Prediction of Angular Distortion in MIG Welding of SS 202 using Taguchi Technique

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Abstract - *Metal inert gas welding (MIG) is a vastly used joining process in fabrication industry. This welding process can weld almost all the weldable materials whose compatible filler wire is available. As the process lends it to semiautomatic, fully automatic and robotic versions, it is finding extensive applications in mass producing industries like automotive, construction food processing and material handling equipments. Like other arc welding processes, uneven thermal expansion and contraction in the weldment generate thermal stresses, which cause weld distortions. Welding distortions are undesirable as they affect the physical appearance and shape of the weld and cause assembly related problems. After extensive literature survey, it is found that angular distortion is the most prominent in weld distortions. It happens because of the different thermal contractions experienced by the top and the bottom layers of the base plate because of different temperatures. The present investigation work is an attempt to predict the angular distortion at a given combination of input parameters so that the same may be accounted for during fabrication. The important input welding parameters having effect on angular distortion are; welding speed, voltage and wire feed rate. SS 202 has been selected for the present study as it provides the low cost alternative to the costly SS 304 and is being preferred for applications which are not too severely corrosive in nature. Taguchi approach has been used for the present work. An orthogonal array (L8), Analysis of variance (ANOVA) was used to check the adequacy of the model.*

Key Words: **MIG Welding, Angular Distortion, Taguchi Approach, Stainless Steel 202, ANOVA, Mathematical Modelling**

1. INTRODUCTION

Metal Inert gas Welding (MIG) is a widely used processes in manufacturing industry. Due to its versatility, Speed and relative ease of adaptability to the automation, it is preferred in robotic welding applications as well. It is a welding process in which an electric arc forms between a consumable MIG wire electrode and the work piece, which melts and joins. Along with the wire electrode, a shielding gas feeds through the welding gun, which shields the process from contaminants in the air. The input parameters in a welding process play a very significant role in determining the quality of a welded joint. Like any other arc welding processes, rapid heating and uncontrolled cooling causes uneven thermal expansion and contraction in the work piece, which is main cause of distortions like transverse, longitudinal, angular (Figure-1) in the work piece [1].

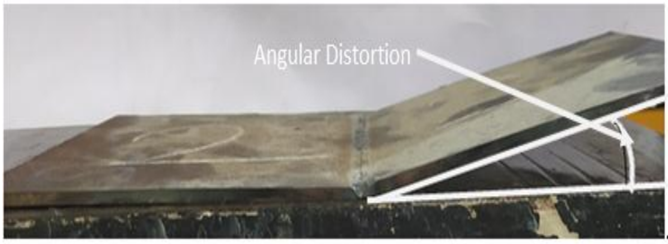

Fig. 1: Angular Distortion

Literature survey revealed that angular distortion is the most critical defect among the various distortions [2-5]. It is one such distortion that requires post welding heat treatment to control this, which also sometimes becomes impractical owing to shape and size of the weldment [6]. Angular distortion not only affects the physical appearance of the welded structure, but also causes assembly related problems and reduces the performance of the welded structure. If distortions in a welded structure are beyond a certain limit, it may result in the rejection of the part and cause economic losses and resource wastage for manufacturer and the end-user. Therefore, the working limits of the input parameters for the welding process should be estimated accurately and their effects on the angular distortion should be predicted before-hand so that a provision for giving an angle to the work-pieces in the reverse order before welding can minimize the final angular distortion in the welded structure [7]. This could be of great value to the fabricators as significant amount of money and efforts can be saved which otherwise could have been wasted in removing the angular distortion related issues [8, 9]. In the present investigation work, a mathematical model has been developed for analysis of effect of input process parameters like welding speed, voltage and wire feed rate on angular distortion in the Metal Inert Gas welding of Stainless Steel 202 using Taguchi's statistical approach. An orthogonal array (L8) has been selected for the present investigation and a regression model has been developed, which relates angular distortion with the input welding parameters. Analysis of Variance (ANOVA) is used to check the adequacy of the developed mathematical model. Graphical analysis is also presented to analyze the results and to arrive at logical conclusions. Stainless Steel 202 is an austenitic grade Stainless Steel, which has been selected for the present work because it offers a low cost alternative to the costly 300 series of austenitic Stainless Steels. It exhibits good workability, strength and corrosion resistance against mild to medium corroding environments. The chemical composition of the material is given in the table-1 below. It is expected that the findings of this work shall be of use to the industrial applications engaged in the fabrication of this material.

