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Arc behavior in two wire tandem submerged arc welding

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ABSTRACT

The behavior of leading and trailing arc root dimensions and arc interaction in the two-wire tandem submerged arc welding process was studied using real-time recorded current and voltage waveforms, and CCD arc images for a wide range of experimental conditions. Physical and regression equations were developed to predict the arc interaction and dimensions as a function of the welding condition. The influence of the arc interaction on the molten droplet transfer direction was studied. The arc center displacements (arc interaction) under different welding conditions were fairly well predicted by the corresponding physical models. The arc root dimensions were unsymmetrical and increased with an increase in the welding current and voltage while the same decreased with the increase in the arc center displacements. This variation was reasonably envisaged by the developed regression models. The detached molten electrode droplet followed the arc axis at the time of detachment and deposited into the weld pool.

1. Introduction

The two-wire tandem submerged arc welding (SAW-T) process is a high-deposition welding process capable of improving the productivity while welding plates with medium to high thicknesses. The leading wire is generally connected to either DC or AC, and the trailing wire to AC. The ease of using the SAW-T process is less when compared to the single-wire SAW process due to the complex arc behavior in the former. The leading and trailing arcs attract during a like-polarity condition of the welding current and repel under unlike polarities, referred to as arc interaction. Arc interaction has a significant influence on the stability of the arc, and there is a possibility that it can also influence the leading and trailing arc root dimensions. Cho et al. (2013a) explained that the arc root dimensions include the effective front and rear arc length from its center in the welding direction as well as the effective transverse length. This variation in the arc interaction and root dimensions with the welding condition can affect the arc energy distribution on the work plate and subsequently the final weld quality. Hence, the successful application of the SAW-T process strongly requires a detailed investigation of the effect of the welding condition on the arc interaction, and the leading and trailing arc root dimensions.

Although significant effort has been put forth to understand the arc behavior during autogenous welding and during single-wire deposition welding processes, similar type of work in relation to multi-wire deposition welding processes is rare. Perry and Paley (1970) examined the influence of the welding current, arc length and welding speed on the arc deflection when a tungsten inert gas (TIG) welding arc was exposed to an external magnetic field. A reduction in the arc deflection was reported with an increase in the welding current and a decrease in the arc length, though the welding speed was found to have no influence on the arc deflection. Ecer (1980) reported that an increase in the electrode diameter and a reduction in the arc length and the electrode vertex angle reduced arc deflection during the pulsed TIG welding process. It was also reported that the deflection of a pulsed current TIG arc was smaller than that of a steady current arc for a constant average current in a parallel magnetic field. Ghosh et al. (2009) examined the overall effect of pulsed-gas metal arc welding (GMAW-P) process parameters on the arc stability using a hypothetical factor. It was reported that an increase in this hypothetical factor at a high arc voltage enhanced the arc length and diameter and decreased the arc stability. Ueyama et al. (2005) studied the influence of leading and trailing arc deflections on the material flow in the two-wire tandem GMAW process and reported that the forward deflection of the trailing arc helps in stabilizing irregular flow of molten metal from the leading wire. Kiran et al. (2012) undertook a detailed experimental investigation of the SAW-T process to understand the influence of numerous process parameters on the

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Table 1
Design table for two wire tandem submerged arc welding experiments.

Set no.	I_L (A)	I_T (A)	v (mm/s)	Set no.	I_L (A)	I_T (A)	v (mm/s)
1	−1 (400)	−1 (400)	10.72	6	+1 (1000)	0 (700)	22.60
2	0 (700)	−1 (400)	14.56	7	−1 (400)	+1 (1000)	19.12
3	+1 (1000)	−1 (400)	18.40	8	0 (700)	+1 (1000)	22.96
4	−1 (400)	0 (700)	14.92	9	+1 (1000)	+1 (1000)	26.80
5	0 (700)	0 (700)	18.76				

V_L and V_T are constant at 32 and 35 V, respectively, for all the sets.

final weld quality. However, no work to explain the arc behavior was reported. Uttrachi and Messina (1968) performed pioneering work on understanding the arc interaction and its effect on the final weld bead quality in a three-wire tandem SAW process. It was reported that maintaining a phase shift of 90° between the leading and the middle arcs and the in-phase conditions of the leading and trailing arcs produced more stable arcs with a continuous forward deflection of the trailing arc. This forward deflection helps to produce a smooth bead. Cho et al. (2013a) measured the TIG welding arc root dimensions by applying the Abel inversion technique to CCD arc images captured while performing the experiments. Subsequently, these arc root dimensions were utilized to define arc models during the numerical modeling of the TIG welding process. Cho et al. (2013b) also studied the influence of the current mode on arc root dimensions in the GMAW process. It was reported that the arc root dimensions vary continuously with a change in the polarity in an alternating current arc and that this has a subsequent influence on the weld bead dimensions.

