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Technical Paper

Mathematical modeling of effect of polarity on weld bead geometry in submerged arc welding

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ABSTRACT

Weld bead geometry parameters are significantly affected by polarity as it affects the extent of heat generated at electrode wire and work in the welding process which further influences the mechanical and metallurgical properties. Essential requirement of a welding process is to obtain a weld joint with desired weld bead parameters and mechanical properties. In present study mathematical models have been developed to evaluate the effect of polarity on weld bead geometry in submerged arc welding. Response surface methodology has been used for predicting the critical dimension of weld bead geometry and shape relationships at straight polarity and reverse polarity. The developed models have been checked for adequacy and significance by *F*-test and *t*-test. Effect of polarity on the response parameters are presented graphically which not only leads to prediction of weld bead geometry and shape relationships but also assisted to achieve the control over weld quality by selecting the appropriate process parameters.

1. Introduction

Welding is one of the most common fabrication techniques which is extensively used to obtain good quality weld joints for various structural components. The present trend in the fabrication industries is to automate a welding process to obtain high production rate. Welding process can be automated by establishing the relationship between the process parameters and weld bead geometry to predict and control the weld bead quality [1]. These relationships can be developed by using of experimental design techniques [2]. The high productivity made submerged arc welding a preferred process over other methods in many welding applications [3]. Due to high deposition rate and excellent surface appearance submerged arc welding process is widely used in fabrication of pressure vessel, marine vessel, pipelines and offshore structures [4]. So, these qualities have made this welding process as a preferred choice in industries for fabrication. Borley et al. [5] found that the variable polarity can be adopted for controlling the chromium carbide fraction in the weld during submerged arc welding process as amount of chromium carbides increases steadily with a decrease in balance which was directly related to decrease in dilution due to variation in heat input. Square wave AC current was found to furnish better results for toughness than DC electrode positive polarity at lower temperature applications [6]. Successful efforts were also made to reduce the heat input during the welding and it was revealed heat input can be reduced by using the bypass electrode in submerged arc welding [7]. Double electrode submerged arc welding process can be adopted to achieve the same metal deposition rate at reduced heat input [8]. Heat input can also be reduced by optimum combination of root opening and travel speed in fillet welding because excess heat input may result in distortion [9]. Li et al. [10] developed a control system based on base metal current which was helpful in monitoring and controlling the weld bead penetration. Podder et al. [11] modeled the heat source by regression equations which can be utilized for determination of heat source parameters in submerged arc welding. Polarity used during the process also influences the metallurgical properties of weld metal by varying the heat input during the welding. Microstructure of duplex stainless steel weld joint was investigated and post weld heat treatment was found to be beneficial for improvement in metallurgical properties. [12]. Hence it can realized that heat input is the most influential control of weld metal properties in submerged arc welding. So, it is essential to investigate the effect of polarity in submerged arc welding at straight and reverse polarity as polarity varies the heat input at the weld joint during the process which further controls the weld bead geometry, mechanical and metallurgical properties of weld.

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Fig. 1. Experimental setup.

2. Submerged arc welding process

Submerged arc welding (SAW) is a mechanized and high deposition rate welding process. It is a fusion welding process in which heat is produced by maintaining an arc between the work and continuously fed filler wire electrode. Submerged arc welding process employs a continuous bare electrode wire in solid form and a blanket of powdered flux. The flux mount is of sufficient depth to submerge completely the arc column so that there is no spatter or smoke and the weld is shielded from the atmospheric gases. Weld bead geometry and load carrying capability of weld metal is influenced by the flux used in the welding process [13,14]. It also affects the mechanical properties and microstructure of the weld metal [15,16]. The heat produced by the arc is used to melt the work piece. Hence a weld bead of good quality of desired composition is obtained by above process without the application of pressure.

3. Experimental work

Research work was planned to be carried out in following manner [17]. * Selection of important process variables and finding their upper and lower limits* Developing the design matrix *Conducting the experiments as per design matrix*Recording the response parameters *Checking the significance of models and arriving at final models *Validation of models *Presenting the effect of process parameters of bead geometry* Analysis of results. Experimental setup used for conducting the experiments has been shown in Fig. 1.

