SYNOPSIS

Investigation of Yield Parameters of Submerged Arc Welding Process

Introduction
Submerged Arc Welding (SAW) is a process for fabricating structures, bridges, ships, boilers, etc. This process of arc welding provides a purer and cleaner high volume weldment that has relatively a higher material deposition rate compared to the traditional welding methods. The application of SAW process raises a concern about the uncertainties involved with the heat affected zone (HAZ) and optimum setting of input parameters for required output parameters. The most important issue is about HAZ softening that imparts some uncertainties in the welded quality.

Higher grain growth increases the probability of fatigue failures at the weakest zones caused by the heating and cooling cycle of the weld zone. In order to bring out an appropriate combination of SAW parameters and a methodology to control such parameters an in depth investigations and characterizations of HAZ softening zone are necessary. A critical investigation of the transient temperature distribution is also important for maintaining the quality of the Submerge welded plates.

Objectives

The aim of the present work is thus identified to be:
• To derive an analytical solution to predict the transient temperature distribution in the plate during the process of Submerged Arc Welding.
• To find out optimum combinations of input process-control variables for achieving the required weld bead quality.
• To critically study the behavior of the yield parameters like bead geometry, hardness of the weld.
• To develop a model to predict the yield characteristics like geometrical dimensions of the bead, HAZ width for a specific set of value of major process parameters.

Motivation for the experiment

In order to carry out fresh investigation into the heat dissipation process of SAW the following arrangements are done.
Experimentation

Fig.1-s: Work piece (length – 30 cm × breadth – 30 cm × thickness - 2 cm).
Representation of axes and identification of few points (P1, P2, P3, P4) where reading of temperature was taken.

A MEMCO semi automatic welding machine (as shown in fig.2-s) with constant voltage, rectifier type power source with a 1200-A capacity is used to join mild steel plates. Basic fluoride type granular flux is utilized. The experiments are carried out as per the design of experiment norms. The experiments were carried out randomly to avoid errors due to noise factors. Two pieces of mild steel plates (breadth (= 15 cm) × length (= 30 cm) × thickness (= 2 cm)) were cut and V grooves of angle 60° were prepared. 1 mm root opening is selected to join the plates in the flat position keeping electrode positive and perpendicular to the plate. The plates are taken firmly fixed to a base plate and then the submerged arc welding is carried out in single pass. Temperatures measured at different points of the welded plates except at the welding line by infrared thermometers. The product is cut at three sections of welded plates. To measure average values of the penetration, reinforcement height using digital vernire caliper of least count 0.02 mm. Results are in table 1-s.

Fig.2-s. MEMCO Semi Automatic Submerged Arc Welding Machine

Experimental Results

<table>
<thead>
<tr>
<th>Sl.No.</th>
<th>Voltage</th>
<th>Current</th>
<th>Travel</th>
<th>Penetration</th>
<th>Reinforcement</th>
<th>Bead</th>
</tr>
</thead>
</table>

Table 1-s. Sample Values for Bead Parameters
### Results and Discussions

For a particular range of input parameters of SAW process, there is no interaction present between a pair of input parameters of SAW process for the consequent output parameters. Within this range, optimum setting of input parameters are determined by applying Taguchi’s methods.

Very good agreement between the predicted and the measured data of output parameters of SAW process is achieved when third degree polynomial equation is assumed.

It is found from literature [18] that most suitable heat source is of double ellipsoidal shape. Double ellipsoidal heat source shape is a combination of two semi ellipsoidal shapes. Semi major axis of one of these ellipsoids is \( m' \) and \( m'' \) as in fig.3. This combination is called double ellipsoidal heat source shape. In present study, from experiments, the shape of weld pool geometry is found to conform better with an oval shape (as shown in fig.3,4). For a representative sample in table-1, equation of oval weld pool geometry is

\[
\frac{x^2}{1.3^2} + \frac{y^2}{1.13^2} \times e^{0.3x} = 1
\]  

(1-s)

Therefore, heat source shape for this study is assumed to be an oval shape whose equation is:

\[
a x^2 + (b y^2 + c z^2) e^{m x} = 1,
\]

where, \( m = 0.3 \).  

(2-s)

Here a= major axis,

b=semi minor axis,

c=another semi-principal axis of an ellipsoid whose equation is \( ax^2 + by^2 + cz^2 = 1 \)

Equation of transient temperature distribution for oval heat source -

\[
T(x, y, z, t) = T_0 - \int_0^t \frac{1}{8 \rho c \pi^2 \pi a^2 (t-t')} \times \frac{1}{\pi^3 v^2} \times \frac{1}{e^{m^2}} \times Q_0 \times I_x \times I_y \times I_z \ dt' 
\]

(3-s)

In equation (3-s)
I_{x(t)}=f(x-vt'),\text{ when } I_s=f(x), \rho = \text{density}, c_p = \text{Specific heat at constant pressure}, \alpha = \text{thermal diffusivity}, t' = \text{time}, T(x, y, z, t) = \text{temperature at point (x,y,z) at time t}, T_0 = \text{initial temperature of work piece}

