MATHEMATICAL ANALYSIS OF ANGULAR DISTORTION ON GTA WELDED HOT ROLLED E250 GRADE LOW CARBON STEEL PLATES

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ABSTRACT - *GTAW is commonly used fusion welding process which can successfully be used to weld almost all the metals. Though the process is basically an autogenous one for welding primarily thin sheets but with the application of external filler wire, it can be used for production applications. It can be automated and be used for mass production manufacturing systems. Presently the process is extensively used in food processing, aviation, automotive and chemical industry. Like other fusion welding processes, in this process as well the weldment is subjected to thermal cycles involving rapid heating and cooling. This results in the generation of non-uniform thermal stresses in the material which if free to deform will experience distortion. The distortions once produced will destroy the aesthetics of the weld and the fitment of the weldment to the parent structure thereby creating design related issues. These distortions cannot be economically corrected once produced. Hence becomes pertinent to optimize the weld parameters in such a manner to minimize the resulting distortion. In the present investigative work, angular distortion is analysed during the GTA welding of carbon steel grade IS 2062 E250 C. This steel is generally used for manufacturing automobile frames, pipes and a variety of industrial products. The input weld parameters like welding current, welding speed and torch angle were selected. Full factorial technique was adopted for the carrying out the weld runs and analysis of results. A mathematical model was developed to predict the angular distortion.*

Key Words: ***GTAW, angular distortion, carbon steel, input welding parameters, mathematical model.***

1 INTRODUCTION

Gas–tungsten arc welding (GTAW), also called tungsten inert gas welding (TIG), is a process that melts and joins metals by heating them with an arc established between a non-consumable tungsten electrode and the work piece under a shielding gas. GTAW is used in modern industry, especially for stainless steel, titanium alloys and other materials for high quality weld. Its applications include welding of sheets, plates and tubes for use in aerospace, food processing and other light fabrication application. GTAW process has many advantages like high quality, easy and precise control of welding parameters, etc. [1].

The heating and cooling cycles in non-uniform manner are part of welding process. During welding process different type of distortions are observed with angular distortion being the most prominent one [2, 3]. The angular distortion in a butt weld is shown in figure 1.

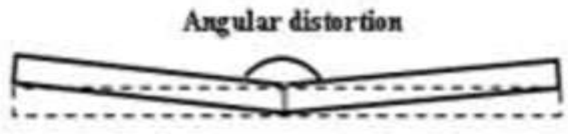

Fig. 1 Schematic view of angular distortion

Angular distortion is a major problem and most pronounced among different types of distortion in the butt welded plates. This angular distortion is mainly due to non-uniform transverse shrinkage along the depth of the plates welded. Restriction of this distortion by restraint may lead to higher residual stresses. Distortion once produced in weldment cannot be removed but can only be minimised by selecting optimum parameters like preheating, one of the methods to remove the angular distortion during the fabrication process is to provide an initial angular distortion in the negative direction. If an exact magnitude of angular distortion is predicted, then a weld with no angular distortion will be the result. It is difficult to obtain analytical solution to predict angular distortion. Costly and time consuming experiments are required to determine the optimum welding process parameters using conventional optimization techniques. These conventional techniques require more computational effort and time. [4] And by selecting favourable input welding parameters to keep angular distortion within permissible limits [5]. Based on the literature survey carried out it was found that angular distortion was dependent on primarily welding current, welding speed and torch angle [6,7]. Further it was found that Angular distortion was affected positively with increase in length of plates and diameter of electrode. Angular distortion was affected negatively with increase in current and time gap between passes [8].

IS 2062 E250 C grade of carbon steel is selected for this investigation, it is a hot rolled steel having a composition Carbon-0.2 % (max), Manganese-1.5% (max), Silicon-0.4% (max), Phosphorous-0.04%, Sulphur-0.04%. This steel can be easily weld and processed by standard fabrication and welding processes with fairly good availability and low cost.

In this Investigation elaborate attempt has been made to analyse the effect of different weld input parameters on the angular distortion experienced during butt welding of IS 2062 E250 C steel. The literature survey suggests many welding parameters that could be of consequence but in order to keep the work in reasonable limits only three input parameters are considered for the present work. These are welding current, welding speed and torch angle respectively. To put the experimental work into the right perspective, and to have a structured and logical conclusion, statistical technique of design of experiments has been adopted. 2^k full factorial approach has been found suitable, where three input parameters have been used at two levels each. The results were graphically analysed and a mathematical model also developed.

2. Experimental Setup

The experimental setup used for carrying out the investigative work is shown in figure 2. The power source used is a constant current type with a rated capacity of 200 amps. In order to ensure repeatability and to have a set value of welding speed, a mechanized carriage unit was used. The speed range obtainable was 0- 50 cm/min with the help of a variable frequency drive. The TIG welding torch was mounted on a radial arm which had arrangement of moving up and down. The shielding gas used for the work was industrially pure Argon being used at a flow rate of 15liters/min.

Fig. 2 The complete welding setup.