In summary, detailed studies of the arc behavior during the two-wire tandem submerged arc welding process are not yet readily available in the open literature. Here, the authors attempt to determine the arc behavior in the SAW-T process for a wide range of leading and trailing arc welding conditions. The welding current and the voltage waveforms as well as arc images are recorded while performing the experiments. Next, using the Abel inversion technique, the displacements of leading and trailing arc centers (arc interaction) and the arc root dimensions are measured from the corresponding CCD images. Finally, equations for predicting the arc center displacement and the root dimensions of the arc as a function of the welding condition are developed.

2. Experimental investigation

Table 1 gives the welding conditions used to perform bead-on-groove experiments in plates of 780 mm × 360 mm × 17.5 mm (thickness) with a groove angle and a depth of 60° and 8.5 mm, respectively, using the SAW-T process. The terms (I_L, V_L), (I_T, V_T) and v in Table 1 refer to the leading arc current and voltage, the trailing arc current and voltage, and the welding speed, respectively. A phase shift of 90° is maintained between the leading and trailing arcs. The inter-electrode distance is set to 18 mm. The leading and trailing electrode diameters and inclination angles confirm to (3.15 mm, 4.0 mm) and (0°, 18°), respectively. Table 2 outlines the chemical composition of the base plate and the electrode wire used in the present study. The flux and electrode combination confirm to AWS A5.23 specification. The instantaneous current waveforms corresponding to the leading and trailing arcs current are monitored in real time with LEM current sensors by placing them in the welding circuit. The leading and trailing arcs instantaneous voltage waveforms are monitored using two voltage pick-up points – one at the corresponding power source terminal and the other at the torch terminal of the welding machine. The sampling rate to record the current and voltage transients is set to 2.0 kHz.

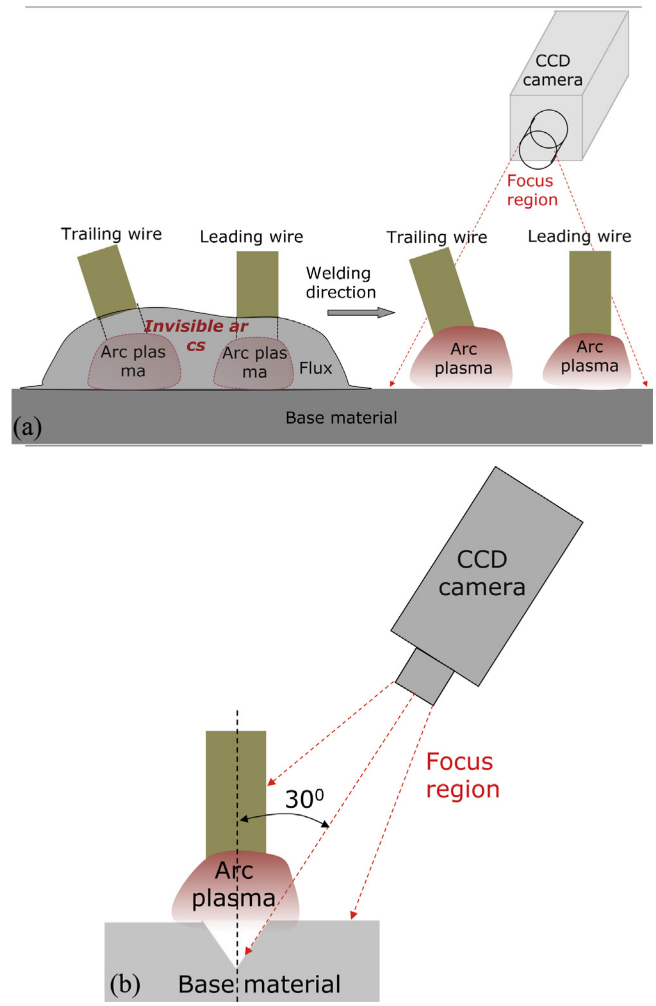

Fig. 1. Schematic representation of the arc images acquisition method.

Fig. 1 illustrates the procedure followed to capture the arc images. Initially, the leading and trailing arcs are completely submerged under the granular flux, and a CCD camera starts to record side images of the arcs at a sampling rate of 1 kHz from the instant both the arcs come out of the flux (as shown in Fig. 1). It is noteworthy to mention that, in SAW process the gases generated inside

Table 2
Chemical composition (wt%) of the base plate and electrode wire.

Element	C	Mn	Si	S	P	Cr	Ni	Al	Mo
Base plate	0.01	1.075	0.307	0.011	0.005	0.162	0.135	0.033	0.10
Electrode wire	0.04	1.30	0.28	0.015	0.025	–	–	–	0.50