Proposal of a Method of Observing Cathode Spots in AC Tungsten Inert Gas Welding

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Abstract: We propose a method of observing the generation of cathode spots at arbitrary times during AC tungsten inert gas (TIG) welding. The observation system includes a high-speed video camera and multi-data acquisition system. First, to accurately observe cathode spots generated during AC TIG welding, we synchronized the data logger and high-speed video camera. Next, in setting the start time for photography by the high-speed video camera, a time delay was set. The observation of cathode spots in the AC TIG welding of pure aluminum confirmed that we could accurately observe the cathode spots generated only during the tungsten electrode-positive polarity. In addition, we attached a timer immediately before the data logger in the system, and set a specific delay time because the system only allowed us to observe cathode spots during the early stage of the AC TIG welding process. The improved system allowed us to observe the generation status of cathode spots at any time during the welding process. The usefulness of the proposed cathode spots observation system was thus verified.

Keywords: AC Tungsten Inert Gas Welding, Cathode Spot, Aluminum Plate, Cleaning Action, High-Speed Video Camera

1. Introduction
Tungsten inert gas (TIG) welding is a method of joining metal melted by the heat of an arc generated between a tungsten electrode and welding base material in an inert atmosphere [1]. TIG welding is widely used because it can form beads with good appearance and it generates low levels of fumes and sputtering [2].

During the welding process, it is important to prevent oxidation and nitridization of the molten metal [3–6]. These processes, if not sufficiently prevented, can cause defects such as breaks or blow holes. In TIG welding, to prevent the oxidation of molten metal, a shielding gas, such as argon or helium, is blown into the welding area. During the welding of aluminum and magnesium alloys with strong oxide films, it is also important to remove the oxide films so as to prevent incomplete fusion [7]. To remove the oxide films, TIG welding uses a cleaning action involving cathode spots [6, 7].

In TIG welding, at first, there is a spark between an electrode and a welding base material, and an arc is then generated with the ionization of a shielding gas by the heat of the spark. Electrons generated by ionizing the shielding gas carry a charge, so that current flows; i.e., the arc generated by the ionization of the shielding gas plays a role in the current flow. This suggests that the shielding gas strongly affects the quality of the welding product.

Next, many cathode spots are observed near the molten pool of the welding base material during the tungsten electrode-positive polarity [5]. It is thought that the cathode spots are generated near the oxide films formed on the surface of the welding base material, and the region in which the cathode spots are distributed has high current density.

The region with high current density in the welding base material is melted easily, so that the oxide films are removed. The cathode spots move to another location at which oxide films are removed, so that the region cleaned by the cathode spots gradually expands.

For TIG welding, we must make a tungsten electrode positive pole at which we weld using a cathode spot-based cleaning action. However, high current cannot flow continuously because the tungsten electrode overheats and wears remarkably. Therefore, when TIG welding an aluminum alloy with strong oxide films, an AC power supply that can utilize the cleaning action of the cathode spots and can induce the flow of high current is used. If the tungsten electrode has a negative pole status, the cleaning action of the oxide film provided by the cathode spots does not work though the wear on the electrode is small.

As mentioned above, it is necessary to appropriately set the polarity ratio (i.e., the ratio of the positive pole and negative pole) of the tungsten electrode. It is also necessary to appropriately set the current and flow rate of the shielding gas.

Maruo, Katoh and Miyasaka clarified the effects of the polarity ratio and change in frequency of the AC power source on the molten pool and region where the oxide films are removed [7–9]. Tashiro clarified the effect of the behavior of cathode spots on the overall cleaning action. In addition, the temperature distribution in the welding area and the depth of the molten pool have been analyzed [10, 11].

However, it is thought that the mechanism of removing oxide films has not yet been adequately clarified owing to the difficulty of directly observing the cathode spot. It is also thought that the relationships between the current and depth of the molten pool and between the flow rate of the shielding gas and the region where the oxide films are removed (i.e., the cleaning zone) are unclear.

In previous investigations on the AC TIG welding process, cathode spot movement and its effect on the cleaning zone have been discussed according to observations made using a high-speed video camera [12,
(HIOKI E.E. CORPORATION, model Hioki 3285), a data logger (KEYENCE CORPORATION, Multi-input-data collecting system, models NR-500 and NR-HV04) and a shielding gas cylinder. We used a tungsten electrode (TOHO KINZOKU CO. LTD., model Eltan) and Helium gas (helium gas) of 25 L/min. The cathode spots were observed as follows.

Observation of the behavior of the cathode spots and the removal of oxide films requires a measuring system equipped with a video camera having extremely high resolution. It is also necessary to establish a method of observing the cathode spots generated during the tungsten electrode-positive polarity.

