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High-Speed Visualization of Electrode Phenomena in Multi-Phase AC Arc
高速度ビデオカメラを用いた多相交流アークの電極現象の可視化

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A multi-phase AC arc has been developed for applications in various fields of engineering because it possesses unique advantages. However, the understandings of fundamental phenomena in the multi-phase AC arc is still insufficient. In particular, the electrode erosion is one of the most important issues to be solved. In the present work, the erosion mechanism in the multi-phase AC arc was investigated based on the high-speed visualization by the high-speed camera and the appropriate band-pass filters system. Obtained results indicated that the both electrode erosion by droplet ejection and by metal evaporation were important to determine the total erosion.

1. Introduction

The concept of controlled generation of an arc by rotated magnetic field or by multiple electrodes has already been studied [1]. These power sources for arc generation are accomplished by DC power supply, although it takes more cost in the apparatus for converting AC to DC. The conventional single-phase and three-phase AC power supplies have a characteristic of intermittent discharge which limits the application of arc systems [2]. To obtain a more effective arc reactor, a multi-phase AC power supply has been developed [3]. The important advantage of this system is larger number of discharging paths among the electrodes. Therefore, discharges among the electrodes always exist to realize smooth arc re-ignition. Consequently, the multi-phase AC arc have been attracted to be applied to waste treatment, synthesis of nanomaterials, and in-flight heat treatments [4].

Only few studies about the arc characteristics and electrode phenomena, however, have been reported since the multi-phase AC arc is still a new type of the thermal plasma generating system. In order to enhance the performance of the multi-phase AC arc in various fields, the electrode erosion mechanism should be understood. The objective of this study is to investigate the electrode phenomena in the multi-phase AC arc by high-speed camera visualization.

2. Experimental Procedure

Figure 1 shows the schematic diagram of the experimental setup of the multi-phase AC arc. It consisted of twelve electrodes, reaction chamber and AC power supply. Twelve electrodes were symmetrically arranged by the angle of 30 degree and were divided into two layers, upper six electrodes and lower six electrodes. The details about the experimental setup can be shown in our previous work [4].

The dynamic behavior of the molten metal droplet on the electrode tip in the multi-phase AC arc was observed by using the high-speed camera system. The conventional observation system for the electrode and droplets during the arc generation cannot be used because the arc emission, especially near the electrode, is strong due to its high temperature. In the present work, an optical system including the band-pass filters was combined with the high-speed camera. Wavelengths for the band-pass filters were selected as 785 and 880 nm, at where negligible arc emission existed. The thermal radiation from the electrode surface was completely separated from the arc emissions, resulting in the clear visualization of the droplet and electrode behavior during arc discharge.

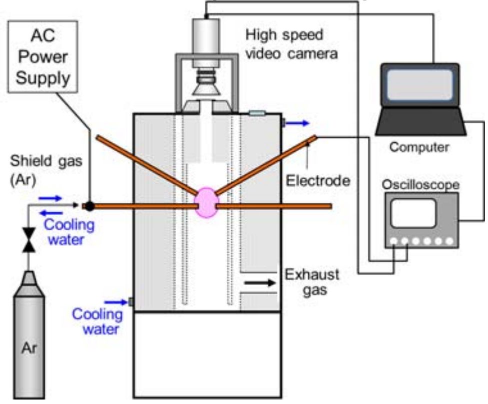

Fig.1. Schematic of multi-phase AC arc reactor.

3. Results and Discussion

Figure 2 (a) shows the representative snapshots of the electrode tip during anodic period. The corresponding voltage waveform is shown in Fig. 2 (b). As the current increases, the molten volume of electrode increases. Due to the shear stress from the surrounding gas, the molten electrode tip becomes hemispherical shape forming a droplet on electrode tip. When the arc current decreases, the droplet becomes small returning to the electrode without detachment from the electrode tip.

Figure 3 (a) shows the representative snapshots of the electrode tip during cathodic period. The corresponding voltage waveform is shown in Fig. 3 (b). As the arc current increases, the molten volume of the electrode increases. As well as the anodic period, the electrode tip in molten state becomes hemispherical shape forming a droplet due to the shear stress from the surrounding gas flow. In contrast to the anodic period, the droplet then detached from the electrode surface.

