac{S}{N} = 10 \log \left(\frac{\bar{Y}^2}{S^2} \right)$$

iii) Larger the better: In a case where we need a output value as large as possible as in case welding joint strength, we need a value which is more than base metal strength in that case Larger the better is used.

$$\frac{S}{N} = -10 \log \left(\frac{1}{n} \sum_{i=1}^n \frac{1}{Y_i^2} \right)$$

Among all the values one has to select depending on the requirement of problem. After calculating the value of S/N ratio for all experiments, data will be analyzed by means of graphical method. The design of experiment is of L9 array size so the response of signal to noise ratio and the mean values of strength for this experiment are calculated as shown in the Table 3. In order to plot the graph, Mean of the mean value and mean of the signal to noise ratio is calculated and it is plotted against the process levels parameters.

Response of Mean:

Level	A	B	C
1	299.98	277.46	358.13
2	403.00	342.90	366.02
3	351.08	433.71	329.92
Delta	51.92	90.81	36.10
Rank	2	1	3

Table 4 Response of Mean value

Response of S/N ratio:

Level	A	B	C
1	49.41	48.68	50.34
2	52.06	50.59	50.57
3	50.01	52.22	50.08
Delta	0.60	1.63	0.49
Rank	2	1	3

Table 5 Response of S/N ratio
REGRESSION ANALYSIS

Regression the term used in 1986 by Francis Galton. This term is different from correlation as correlation is used to represent the linear relationship between two factors while regression is used to find out best possible fitted line relationship between two factors. It is used to predict the output value based on a change in input variable values. It is done by using MS excel.

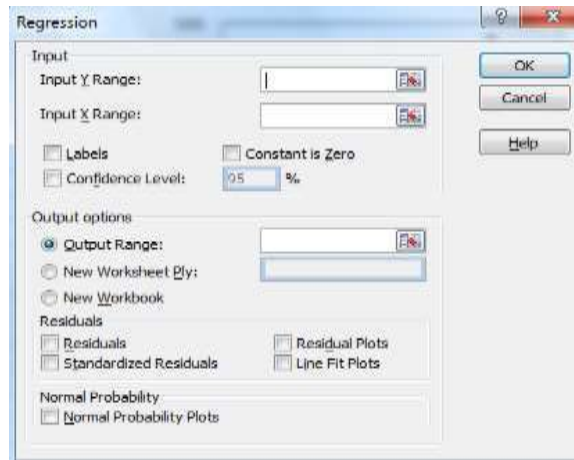


Fig 2 Multiple regression in MS Excel

Multiple regressions is done by taking weld current, arc voltage and wire feed rate as input and welding strength as output. Data analysis tool of the MS excel is selected, select Regression and press Ok. Give the output column in Y range and three input variables in X range. Select output range in order to receive the result. Initial regression equation is given by:

$$Y = \text{Constant} + B_1 X_1 + B_2 X_2 + B_3 X_3$$

Input and output is given as per Table. 3

Regression 1:

SUMMARY OUTPUT:

Regression Statistics	
Multiple R	0.83
R Square	0.68
Adjusted R Square	0.49
Standard Error	62.48

	Observations	9.00		
Table 6 Regression Summary				
ANOVA:				
	df	SS	MS	F
Regression	3	41730.04	13910.01	3.56
Residual	5	19516.66	3903.33	
Total	8	61246.70		

Table 7 Residual Summary
ANOVA: Analysis of variance is done by checking various levels given by the equation:

$$Y_i = (\bar{y} - \bar{y}) + (Y_i - \bar{y})$$

Degrees of freedom indicate the number of input values that can be changed in the equation without violating any condition.

	Coefficients	Standard Error	t Stat	P-value
Intercept	-280.95	233.30	-1.20	0.28
A	0.85	0.85	1.00	0.36
B	26.04	8.50	3.06	0.03
C	-14.10	25.51	-0.55	0.60

Table 8 Outcomes of Regression

Difference between observed value of the output and predicted value of the output is called as residual. P values are very meaningful values for relation between variables. The models having P values less than 0.15 is meaningful and which are greater than 0.15 are meaningless.

Initial Regression equation is

$$Y = -280.94 + 0.85A + 26.04B - 14.10C \text{ -----1)}$$

Where Y = Welding strength

A = Weld current in ampere

B = Arc voltage in volts

C = Wire feed rate in m/min.