Table-1: Chemistry of SS 202 [10]

Material Name	Manganese(Mn)	Chromium(Cr)	Nickle(Ni)
Stainless Steel 202	7.5-10%	17-19%	4-6%

2. EXPERIMENTAL SET-UP

The experimental setup used to carry out the present investigative work is shown in figure 2. It consists of a MIG welding power source of rated capacity 400 Amps with 100% duty cycle and flat V-I characteristics of a specially designed four roller wire feeding unit is used. The four roller design facilitates positive wire feed without any slippage, ensuring a constant arc gap and performance of the system. A specially designed straight head MIG welding torch is used to facilitate machine welding. In order to ensure consistency, reproducibility of results and to have different correctly set welding speed a mechanized weld traversing unit is also used. Commercially pure grade of argon is used for shielding purpose at a rate of 15 m/min. The actual photograph of the experimental setup is given in fig 2 below.

Fig 2: Experimental Setup of MIG Welding

3. PLAN OF INVESTIGATION

The complete research work was done by following the stages given below:
1. Selection of the input process variables.
2. Identification of the working ranges of the process variables.
3. Experimental design.
4. Development of a design matrix.
5. Performing the experiments.
6. Measurement of the response parameter.
7. Development of a mathematical model.
8. Examining the significance of the mathematical model.
9. Results.
10. Conclusions.

3.1. Selection of the input process variables

On the basis of literature survey, past experience and a no. of trials conducted, the input process variables like welding speed, voltage and wire feed rate has been selected, as they were found to have significant effect on the output which is angular distortion.

3.2. Identification of the working ranges of the process variables

The maximum and minimum limits of the input process variables were determined as per the below observations obtained from a number of trials runs conducted at different values of selected parameters.

The observations are:
- No visual defects on the weldment.
- No under filling
- No depression in the weld zone

The maximum and minimum limits of the process variables are represented as +1 and -1and their respected values are shown in the table 2 given below;

Table- 2: Working Limits of Input Parameters

Input factor	Name	Units	High(2)	Low(1)
A	Welding Speed	Cm/min	35	40
B	Voltage	Volt	20	24
C	Wire Feed Rate	m/min	4	6

3.3. Experimental Design

For this research work, Taguchi's statistical approach has been used to plan the experiment in a structured manner. Taguchi has developed a statistical method as per orthogonal array experiments for the quality improvement of the process and for the better prediction of the optimum results [11]. Orthogonal arrays in Taguchi's statistical technique reduce experimental resources and time. The orthogonal array suggested by Taguchi defines the parametric level combination of the process parameters. The experiments are to be done as per the combinations. The input process variables are represented by the columns and the individual trials are represented by the rows of an orthogonal array [12]. For the present investigative work, an orthogonal array denoted as L_8 is used to plan the experimental work involving three, two- level input process variables. Next, an analysis is required to be done to reduce the variations around the mean performance, which are due to the noise factors such as power fluctuations, wire slippage etc. For this, Signal-to-noise ratio is required to be calculated, which are the log function of the desired response parameter and should have a higher value for a robust design. This analysis helps to get the optimum levels for the input process variables to have minimum angular distortion in Metal Inert Gas Welding process.

3.4. Development of a design matrix

An L8 orthogonal array (OA) of Taguchi's approach was used to develop the design matrix for 3 input factors at 2 levels each so that a limited number of experiments are performed in a structured manner. The developed design matrix by using statistical design software MINITAB 19 is given in the table 3 below,

Table- 3: Developed Design Matrix by MINITAB 19

Run	Welding Speed	Voltage	Wire Feed Rate
1	1	1	1
2	1	1	2
3	1	2	1
4	1	2	2
5	2	1	1
6	2	1	2
7	2	2	1
8	2	2	2

3.5. Performing the experiments

As, an orthogonal array (L8) of Taguchi approach was used for 3 factors and 2 levels each that makes 8 runs for the present experiment. The experiments were done according to the developed design matrix given by the statistical software MINITAB 19 to avoid any error. These experimental runs were done on the plates of Stainless Steel 202 of size 150 mm x150 mm x 6 mm.

3.6. Measurement of the Response Parameter

The basic equipment required for the measurement of the response parameters which is angular distortion in this case is as follows;
1. Vernier height gauge (300mm)
2. Surface Plate (450mm x 450mm)
3. V- Block
The weld specimen is first positioned on the surface plate in such a manner that one of the weld plates is pressed against the surface plate. At this point the measuring envil of the vernier height gauge is brought into contact with the edge of this plate and reading R_1 is measured with the resolution of 0.02 mm. Now, the other plate is pressed against the surface plate such that the former is raised by an amount equals to angular distortion present. At this point the measuring envil of vernier height gauge is again brought in contact with the raised edge of the same plate and reading (R_2) is measured. The difference (R_2-R_1) gives the perpendicular height corresponding to the angular distortion. The same procedure is repeated to take at least two readings on each work piece and their average was taken as the final measurement. Similar treatment is given to all the weld specimen to measure their respective $R_2 - R_1$ readings. Then by using simple formula $\sin \emptyset = (R2 - R1)/l$ gives the angular distortion experienced by the work pieces. Where, l is the width of each plate. The setup used to perform angular distortion measurement is shown in figure 3. The measured angular distortions with their S/N ratios and mean values have been given in the table 4.