Also

\[ I_x = \int_{-\infty}^{\infty} e^{-\left(\frac{(x-x')^2}{4\alpha(t-t')}\right)} \times e^{-\left(\frac{e^x_{\text{mx}}}{e^{\text{mx}}_{\text{t}}}\right)} \, dz' = \frac{\sqrt{\frac{4\pi \alpha(t-t')}{4c\rho(t-t')} + 1}}{4c\rho(t-t')} \times e^{-\frac{e^x_{\text{mx}}e^2}{4c\rho(t-t')} + 1} \tag{4-s} \]

\[ I_y = \int_{-\infty}^{\infty} e^{-\left(\frac{(y-y')^2}{4\alpha(t-t')}\right)} \times e^{-\left(\frac{e^y_{\text{my}}}{e^{\text{my}}_{\text{t}}}\right)} \, dy' = \frac{\sqrt{\frac{4\pi \alpha(t-t')}{4b\rho(t-t')} + 1}}{4b\rho(t-t')} \times e^{-\frac{e^y_{\text{my}}e^2y^2}{4b\rho(t-t')} + 1} \tag{5-s} \]

Accordingly,

\[ I_s = \int_{-\infty}^{\infty} e^{-\left(\frac{(x-x')^2}{4\alpha(t-t')}\right)} \times e^{-\left(\frac{e^{\text{mx}}_{\text{t}}}{e^{\text{mx}}_{\text{t}}}\right)} \times I_x \times I_y \, dx' \]

Finally, considering oval heat source shape in the present study, transient temperature distribution equation (3) is developed and very good agreement between predicted data and measured data is observed.

HAZ width of mild steel is the region heated at eutectoid temperature (i.e., 727°C) to the temperature just below the melting point temperature of welded materials (i.e., 1495°C).

Substituting these values in the equation (3), HAZ width can be calculated at z = 0, x = vt', Equation (3) gives the temperature increment at a point (x, y, z) at an instant t for the heat source applied at point (x', y', z') at an instant t'. For representative sample in table No. 1-s, the measured HAZ width is 0.156 cm (as shown in fig. 5-s) and the predicted value is 0.17 cm.

Studies of the variation in hardness (shown in fig. 5-s), and microstructure analysis (shown in fig. 6-s) of the variation of hardness (shown in fig. 5-s) of the variation of hardness (shown in fig. 5-s) of welded plates are also been made. At HAZ, prominent grain growths and low hardness are observed. It is found from literature [12] that the hardness of the grain growth portion will also manifest lower values related to higher grain sizes.
The observations (from fig.5-s, 6-s) dictate that hardness of the grain growth portion produce lower values due to larger grain size formation.

Fig.3-s: Oval heat source (three dimensional) and oval weld pool geometry

Fig.4-s. Comparison of ellipse ($\frac{x^2}{1.3^2} + \frac{y^2}{1.13^2} = 1$) and oval ($\frac{x^2}{1.3^2} + \frac{y^2}{1.13^2} \times e^{0.3x} = 1$) shapes.

It was found from experiment that shape of weld pool geometry is oval and equation of weld pool geometry is $\frac{x^2}{1.3^2} + \frac{y^2}{1.13^2} \times e^{0.3x} = 1$, when heat input 2.84KJ/mm.
Fig. 5-s: Hardness Variation of welded plates and Identification of different portion of submerged arc welded plates.

Fig.6-s: Microstructure at the Heat Affected Zone (as shown in fig.5-s(c)) of 3000x magnification for 2.84 kJ/mm heat input.
Conclusions drawn in the thesis

- If current increases, penetration and reinforcement height increase along with the increment of metal deposition rate. If voltage increases, there is no change in metal deposition rate. If travel speed increases, all bead parameters will be decreased.
- In particular situations, there is no interaction effect among the input variables for the output parameters. So by applying Taguchi’s method optimum setting of input parameters of SAW process can be found out.
- Very good agreement between the predicted and the measured data of output parameters are achieved with 3rd degree polynomial equation is assumed.
- HAZ width, microstructure, strength etc. of the welded plates are changed with the change of heat input.
- In this study, analytical solutions for the transient temperature field of a semi-infinite body subjected to 3-D power density moving heat source (such as oval) are carried out and experimentally validated.
- Good agreement between the calculated and measured temperature data, is observed.
- Lower $R_B$ hardness results are manifested of softening around HAZ. It is an indication of larger grain size with low yield strength. It conforms to the finding [12].

Outcome of the thesis

In present work, role of the major process control parameters on the yield parameters are investigated. An attempt is made to develop a mathematical model for the prediction of the heat affected zone width with the aid of analytical solutions. Using Taguchi’s method, optimum values of the process control parameters of SAW process are determined to obtain a robust way for the best possible weld bead penetration. Assumption of convective and radiative heat loss of welded plate resulted in good agreement in between the analytical and practical and the measured transient temperature distribution. It is found that the shape of the heat source for submerged arc welding process is oval in contrary to the commonly used double ellipsoidal shape of heat sources as revealed by the earlier researchers.