3.1. Selection of process variables and their limits

Independent process variables selected for study were wire feed rate (W), open circuit voltage (OCV), travel speed (S) and contact tip to work distance (N). Trial runs were carried out on the base material by varying one of the process parameters while keeping all other parameters at constant value. The range of the parameters was decided by inspecting the bead for smooth appearance and absence of any visible defect for both the polarities. Lower, middle and upper limits were coded as −1, 0 and +1 for conveniently recording and analyzing the results. Process parameters selected for study with their working range are shown in Table 1.

3.2. Developing the design matrix

Design of experiments is a powerful tool for evaluating the effect of process variables over response parameters which are unknown function of these variables. It is a method of planning the experiments so that data can be analyzed statistically resulting in some meaningful and valid conclusions. So design matrix was developed using the designer expert software keeping in view in the selected process variables and their range mentioned in Table 1 to carry out this study in systematic manner which is shown in Tables 2 and 3 for DCEP and DCEN polarity respectively.

3.3. Conducting the experiments as per design matrix

Experiments were performed on CPRA 1200 S submerged arc welding machine. The material and consumables used for carrying out experimental work are enlisted below:

- Work piece material: Mild steel plates of 12 mm × 100 mm × 300 mm size
- Electrode used: EL-8, 3.2 mm electrode diameter
- Type of joint: Bead on plate
- Flux used: Ok 10.71
- Polarity used: DCEP and DCEN

Composition of the base metal, electrode and flux used is mentioned in Table 4.

3.4. Recording the response parameters and developing the models

Transverse specimens were sectioned from the welded plates at reverse (DCEP) and straight (DCEN) polarities. Sectioned specimens were ground and then polished on automatic multispecimen polishing machine using emery papers of grade 220 to 1200 and finally etched with 2% nital solution [18–20]. Bead geometry response parameters viz. bead width (w), penetration (p), reinforcement (h) and percentage dilution ($\%D$) of polished, etched and scanned specimens thus obtained was measured by adobe acrobat professional software for DCEP and DCEN polarity. Shape factors weld penetration size factor (WPSF) which is ratio of bead width to penetration and Weld reinforcement form factor (WRFF) which is ratio of bead width to reinforcement were also calculated which are tabulated in Tables 2 and 3 for DECP and DCEN polarity respectively. Fig. 2 shows the cross sections of weld bead profiles of the weld samples for DCEP and DCEN polarity.

The reduced models developed from this data are given below from Eqs. (1)–(12) for both the polarities.

Reduced models of weld bead geometry response parameter for DCEP polarity

$$w = 17.78 + 1.59 * \text{OCV} + 1.64 * \text{W} * \text{OCV} \quad (1)$$

$$p = 3.92 + 1.01 * \text{W} \quad (2)$$

$$h = 2.29 + 0.36 * \text{W} \quad (3)$$

$$\text{WPSF} = 4.99 - 0.90 * \text{W} + 0.98 * \text{OCV} - 0.50 * \text{W} * \text{S} - 0.43 * \text{OCV} * \text{N} \quad (4)$$

$$\text{WRFF} = 8.13 - 0.95 * \text{W} + 1.29 * \text{OCV} \quad (5)$$

$$\%D = 62.23 + 4.54 * \text{W} - 1.47 * \text{OCV} + 1.23 * \text{W} * \text{OCV} - 1.39 * \text{W} * \text{S} \quad (6)$$

Reduced models for weld bead geometry response parameter for DCEN polarity

$$w = 15.7 + 1.32 * \text{W} + 0.99 * \text{OCV} - 2.53 * \text{W} * *2 \quad (7)$$

$$p = 2.34 + 0.49 * \text{W} \quad (8)$$

$$h = 2.85 + 0.41 * \text{W} - 0.28 * \text{OCV} \quad (9)$$

$$\text{WPSF} = 7.85 - 0.83 * \text{W} - 2.07 * \text{OCV} * *2 \quad (10)$$

$$\text{WRFF} = 2.85 - 0.28 * \text{OCV} + 0.52 * \text{OCV} * *2 \quad (11)$$