3. Plan of Research

The present investigative work was accomplished by following the steps given below

- ***i.*** Identification of process parameters and their operating ranges.
- ***ii.*** Development of a design matrix.
- ***iii.*** Conducting the experiment as per the design matrix.
- ***iv.*** Development of a mathematical model.
- ***v.*** Testing the adequacy of the developed model.
- ***vi.*** Analysis of the results.
- ***vii.*** Conclusions.

3.1 Identification of process parameters and their operating ranges

For the present experimentation work, out of many probable input parameters welding current, welding speed and torch angle were selected and varied accordingly to find their effects on the welding. In order to find the working ranges of these parameters, a number of trial experiments were conducted. The upper and lower limits of the parameters were then finalised on the basis of the visibly good quality of the weld produced. The upper value of parameters is represented by +1 and the lower one is represented by -1, as shown in table-1.

Table 1: The operating ranges of input parameters

Factor	Name	Unit	Minimum Value(-1)	Maximum Value(+1)
A	Welding current	Ampere	140	160
B	Welding speed	Cm/min	35	40
C	Torch angle	Degrees	0	22.5

3.2 Development of Design matrix

A Design matrix was developed to conduct the experiments and analyse the results in a logical manner. Design Expert software was used for this purpose. The matrix developed is shown in the table-2.

Table 2: The design matrix

Std	Run	Factor 1 A:welding current amp	Factor 2 B:welding speed cm/min	Factor 3 C:torch angle degree	Response 1 angular distortion degrees
1	1	-1	-1	-1	-4.55
7	2	-1	1	1	9.175
3	3	-1	1	-1	4.225
8	4	1	1	1	1.5
5	5	-1	-1	1	3.275
6	6	1	-1	1	1.3
4	7	1	1	-1	4.525
2	8	1	-1	-1	3.075

3.3 Conducting the experiment as per the design matrix

Referring to the design matrix given in table 2, weld specimen were prepared at the combination of input parameters shown in the matrix. For this purpose 2mm thick plates of the subject material were cut in a 100mmx100mm. The plates were first tack welded with a uniform gap of 1mm. These joints were then welded on the setup whose details have already been mentioned. During the preparation of these welds it was ensured that the continuity of each weld was not disturbed and all the set parameters were closely monitored.

3.4 Development of mathematical model

The response parameter can be related to the input parameters by the following relation

Y =f (A, B, C)

Where, Y= angular distortion

A= welding current

B= welding speed

C= torch angle

The regression equation relating the response to the input values could be a second order polynomial in the following form

$Y=b_0+b_1A+b_2B+b_3C+b_{12}AB+b_{23}BC+b_{31}CA$ where b_0 is model coefficient b_1, b_2, b_3 are linear coefficient b_{12}, b_{23}, b_{31} are interaction coefficient.

The mathematical equation developed by the software in coded form is given below.

Angular distortion =2.82-0.21A +2.04B+0.99C -1.63AB -2.20AC -0.51BC

3.5 Testing the adequacy of the developed model

The adequacy of the developed model was checked by carrying out ANOVA analysis with the help of the software. The results obtained are satisfactory. The high value of R^2 and adjusted R^2 indicate the adequacy of the developed model. These values are given in table-3.

Table 3: Fit statistics

Std. Dev.	1.06	**R^2**	0.9886
Mean	3.23	**Adjusted R^2**	0.9203
C.V. %	32.89	**Predicted R^2**	0.2714
		Adeq Precision	13.4051

Further, the scatter diagram showing the predicted Vs. actual values also substantiate the claim as it is visible that the points are very closely placed around the central line as shown in figure-3

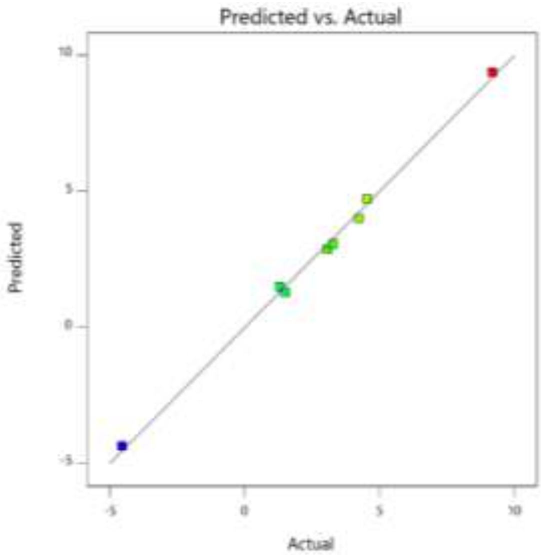

Fig.3 Predicted Vs. Actual scatter diagram

3.6 Analysis of the results

The graphical plots obtained from the software depicts the direct, interaction effects and 3-D surface plots. In order to keep the text within reasonable limits, 3D surface plots depicting the interaction effects are explained in the following sections

3.6.1 Interaction effects of welding current and welding speed on Angular distortion

Fig.4 shows the interaction of welding current and welding speed on Angular distortion

