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Optical Observation of Cathode Spot in AC Tungsten Inert Gas (TIG) Welding on Aluminum Plate using Helium[†]

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Abstract

The cleaning action in AC TIG welding is attributed to the oxide film removal process caused by cathode spots. Clarifying the behavior mechanism of these cathode spots could enable the control of the cleaning action. However, the behavior mechanism of cathode spots has not yet been experimentally clarified. This study reports that observations by high-speed video camera revealed the absence of cathode spots at the center of the molten pool for AC TIG welding using helium as the shield gas on aluminum plates.

KEY WORDS: (Cathode spot), (AC TIG welding), (Optical observation), (Aluminum)

1. Introduction

Currently, TIG (tungsten inert gas) welding is a technique widely used in the welding of products made of various materials such as carbon steel, stainless steel and other alloys consisting of aluminum, titanium and magnesium. Similarly TIG welding is used in the most advanced products such as semiconductor manufacturing equipment, bio-related systems and aerospace-related equipment. In TIG welding, arc plasma serves as the heat source for the welding and is generated between the tungsten electrode, which does not melt due to its high melting point, and the base material. By controlling the heat source properties of the arc plasma, weld penetration with a desired shape can be produced. Such control ensures the required weld penetration, whether in thin or thick plate, and allows for uniform weld penetration along the entire weld line. These characteristics of TIG welding provides high quality welds. At the same time, the metal melteotected by an inert gas such as argon, which is fed by the arc plasma is pro the welding section. This shielding gas also makes high quality welds possible, in terms of low contamination of the base metal component [1].

AC TIG welding, which utilizes the cleaning action of cathode spots, is used especially for arc welding of aluminum plates [2-4]. The mechanism of the molten pool formation during AC TIG welding still involves many unsolved issues such as the behavior of the cathode

spot, details of the removal process of the oxide film forming on the base metal surface and heat transport phenomena clarifying the spot mechanism through experiments, requires observation with extremely high time resolution.

It is generally known that the oxide film on the surface of the base material is removed through the cleaning action of the cathode spot when the electrode is positive and the base material acts as a cathode. Since the base material and oxide film are materials with low melting point, the base material becomes a cold cathode at this point, and no stable cathode spot will be formed. The behavior of the cathode spot is directly linked to the current distribution in the arc plasma and strongly affects the heat transport from the arc plasma to the base metal. Understanding the heat transport phenomena during the oxide film removal process with cathode spots is important to clarify the role of removal of the oxide film on the surface of the material [5].

In most of previous experimental investigations on the cathode spot in AC TIG welding, only influences of the cleaning zone caused by the cathode spot on the welding process were discussed due to the difficulty of direct observation of the cathode spot with high speed video cameras [6,7]. Recently, Sarrafi directly observed the cathode spot at 2,074 frames per second (fps) and roughly explained the relationship between the cleaning zone and the cathode spot position [8]. However,

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behavior of the cathode spot is not yet clear because of insufficient time resolution.

Using a high-speed video camera with the high time resolution of 500,000 fps, we observed through experiments the behavior of the cathode spots on the oxide film in AC TIG welding on an aluminum plate and the oxide film removal process by the cathode spot immediately after arc ignition. This paper shows that high-speed video camera observation at the vicinity of the molten pool proved that no cathode spot exists at the center of the molten pool during AC TIG welding on aluminum using helium as shield gas, and discusses the factors affecting the behavior of the cathode spots.

2. Experimental method

Figure 1 shows the outline of the experimental system for observing the molten pool and the behavior of the cathode spot on the oxide film at the time of AC TIG welding. Using an AC TIG welding power supply (DAIHEN Co., DA300PO) and helium for the shield gas (25 L/min), the touch-start method was used with a current of 250 A, a frequency of 70 Hz the fraction of time that the electrode is positive is 0.3, with an aluminum plate (24 mm thickness). For the electrode positive, the tungsten electrode is positive and the base material is negative. This results in excellent consumption of the electrode and the cleaning action works effectively on the aluminum plate. In the experiment, we used a 2.0% lantana-added tungsten electrode (quality: WL, size: 3.2x150 mm/Toho Kinzoku) with an electrode diameter of 3.0 mm, tip angle of 60 degrees and an arc length of 5.0 mm. An high speed video camera (SHIMADZU: HPV-1) imaged the molten pool and cathode spot from 1.0 second after arc ignition with an external trigger (500,000 fps, 200 μ s interval, gain x 1.0, exposure 1/2).

