Process Parameter Optimization in Metal Inert Gas Welding of 6mm Mild Steel Plate Using Taguchi Robust Design Method for Improving Quality of Welded Joints

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***Abstract*—Welding is a basic manufacturing process for making components or assemblies. Research on welding of materials like steel is still critical and ongoing. Welding input parameters play a very significant role in determining the quality of a weld joint. The gas metal arc welding parameters are the most important factors affecting the quality, productivity and cost of welding in many industrial operations. The aim of this study is to investigate the optimization process parameters for metal inert gas welding for 6mm mild steel plate work piece using Taguchi method to formulate the statistical experimental design using semi-automatic welding machine. Experimental study was conducted at Bishoftu Automotive Engineering Industry, Bishoftu, Ethiopia. This paper presents the influence of three welding parameters (control factors) like welding current (Amp.), wire speed/feed rate (mm/min.), and shielding carbon dioxide gas pressure flow rate (lit./min.) with two different levels for variability in the welding strength. The objective function have been chosen in relation to parameters of metal inert gas welding i.e. final welding quality (better, medium and bad) and minimum number of defects in final products. Eight experimental runs based on an L8 orthogonal array Taguchi method were performed. An orthogonal array, signal-to-noise ratio and analysis of variance are employed to investigate the welding characteristics of mild steel plate and used in order to obtain optimum levels for every input parameter at 95% confidence level. The optimal parameters setting was found is arc strength (A2), wire speed (B1), and gas pressure flow rate (CO2) within the constraints of the production process. Finally the twelve conformations welding tests have been carried out to compare the predicated values with the experimental values confirm its effectiveness in the analysis of weld quality in final products. It is found that welding wire speed has major influence on quality of welded joints. Experimental result for optimum setting gave better quality welding condition than preliminary setting. This study is valuable for different material and thickness variation of welding plate for Ethiopian industries.**

Manuscript received October 18, 2015.

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***Index Terms*— Weld quality, metal inert gas welding, mild steel plate, orthogonal array, analysis of variance, Taguchi method.**

I. Introduction

In today's manufacturing world, quality is vital importance. Quality can be defined as the degree of customer's satisfaction as provided by the produced product. The product quality depends on the desired requirement gained in the products that suit its functional requirement in various areas of application. In the field of welding, weld quality mainly depends on the mechanical properties of the weld metal and heat affected zone, which in turn is influenced by metallurgical characteristics and chemical compositions of the weld. Moreover, these mechanical metallurgical features of the weld quality depend on the welding process parameter (i.e. arc strength, gas flow rate and wire speed). These parameters will affect the weld characteristics to a great extent. Because these factors can be varied over a large range, they are considered the primary adjustments in any welding operation.

There are various types of welding methods; from those types tungsten inert gas (TIG) and metal inert gas (MIG/MAG) welding method are more vital in fabrication process. MIG welding is well established semi-automatic process. Continuous welding with coiled wire helps high metal deposition rate and high welding speed. MIG gives less distortion and there is no slag removal and its associated difficulties like interference with accurate jigging.

Bishoftu Automotive Industry, Bishoftu (Ethiopia) is one of the giant industries organized under the Metals and Engineering Corporation (METEC) of the FDREMoD. The Bishoftu Automotive Industry thrives to alleviate the burden of foreign expense allotted to import vehicles such as station wagons, mid bus's, different trucks and cross country buses by manufacturing them locally.

Optimization of quality characteristics parameters in a pulsed metal inert gas welding process using grey based Taguchi method studied [1]. Kumar and Sundarrajan (2009) [2] use Taguchi method was applied to optimize the pulsed TIG welding process parameters of AA 5456 aluminum alloy welds for increasing the mechanical properties. An investigation of the effect and optimization of welding parameters on the tensile shear strength in the resistance spot welding process, and the experimental studied were conducted under varying electrode forces, welding currents, electrode diameters and welding times [3]. Patil and

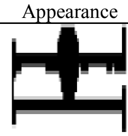
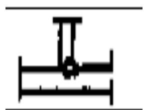
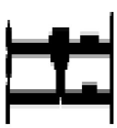
Waghmare (2009) has done experiment on optimization of MIG welding parameters for improving strength of welded joints by taking the main factors of current, voltage and welding speed. They didn't consider shielding gas flow rate as a factor [4]. Menberu Lulu and Rao (1990) has done experiment on parameter design for a solder process wave using Taguchi method [5].

