Effect of Welding Parameters on Angular Distortion of Submerged Arc Welded Low Carbon Steel Plates.

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Abstract: Submerged Arc Welding is an important industrial joining process used extensively for welding of thick plates. Hence, finds utility in heavy fabrication industries like ship building and pressure vessel industry. The process is characterized as a high heat input process which sometimes leads to certain weld abnormalities of which angular distortion is the one. The present work is an attempt to analyse the effect of input welding parameters like Wire Feed Rate, Voltage and Welding Speed on angular distortion which is a response parameter. Angular Distortion is caused because of the non uniform thermal stresses experienced by the top and bottom surfaces of the weld with top surface getting the maximum and the bottom surface getting the minimum thermal effects. This causes top surface to experience more contraction as compared to bottom resulting in distortion of weld across the line of weld known as angular distortion. This distortion may result in rejection, scrap or misfit of the weldment with parent structure. It is therefore important to keep this defect to a minimum and the present study is an attempt to work in this direction. The results are expected to be of practical importance from the industrial viewpoint.

Keywords: Submerged Arc Welding, Angular Distortion, Input Parameters, Response Parameters. Mathematical Modelling.

1. Introduction:
Submerged arc welding is one of the extensively used arc welding process which was developed in early 1940s to meet the demands of heavy fabrication industries like ship welding. The process since then has gained popularity owing to its ability to get automated and making long continuous joints on these sections. The process can join plates up to a thickness of 16 mm without the need of any specific edge preparation because of deep penetration capability and high deposition rates\textsuperscript{1}. It is also suited for circumferential butt-welds on pipes, pressure vessels and rail wagons in the horizontal position and finds a wide industrial applications\textsuperscript{2}. An arc is created between the work piece and a bare solid wire, which is consumed during the welding operation. The electrode is in the form of a spool and the shielding is provided by a blanket of granular, fusible flux, which covers both the arc and molten metal by forming a slag blanket to prevent oxidation\textsuperscript{3}. It acts as a thermal insulator, permitting deeper heat penetration\textsuperscript{4}. The process involves minimum heat loss, provides flexibility of automated and semi automated welding with no weld spatters, ensure increased protection of weld from atmospheric gas contamination, etc\textsuperscript{5}. All the above listed features make SAW a prevalent and popular metal joining process. However, a disadvantage of SAW is that; because of large heat inputs, it often results in unacceptable levels of geometric imperfections such as shrinkage and angular distortion\textsuperscript{6}. Angular distortion as shown in fig. 1, is caused when the stresses generated from non uniform thermal expansion/contraction exceed the yield strength of the parent metal, plastic deformation of the metal occurs and this plastic deformation causes the plate edges to rise about the weld line in across the weld\textsuperscript{7}. Such welding distortions can lead to rejection of the weldment with high rectification costs\textsuperscript{8}. Therefore, distortion needs to be controlled at all stages of the fabrication. The welding distortions are strongly influenced by welding process parameters. Hence, estimating the magnitude and distribution of welding distortions and characterizing the effects of the welding conditions can be of significant importance\textsuperscript{9}. The major input factors influencing welding distortion are; weld current, weld voltage, and travel speed. One of the methods to avoid the angular distortion during the fabrication process is to provide an initial angle in the negative direction\textsuperscript{10}. This could be an effective way to reduce the angular distortion produced in the workpiece up to a certain level. However, it is difficult to predict the value of negative angle to be given to counter the final angular distortion. This can however be
done by conducting structured preliminary experiments by using some statistical tool to establish relationship between angular distortion and the input parameters. In the present work, an attempt has been made to develop a mathematical model relating the various input welding parameters with the angular distortion produced. The statistical method of Design of Experiments was found useful for the purpose, where, full factorial technique with three factors, each at two levels was adopted. The developed model can be used to predict the value of angular distortion produced for a given set of input conditions selected from the working range.

![Angular Distortion](image1)

**Fig. 1 Angular Distortion**

2. Experimental setup and Experimentation:
The experimental setup used to carry out the present investigative work is shown in fig. 2. It consists of a weld power source with flat V-I characteristics with ampere rating of 800 amps, 100 % duty cycle, 440 volts, three phase.

![The welding setup](image2)

**Fig. 2 The welding setup**

The weld carriage is mounted on the guide rail with the facility of having different welding speeds. A total of eight butt welds were made with mild steel plates of thickness 10 mm. The range of input parameters with respective codes is shown in table 1. Lower limit of the parameter is coded as (-1) and upper limit is coded as (+1).
Table-1 input parameters and their values.

| S no. | Input Parameters | Symbols | Unit | Levels |
|-------|------------------|---------|------|--------|
| 1.    | Welding speed    | A       | cm/min | 10 20 |
| 2.    | Arc voltage      | B       | V     | 30 40 |
| 3.    | Wire feed rate   | C       | m/min | 5 7   |

The experimentation was carried out as per the combinations shown in table 2. All the welds were cleaned especially on the back side to ensure flatness while measuring angular distortion. The values of angular distortion measured on each weldment are also shown in table-2.