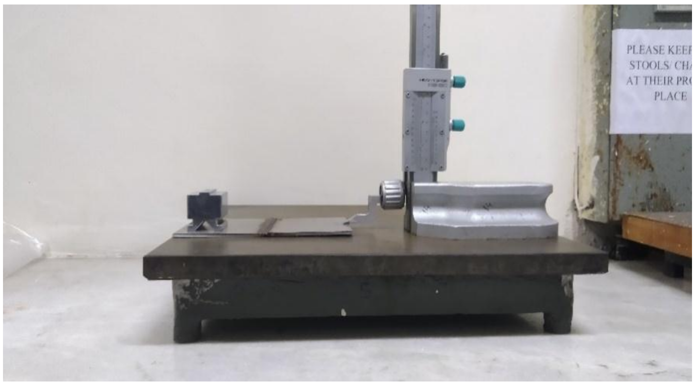

Fig- 3: Measurement of angular distortion

Table- 4: Observations

	Welding Speed	Voltage	Wire Feed Rate	Angular Distortion	MEAN1	SNRA2
1	1	1	1	8.20	8.20	18.2763
2	1	1	2	6.28	6.28	15.9592
3	1	2	1	8.66	8.66	18.7504
4	1	2	2	5.14	5.14	14.2193
5	2	1	1	10.14	10.14	20.1208
6	2	1	2	8.46	8.46	18.5474
7	2	2	1	9.65	9.65	19.6905
8	2	2	2	7.59	7.59	17.6048

3.7. Development of a Mathematical Model

Statistical software MINITAB 19 was used to develop a mathematical regression equation for the given set of input process variables. This regression equation helps to predict the output variable i.e. angular distortion for the MIG Welding Process.
The regression equation obtained is,

Angular Distortion = 2.38 + 0.3780 Welding speed - 0.1275 Voltage - 1.147 Wire Feed rate

3.8. Examining the Significance of the Mathematical Model.

ANOVA analysis was done using the same statistical software MINITAB 19 to depict the appropriateness of the developed model. This analysis is performed on the measured response values. The result produced by the ANOVA by the software is shown in the table- 5,

Table 5: ANOVA Results

Sources	DOF	Adj Sum of squares	Adj Mean Squares	F-ratio value	P-value
Regression	3	18.1985	6.0662	22.16	0.006
Welding speed	1	7.1442	7.1442	26.09	0.007
Voltage	1	0.5202	0.5202	1.90	0.240
Wire feed rate	1	10.5340	10.5340	38.48	0.003
Error	4	1.0952	0.2738		
Total	7	19.2936			

The R^2 value given by the statistical software is 94.32%, which indicates the significant accuracy of the mathematical model. The R values obtained from the software is given below,

S	R-sq	R-sq(adj)	R-sq(pred)
0.523247	94.32%	90.07%	77.30%

3.9. Analysis of the Results

3.9.1. Analysis of Signal-to-Noise Ratio

The signal-to-noise(S/N) ratio in the Taguchi's approach is the ratio of the desired mean values of the output parameter to the undesired values of the output. In this research, smaller the better signal-to-noise(S/N) ratio is considered because here the response parameter is angular distortion. The relation for the signal-to-noise(S/N) ratio is shown below [13],

$$S/N = -10 * (\log (\sum(Y^2)/n))$$

$$Y = (Y_1 + Y_2 + Y_3 + ... + Y_n)/n$$

Where $Y_1, Y_2, Y_3 ... Y_n$ are the calculated values of the response parameter and n is the no. of experiments conducted. The calculated results of the signal to noise(S/N) ratio has been given in the above table 3. A combination of process variables with lowest S/N ratio is the optimal solution in which the response i.e. angular distortion is lowest. The table 6 shows the result of the analysis.

Table- 6: Result table for S/N ratio

Smaller is better

Level	Welding Speed	Voltage	Wire Feed Rate
1	-16.80	-18.23	-19.21
2	-18.99	-17.57	-16.58
Delta	2.19	0.66	2.63
Rank	2	3	1

From the above table, it is clear that the optimum levels for the minimum angular distortion are at welding speed (40cm/min), Voltage (20V) and Wire feed rate (4m/min), as the level at which the S/N ratio is maximum, is the optimal values for targeted output. The result table shows the ranks based on the delta statistics values. From the above ANOVA and Signal-to-noise ratio analysis, it is clear that wire feed rate has more influence on the angular distortion than welding speed and voltage.