The Taguchi method has become a powerful tool for improving productivity during research and development, so that high quality products can be produced quickly at lowest cost. Dr. Taguchi of Nippon Telephones and Telegraph Company, Japan has developed a method based on Orthogonal Array experiments which gives much reduced variance for the experiment with optimum settings of control parameters [6].

Orthogonal arrays (OA) provide a set of well balanced minimum experiments and Signal-to-Noise ratio (S/N), which are log functions for desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results.

If the causes of variation could be well controlled, then product process variation would be reduced, and therefore, quality would be improved. Based on the Table I, defect type and causes factor that may influence the welding strengths are; power (voltage), current (arc strength), wire speed, operator skill, shielding gas flow rate, position (torch inclination), wire diameter and wind effect.

TABLE I
WELDING DEFECT TYPES AND CAUSES

Defect type	Appearance	Cause
Excess thickness of weld		▪ No load voltage or welding speed to low ▪ Incorrect torch inclination ▪ Wire diameter to large
Insufficient metal		▪ Welding speed to high ▪ Welding voltage too low for weld application
Insufficient penetration		▪ Incorrect torch inclination ▪ Irregular or insufficient distance ▪ Wire speed too slow for voltage used or for welding speed
Lack of fusion		▪ Distance too short ▪ Shielding gas pressure is too low
Oxidized bead		▪ Shielding gas pressure is too low ▪ Wire is bent or over-protruding from the wire guide tube

II. MATERIALS AND METHOD

A. Detailed Experimental Scheme

In order to determine and set optimum welding parameters to meet high quality product, the present investigation has been made in the following sequence.

- Selection of specific product part.
- Identify important MIG welding process parameters.
- Determine and analyze the upper and lower limit (Range) of process parameters.
- Select the orthogonal array.
- Conduct the experiment as per selected parameters and orthogonal array.
- Record the quality characteristics and find the optimum process parameters of MIG welding.
- Conduct confirmation test.
- Identify the significant factor and check adequacy of the developed models.

B. Experimental Design

Based on the list of defect types and corresponding probable causes an appropriate set of control, noise and interaction factor is selected for experimentation (Fig. 1).

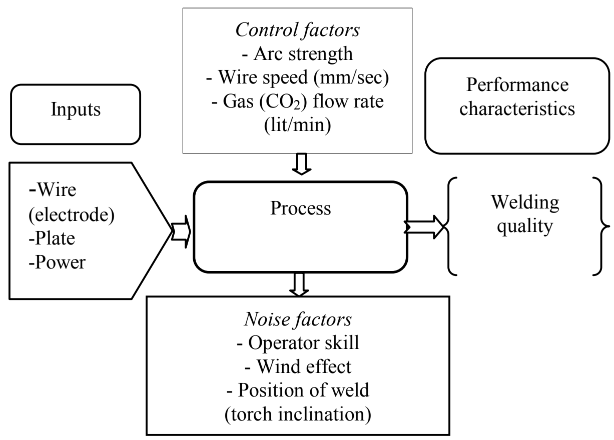


Figure 1: Taguchi's principle

C. Control Factors

The main selected factors on welding qualities are arc strength (current), wire speed and shielding gas pressure flow rate. These three factors are taken as control factors and the following Table II shows factors with their setting levels.

TABLE II
FACTORS WITH THEIR SETTING LEVEL

Control factors	Levels	
	1	2
Arc strength (gauge setup)	2	3
Wire speed (m/min)	4	5
CO_2 flow rate (lit/min)	12	15

Interaction between Control Factors

Interaction of factors is the synergistic effect of two or more factors in a factorial experiment. Thus, the heat required for melting is generated by an electric arc that strikes between the wire (electrode) and the work piece to be welded. So as we increase the arc strength to melt the piece as possible as, we should also increase wire speed and maximize shielding gas flow rate to get sufficient penetration, good fusion and eliminate bead oxidation. A shield gas protects both the arc and molten metal from the atmosphere. Therefore, for this experiment influential interaction factors are:

- Arc strength and wire speed,
- Arc strength and shielding gas flow rate and,

- Arc strength × Wire speed × Shielding gas flow rate.

