Mathematical Modelling of Angular Distortion in GTA Welded Low Carbon Alloy Steel Butt Welds

Ishika tiwari, Laksha, Pradeep Khanna

Abstract - Arc welding processes are extensively used in variety of fabrication works. The process however involves localised melting at the faying surfaces. This results in rapid heat dissipation to the neighbouring cold area of the work pieces. The rapid cooling cycle brings about internal as well as external changes. On one side it causes metallurgical changes and formation of different zones inside the weldment. On the other because of differential cooling rate it causes distortion in the physical shape of the weld. Out of a number of different types of distortion, angular distortion is the most critical as it not only affects the aesthetics but also results in the misfit of the components with parent structure. It should therefore be the endeavour of the welding system to keep angular distortion to its minimum. The present investigation work has been carried out to analyse the effects of various welding input parameters on angular distortion. Low carbon alloy steel has been selected as a research material because of its widespread use in fabrication industry. A mathematical equation has been developed by using statistical technique of central composite face centred methodology. The model has been optimised by using response surface methodology. It is expected that the research work carried out shall be useful for industry and for further advanced studies on the subject.

Keywords*: arc welding, angular distortion, input parameters, mathematical equation, statistical technique*

I. Introduction

Gas Tungsten arc welding is a joining process primarily used to weld thin sheets. The process finds extensive applications in aircraft, food and general light duty fabrication industry owing to its ability to join any metal and producing best quality welds amongst all the conventional arc welding process. Angular distortion produced due to rapid heating and cooling cycles during welding has been a major concern for designers and fabricators as it is not possible to correct the same once occurred. This when goes beyond a certain limit distorts the weldment and can render in its rejection all together. The only way to prevent this defect from occurring is to take preventive measures like preheating or smartly select the input welding parameters to keep angular distortion within permissible limits. The schematic of angular distortion in a butt weld is shown in figure 1.

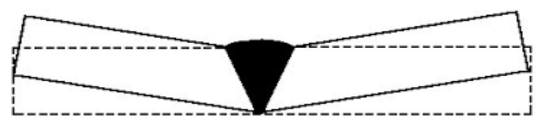

Fig. 1 Schematic of angular distortion in butt weld

A number of research works have been surveyed to have an insight into the problem. According to Raj et.al.[2] maximum distortion occurs along the direction of weld during welding of low carbon steel. Aggarwal et.al.[3] have carried out elaborated study on angular distortion of stainless steel and presented the effects of welding input parameters on angular distortion. Duhan et.al.[4] concluded that length of plates and the diameter have a positive effect on angular distortion. Kumar et. al.[5] inferred that by reducing the angular distortion, depth to width ratio in TIG welding of stainless steel can be increased. According to Ahir et.al[6] grove angle has a positive effect on angular distortion.

In the present work an attempt has been made to investigate the effect of different welding parameters like welding current, welding speed and torch angle on angular distortion of low carbon alloy steel. Elaborated experimentation was done by using statistical techniques of face centred composite design to develop a mathematical equation. ANOVA analysis was carried out to check the adequacy of the equation and significance of regression coefficients. Response Surface Methodology (RSM) was used to further optimize the developed model.

Ishika tiwari is a student, MPAE Engg. Division, NSIT, New Delhi, India (email: ishi.tafs.it@gmail.com)
Laksha is a student, MPAE Engg. Division, NSIT, New Delhi, India
Pradeep Khanna is Associate Professor, MPAE Engg. Division, NSIT, New Delhi, India

II. Experimental Set Up

The weld set up consist of DC power source with drooping V-I characteristics of 200amp capacity. Welding was carried out on a mechanised carriage unit to facilitate welding at different speed. This unit consisted of weld table that could move on ball screw and nut assembly powered by one horse power, 1400rpm AC induction motor through a reduction gear box. The speed control was affected by a variable frequency drive (VFD). In this way welding speed could be controlled steplessly in a speed range of 0 to 50cm/min. Industrially pure argon gas was used to provide inert atmosphere during welding.

