Influence of Admixture of Oxygen into Shielding Gas on Cathode Spot Behavior*

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The cleaning action with AC Tungsten Inert Gas (TIG) welding is attributed to the removal process of oxide film caused by cathode spots. In this study, a double shielding gas torch, which used the internal shielding gas of helium and the external shielding gas of helium or helium with 5.0 % oxygen, was employed to investigate influence of admixture of oxygen into the shielding gas on the cathode spot behavior in AC TIG welding. The cathode spots were photographed by a high-speed video camera and their distribution and velocity are discussed. Consequently, it was found that when the oxygen was mixed into the shielding gas, the number of cathode spots seemed to increase. Furthermore, the average velocity of cathode spots was considerably decreased to approximately 50 m/s near the center of the weld pool compared with 100 m/s in case of pure helium shielding gas.

Key Words: Double Shield Gas Torch, Helium, Oxygen, Cathode Spot, Aluminum Plate, High-Speed Video Camera, Weld Pool

1. Introduction

Currently, Tungsten Inert Gas (TIG) welding is a technique widely used in welding, from general products made of various materials such as general carbon steel, stainless steel and other alloys consisting of aluminum, titanium and magnesium, to the most advanced products such as semiconductor manufacturing equipment, bio-related systems and aerospace-related equipment represented by rockets. 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. This 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 welds1,2).

AC TIG welding has a long technical history; however, due to the complexity of the movement of cathode spots, the mechanism of AC TIG welding is not yet clearly understood, including the details of the behavior of, and the oxide removal by, cathode spots as well as the additional physical quantities such as the speed; most importantly, they are not firmly supported by experimental evidence.

Therefore, using a high-speed video camera having a high time-resolution, we attempted to experimentally observe the behavior of cathode spots on both the molten pool and the oxide film in AC TIG welding of aluminum plates as well as the oxide film removal by cathode spots3). As a result, we found that there was no cathode spot near the center of the weld pool4).

The weld pool surface is protected by inert gas such as argon or helium fed from a shielding gas nozzle of a torch during welding. This allows the realization of quality welding with low contamination of the base metal component. However, it is pointed out that a small amount of surrounding air can be drawn into the welding arc due to insufficient shielding effect5). In this case, the cleaning action of the cathode spot is expected to be greatly influenced by admixture of oxygen into the arc.

In this study, a double shielding gas torch6), which used the internal shielding gas of helium and the external shielding gas of helium or helium with 5.0 % oxygen, was employed to investigate influence of admixture of oxygen into the shielding gas on the cathode spot behavior in AC TIG welding. The cathode spots were photographed by a high-speed video camera and their distribution and velocity are discussed.

2. Experimental procedure

Fig. 1 shows the experimental setup for monitoring the behavior of cathode spots on both the weld pool and the oxide film in the AC TIG welding of aluminum plates. The experimental setup consists of a TIG welding power source (DAIHEN Co. Ltd: DA300P), a double shielding gas torch, base metal, shielding gas, a clamp meter (HIOKI: 3285), a data logger (KEYENCE: NR-500-HV-04), high speed video cameras (SHIMADZU: HPV-1; 500,000 fps, 2.0 µs interval or Vision Research Inc.: Miro eX4; 1,200 fps, 0.83 ms interval), PCs for

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controlling the high speed video cameras and the data logger. In the experiment, a tungsten electrode with addition of 2.0% lantana was used, of which the cathode diameter was 3.2 mm and the tip angle was 60°.

As the figure shows, in AC TIG welding with a double shielding gas torch, helium was introduced from the inner shielding gas nozzle at the flow rate of 10 L/min and helium or the oxidizing shielding gas of helium with 5.0% oxygen was introduced from the outer shielding gas nozzle at the flow rate of 10 L/min. The inner shielding gas of helium was used to protect the tungsten electrode from the oxidation. The base metal was pure aluminum plate. The welding power supply was set at the current of 200 A, the frequency of 70 Hz, and the EP ratio (EP time/(EN time + EP time)) of 0.3. The weld pool was photographed by high-speed video cameras approximately 1.8 s after the arc ignition with an external trigger.