D. Selection and Assigning of Orthogonal Arrays

The selection of which OA to use predominantly depends on the following items in order to priority.

- The number of factors and interaction,
- The number of levels for the factors of interest,
- The desire experimental resolution or cost limitation.

This experiment has three main factors and three interactions had to be accommodated in the design matrix. Since each factor is tested at two levels it will have one degree of freedom, any column of an OA that assigned for listing factor at two levels has two degree of freedom. Also the interaction terms have one degree of freedom, each interaction has one column.

Therefore, for the three main factors and three interactions, a minimum of six columns were needed. To conduct ANOVA on the experimental data an additional degree of freedom available for residual error, which means another one array columns added. A summary of column assignment of control factors is shown in Table III. Thus an L8 orthogonal array selected as a design matrix, because it has seven columns and is used for testing each factors at two levels (Table IV).

TABLE III
SUMMARY OF COLUMN ASSIGNMENT OF CONTROL FACTORS

Design factors (L8 OA)	Column assignment
A-Arc strength	1
B-Wire speed	2
C-CO_2 gas flow rate	4
A × B (Arc strength × Wire Speed)	3
A × C (Arc strength × CO_2 gas flow rate)	5
A × B × C (Arc strength × Wire speed × CO_2 gas flow rate)	7

TABLE IV
L8 ORTHOGONAL ARRAY WITH FACTOR ASSIGNED TO COLUMNS

Experiment number	Column factors						
	1	2	3	4	5	6	7
	A	B	A × B	C	A × C		A × B × C
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	1	2	2
4	1	2	2	2	2	1	1
5	2	1	2	1	2	1	2
6	2	1	2	2	1	2	1
7	2	2	1	1	2	2	1
8	2	2	1	2	1	1	2

The experiment was conducted by running eight different factor-level combinations as indicated by the L8 OA. At each combination, six pieces of plate were welded. Those welds were inspected and classified type of defect in to three classes i.e., bad, medium and better in terms of quality and weld strength.

E. Experimental Analysis and Results

Accumulation Analysis: Selection of an optimal factor-level combination is based on ANOVA and response table. Although designing an experiment is the same regardless of the type of data, variable or attribute, the application of ANOVA is slightly different with attribute data. Therefore, the accumulation analysis method is appropriate for this experiment.

Accumulation analysis takes frequency and severity of occurrences in to account and is used when the class number has an engineering meaning. The classes for weld strength (quality) can be described along with the accompanying rating value (Tables V and VI).

TABLE V
CLASS NUMBER FOR RESPONSE

Response	Class number
Better	1
Medium	2
Bad	3

TABLE VI
FREQUENCY OF OCCURRENCE

Trial number	Class			Total
	1	2	3	
1	4	2	0	6
2	3	3	0	6
3	1	1	4	6
4	1	2	3	6
5	2	3	1	6
6	2	3	1	6
7	1	3	2	6
8	3	1	2	6
Total	17	18	13	48

Step 1. Table VII shows determination of frequency occurrence.

TABLE VII
CUMULATIVE FREQUENCY OF OCCURRENCE

Trial number	Cumulative class		
	I	II	III
1	4	6	6
2	3	6	6
3	1	2	6
4	1	3	6
5	2	5	6
6	2	5	6
7	1	4	6
8	3	4	6
Total	17	35	48

Step 2. Calculate a weigh value for each class, which is a function of the cumulative frequency of occurrence in that class.

