PREDICTION OF SAW WELDMENT SHAPE PROFILES FOR OPTIMIZING RESIDUAL STRESS AND DEFORMATION

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ABSTRACT

The shape of weldment obtained during the fusion welding play a vital role in inducing residual deformation and stresses. Submerged arc welding (SAW) process is a high metal deposition process and used for thick plate welding. During SAW the high heat input is applied for joining thick plates. Improper process parameter setting during SAW can lead to excessive residual stress and deformation as the weldment cooling rate of thicker plate is drastic in nature. Hence optimization of SAW process parameter is required to minimize the occurrence of distortion and residual stresses. The present investigation is aimed at prediction of optimized SAW weldment shape profile which also includes the shape of heat affected zone (HAZ). In the contemporary literature modeling works related to weldment only give the overall bead height and width of the weldment. Very rarely a complete picture of weldment including that of HAZ is predicted. The present research is aimed at predicting the entire weldment shape profile characteristics during SAW. A design matrix was used for SAW butt bead-on plates with a range of input process parameters. The beads were cross sectioned polished and etched for measuring the various zones of macrostructures including that of HAZ. The output of the welding i.e. the macrostructure characteristics, were modeled with respect to the input process parameters. The present modeling technique can be used for optimization of the weldment shape profile based on input process parameters for minimizing the distortion and residual stresses. The modeling technique developed can also be conveniently used for prediction of fusion zone boundary and HAZ boundary.

INTRODUCTION

The weldments characteristics of submerged arc welding (SAW) like the weld reinforcement, weld penetration depth and heat affected zones (HAZ) are important considerations which affect the overall weld integrity. The weldment cross-section shape profiles not only depend on the welding process but also on the input process parameters and determine the quality of the weld [1, 2]. During SAW arc length and spread are difficult to estimate as it is covered with flux. Hence modeling of SAW arc is difficult. The weldment characteristics of SAW like the weld reinforcement, weld penetration, HAZ boundaries are the used for validating the simulation done using numerical methods. Researchers have tried to predict the SAW and other fusion weldment characteristics using statistical and soft computing methods. Most of the research work related to arc weldment characteristics involves prediction of maximum reinforcement height, width and penetration. Rarely a complete prediction of weldment shape profile including that of HAZ is observed in the contemporary literature [3-5]. Investigators have also resorted to experimentation and prediction of weldment characteristics based on experimental results using statistical modelling like regression analysis and response surface methods [6-13]. Tarng et al. [8] had optimized the weldment bead geometry of GTAW by using the Taguchi method. Karaoglu et al. conducted the sensitivity analysis in order to compare relative impact of process parameters on bead geometry of SAW welding using a mathematical model. They had used sensitivity analysis to predict the variation in the objective function due to small changes from the optimum values of constraints. However they did not predict the complete shape profile of weld [14]. Kumanna and Das had determined the bead width of SAW using adaptive neural fuzzy inference systems [15]. The Response surface technique was used to determine and represent the cause and effect relationship of inputs and output characteristics of weldment by Gunaraj et al. [16]. The process parameters were determined for the quality weld bead in MIG welding by Ganjigatti et al. for obtaining bead characteristics [17].

In this investigation the SAW weldment characteristics and shape proile (complete weldment profile including bead width, bead height, depth of HAZ, width of HAZ and weld bead crass-sectional area) have been predicted with respect to the input process parameters by constructing mathematical model based on the experimental data. The mathematical relations of SAW process were carried out by multiple regression analysis. Test cases were also investigated to verify the adequacy of the model developed.

EXPERIMENTAL DETAILS

A constant current submerged arc welding power source (Tornado SAW M-800/1000/1250) and FD 1X-200TZ Welding Tractor of Ador Frontech was used in the experiment [18]. The SAW setup for experiment is shown in Fig. 1. Copper coated electrodes AWS (EH-14, Grade C) of 4 mm diameter with basic-fluoride-type granular flux was used. The composition of electrode and flux is given in Table 1 and Table 2 respectively. Trial runs were initially conducted for the butt bead on plates to set the levels of three input process parameters. The trials experiment runs were conducted to select the range (Table 4) of welding input parameters such that no observable defects like slag inclusion, undercutting and porosity occurred.