Fig. 2 Experimental setup

III. Plan of investigation

The investigative work was carried out by following the research plan given below:

- Identification of independently controllable input parameters
- Finding the working ranges of these parameters
- Development of design matrix
- Conducting the experiment as per the design matrix and recording the observation
- Development of mathematical model
- Checking the significance of the developed model and lack of fit
- Results and their analysis
- Conclusions

3.1Identification of independently controllable input parameters

Within the given experimental setup a number of input variables like welding current ,welding speed, torch angle , gas flow rate were identified and were varied one by one to see their effects on the weld. After conducting a number of preliminary trial runs it was found that gas flow rate had a negligible effect on the resulting angular distortion and was therefore dropped.

3.2 Finding the working ranges of these parameters

Trial runs were again conducted by varying the selected input variables in step 3.1 and their useful working ranges were found on the following visual results

1. There is no crack on the weld bead
2. The joint is uniform
3. There is no overheating of the joint.

The working ranges of the variables thus found are given in table 1. The lower value of the range is represented by(-1) and the upper value of the variable is shown as (+1).

Table:1 The working ranges of input parameters

Factor	Name	Units	Minimum	Maximum
A	Welding Current	Amp	100	140
B	Welding Speed	Cm/min	30	40
C	Torch Angle	degrees	0	45

3.3 Development of design matrix

In order to conduct the experiments in systematic manner so as to cover the single and interaction effect of input variables, experiment design matrix was developed using design expert software. Statistical technique of FCC was used to determine the total number of experiments which came out to be 20 in numbers as per the relation (2^3 +2*3+6=20). 2^3 denote the full factorial points, 2*3 denotes the star points and 6 denote the centre points of the model. The 20 combinations of input variables are shown in the design matrix in table 2.

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Table2:- Design Matrix

Std	Run	Factor 1 A:Current Amp	Factor 2 B:Speed cm/min	Factor 3 C:Torch Angle degree	Response 1 Angle of distorti... degree
11	1	0	-1	0	7.84
14	2	0	0	1	3.22
1	3	-1	-1	-1	2.8
4	4	1	1	-1	6.02
2	5	1	-1	-1	5.1
19	6	0	0	0	5.1
17	7	0	0	0	6.7
9	8	-1	0	0	5.5
20	9	0	0	0	6
5	10	-1	-1	1	6.38
13	11	0	0	-1	2.74
15	12	0	0	0	5.8
18	13	0	0	0	4.92
6	14	1	-1	1	0
10	15	1	0	0	3.32
7	16	-1	1	1	6.78
16	17	0	0	0	5.5
8	18	1	1	1	3.22
3	19	-1	1	-1	3.08
12	20	0	1	0	5.98

20 numbers of runs were carried out as per the design matrix on steel plates of size 150mm*100mm*2.5mm.

The weldments so produced were then inspected one by one to measure the angular distortion they had encountered. The setup used for this purpose is shown in figure 3. It consists of placing the welded piece on the surface plate. The initial reading is taken by first pressing one half of the weld to coincide its free edge parallel to the weld. A vernier height gauge is used for this purpose. The final reading was taken by pressing the other half of the weld and taking the reading of the raised free edge parallel to the weld. The difference between these two readings gives the proportion of angular distortion. The same procedure is repeated for the opposite edge and the average of the two is recorded in table 2 for all the 20 welds.

Fig. 3 Angle measuring set-up

IV. Development of mathematical model

The dependence of angular distortion on the selected input variables can be expressed as a simple relation Y= f(A,B,C)

Where Y= response parameter i.e angular distortion.
A= welding current in amperes
B= welding speed in cm/min
C= torch angle in degree

The general regression equation presenting the relationship between the input and output parameters

$$Y= \beta_0 + \beta_1 A + \beta_2 B + \beta_3 C + \beta_{12} AB + \beta_{13} AC + \beta_{23} BC + \beta_{11} A^2 + \beta_{22} B^2 + \beta_{33} C^2$$

Where β_0 is model coefficient, β_1 ,β_2 ,β_3 are regression coefficient of linear term , β_{12} , β_{13}, β_{23} are regression coefficient for the interaction terms β_{11}, β_{22}, β_{33} are regression coefficient for square terms. The actual regression equation generated by design expert software in the coded form is given as equation 2.

