Fluctuation Analysis of Diode-rectified AC Arc by High-speed Visualization

Y. Sogo[1] , R. Takenaka[1] , M. Tanaka[1] , T. Watanabe[1] , M. Shigeta[2] and T. Matsuura[3]

[1] *Department of Chemical Engineering, Kyushu University, Fukuoka, Japan*
[2] *Department of Mechanical Engineering, Tohoku University, Miyagi, Japan*
[3]*Taso Arc Co., Fukui, Japan*

Abstract: Planer-shaped thermal plasma jet generated by diode-rectified multi-electrode AC arc can be used for rapid and uniform surface treatment. The purpose of this study is understanding factors affecting arc fluctuations to improve uniformity of plasma jet. Arc fluctuation phenomena were revealed by high-speed camera observation synchronized with an oscilloscope. Uniformity of the arcs was quantified by analysis of arc voltage waveforms. Analysis results revealed factors contributing to improvements of arc uniformity.

Keywords: thermal plasmas, planer plasma jet, AC arc fluctuation

1. Introduction

Thermal plasma is applied to material processing and decomposition of harmful substances due to its high temperature and high chemical reactivity. In particular, thermal plasma jet is most convenient plasma source for high temperature processes. However, conventional thermal plasma jet has the problems due to limited dimension in the scale of 1-10 mm in radial direction. Recently, planar-shaped plasma jet generation by diode-rectified multi-electrode AC arc has been developed to solve above problems [1].

Planar thermal plasma jet is expected to be applied to large-scale, uniform, and rapid surface treatment of materials. However, the fundamental phenomena in the diode-rectified AC arc have not been understood yet due to its novelty, while these understandings are important for achievement of sufficiently uniform plasma jet generation. The purpose of this study is to elucidate the fluctuation phenomena in diode-rectified AC arc by synchronized observation of a high-speed camera and an oscilloscope.

2. Experimental Setup

Figure 1 shows a diagram of the principle of diode-rectified AC arc generation. Four electrodes comprise one section, consisting of AC electrodes AC(-+) and AC(+-) in opposite phases, a half-wave rectified anode AN, and a half-wave rectified cathode CA. Arcs are alternately generated between the two adjacent electrodes by rectifying current with a diode to produce a time-averaged uniform planar plasma.

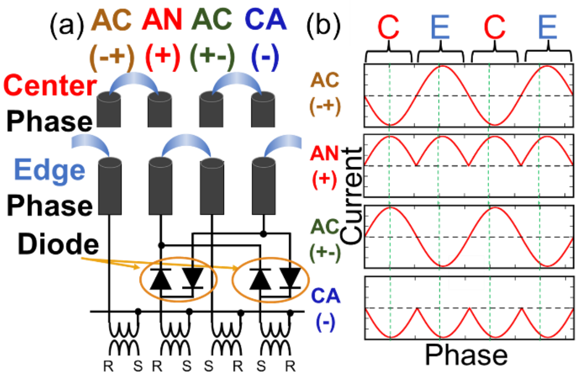

Fig. 1. (a) Conceptual diagram of Diode-rectified AC Arc and (b) ideal current waveform of each electrode.

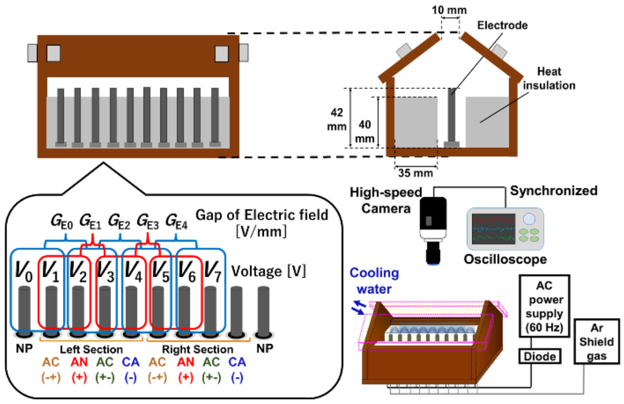

Fig. 2. Schematic image of diode-rectified AC arc.

A schematic image of the experimental setup is shown in **Fig. 2** The electrodes were made of graphite and were arrayed in a single line. Neutral point (NP) electrodes with no voltage applied are placed at both ends of the electrode array. Two phases are classified into "edge phase" and "center phase". Edge phase includes the discharge with edge electrodes, while discharge without edge electrodes occurs in center phase. Each phase switches according to AC cycle. The flow rate of Ar shielding gas was set to 3 L/min. Diode-rectified AC arc was generated at arc current of 80, 95, and 110 A. The discharge was observed vertically by a high-speed camera synchronized with an oscilloscope.

Arc fluctuations under two different electrode placement conditions were compared. The first one is "equalized gap distance", with all gap distances in the electrode array are equalized at 10 mm. The second one is "equalized electric field", with electric field strength at no-loading in the electrode array is equalized. Under this condition, the gap distances between NP electrode and its adjacent electrode are set at 5 mm, while the others are set at 10 mm.