Proper selection of voltage, current, wire feed rate, welding speed and stick-out length play important part in controlling the weld quality [19- 20]. The 27 test experiments of butt-bead-on plates were conducted to obtained test data for mathematical modeling. The length, width and thickness of mild steel plates used in the experiments were 300, 100, and 12 mm respectively. The composition of steel plate is given in Table 3. The welding process parameter chosen for the experiment is given in Table 4. Three input parameters, current, voltage, traverse speed were used at three levels as shown in the Table 4. The electrode was set perpendicular to the plate. The SAW weld bead on plate is shown in Fig. 1. Weld samples were cut from the test pieces and polished by silicon carbide paper with different grades and etched by nital solution (5-10%, Nitric Acid with water) and then bead geometries were measured including the bead width, bead height, depth of penetration, width of HAZ, depth of HAZ and weld bead cross-sectional area.

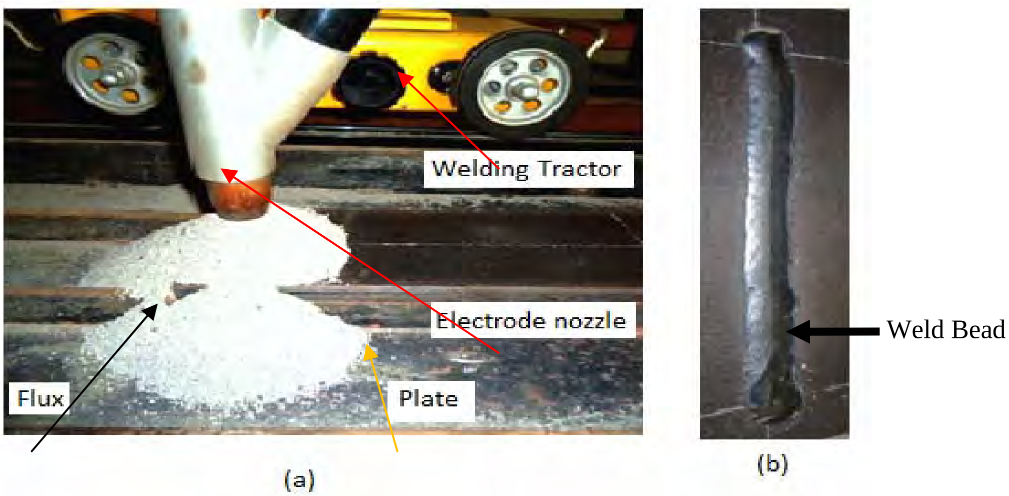

Fig. 1 (a) The SAW setup for experiment and Fig. (b) The butt-bead-on plate

Table 1 Composition of flux

CaF2%	CaO + MgO%	Al2O3 + MnO%	SiO2 + TiO2%	Fe
25	40	20	15	Balance

Table 2 Chemical composition of SAW wire

C %	Mn %	Si %	S %	P %	Cu %	Fe
0.10	0.30-0.62	0.03	0.03	0.03	0.15	Balance

Table 3 Chemical composition of the mild steel

C%	Si%	Mn%	P%	S%	Ni%	Cr%	Fe%
0.16011	0.17774	0.45330	0.17975	0.06918	0.1324	0.01567	98.8413

Table 4 Input parameters for SAW

Parameters	High	Medium	Low
Current (A)	525	475	450
Voltage (V)	29	32	36
Traverse speed (mm/s)	8.33	6.94	5.55

Bead Characteristics from Experiment

The experience on SAW indicates the repeatability of the process which facilitates modelling the bead characteristics. The SAW bead can be cross sectioned as shown schematically in Fig. 2 and the various zones of it can be measured. From Fig. 2 it can be observed that the HAZ width (HW) is the distance AB. Similarly BD, HC, CG and GF can be measured for representing bead width (BW), reinforcement height (H), penetration depth (P) and depth of HAZ (DHAZ) respectively. These dimensions of various zones can be utilised in graphical software for representing the complete weldment shape profile. In the present investigation the bead cross sections were measured. The regression equations were derived to study the suitability of the relations for predicting the bead characteristics of test cases. The full factorial design method was employed to decide the combination of process variables for experiments. The full factorial design method was suitable to study the effects of variables and outputs.