Fig. 1 Experimental setup

Fig. 2 Voltage and current waveforms

3. Result and discussion

Fig. 2 shows an example of the voltage and current waveforms 1.8 s after the arc ignition. The output voltage approximately -10 V and 15 V in EN and EP. The observation by high speed cameras started just after the beginning of EP.

Fig. 3 shows the images observed with the high speed camera Miro eX4 in the condition using the inner shielding gas of helium and the outer shielding gas of helium with 5.0% oxygen. The sequential color images show discharge phenomenon occurring when the voltage-current waveform turned from EP to EN. In the figure, it was observed that the bright blue radiation with shorter wavelength caused by the metal vapor from 0s to 2.8 ms in EP and then the radiation in purple unique to helium after 3.6 ms corresponding to EN. It was confirmed cathode spots were able to be observed before about 1 ms without influence of the arc radiation. In EP, heat input from the arc to the tungsten electrode largely increased mainly by the electron condensation. Therefore, an amount of the metal vapor in the arc evaporated from the tungsten electrode was gradually increased due to increase in the electrode temperature. Because, it was difficult to observe the weld pool around the end of EP, cathode spots were imaged immediately after the beginning of EP.

Fig. 3 Arc dynamics in double shielding gas torch with the inner shielding gas of helium and the outer shielding gas of helium with 5.0% oxygen.
After the arc ignition with an external trigger photographed by high-speed video cameras approximately 1.8 s time/(EN time + EP time) of 0.3. The weld pool was current of 200 A, the frequency of 70 Hz, and the EP ratio (EP pure aluminum plate. The welding power supply was set at the 10L/min. The inner shielding gas of helium was used to protect introduced from the outer shielding gas nozzle at the flow rate of 5.0 % oxygen. The shielding gas torch, helium was introduced from the inner shielding gas nozzle at the flow rate of 10 L/min. and helium or shielding gas torch, helium was introduced from the inner tip angle was 60˚.

As the figure shows, in AC TIG welding with a double lantana was used, of which the cathode diameter was 3.2 mm and the experiment, a tungsten electrode with addition of 2.0 % controlling the high speed video cameras and the data logger. In the (a) case, inner and outer shielding gas of pure He was used. On the other hand, the cathode spots inside the weld pool, near the edge, where the oxide had been mostly removed, moved at high speed. Furthermore, in the oxide case, the number of cathode spots seemed to increase compared with the pure Helium case.

In fig (a), the cathode number 10 (C10) was on oxide and its average velocity was 84 m/s. On the other hand, the other cathode spots had average velocity that exceeded 150m/s. In fig (b), the average velocity of cathode spots decreased in comparison with pure Helium case. Special, cathode spots number 9, 13, 14 are on the oxide and has low velocity with average value was about 40 m/s. And the other cathode spots had average velocity was approximately 125 m/s. As the result, the average velocity of cathode spots in case of Helium with 5% Oxygen decreased compared with the pure Helium case. The cause for them is considered that, when a certain amount of oxygen was added to the molten metal from the out shielding gas, a greater amount of oxide was formed and the oxide film became thicker.

Fig. 4 shows the sequential images of cathode spot behavior on weld pool surface in double shielding gas torch with the inner shielding gas of helium and the outer shielding gas of helium.

The formation of the cathode spots themselves tends to take place on the edge of the oxide film on the surface of the base metal due to lower work function than that of pure metal, and it is known that the formation of the cathode spots causes the destruction or removal of the oxide film at the same time by the 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.

