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A primary study on testing the electrical property of arc column in plasma arc welding

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ABSTRACT

A welding arc is considered a composite of electron flow and electrically neutral arc plasma. Their interaction significantly affects the transmission and conversion process of the heat and momentum in welding process. Studying the electrical property of arc plasma is significant for understanding this interaction, but directly testing such property in arc column is still a challenge. In this paper, a novel method based on active probes was proposed/designed and used to test such a property in a welding arc plasma. The probes were partially coated to electrically insulate except for their tips. During test, the probes moved into the arc zone to detect the resistance between the tips. To minimize the damage to the probes, the movement of the probes was relatively quick such that the stay of the tips in the arc zone is minimal. In the meantime, electrical signals of the detection circuit and arc images were collected by a data acquisition system and a high-speed camera system. Images suggested that the movement of the probes imposed no noticeable effect on the behavior of the arc. On the other hand, the voltage to current ratio (V–I ratio) between the probe tips reduces as the moving speed of the tips reduces. Analysis suggests that the detection circuit is not purely resistive. As such, when the moving speed was reduced sufficiently, the V–I ratio approaches to a constant without changing with the moving speed. The effect from the dynamic property of the circuit on the measurement of the V–I ratio was thus eliminated. As such, the moving speed can be selected such that the dynamic behavior of the detection circuit becomes insignificant while the speed is still sufficient to minimize possible damage to the tips due to high temperature of the arc. Furthermore, the parameters of detection circuit were also discussed. As such, a novel method becomes available to study the electrical behavior of the arc plasma in the future study.

1. Introduction

Welding plays a critical role in many manufacturing industries [1–3]. Compared with emerging processes, such as laser welding (LW), electron beam welding (EBW) and friction stir welding (FSW), arc welding is still the major process used for metals joining due to its flexibility, low capital investment, high quality and acceptable productivity. Its better understanding will help optimize this most widely used welding process to generate broad impact on manufacturing industry.

Recently, the separability of welding arc has been studied by the authors [4–6]. It is found that the welding arc could be separated into two parts, the electrically neutral arc plasma and the electron flow, as the anode is deviated from the electrode (axis). In particular, the welding arc is generally considered a composite in which the arc plasma is the carrier and channel of the electron flow and the electron flow flows through the arc plasma and keeps it ionized. Studying the interaction of arc plasma and electron flow can lead to better understanding of physical properties of the arc.

Measurement plays an important role in understanding the properties of the welding arc. Researchers around the world have made significant efforts and progresses. The pressure/force distribution of welding arc has been measured and studied by using the U-tube barometer, torsion balance, pendulum with rotary optical encoder and the piezoelectric pressure transducer [7–9]. The density distribution of arc current has been studied using anodic splitting and tungsten probe [10–12]. While such methods are able to obtain measurements from arc effectively, they lose lots of details and are unable to provide the great details needed for sophisticated studies such as on the interaction between arc plasma and electron flow. There are methods that focus on the plasma physics state and the temperature distribution in arc column, such

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as Infrared ray method (IR), spectroscopy (spectral diagnostics of plasma) [13–16] and single probe method [17,18]. However, they hardly obtain electrical property distribution of arc column directly.

Careful observation leads to conclusion that existing measurement methods may be suitable for studying arc as an entire subject, but not enough for further understanding the physical properties of welding arc as current-carrying plasma. Furthermore, newly developed arc welding processes, such as double-electrode gas metal arc welding (DE-GMAW) [19–21], arcing – wire GTAW [22], laser enhanced GMAW [23,24], cross arc welding process [25–27], etc., are all based on characteristics of the current-carrying plasma. For such innovative processes that provide unique advantages, the conventional view of arc as an "entire subject" and associated existing measurement methods are often insufficient to understand their fundamental mechanisms or provide the needed measurements to facilitate fundamental understanding. Hence, it is imminent to design appropriate measurement methods to study such electrical properties for the current-carrying plasma.

The arc conductivity is a fundamental electrical property which is considered the interaction interface between arc plasma and electron flow. Its distribution in the arc column can be used as an index to evaluate the heat and electromagnetic interaction. In common understanding, the voltage to current ratio (V–I ratio hereafter) could reflect the electrical characteristics of our concern. Applying a voltage/current to positions concerned in the arc column and calculating the resultant V–I ratio are an effective mean to obtain the distribution of the electrical conductivity. The probe method is an easy way to achieve it by placing two tips at the positions concerned. However, damage to the probes under high temperature of the arc zone limits its effectiveness. In this paper, a novel experimental setup based on moving active probe is designed and built to measure the electrical property of plasma arc directly. The effect from probes on the arc column and from dynamic responses of detection circuit with its related parameters (i.e. probes rotation angular velocity, sampling resistance, and constant voltage in the detection circuit etc.) are analyzed and discussed. As a result, the V–I ratio is effectively measured and calculated without probe damages. The method proposed in this study can thus be expected to provide an effective novel approach to better understand the physical properties of conventional welding arc and novel welding arc toward improving the controllability of the existing welding processes and expanding the application of welding processes.