$$W_i = \frac{N^2}{T_i(N - T_i)} \tag{1}$$

where, N=total number of test, T_i=cumulative occurrences in class i

$$W_i = \frac{48^2}{17(48 - 17)} = 4.372$$

$$W_{11} = \frac{48^2}{35(48 - 35)} = 5.0637$$

Step 3. Calculate the total sum of squares:

$$SS_{Ti} = T_i - \frac{T_i^2}{N} \tag{2}$$

$$SS_I = 17 - \frac{17^2}{48} = 10.979 \text{ and } SS_{II} = 9.479$$

$$SS_T = \sum_{i=1}^{Nca} SS_{Ti} W_i \quad (3)$$

where, Nca = number of classes analyzed

$$SS_T = 10.979(4.372) + 5.1(9.479) = 96$$

Step 4: Calculate the OA column sums of squares

$$SS_{Ai} = \frac{[A_{1i} - A_{2i}]^2}{H} \quad (4)$$

where, A_{1i} =cumulative occurrences for the first level of factor A in class i. Thus,

$$SS_{AI} = \left[\frac{[(4+3+1+1)-(2+2+1+3)]^2}{48}\right] = \frac{(9-8)^2}{48} = \frac{1}{48} = 0.0208$$

$$SS_{AII} = \left[\frac{[(6+6+2+3)-(5+5+4+4)]^2}{48}\right] = \frac{(22-13)^2}{48} = \frac{1}{48} = 0.0208$$

Therefore,

$$SS_A = \sum_{i=1}^{Nca} SS_{Ai} W_i \quad (5)$$

$$SS_A = 0.1962, SS_B = 10.822, SS_C = 0.1965$$

$$SS_{(A\times B)i} = \left[\frac{(A\times B)_{1i} - (A\times B)_{2i}}{N}\right]^2 \quad (6)$$

$$SS_{(A\times B)I} = \left[\frac{(4+3+1+3)-(1+1+2+2)}{48}\right]^2 = 0.5208$$

$$SS_{(A\times B)} = 0.5208(4.372) + 0.5208(5.0637) = 4.914$$

$$SS_{(A\times C)} = 0.1875(4.372) + 0.02083(5.0637) = 0.9252$$

$$SS_{(A\times B\times C)} = 0.02083(4.372) + 0.02083(5.0637) = 0.1965$$

Step 5. Calculating degree of freedom and preparing ANOVA summary Table VIII.

Dof A = Dof A(Nca) = 1(2) = 2

Dof B = Dof B(Nca) = 1(2) = 2

Dof C = Dof A × B = Dof A × C = Dof A × B × C

Then the total degree of freedom is

$$Dof_T^1 = Dof_T(Nca) = (N-1)(Nca) = (48-1)(2) = 94$$

The critical F-value obtained from appropriate F tables for 95% confidence interval

$$F_{x,v1,v2} = F_{0.05,2,82} = 3.108$$

Thus at the 0.05 level of significance only factor "B" is significant that is

$$F_{test} = 5.634 \rangle F_{crticial} = 3.108$$

Based on the result we would conclude that factor B has strong effect than factor A and C.

TABLE VIII
ANOVA SUMMARY FOR ACCUMULATION ANALYSIS

Source	SS	Dof	Mean square	F_0
A	0.1962	2	0.0981	0.102
B	10.822	2	5.411	5.634
C	0.1965	2	0.0983	0.104
A×B	4.914	2	2.4570	2.611
A×C	0.9252	2	0.4624	0.491
A×B×C	0.1965	2	0.0983	0.104
Error	78.7496	82	0.9604	
Total	96	94		

Step 6. Optimal setting parameter selection.

Using the response table we can determine the optimal parameter setting (Table IX).

TABLE IX
RESPONSE TABLE FOR OPTIMAL PARAMETER SETTING

Factor	Level	Frequency occurrence "for better"
A	1	6
	2	11
B	1	12
	2	7
C	1	7
	2	10

Therefore the optimal parameter of MIG welding is the following factor level combination is identified, i.e. $A_2B_1C_2$.

F. Confirmation Experiment

A confirmation experiment is used to verify that the factors and levels chosen from an experiment cause a product or process to behave in a certain fashion. For confirmation experiment we use the following response value for the true mean (Tables X and XI).