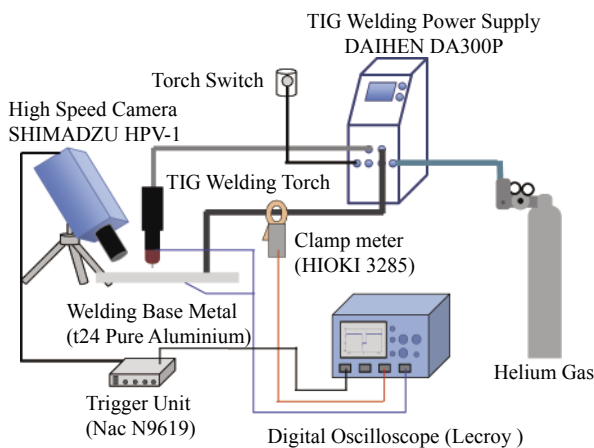


Fig. 1 Experimental setup.

3. Results and discussion

Figure 2 shows an example of the voltage and current waveforms immediately after arc ignition during AC TIG welding on the aluminum plate. The

current-voltage waveform was measured using a digital oscilloscope (LeCroy, Wave Surfer Xs series, frequency of 47 to 63 Hz with voltage range of 90 to 264 Vrms, and frequency of 380 to 420 Hz). The polarity observed is the waveform observed with EP. Thus, this is the period when the behavior of the cathode spot on the molten pool can be reliably verified.

Figure 3 shows the images shot by the high-speed camera in the vicinity of the molten pool in EN polarity during AC TIG welding. Cathode spots cannot be observed in EN polarity. The diameter of the molten pool is approximately 12 mm. In the EN polarity, the current distribution shows particularly high density at the cathode (tungsten electrode) and lower density at the anode (base metal), causing plasma flow with large velocity through electromagnetic force from the cathode toward the anode. It can be seen that the molten pool surface is largely depressed in the central region with a diameter of approximately 5mm, because of the high arc pressure caused by plasma flow with large velocity and of the light mass of the molten aluminum as well.

Figure 4 shows the images shot by the high-speed camera in the vicinity of the molten pool in EP polarity. We can observe that a large number of cathode spots are formed in the vicinity of the molten pool in EP polarity. Normally, the cathode spots have extremely high current density accompanied by metal vapor evaporated from the base metal. However, the formation of the cathode spots themselves tends to take place on the edge of the oxide film on the surface of the base material or on pinholes, due to a lower work function than that of pure metal. It has also been reported that the formation of the cathode spots causes the simultaneous destruction or removal of the oxide film by high current density. Due to a series of these phenomena, the oxides will be thoroughly removed from the surface of the base metal after the cathode spot has passed. It was observed that the cathode spots moved slowly on the oxide and their average velocity was in the order of 10 m/s. On the other hand, the cathode spots near the center of the molten pool, where the oxide had been mostly removed, moved at high speeds and their average velocity reached an order of 100 m/s.

The cathode spot and the molten pool surface observations in EP polarity were repeated 10 times under the same experimental conditions. **Figure 5** shows 4 examples from the results. In each result, the time variations in the positions of 15 cathode spots were traced. In all the results including the 4 examples presented here, cathode spots were not observed near the center of the molten pool (especially in the depressed central region). Two reasons are mainly considered for this phenomenon. One reason is the influence of the depression of the molten pool surface, as explained in the discussion of Fig. 3. In AC TIG welding of aluminum plates, the molten pool surface is largely depressed in the central region because of the high arc pressure caused by plasma flow with large velocity and of the light mass of the molten aluminum as well.

This depression leads to an increased distance

between the electrode and the molten pool surface near the center compared with the surrounding region, and therefore to a lack of cathode spots near the center. Another reason is the influence of oxidation of the molten pool surface. It is possible that the surface near the edge of the molten pool is insufficiently protected from oxidation by the shielding gas. In this case, cathode spots tend to remain for a long time near the edge region.

From these discussions, the behavior of cathode spots can be considered to be greatly affected by various factors such as shielding gas, welding current and composition of the base metal. Understanding these phenomena will greatly contribute to clarifying the mechanism of molten pool formation in AC TIG welding.