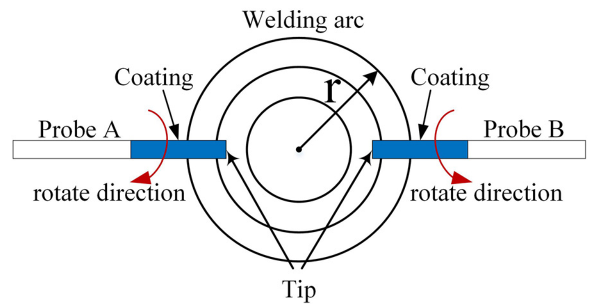

Fig. 1. Rotating tungsten bars with insulation treatment.

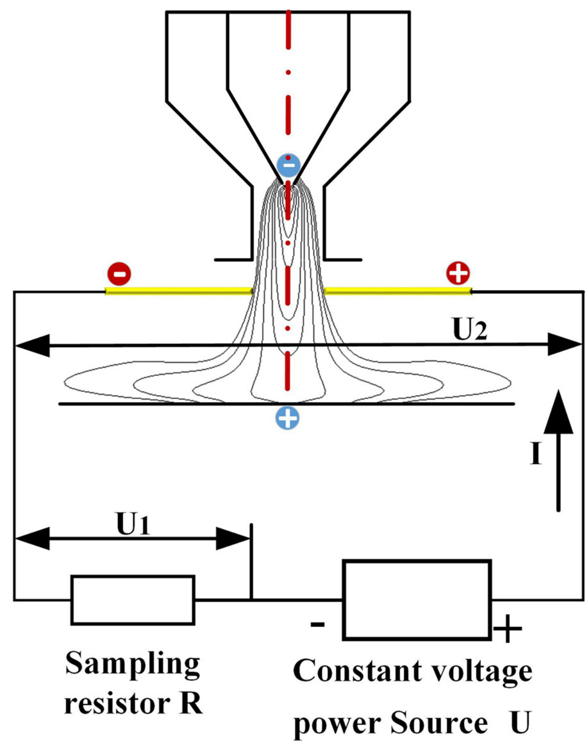

Fig. 2. The schematic diagram of detection circuit in the turn-on state.

2. Experimental procedure

2.1. Experimental principle

The major challenge for the probe method in measuring a welding arc column is the ultra-high temperature from the arc that damages the probes quickly because the arc temperature is generally considered to be in the range from 5000 K to 30000 K, or even higher. To resolve this issue, the authors propose to rotate two probes as shown in Fig. 1 such that they both pass through the arc zone rapidly to avoid damages. Both probes are coated to insure such that only their tips will determine the two points between which the responded voltage is measured. By controlling/adjusting the trajectories of the scans of the tips and their synchronization, the measurements may be made for different pairs of points.

The schematic diagram of the detection circuit in the turn-on state is shown in Fig. 2. When the tips of two probes both enter into the arc column, the detection circuit is closed and a small current flows through the arc zone. The corresponding voltage to the small current in the detection circuit is measured to analyze the electrical characteristics of the concerned arc zone between the tips of two probes. Since the distance of the two points being tested changes as the probes rotate, the current in the detection circuit and voltage between the two probes also change. Once the tips of the probes rotate out of the arc column, the detection circuit is turned off. The V–I (R_0) is thus used here to represent the electrical conductivity of the selected arc zone such that the Ohm's law is applicable to the arc. Hence, the V–I (R_0) of the arc between the two tips of the probes can be derived below:

$$U_2 = U - U_1 \tag{1}$$

$$R_0 = \frac{U_2}{I} = \frac{U - U_1}{U_1} R = \left(\frac{U}{U_1} - 1 \right) R \tag{2}$$

where U is the constant voltage of the power source which drives the detection circuit, U_1 is the voltage across the sampling resistor R, and I is the current flowing through the detection circuit. A smallest V–I (R_0) will be obtained during the rotation when the distance of the two probes is the smallest and can thus be used as a measurement of the electrical property between these two points in the arc zone.