The preferred combination of levels and factors are $A_2B_1C_2$. For this factor level combination determine the mean value by using the following equation:

$$\hat{\mu}.A_2.B_1.C_2 = \bar{T} + (\bar{A}2 - \bar{T}) + (\bar{B}1 - \bar{T}) + (\bar{C}2 - \bar{T})$$

Response table:

Level	A	B	C	Sum
1	46	39	47	132
2	46	53	45	144
Sum	92	92	92	176

Thus,

$$\hat{\mu}.A_2.B_1.C_2 = \bar{T} + (\bar{A}2 - \bar{T}) + (\bar{B}1 - \bar{T}) + (\bar{C}2 - \bar{T}) \quad (7)$$

$$= \frac{92}{48} + \left(\frac{46}{24} - \frac{92}{48}\right) + \left(\frac{39}{24} - \frac{92}{48}\right) + \left(\frac{45}{24} - \frac{92}{48}\right) = 1.583$$

The predicted optimal parameter can be achieved using the indicated optimal factor level combination run is made to determine how close the process average is to the predicated 1.583. Calculating the confidence interval as:

$$CI_3 = \sqrt{F_{\alpha,1,Ve} V_e \left[\left(\frac{1}{n_{eff}}\right) + \left(\frac{1}{r}\right)\right]} \quad (8)$$

where, $F_{0.05,1,82} = 3.958$

Error variance $V_e = 0.9411$

TABLE X
RESPONSE VALUE FOR TRUE MEAN

Response	Response value
Better	1
Medium	2
Bad	3

TABLE XI
COLUMN FACTORS AND RESPONSE FOR CONFIRMATION

Experiment No.	Column factors							Response						Sum
	1	2	3	4	5	6	7	Trail						
	A	B	A × B	C	A × C		A × B × C	1	2	3	4	5	6	
1	1	1	1	1	1	1	1	2	2	1	1	1	1	8
2	1	1	1	2	2	2	2	1	1	2	2	2	1	9
3	1	2	2	1	1	2	2	3	3	1	3	3	2	15
4	1	2	2	2	2	1	1	3	3	3	2	1	2	14
5	2	1	2	1	2	1	2	2	2	3	2	1	1	11
6	2	1	2	2	1	2	1	2	1	1	2	2	3	11
7	2	2	1	1	2	2	1	1	2	2	2	3	3	13
8	2	2	1	2	1	1	2	1	1	3	2	3	1	11
													Sum	92

$$n_{eff} = \frac{N}{1 + (\text{Total degree of freedom for } C_2A_2B_1)}$$

r=sample size for the confirmation experiment = 12

$$CI = \sqrt{3.958 \times 0.9411\left[\left(\frac{1}{16}\right)+\left(\frac{1}{12}\right)\right]} = \pm 0.737$$

Hence, CI of $A_2B_1C_2 = 1.583 \pm 0.737$

$0.846 < \mu\, A_2B_1C_2 < 2.32$

Verification experiments were conducted with a selecting the optimum level combination of optimal parameter sets to validate the predicted average response. Twelve trails were run for the optimal level combination parameter sets.

Tables XII and XIII show responses of confirmation experiment. For this confirmation experiment we use the above selected parameter. The selected parameters are: $A_2B_1C_2$.

Since this experiment has shown us a satisfactory optimum parameter selected variables. This parameter setting maximizes the welding quality. The data obtained from the verification runs of $A_2B_1C_2$ was compared with past data; and it is evident that there has been a remarkable improvement in the quality of MIG welding process**.**

TABLE XII
RESPONSES OF CONFIRMATION EXPERIMENT OCCURRENCE

Response type	Responses of occurrence
Better	10
Medium	1
Bad	1

Therefore the optimal parameter of MIG welding is the following factor level combination is identified, i.e. $A_2B_1C_2$.

TABLE XIII
RESPONSE VALUE FOR VERIFICATION TEST

Parameter setting	Response and number of trials						Sum
	1	*2*	*3*	*4*	*5*	*6*	
$A_2B_1C_2$	1	1	1	1	1	1	15
	7	*8*	*9*	*10*	*11*	*12*	
	1	1	3	1	1	2	

Optimization of MIG Welding using S/N Ratio and Percentage Frequency of Occurrence

(i) Analysis using Frequency of Occurrence (Percent occurrence)

The most meaningful ANOVA that may be performed is one using the frequency of occurrence of defects within trails. This approach will be identical analytically with continuous data. The magnitude of frequency of occurrence is a measure of how poor a given process condition is in providing good welding. The data takes from the experiment as the form of integers, since a welding is either acceptable or unacceptable weld quality. The experimental data that were taken from the process is shown in Tables XIV to XVI.