In the present study, to accurately observe cathode spots, we used a high-speed video camera and a data logger that is a multi-input-data collection system. We first synchronized the data logger and high-speed video camera to allow simultaneous measurement of the current and voltage between the tungsten electrode and the base material during welding and observation of the welding area. We then observed the cathode spots with a high-speed video camera by setting a delay function. The measuring system allows the accurate observation of cathode spots generated only during the tungsten electrode-positive polarity.

However, this observation system for cathode spots can take photographs for only a very short period at the early stage of the welding process owing to the restriction of the duration of photography due to the use of the high-speed video camera. We therefore attached a delay timer immediately before the data logger in the system so that we can observe the generation of cathode spots at any time. We can thus observe the generation status of the cathode spots at any time during the welding process.

The present study demonstrated the system and method for observing cathode spots in AC TIG welding in detail by conducting experiments using pure aluminum.

2. Experiments

2.1 Experimental apparatus

Figure 1 is a schematic illustration of an experimental apparatus used in the AC TIG welding of pure aluminum. The experimental apparatus comprised a TIG torch, an inverter AC power supply (DAIHEN CO. LTD., model DA300P) and a shielding gas cylinder. We used a tungsten electrode (TOHO KINZOKU CO. LTD., model Eltan) including 2.0% lanthanum. The tungsten electrode had a diameter of 3.2 mm, a length of 150 mm and a point angle of 60°. As a welding base material, we used 50-mm squares of pure aluminum A1050 with thickness of 10 mm. The length of the arc was 5 mm. We carried out the static welding of one piece of pure aluminum without a filler material as shown in Fig. 1.

In the experimental apparatus, the tungsten electrode was connected to the positive terminal of the inverter AC power supply and the welding base material was connected to the negative terminal. The frequency of the AC power source was 70 Hz. The polarity ratio (positive electrode time/cycle time) of the AC power source was 0.3. In this setting, it is believed that cathode spots are generated when the tungsten electrode has a positive pole status. The current of the inverter AC power supply was set to 150-250 A. Helium gas was used as the shielding gas. The flow rate of the gas was 25 or 30 L/min.

The observation system for cathode spots comprised a high-speed video camera (SHIMADZU CORPORATION, model HPV-1, frame rate of 500,000 frames per second, exposure time of 1 μs, resolution of 312 × 260 pixels, no filter, gradations of monochrome 10 bits), a clamp meter (HIOKI E.E. CORPORATION, model Hioki 3285), a data...
logger (KEYENCE CORPORATION, Multi-input-data collecting system, models NR-500 and NR-HV04) and personal computers.

The current during AC TIG welding was measured using the clamp meter fitted to the cable connecting the inverter AC power supply and the welding base material. The voltage between the tungsten electrode and welding base material during AC TIG welding was measured using the data logger equipped with the voltmeter (NR-HV04). The current and voltage were recorded at intervals of 1 μs to a personal computer.

2.2 System and method of observing cathode spots

The cathode spots were observed as follows.

(1) For the trigger setting condition of the data logger, the edge-trigger of either voltage or current was set. The rise of the edge-trigger was set so the data logger began recording measurements when the voltage or current between the tungsten electrode and welding base material reached a specified value after the welding started.

(2) In measuring the condition of the data logger, the measurement interval and measuring time of the voltage and current during AC TIG welding were set to 1 μs and 50 ms-1 min, respectively.

(3) The output trigger terminal of the data logger was connected with the input trigger terminal of the high-speed video camera. Thus, the high-speed video camera began photographing immediately after the camera received the trigger signal from the data logger. Here, the time lag between the high-speed video camera and data logger was 2 μs.

(4) The setting up of the photography should start with the high-speed video camera and setting of the delay. Thereby, a specific delay between the start time of the current and voltage recording by the data logger and the start of photography by the high-speed video camera was set. In this study, the delay for the high-speed video camera was set at 0–8 ms.

By changing this time delay, we were able to observe the generation status of cathode spots in cases that the tungsten electrode had either the positive or negative pole status. Here, the measurement interval and duration of photography by the high-speed video camera were 2 μs and 0.2 ms, respectively.

3. Results and Discussions

3.1 Observations of cathode spots

AC TIG welding of pure aluminum was performed to verify whether we could accurately observe the cathode spots generated only during the tungsten electrode-positive polarity using the measurement system.

The experiments on AC TIG welding were carried out for current of the AC power supply of 150 A, a frequency of 70 Hz, a polarity ratio of 0.3, and a flow rate of shielding gas (helium gas) of 25 L/min. The cathode spots were photographed by changing the delay of the high-speed video camera from 0 to 2 ms.

Figure 2 shows the current waveforms obtained using the measurement system (a) and the appearance of cathode spots photographed by the high-speed video camera (b). Figure 2(a) confirms that the period of current is 14 ms, that the polarity ratio becomes the set value of 0.3, and that the value of the current almost reaches the set value of 150 A. Each photograph in Fig. 2(b) is one of 100 photographs taken at intervals of 2 μs over 0.2 ms by the high-speed video camera. Each photograph was taken at the photography start time given above the current waveform graphs shown in Fig. 2(a). It is seen that we can accurately photograph the cathode spots generated only
during the tungsten electrode-positive polarity.