Average electric field between electrodes was estimated from the measured arc voltage and the distance between electrodes. Uniformity of arc fluctuation was evaluated. The electric field $E_{i,i+1}$ [V/mm] (i=0, 1, 2, 3, 4, 5, 6) between electrodes is shown in Eq. (1) at the gap distance L [mm] between two adjacent electrodes. Gap of electric field G_{Ei} [V/mm] of the two locations is calculated as shown in Eq. (2). In center phase, G_{E1} and G_{E3} were calculated, while G_{E0}, G_{E2} and G_{E4} were calculated in edge phase.

$$E_{i,i+1} = \frac{|V_i|+|V_{i+1}|}{L} \quad (1)$$

$$G_{Ei} = |E_{i,i+1} - E_{i+2,i+3}| \quad (2)$$

Uniformity U_i was defined as the ratio of t_{Ei} to t_{total} as shown in Eq. (3),

$$U_i = \frac{t_{Ei}}{t_{total}} \quad (3)$$

where t_{Ei} is the time when G_{Ei} was within the threshold value. The total analysed time is expressed as t_{total}.

3. Results and Discussion

Figure 3 shows the high-speed camera snapshots at a current value of 80 A for the equalized gap distance and the equalized electric field. Different arc shapes between the two conditions were observed in edge phase, while significant difference was not observed in center phase. Under the equalized electric field condition, high brightness region on each NP electrode was found. This suggested the arc generation between those electrodes. On the other hand, long arcs were formed without arcing to the NP electrodes under the equalized gap distance condition.

Figure 4 shows the gap of electric field G_{Ei} under the equalized gap distance condition. Figure 4(a) and (b) show the difference in G_{Ei} at 80 A and 110 A, respectively. Sudden increase of G_{E0} is frequently observed at 80 A. Synchronized high-speed images indicate that an abnormal arc fluctuation was observed at those moments. The threshold value of 3 V/mm was determined as the lower limit of the electric field difference at which abnormal arc fluctuation were observed.

The relationship between arc current and uniformity is shown in **Fig. 5**. Under the equalized electric field condition, the uniformity is closer to 1.0 than the equalized gap distance condition. Obtained results suggest that the arc uniformity improves with increasing current value.

4. Conclusion

Fundamental phenomena in a diode-rectified AC arc as an innovative thermal plasma source have been successfully clarified in terms of arc fluctuation and its uniformity. A more uniform arc can be generated by equalizing the electric field strength between electrodes at no load. These understandings are essential to apply this new plasma source to rapid surface treatment of materials.

5. References

[1] M. Tanaka, et al., Proc. 5th Asia-Pacific Conference on Plasma Physics (Online, 2021) A-I19.

6. Acknowledgements

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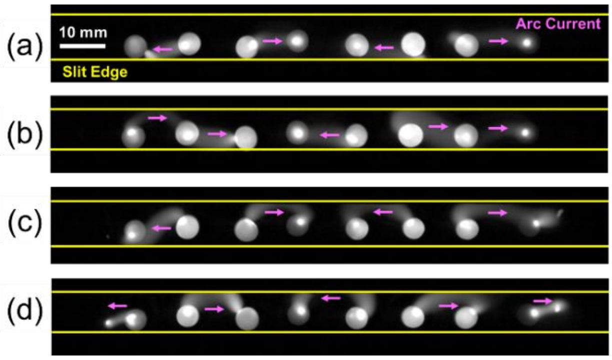

Fig. 3. Representative high-speed snapshots of arc at 80 A. Equalized gap distance, (a) Center phase and (b) Edge phase. Equalized electric field, (c) Center phase and (d) Edge phase.

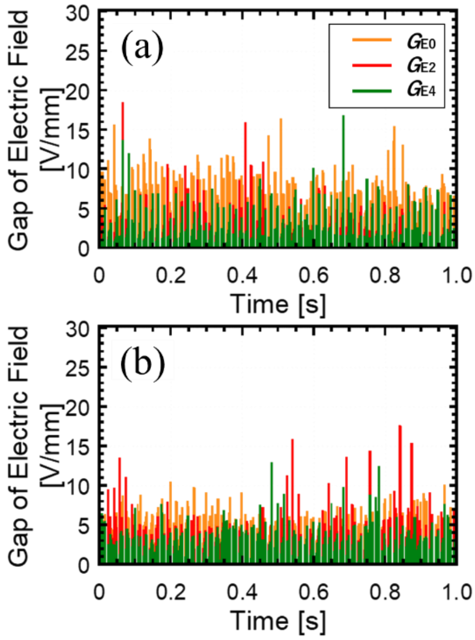

Fig. 4. Gap of electric field under the equalized gap distance condition. (a) 80 A, (b) 110 A

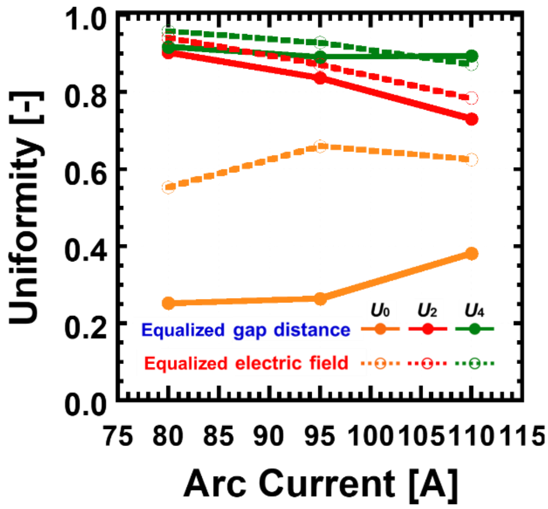

Fig. 5. Relationship between arc uniformity and arc current.