TABLE XIV
RAW DATA (ACCEPTABLE AND UNACCEPTABLE)

Experiment Number	C1	C2	C3	C4	C5	C6	C7	C8	C9
	A	B	A × B	C	A × C		A × B × C	Acceptable	Un-acceptable
1	1	1	1	1	1	1	1	5	1
2	1	1	1	2	2	2	2	6	0
3	1	2	2	1	1	2	2	2	4
4	1	2	2	2	2	1	1	3	3
5	2	1	2	1	2	1	2	2	1
6	2	1	2	2	1	2	1	5	1
7	2	2	1	1	2	2	1	4	2
8	2	2	1	2	1	1	2	4	2

Using the response Table XVI, optimal parameter setting can be determined. Therefore the optimal parameter of CEMONT model MIG welding is $A_2B_1C_2$ factor level combination is identified.

TABLE XV
PERCENTAGE FREQUENCY OF OCCURRENCE
(UNACCEPTABLE)

Experiment Number	Column factors							Unacceptable percentage occurrence
	1	2	3	4	5	6	7	
	A	B	A × B	C	A × C		A × B × C	
1	1	1	1	1	1	1	1	16.67
2	1	1	1	2	2	2	2	0.00

3	1	2	2	1	1	2	2	66.67
4	1	2	2	2	2	1	1	50.00
5	2	1	2	1	2	1	2	16.67
6	2	1	2	2	1	2	1	16.67
7	2	2	1	1	2	2	1	33.33
8	2	2	1	2	1	1	2	33.33

TABLE XVI
RESPONSE TABLE FOR PERCENTAGE OCCURRENCE

Factor	Level	Frequency occurrence "for bad"
A	1	133.34
	2	100
B	1	50.01
	2	183.33
C	1	133.34
	2	100

(ii) Analysis of Variance for Unacceptable, using Adjusted SS for Tests

Table XVII shows ANOVA for percent occurrence.

TABLE XVII
ANOVA FOR PERCENT OCCURRENCE

Source	Df	Seq. SS	Adj. MS	F	P
A	1	138.94	138.94	2.00	0.293
B	1	2221.78	2221.78	31.98	0.030
A×B	1	555.78	555.78	8.00	0.106
C	1	138.94	138.94	2.00	0.293
A×B×C	1	0.00	0.00	0.00	1.000
Error	2	138.94	69.47		
Total	7	3194.39			
S=8.335		R-Sq.=95.65 %			

The critical F-value obtained from appropriate F tables for 95% confidence interval

$$F_{x,v1,v2} = F_{0.05,1,2} = 18.5$$

Thus at the 0.05 level of significance only factor B is significant that is

$$F_{test} = 31.98 \rangle F_{critical} = 18.5$$

Based on the result we would conclude that factor B has strong effect than factor C and A.

(iii) Analysis using Signal to Noise Ratio

The control factors that may contribute to reduce variation (improved quality) can be quickly identified by looking at the amount of variation present as a response. Taguchi has created a transformation of the repetition data to another value which is a measure of the variation present. S/N ratio values were calculated for each factor level combination using Taguchi's expression for the "larger-is-better" type performance characteristic. The S/N ratio data are treated as a response of the experiment, which is a measure of variation from target within a trial when noise factors are present. A standard ANOVA was then done on the S/N data which identified factors that affect both the average and variation of the response variable. Taguchi's transformation criterion for the "larger-the-better" case is shown in (10).

$$S/N_{HB} = -10\log\left(\frac{1}{r}\sum_{i=1}^{r}\frac{1}{y_i^2}\right) \quad (10)$$

where, Y_i=response value of weld at a given factor-level combination, r=Number of test in a trial, S/N_{HB}=signal to noise ratio for the higher the better

For each category of experimental value of the raw data are transformed to frequency classes and signal to noise ratio. Raw and transformed data for experimental response value are shown in Table XVIII. The S/N ratio computed using raw data shown in last column of the same table. For example, consider the data for experiment no. 1 response trial columns I. Where, Y_I =2, Y_{II} =2, Y_{III}=1, Y_{IV} =1, Y_V =1 and Y_{VI}=1. Substituting these values in S/N ratio equation, we obtain 1.249

$$S/N_{HB} = -10\log\left(\frac{1}{6}\sum_{i=1}^{6}\frac{1}{2^2}+\frac{1}{2^2}+\frac{1}{1^2}+\frac{1}{1^2}+\frac{1}{1^2}+\frac{1}{1^2}\right) = 1.249$$