Angle of Distortion = 5.49 – 0.68*A+0.29*B-0.01*C+0.43*AB-1.90*AC+0.30*BC-0.81*A^2+1.68*B^2-2.25*C^2

3.6Checking the significance of the developed model and lack of fit

ANOVA analysis was carried out using design expert software and it was found that the developed model was significant and the lack of fit is insignificant pointing to the correctness of the investigation. This analysis is shown in table 4.

Further the closeness of predicted and actual value plotted on scattered diagram (figure 4) also substantiates the validity of the developed model.

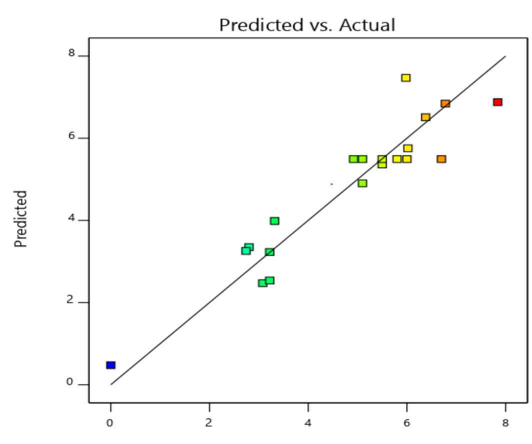

Fig 4.Scatter diagram

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V. Results and their analysis

The graphical representation of the results obtained is shown in fig. 5-7.

Interaction effect of Welding current and welding speed

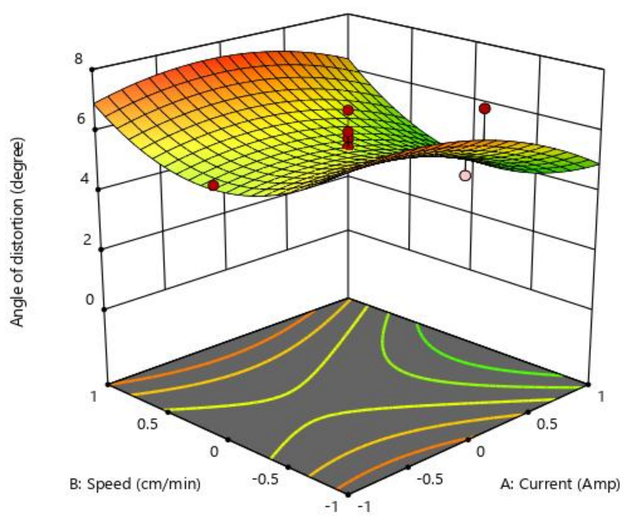

Fig 5 Interaction effect of Welding current and welding speed

It is evident from figure 5 that angular distortion is initially increased and then decreased with the increase in current. The reason could be attributed to the fact initially with the increase in current more amount of heat goes into the weld which results in a higher heat gradient between the weld line and the plates resulting in more distortion. Whereas at higher values of current the heat is utilised more for melting of the metal and spread more uniformly with slower cooling rates resulting in decreased distortion. With the increase in speed the distortion initially decreased and then increased. The probable reason could be that initially the heat input to the weld decreased which resulted in less heat input thereby reducing the distortion effect. But with the further increase in speed the heat input is so less that it predominantly spreads rather than melting the metal causing more distortion.