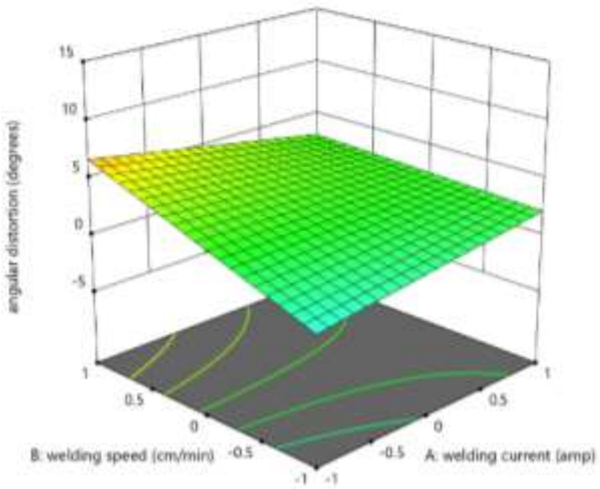

Fig 4 Interaction effects of welding current and welding speed on Angular distortion

The fig. 4 clearly shows that angular distortion increased with the increase in welding current and welding speed,

The angular distortion increases with increased welding current due to increase in heat input. This increased heat give rise to more molten metal which on cooling increase the angular distortion. With increasing welding speed, Angular distortion is increasing as unsteady heat distribution increases. With increase in welding speed angular distortion is increasing but at higher welding current heat input in dominating thus effect due to welding speed has little or no effect on angular distortion this is probably because at higher welding current heat input is significantly higher, heat penetration is very high which increases the unsteady heating in such a manner that there is no role of speed in angular distortion, all the effect is governed by welding current.

3.6.2 Interaction effect of welding current and torch angle on Angular distortion

Fig.5 shows effect of welding current and torch angle on Angular distortion.

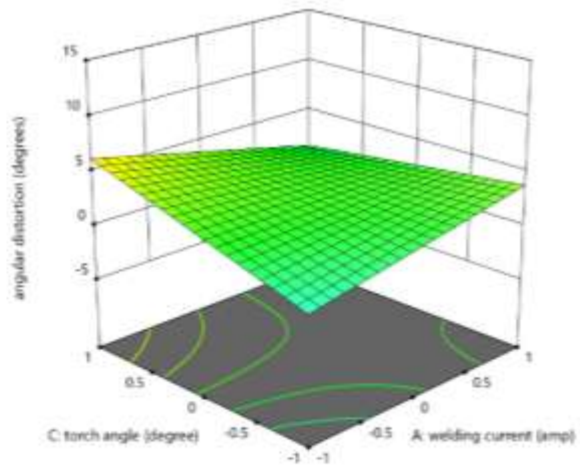

Fig 5 Interaction effect of welding current and torch angle on Angular distortion

With increasing the torch angle angular distortion increased as heat distribution gets spread over a wider area because of the more arc spread thus increasing the distortion. As described in section 3.6.1, the effect of welding current follows same trend. At low welding current torch angle has significant effect on angular distortion which become insignificant at higher welding current.

3.6.3 Interaction effect of torch angle and welding speed on Angular distortion

Fig.6 shows the interaction effect of torch angle and welding speed on angular distortion.

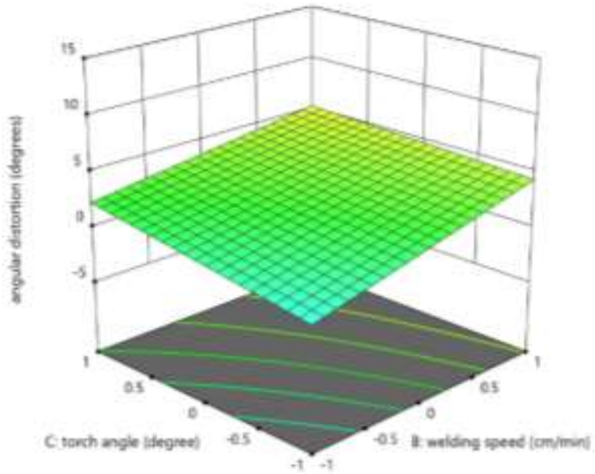

Fig.6 Interaction effect of torch angle and welding speed on Angular distortion

As explained in section 3.6.1 and 3.6.2, angular distortion increases with increasing welding speed and torch angle. The combined effect of both the input factor can be seen in clearly in Fig.5. At increased welding speed, increasing the torch angle increases the angular distortion or vice versa.

3.7 CONCLUSIONS

- The full factorial approach has been satisfactorily used in the present study
- Welding current has positive effect on angular distortion
- Welding speed has positive effect on angular distortion
- Torch angle has positive effect on angular distortion
- Maximum angular distortion was obtained at a welding speed of 40 cm/min and welding current of 140 A, and minimum angular distortion was obtained at welding current of 140 A and welding speed of 35 cm/min.
- Maximum angular distortion was found at torch angle of 22.5^0 and welding current of 140 A, and minimum angular distortion was obtained at torch angle of 0^0 and welding current of 140 A.
- Maximum angular distortion was obtained at 22.5^0 and welding speed of 40 cm/min and minimum angular distortion was obtained torch angle 0^0 and welding speed of 35 cm/min.

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BIOGRAPHIES

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