It is observed that P value of the initial regression is greater than 0.15 for weld current and wire feed rate so they removed from analysis and second regression is done by using a voltage value. Coefficients are the values which appear in the equation as a constant.

$$Y = -195.51 + 26.04 B \text{ -----2)}$$

RESULTS:

1) Mean VS weld current

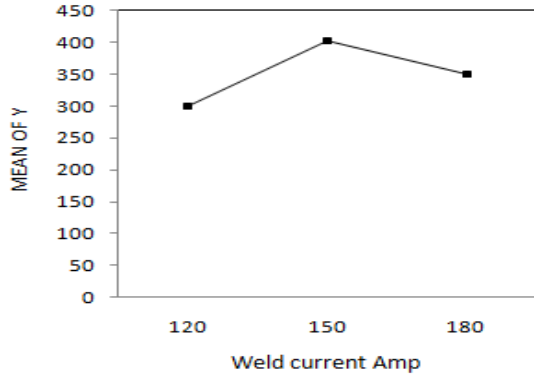


Fig. 3 Mean Vs weld current

2) S/N ratio Vs weld current

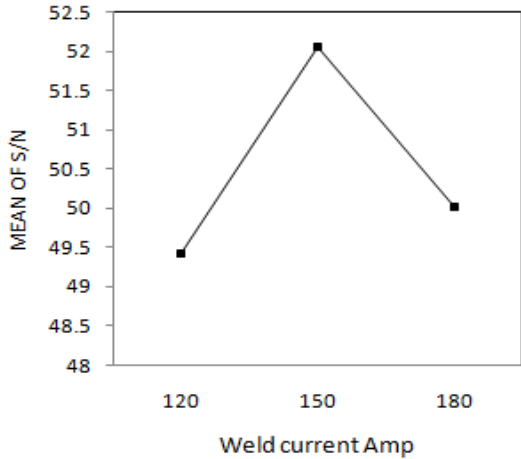


Fig. 4 S/N ratio Vs weld current

3) Mean VS Arc voltage

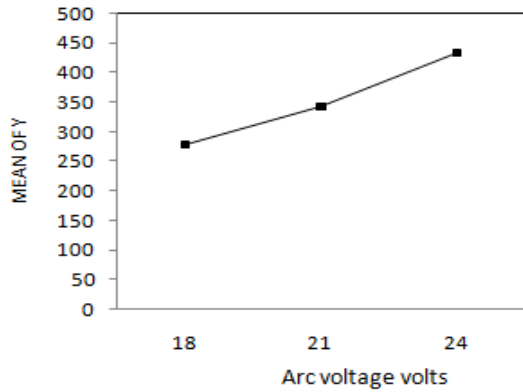


Fig 5 Mean Vs Arc voltage

4) S/N ratio Vs arc voltage

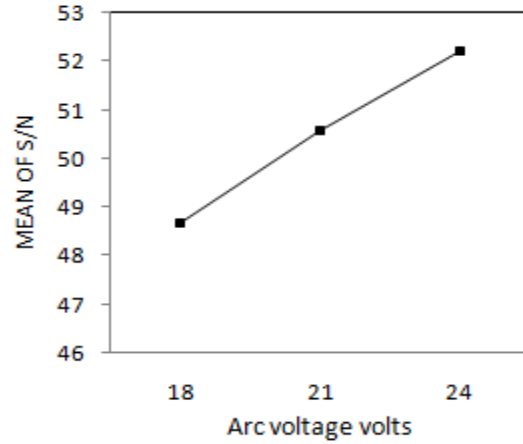


Fig. 6 S/N ratio Vs arc voltage

5) Mean Vs wire feed rate

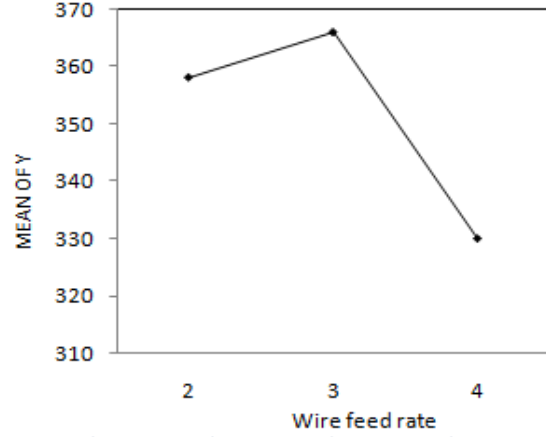


Fig 7 Mean Vs wire feed rate

6) S/N ratio Vs wire feed rate

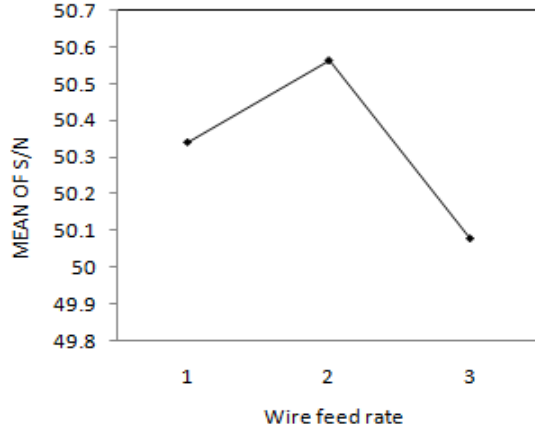


Fig 8 S/N ratio Vs wire feed rate

7) Regression for weld current and strength

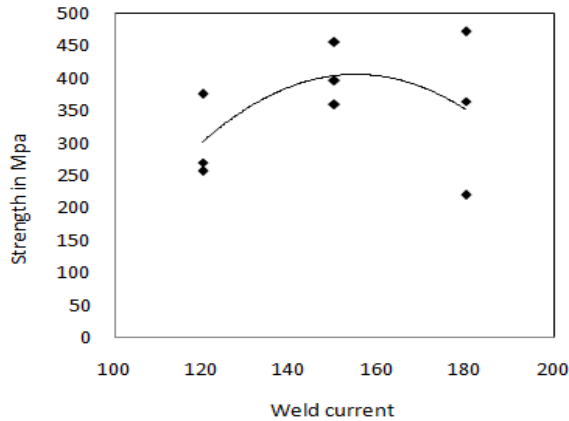


Fig 9 weld current and strength

8) Regression for arc voltage and strength

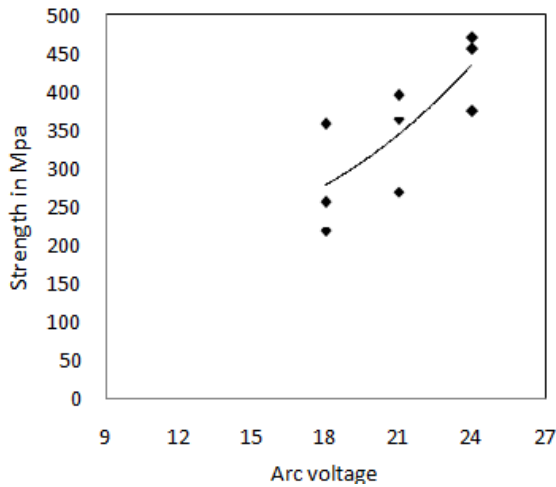


Fig 10 Regression for voltage and strength

9) Regression for wire feed and strength

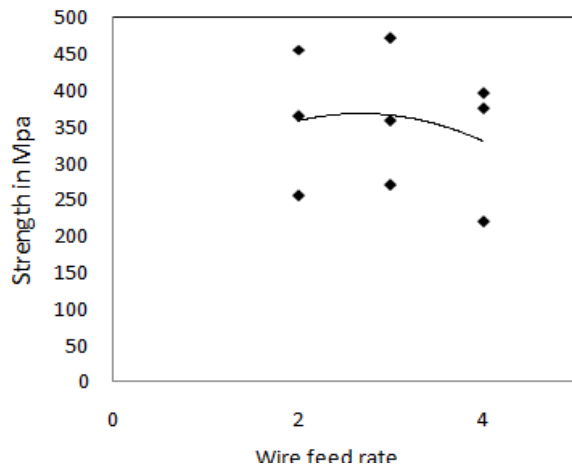


Fig 11 Regression for wire feed and strength

DISCUSSION

1) Taguchi DOE: As seen from Fig 3 & 4 the results of S/N ratio and mean the strength of the welding is lower at 120Amp it increases at 150 Amp and again reduces at 180Amp. It is showing that maximum welding strength exists at 180Amp. Similarly S/N ratio and mean values of arc voltage are showing that there is a linear relationship between arc voltage and welding strength. At voltage of 18V strength value is found to be 358 Mpa, at 22V it is found to be 395.75 Mpa and at 24 V the strength is maximum as 455.25 Mpa. The higher is the voltage, higher is the strength.

In the case of wire feed rate for 2m/min the welding strength observed to be 358.13 Mpa, at 3m/min it is increased at 366.02Mpa but reduces at 4m/min on the value of 329.92 Mpa. That means the maximum welding strength is exists at wire feed rate of 3m/min.