TABLE XVIII
SIGNAL TO NOISE RATIO

Exp. No.	Column factors	Response Trail I	II	III	IV	V	VI	Sum	S/N ratio
1		2	2	1	1	1	1	8	1.249
2		1	1	2	2	2	1	9	2.041
3		3	3	1	3	3	2	15	5.491
4		3	3	3	2	1	2	14	5.149
5		2	2	3	2	1	1	11	3.216
6		2	1	1	2	2	3	11	1.308
7		1	2	2	2	3	3	13	4.832
8		1	1	3	2	3	1	11	6.102
							Sum	92	29.388

S/N ratio response table are constructed and is shown in Table IXX.

TABLE IXX
S/N RATIO RESPONSE TABLE

		Factors and interaction factors		
		A	B	C
Level	1	13.93	21.574	14.6
	2	15.458	7.814	14.788
		Factors and interaction factors		
		A×B	A×C	A×B×C
Level	1	14.224	14.15	12.88
	2	15.164	15.238	16.85

Examination of the S/N ratio response table indicates the strong factor seems to be B, and that the three way interaction A×B×C seems to relatively little strong. Figure 3 shows main effect plot for mean.

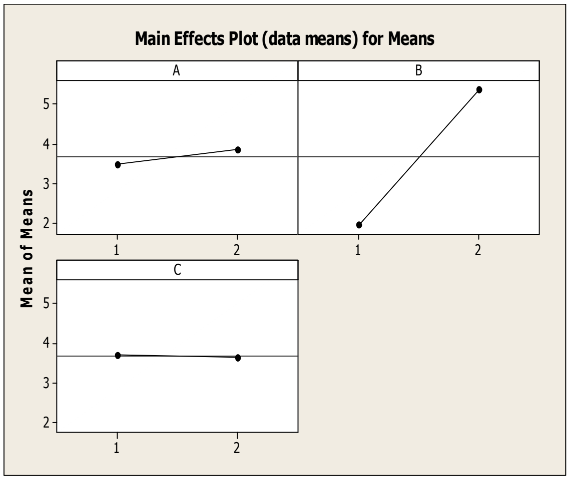


Figure 3: Main effect plot for mean

The analysis of variance of the S/N ratio in this experiment is shown Table XX.

TABLE XX
ANALYSIS OF VARIANCE FOR S/N USING ADJUSTED SS FOR TESTS

Source	Df	Seq. SS	Adj. MS	F	P
A	1	0.292	0.292	1.11	0.403
B	1	23.67	23.67	89.88	0.011
A × B	1	0.110	0.110	0.42	0.584
C	1	0.148	0.148	0.56	0.532
A × B × C	1	2.324	2.324	8.83	0.097
Error	2	0.527	0.263		
Total	7	27.07			
S=0.513157		R-Sq.=98.05%		R-Sq.(adj)=93.19%	

Here also, the critical F-value obtained from appropriate F tables for 95% confidence interval

$$F_{x,v1,v2} = F_{0.05,1,2} = 18.5$$

Thus at the 0.05 level of significance only factor B is significant that is,

$$F_{test} = 89.88 > F_{crtifical} = 18.5$$

Based on the result we would conclude that factor B has strong effect than factor C and A.

CONCLUSION

This study conducts with principles of Taguchi quality improvement for parameter design method. By using ANOVA in the three cases i.e., accumulation analysis, percentage frequency occurrence and S/N ratio the significant factor is factor "B" (wire speed or feed rate). To select the optimal parameter setting (factor level combination), using response table is A2B1C2. In addition the value of R-square is greater than 90%, therefore the selected factor combination is acceptable.

In general, from quality engineering point of view, the best identified optimal parameter setting is A2B1C2 within the constraints of the production process. The parameter setting identified in this study is optimal for processing a specific type of product. This specific product is welding of 6mm thick steel plate with CEMONT model of TF 300 for wire, and BLUSMIG 4035 for power semi-automatic MIG welding operation.

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