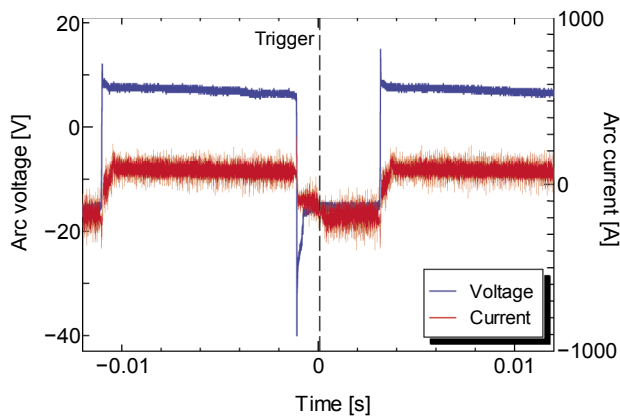


Fig. 2 Arc voltage and current waveforms.

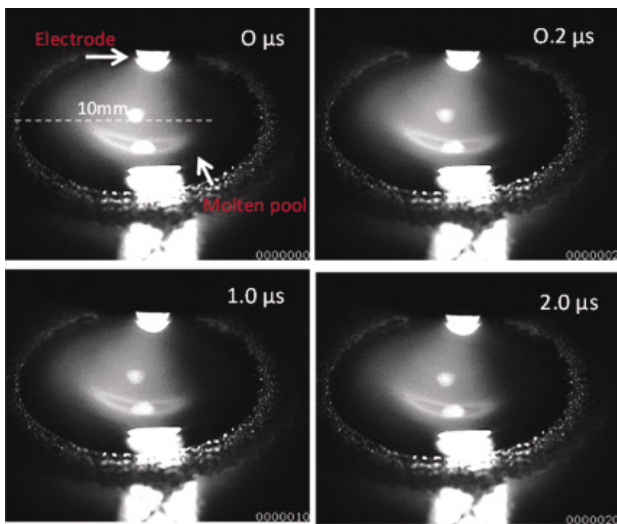


Fig. 3 Molten pool surface in EN polarity imaged with high-speed camera.

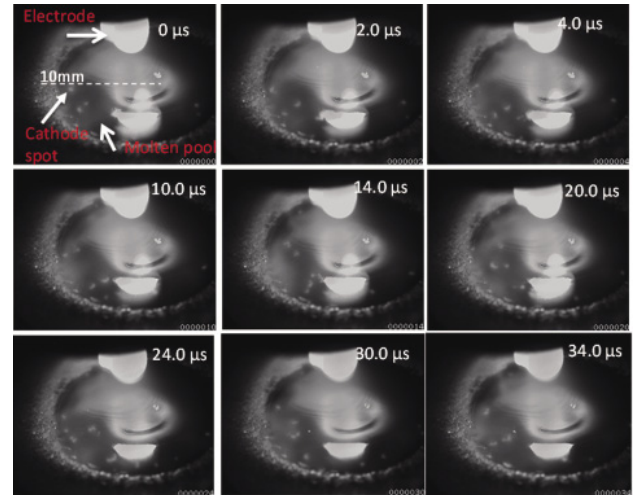
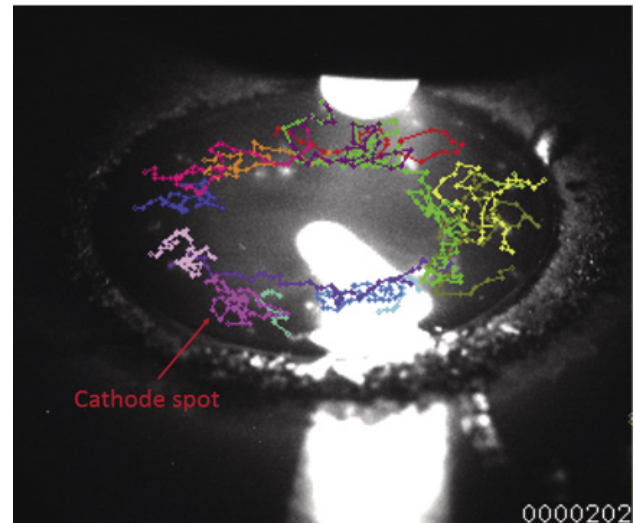
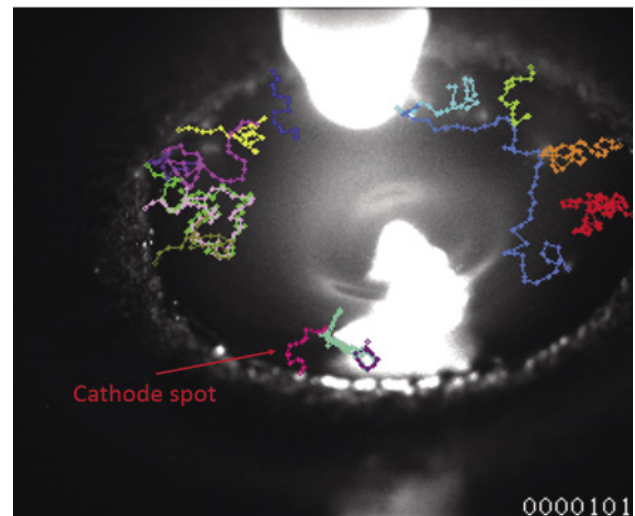