Table-2 the values of angular distortion measured as per combinations.

| S. No. | Welding speed | Voltage | Wire feed rate | Angular distortion |
|--------|---------------|---------|----------------|--------------------|
| 1.     | -1            | -1      | -1             | 1.25               |
| 2.     | +1            | +1      | +1             | 2.15               |
| 3.     | +1            | +1      | -1             | 2.96               |
| 4.     | -1            | +1      | +1             | 4.2                |
| 5.     | -1            | +1      | -1             | 4.0                |
| 6.     | -1            | -1      | +1             | 4.88               |
| 7.     | +1            | -1      | +1             | 3.01               |
| 8.     | +1            | -1      | -1             | 3.85               |

2.1 Measurement of Angular Distortion:
The angular distortion of the weldments was measured by using the setup shown in fig 3. The setup consists of a properly levelled surface plate, a vernier height gauge and some suitable weights. The weld specimen was placed on the surface plate with one of the edges pressed against it. In this position initial reading $R_1$ is taken with the help of vernier height gauge as shown. The same edge is now raised by an amount of angular distortion when a suitable weight is placed on the other plate of the joint. In this position reading $R_2$ of the raised edge is again taken. The angular distortion can now be easily determined by using the relation, $\sin \theta = (R_2 - R_1)/l$, where $l$ is the width of one plate which is 100 mm in this case. By using same procedure, angular distortion of all the weldments was measured.
3 Results:
The values of angular distortion measured were used in design of expert software. The mathematical model developed is given below-
Angular Distortion = 3.3 − 0.28A + 0.02V + 0.28C − 0.48AB − 0.67AC − 0.43BC
This equation can be used to predict values of angular distortion at different values of input parameters A, B and C within their operating range. The equation also shows the interaction effect of variables. The higher order terms, insignificant terms and triple interaction terms have been ignored for the sake of calculation convenience.
The graphical results produced by the software are given Fig. 4-8 in the next section.

4 Analysis of Results:
The graphical results produced by the software are discussed under two categories-
1. Direct effect plots.
2. Interaction plots (surface plots).

4.1 Direct effects of input parameters on angular distortion:
Fig. 4 shows the direct effects of input parameters on angular distortion. From the figure it is evident that wire feed rate has a positive effect on angular distortion. The probable reason could be that with the increase in wire feed rate, the welding current also increases which increases the depth of penetration of heat into the work piece. More amount of heat causes more thermally generated stresses causing more angular distortion.

Voltage is also found to have a positive effect on angular distortion but in a very less magnitude than the wire feed rate. The probable reason could be that with the increase in voltage the arc length increases which results in the redistribution of the heat in the arc giving more of a spreading effect. As the heat now spreads in a wider area, the angular distortion increases but very less as compared to its value with the increase in wire feed rate where the heat could penetrate much deeper into the weld.

Welding speed has been found to have negative effect on the angular distortion. The probable reason could be that with the increase in speed, the heat input per unit length of the weld decreases sharply. With less amount of heat, lesser thermally generated stresses are produced, resulting in sharply reducing angular distortion with the increase in welding speed.
4.2 Interaction effects of input parameters on angular distortion:

It can be observed from fig. 5 that the input parameters are non-parallel and intersecting each other in all the given graphs. Thus, these parameters interact with one another.

4.2.1 Interaction effect of welding speed and voltage:
From fig. 6 it is observed that at all values of welding speed, the angular distortion increased with the increase in voltage except at maximum speed where the trend appears to be opposite. The probable reason could be that at maximum speed the arc spreading effect doesn’t have any effect on the spread of heat.
4.2.2 Interaction effect of wire feed rate and voltage:
From fig. 7 it can be observed that with an increase in wire feed rate and voltage, angular distortion increases in general. It is already inferred that wire feed rate has a pronounced positive effect on angular distortion, but from the figure it is also observed that at maximum voltage, the angular distortion decreased with the increase in wire feed rate. The probable reason could be that the spreading effect of voltage might have outweighed the penetrating effect of current.

4.2.3 Interaction effect of welding speed and wire feed rate:
From fig. 8 it can be concluded that wire feed rate has a positive effect on angular distortion whereas, welding speed has a negative effect. The Wire feed rate controls the amperage as well as the amount of weld penetration. Therefore, with an increase in wire feed rate, current increases as discussed above. The maximum angular distortion can be at minimum welding speed and maximum wire feed rate.
5. Conclusions:

The following conclusions can be drawn from the above investigation:-

1. Welding speed has a negative effect on angular distortion whereas, wire feed rate and voltage have a positive effect on angular distortion.
2. The maximum angular distortion attained is 4.85° at welding speed of 10 cm/min and wire feed rate of 7 m/min.
3. The minimum angular distortion attained is 2.50° at wire feed rate 7 m/min and voltage of 40 V.

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