Droplet formation and detachment are the result of the forces acting on the electrode tip in molten state such as surface tension, electromagnetic force, and ion pressure. The evaluation of these forces gives the dominant force at cathodic period was electromagnetic force, while that at anodic period was surface tension. This difference was originated in the different droplet radii. Smaller radius of molten droplet at the cathodic period leads to larger electromagnetic force, resulting in the droplet ejection from the electrode tip.

The electrode temperature measurements were also conducted to evaluate the evaporation rate from the molten electrode. Evaluated evaporation rate and the electrode erosion rate by the droplet ejection were on the same order. Consequently, both droplet ejection and metal evaporation are important to determine the total erosion rate.

5. Conclusion

The high-speed visualization of electrode phenomena were successfully conducted by using the high-speed camera with appropriate band-pass filters. Both the droplet ejection at the cathodic period and the metal evaporation at the anodic period are important to determine electrode erosion in the multi-phase AC arc. Understanding the erosion mechanism will make progress of the multi-phase AC arc in various applications.

References

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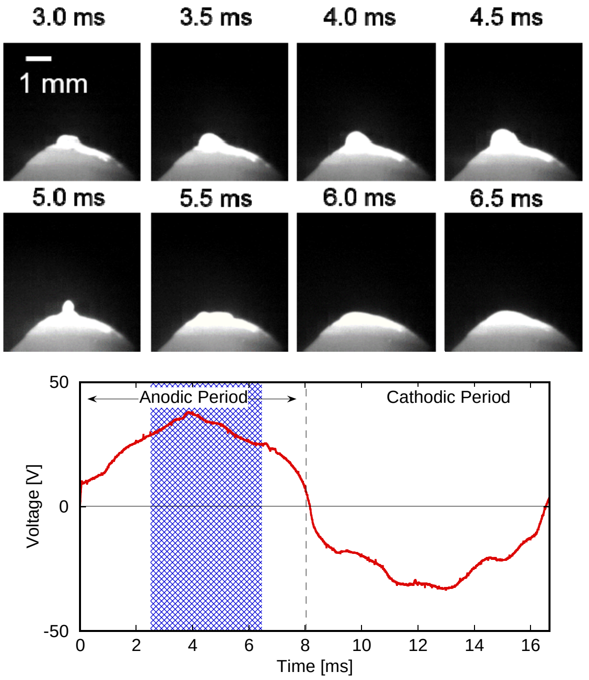

Fig.2. High speed images of molten electrode tip observed at anodic period (a) and synchronized voltage waveform (b).

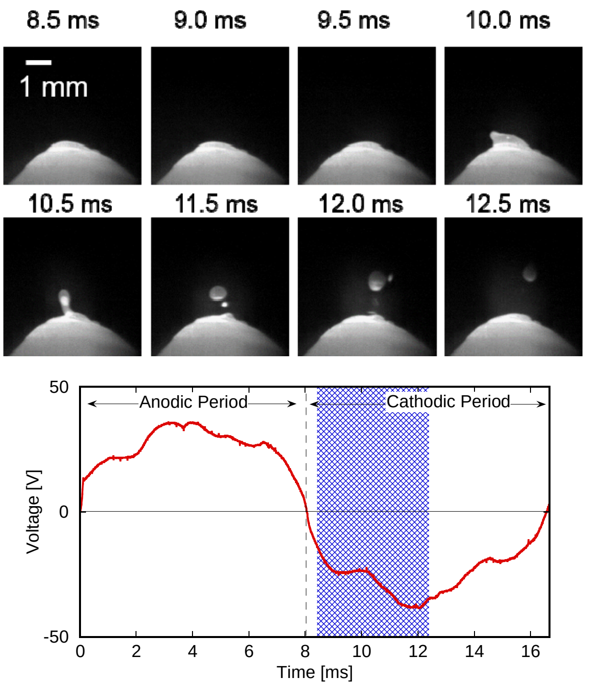

Fig.3. High speed images of molten electrode tip observed at cathodic period (a) and synchronized voltage waveform (b).