As per the result optimized parameters to achieve maximum tensile strength of the welded joint are as follows;

Weld current = 150 Amp

Arc voltage = 24 volts

Wire feed rate = 3 m/min

2) Regression analysis: Multiple regressions is done by taking weld current, arc voltage and wire feed rate as input and welding strength as output. The models having P values less than 0.15 is meaningful and which are greater than 0.15 are meaningless.

Initial Regression equation is

$$Y = -280.94 + 0.85A + 26.04B - 14.10C$$

It is observed that P value of the initial regression is greater than 0.15 for weld current and wire feed rate so they removed from analysis and second regression is done by using a voltage value.

$$Y = -195.51 + 26.04 B$$

By using second regression equation we can predict the values of welding strength. The factor which has maximum contribution towards welding strength is the arc voltage than any other parameters in this study.

Correlation between weld current and strength in terms of second order equation is given by

$$y = -0.086x^2 + 26.67x - 1661.$$

Correlation between arc voltage and strength in terms of second order equation is given by

$$y = 1.409x^2 - 33.15x + 417.5$$

Correlation between wire feed rate and strength in terms of second order equation is given by

$$y = -21.99x^2 + 117.8x + 210.3$$

CONCLUSION

Optimization of the MIG welding process parameters is done by using Taguchi method and L9 array. Samples are prepared, tensile testing is carried

out. Following parameters are selected as optimized parameters Weld current = 150 Amp, Arc voltage = 24 volts, Wire feed rate = 3 m/min. Regression analysis is also carried out for the results of tensile testing. Arc voltage has maximum contribution towards attaining higher welding strength. Equation predicting the relationship of welding strength with arc voltage is obtained.

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