3.9.2. Main Effect Plots

The main effect plot of the process variables on the output for signal-to-noise ratio is generated as graphical forms by using the same statistical design software. The main effect plot represents how each process parameters affect the response characteristics. Each level of input process parameters have different effects on the response characteristics, which is represented by the main effect plots for different characteristics i.e. signal-to-noise ratio. The horizontal line on the plot indicates that there is no effect and vice versa. The larger the distance of the plotted points vertically, the larger the magnitude of the main effect for that parameter. The main effect plot of the input process variables on angular distortion is given in the figure 4 below.

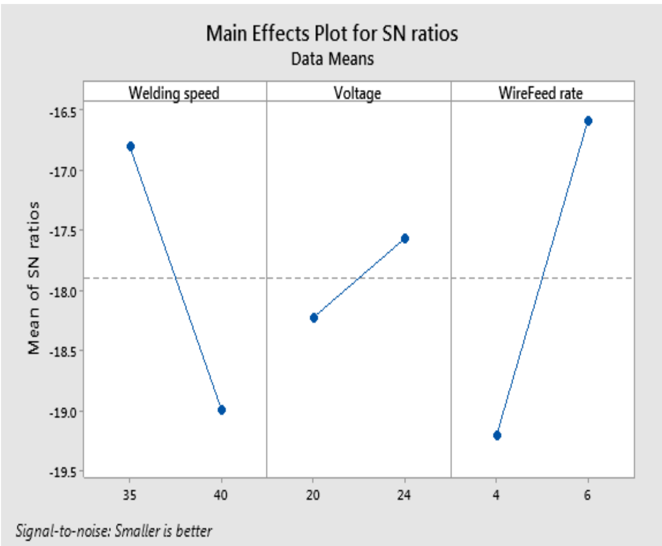

Fig- 4: Main effects plot for Signal-to-noise ratios

The above main effect plot for signal-to-noise ratios depicts that wire feed rate has more significant effect on the response parameter i.e. angular distortion than the welding speed and voltage. As depicted in the above figure 4, welding speed is found to have a negative while the voltage and the wire feed rate are having a positive effect on the response parameter i.e. angular distortion. The probable explanation for the same is that with the increase in welding speed, the heat input into the weld reduces which results in lesser amount of angular distortion. Whereas, with increment in the voltage, heat input into the weld plate increases and forward spread of the arc also increase, which injects more heat on a wider area resulting in more angular distortion. This causes more thermally generated stresses resulting higher angular distortion. At higher value of the wire feed rate, the arc length tends to decrease which the welding power source restores by increasing the welding current, which increases the arc force and the heat input into the weld zone resulting more angular distortion.

3.9.3. Interaction Plots

The interaction plot generated by the same statistical software represents the interaction between all the input process parameters. The levels of one input parameter are presented on the horizontal axis, where as the levels of other input parameters are represented by different colored lines and symbols. In the interaction plot, if the lines are parallel to each other, then there is no interaction between the two factors and vice versa. The interaction plots between the input parameters for signal-to-noise ratios are given in the fig 5 below.

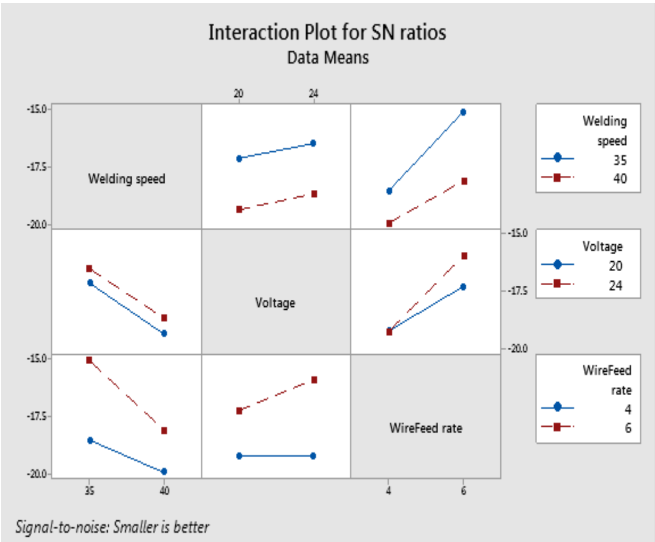

Fig- 5: Interaction Plot for S/N ratios

The above interaction plot shows that the minimum interaction is in between the welding speed and voltage and the maximum interaction is in between voltage and wire feed rate.

4. CONCLUSIONS

1. Taguchi's approach of design of experiment has been proved satisfactory for the present investigation.

2. A mathematical expression is developed with its adequacy checked.

3. Wire feed rate has maximum positive effect, whereas voltage has moderately positive effect on the response variable i.e. angular distortion.

4. Interaction effects between these input parameters are also analyzed.

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