Figure 3 is a photograph of the welding area taken when the delay for the high-speed video camera was set at 8 ms. The photograph shows the welding status when the tungsten electrode has a negative pole status. We found no cathode spots at all even though the experiment was carried out five times. The above results verify the usefulness of the system and method of observing cathode spots used in this study.

It was found that we could accurately photograph cathode spots during the tungsten electrode-positive polarity. However, using this observation system, we could take photographs for only a very short time during the early stage of the welding process because the duration of photography using the high-speed video camera was only 0.2 ms. We therefore attached a delay timer just before the data logger in the observation system so that we could observe the generation status of the cathode spots at any time during the welding process. We photographed the welding status after the set time had elapsed by setting the timer to a certain time delay.

Here, the trigger setting condition of the data logger was maintained as it was. The data logger began recording when the current reached the set value (180 A) after the set time had passed. The delay of the high-speed video camera was similarly set from 0 to 5 ms.

Figure 4 shows current waveforms and the generation status of cathode spots for a timer delay of 1.8 s and a high-speed video camera delay from 0 to 5 ms. The photographs demonstrate that we can observe cathode spots when the high-speed video camera delay ranges from 0 to 3 ms but not when the delay ranges from 4 to 5 ms. The current waveforms confirm that we could observe the generation status of cathode spots at any time during the welding process. We photographed the welding status after the set time had elapsed by setting the timer to a certain time delay.

Here, the trigger setting condition of the data logger was maintained as it was. The data logger began recording when the current reached the set value (180 A) after the set time had passed. The delay of the high-speed video camera was similarly set from 0 to 5 ms.

The photographs suggest that the cathode spots are distributed and the location where the cathode spots were generated is near the molten pool. The surface of the cleaned area adjacent to the molten pool was smooth, and the cleaned surface suggested a close relationship between the distribution of the cathode spots and the proximity to the molten pool of the welding base material. To examine the relationship between the location where the cathode spots were distributed and the location where the molten pool was smooth, we performed a series of experiments.

Figure 5 shows consecutive shots of cathode spots during the welding process. The photographs demonstrate that we can observe cathode spots when the high-speed video camera delay ranges from 0 to 3 ms but not when the delay ranges from 4 to 5 ms. The current waveforms confirm that we could observe the generation status of cathode spots at any time during the welding process.

Figure 6 shows the appearance of cathode spots and the closeness of the molten pool in the welding base materials.
Figure 5 shows consecutive shots of cathode spots captured for 200 µs under the setting conditions of a timer delay and camera delay of 1.8 s and 0 ms, respectively. Many cathode spots appeared in succession during the photography and disappeared rapidly within 10–50 µs. Tracing the movement of individual cathode spots therefore requires a high-speed video camera with a resolution of over 100,000 frames per second.

Most cathode spots appeared outside rather than at the center of the molten pool and moved toward the outside of the molten pool after wandering for a few tens of microseconds. The cathode spot indicated by the arrow in Fig. 5 moved about 2 mm toward the edge of the molten pool in about 20 µs. The average velocity of the cathode spot was estimated at approximately 100 m/s.

3.2 Distribution of cathode spots
To examine the relationship between the location where the cathode spots were distributed and the location where the oxide film on the welding base material was being removed, we compared the location where the cathode spots were photographed using the high-speed video camera with the proximity to the molten pool of the welding base material.

Figure 6 shows the appearance of cathode spots and the closeness of the molten pool in the welding base material approximately 2 s after the beginning of welding. Here, the welding was performed by setting a welding time of 2 s for the power supply. The closeness of the molten pool in the welding base material was photographed using a digital camera after welding. The photography start time of the high-speed video camera was 1.8 s after the beginning of welding (while the timer and camera delay times were set to 1.8 s and 0 ms, respectively).

The photographs suggest that the cathode spots are distributed over the region from the inside to the outside of the molten pool. The surface of the cleaned area adjacent to the molten pool was smooth, and the cleaned surface located farther from its outer edge was rough. This result suggests a close relationship between the distribution of the cathode spots and the region where the oxide film on the welding base material was being removed. Clarifying the behavior of the cathode spots during AC TIG welding is a
subject for future study.

4. Conclusions
The present study synchronized a data logger and high-speed video camera to accurately observe cathode spots generated during AC TIG welding. Next, when setting the photography start time for the high-speed video camera, we added a time delay. Observations of cathode spots in the AC TIG welding of pure aluminum confirmed that we could observe accurately cathode spots generated only during the tungsten electrode-positive polarity.

Additionally, we introduced a timer immediately before the data logger in the system, and set a specific delay for the timer because the system allowed us to observe cathode spots only in the early stage of the AC TIG welding process. The system allowed us to observe the generation status of cathode spots at any time during the welding process.

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References