Interaction effect of welding current and torch angle

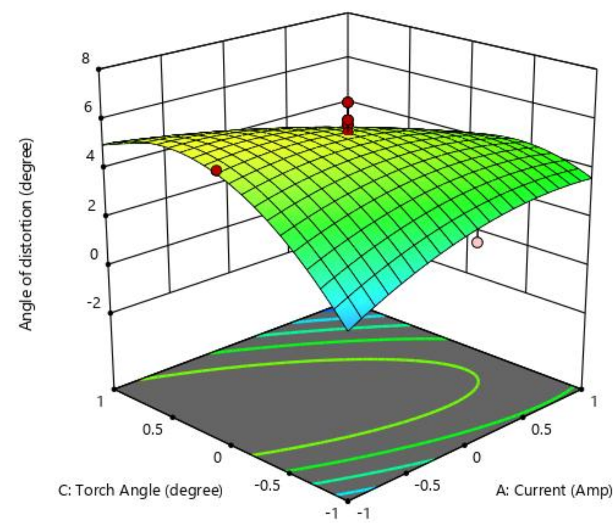

Fig 6 Interaction effect of welding current and torch angle

It is evident from figure 6 that at lower values of torch angle, the angular distortion increased with the increase in current. The reason could be that with the increase in current the total heat input to the weld increased resulting in more melting and more heat spread resulting in more distortion on cooling. At higher values of torch angle the arc as a spreading effect making the heat to be absorbed by the plates in wider areas rather than melting the interfaces. This results in gradual cooling which caused a decrease in angular distortion.

Interaction effect of welding speed and torch angle

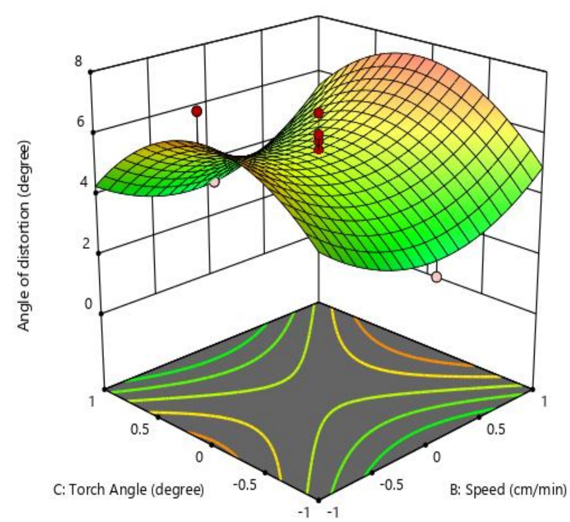

Fig 7 Interaction effect of welding speed and torch angle

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It can be seen in figure 7 that the angular distortion decreased with initial increase in speed. The possible explanation for this could be that initially the heat input to the weld decreased which resulted in less heat input hence reducing the distortion effect. But as the speed is increased further the heat input is so less that it predominantly spreads rather than melting the metal causing more distortion.

VI. Conclusions

On the basis of investigation carried out , the following conclusions can be drawn

1. The statistical technique of face centred composite design was satisfactorily used in the present investigation .
2. Angular distortion is initially increased and then decreased with the increase in current.
3. Angular distortion decreased at initial values of speed and then increased with further increase in speed.
4. At initial values of torch angle angular distortion increased and then decreased.

References

[1] ESDEP LECTURE NOTE http://goo.gl/images/1cHXr5

[2] Raj, A., Varghese, J., "Determination of Distortion Developed During TIG Welding of Low Carbon Steel Plates". International Journal of Engineering Research and General Science, Vol. 2, pp, 756-767,August-September 2014.

[3] Aggarwal, I., Faujdar, N., Das, A., Khanna, P., "Mathematical Modelling for Predicting Angular Distortion in TIG Welding of Stainless Steel 409L Butt Welds". International Journal of Research in Engineering and Technology, Vol. 7, pp, 92-97, June 2018.

[4] Duhan, S., Mor, A., Malik, D., "Study of Angular Distortion of SS 302 and MS plate with GTAW". International Journal of Recent Research Aspects, Vol. 2,pp, 159-163, June 2015.

[5] Kumar, R., Bharathi, S., "A Review Study on a TIG Welding of 316(L) Austenitic Stainless Steel". International Journal of Emerging Trends in Science and Technology, Vol. 2, pp, 2066-2072, March2015.

[6] Ahir, S., Patel, N., Patel, K., "Experimental Investigation of Welding Distortion of Austenitic Stainless Steel 316 in TIG Welding", ". International Journal of Engineering Development and Research, Vol. 3, pp, 781-785, 2015.