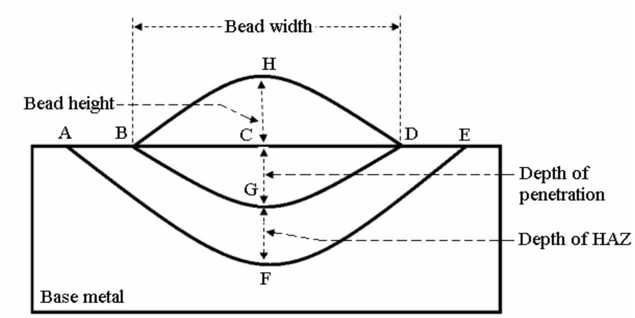

Fig. 2 Schematic of SAW weldment shape profile

Table 5 Statistical analysis of SAW bead data

S.N	Statistics	R^2 (%)	Adjusted R^2 (%)	Regression Equation
1	Bead height, (H)	94.1	93.3	5.09 +0.000552 *(I) - 0.0319*(V) - 0.228*(TS) + error
2	Depth of penetration, (P)	94.4	93.7	- 5.02 + 0.0202*(I) + 0.0535*(V) - 0.268*(TS) + error
3	Depth of HAZ, (DH)	90.8	89.7	- 0.931 + 0.00838(I) + 0.0343*(V) - 0.293*(TS) + error
4	Bead width, (BW)	98.6	98.4	5.40 + 0.0211*(I) + 0.344*(V) - 1.31*(TS) + error
5	Weld cross-sectional area, (CSA)	89	87.6	22.8 + 0.127*(I) + 2.27*(V) - 11.2*(TS) + error

MODELLING OF SAW WELDMENT SHAPE PROFILES

The mathematical modelling of SAW parameters based on three input parameters were constructed by using multiple regression analysis. The mathematical simulation was intended to establish the relationship of weldment characteristics with respect to the input process parameters. The regression coefficients were calculated based on selection of correlating the experimental data series. The Statistical relations of weld bead characteristics of SAW are shown in Table 5.

RESULTS AND DISCUSSION

The results from analysis of variance (ANOVA) indicated that welding current and welding speed here the significant welding process parameters. For the experiments the regression analysis of process parameters were investigated. The observed and predicted bead height and HAZ width respectively. The expected values of weldment characteristics and experimental values show considerable linearly. In some cases the predicted values and experimental values are observed little deviated. That might be due to some experimental error. The maximum deviation is shown in case of HAZ since it's very difficult to measure the exact HAZ boundary of weldment.

Table 6 Percentage of error for test cases from regression equations

Sl. No	**Current (A)**	**Voltage (V)**	**Arc traverse speed (mms^{-1})**	**Bead width, (BW) (%)**	**Error of bead height, (H) (%)**	**Error of depth of penetration, (P) (%)**	**Error of depth of HAZ, (DH) (%)**	**Error of weld cross-sectional area, (CSA) (%)**
1	410	38	7.78	6.30	-10.03	-12.44	10.24	17.07
2	420	25	5.00	0.85	-1.11	-8.41	5.93	4.65
3	430	31	5.56	2.36	3.05	4.61	9.38	7.33
4	470	28	7.50	-4.78	-6.38	-5.24	3.39	-11.43
5	500	34	6.94	-8.98	0.34	-8.80	9.36	-8.96
6	500	35	8.06	-2.25	2.85	1.89	10.32	9.90
7	510	35	8.61	-1.92	2.83	11.85	15.43	11.80

Since the SAW inputs process parameters have combinational effect on the weldment characteristics, it is desirable to study their effects. The bead width increases with increase in voltage and current but the rate of increase in bead width with respect to the current seems lower than the voltage. The increase of welding speed indicates it is negative effect on bead width as at high welding speed bead width is of lower value. The maximum bead width has found in case of high voltage, high current and low speed. This is because of the higher heat input for high voltage and current. On other hand the slow speed has provided sufficient fusion time for archiving more bead width. The effects of process input variables on depth of penetration are observable that current is more critical process parameter for depth of penetration. The penetration has not shown remarkable changes up to current 475A, also it is observed that the voltage has not played significant role on increasing further depth of penetration. Researchers have found that welding speed is second most critical process parameter after welding current which affect the HAZ of weldment [16]. The drastic effects of welding speed on HAZ of weldment. It's clearly observable that the HAZ decreases as the welding speed increase. The reason behind this is the heat input which is inversely proportional to welding speed. As welding speed increases the heat input decreases. The faster travel speeds allow a greater portion of arc energy per unit length to be utilized in affecting the base metal. Current and traverse speeds seem to the more dominating factors for bead height as compared to voltage. The bead height shows more value for higher current range.

The process parameters of arc welding processes like SAW are such inter dependent that it is may not be adequate to represent one output with respect to another input in a two dimensional graph. The combined effect of current and voltage on bead width can be observed with a quadratic relationship. The equations of regression show considerable accuracy for the prediction of test run outputs. The percentage error of regression analysis is shown in Table 6 for test cases. The maximum percentage of error for prediction (for cross sectional area) is found out to be 17.073 in test cases. The experimentally observed and predicted values of output weldment shape profiles have been compared graphically and presented for two test cases (No.3 and 5, Table 6) in Figs 3 and 4. It can be observed that there is good agreement between the experimental and predicted values of shape profile characteristics.