Fig. 4 Cathode spots and molten pool surface in EP polarity imaged with high-speed camera.

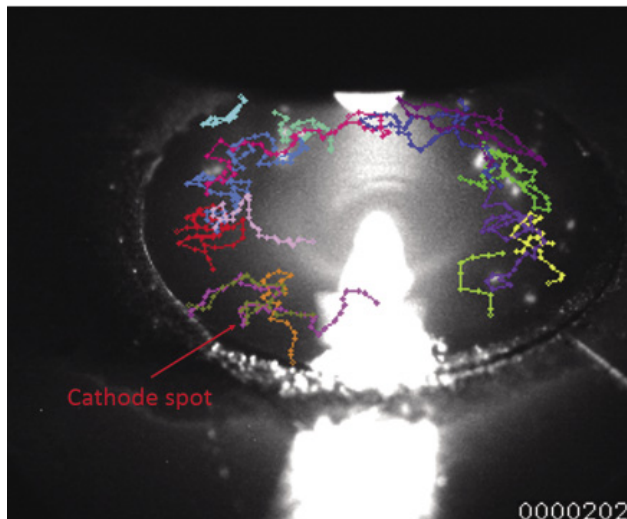


(a) Case 1

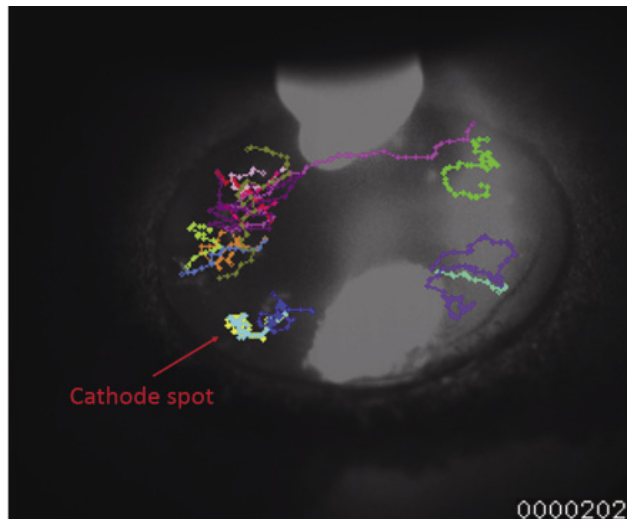


(b) Case 2

Fig. 5 Traces of cathode spots.



(c) Case 3



(d) Case 4

Fig. 5 Continued.

4. Conclusions

In this study, high-speed video camera observations were conducted on the molten pool vicinity during AC TIG welding using helium as shield gas on aluminum steel. The findings from this study are as follows.

- (1) The behavior of cathode spots inside the molten pool during AC TIG welding can be captured using high time resolution video camera.
- (2) With EP polarity, a large number of cathode spots can be captured while observing the behavior of cathode spots inside the molten pool.
- (3) With EN polarity, the presence of cathode spots cannot be confirmed while observing the behavior of cathode spots inside the molten pool.
- (4) The observations revealed that cathode spots do not exist at the center of the molten pool.

The behavior of cathode spots can be considered to be greatly affected by various factors such as shielding gas, welding current and composition of the base metal. Understanding these phenomena will greatly contribute to clarifying the mechanism of molten pool formation in AC TIG welding.

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