Fig. 5 shows the behavior of the cathode spot on weld pool surface in two cases, observed with the high speed camera HPV-1. In the (a) case, inner and outer shielding gas of pure He was used. In the (b) case, outer shielding gas of Helium with 5.0% oxygen was used. On the weld pool surface, there were so many cathode spots which appear and move randomly. But in each case, 16 examples of cathode spots were traced and overwritten to the picture (C 1 to C 16). The moving velocity of the cathode spot was analyzed by the Dipp Flow software (DITECT Co.). In two cases, cathode spots were also not found at the central area of the weld pool. It was observed that the cathode spots move slowly on the oxide. On the other hand, the cathode spots inside the weld pool, near the edge, where the oxide had been mostly removed, moved at high speed. Furthermore, in the oxide case, the number of cathode spots seemed to increase compared with the pure Helium case.
Consequently, cathode spots required longer time to remove the oxide film, therefore their velocity decreased.

4. Conclusions

In this study, a double shielding gas torch, which used the internal shielding gas of helium and the external shielding gas of helium or helium with 5.0 % oxygen, was employed to investigate influence of admixture of oxygen into the shielding gas on the cathode spot behavior in AC TIG welding. The cathode spots were photographed by a high-speed video camera and their distribution and velocity were discussed. The obtained conclusions are as follows:

(1) In the photographs taken with a high-speed video camera having a high time resolution, the behavior of cathode spots was successfully captured around the weld pool in the AC TIG welding using the double shielding gas torch.

(2) An amount of the metal vapor in the arc evaporated from the tungsten electrode was gradually increased due to increase in the electrode temperature. Because, it was difficult to observe the weld pool around the end of EP, cathode spots were imaged immediately after the beginning of EP.

(3) In case of the outer shielding gas of helium, the cathode spots moved slowly on the oxide and their averaged velocity was approximately 10m/s. On the other hand, the cathode spots near the center of the weld pool, where the oxide had been mostly removed, moved at high speed and their averaged velocity exceeded 100 m/s.

(4) In case of the outer shielding gas of helium with 5.0 % oxygen, the number of cathode spots seems to be increased compared with the pure helium case. As a result, the average velocity of cathode spots was considerably decreased to approximately 50 m/s near the center of the weld pool.

The removal of the oxide film and the protection of the weld pool surface are required for performing AC TIG welding of aluminum plates. Thus we will clarify the behavioral mechanism quantitatively in comparison with the simulation results to explain the mechanism of AC TIG welding, which depends on the behavior of cathode spots, for realizing suitable control of the welding conditions.

Reference

1) Larry F. Jeffus: Welding Principles and Applications Publisher Cengage Learning (2002).
2) M.Tanaka and J. J. Lowke: Predictions of weld pool profiles using plasma physics, J. Phys. D: Appl. Phys. 40 (2007), R1-R23.
3) S. Tashiro, T. Yuji, A. Fujimaru, H. Kinoshita, K. Yasui, T. Bouno, T. Methong and M. Tanaka: Optical Observation of Cathode Spot in AC Tungsten Inert Gas (TIG) Welding on Aluminum Plate using Helium, Transactions of JWRI, 44(2) (2015), 1-4.
4) T. Yuji, S. Tashiro, A. Fujimaru, H. Kinoshita, K. Yasui, T. Bouno, T. Methong and M. Tanaka: Observation of the Behavior of Cathode Spots in AC Tungsten Inert Gas Welding on Aluminum Plate, Quarterly J. Japan Welding Soc., 33(2) (2015), 135-138.
5) S. Kodama, K. Sugiura, S. Nakanishi, Y. Tsujimura, M. Tanaka, A. B. Murphy, Nitrogen Absorption Phenomenon of GTA Welding With Nitrogen Mixed Shielding Gases, Quarterly J. Japan Welding Soc., 31 (2013), 41-47.
6) H. Fujii, T. Sato, S. Lu and K. Nogi: Development of an advanced A-TIG (AA-TIG) welding method by control of Marangoni convection, Materials Science and Engineering A, 495 (2007), 296-303.
7) K. Yasui, H. Kinoshita, T. Yuji, A. Fujimaru, T. Bouno, T. Methong, S. Tashiro and M. Tanaka: Proposal of a Method of Observing Cathode Spots in AC Tungsten Inert Gas Welding, Advanced Experimental Mechanics, 1 (2016), 231-236.