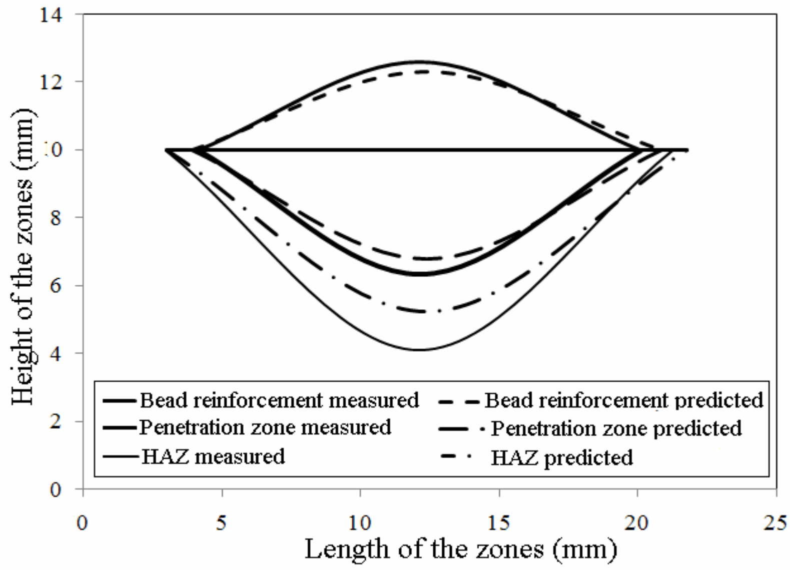

Fig. 3 SAW weldment shape profile of test case NO. 3 (Table 7)

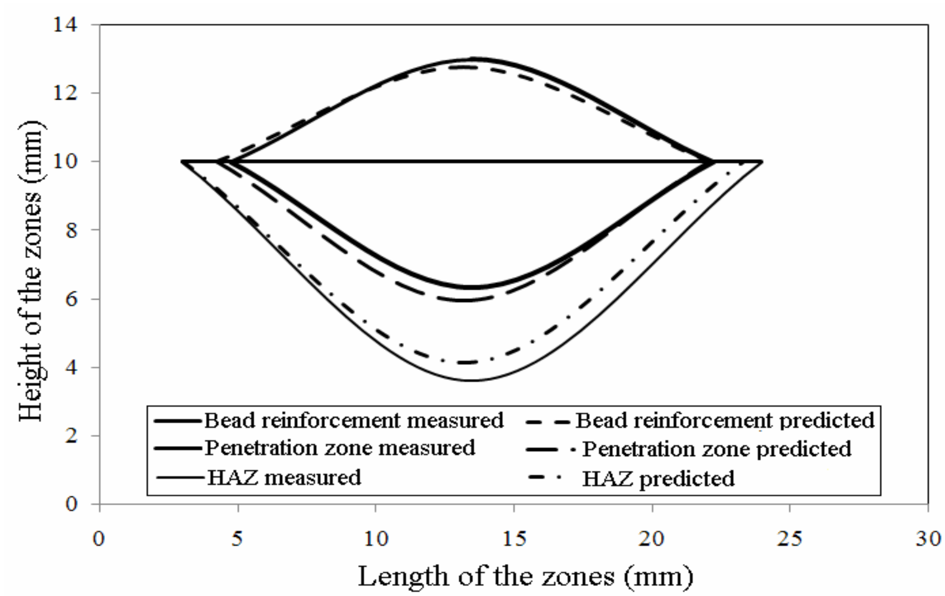

Fig. 4 SAW weldment shape profile of test case NO. 5 (Table 7)

CONCLUSIONS

In this study, the mathematical model was developed by using regression equations from experimental data. The effects of process parameters of weldment characteristics were also investigated. While investigating the effects of process variables on the weldment characteristics of SAW bead-on-plates following conclusions can be made.

- The statistical analysis of weldment shape profile has found that more significant for predicting the effects of process parameters.
- It is concluded that the multiple regression analysis prediction within an accuracy limit of 18%, for a full factorial three level and three factor based design of experiment of weldment characteristics.
- Depth of penetration is more influenced with welding current and welding speed.
- Bead width is dependent more on the values of voltage and travelling speed as compared to other weldment characteristics.

- It's always conflicting for the researchers to give the direct individual effects of process parameters on Depth of HAZ, here concluded that welding speed is more sensitive and slightly affected by current variation than that of bead width and penetration.
- Current is the most important parameter in determining the penetration and welding speed is the most important for depth of HAZ.
- The SAW deposit width can be divided into a number of equal segments; corresponding weld deposit heights, penetration depths and depths of HAZ at these segments can be used for effective graphical representation of the weldment shape profile.

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