Characteristics of Planar Thermal Plasma Jet by Diode-rectified AC Arc

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Abstract: An innovative planar thermal plasma generator for rapid surface treatment has been developed. Planar thermal plasma jet was successfully generated by diode-rectified AC arc under atmospheric pressure. The purpose of this study is to investigate the fundamental phenomena such as plasma jet fluctuation. The thermal plasma jet was characterized by high-speed visualization of its fluctuation. Obtained results indicate that the planar plasma jet can be controlled by gas flow rate.

Keywords: Planar thermal plasma, fluctuation, AC arc plasma

1. Introduction

Thermal plasma is expected to be applied to various material processing due to its features such as high temperature, high enthalpy, and high chemical activity. Thermal plasma jet is one of the most convenient plasmas for high temperature processes, while dimension of conventional plasma jet is only limited within 1-10 mm in its radial direction. Hence, utilization of plasma jet in rapid processing for surface treatment is inadequate.

Unique thermal plasma generation has been developed [1] to solve afore-mentioned disadvantage. Planar shaped plasma jet by loop-type induction thermal plasma is available for rapid surface treatment, while its relatively low temperature and dimension is still limited to be utilized in industrial process.

An innovative planar thermal plasma generator based on diode-rectified multi-electrode AC arc has recently been developed [2]. This plasma generator enables high-speed and large-area processing by its high energy efficiency and sufficiently large dimension in horizontal direction. However, fundamental phenomena such as planar thermal plasma jet fluctuation have not been understood yet. The purpose of this study is to investigate the fundamental phenomena of planar thermal plasma jets based on the analysis of fluctuations using a high-speed camera.

2. Experiments

The conceptual diagram of the diode-rectified AC arc is shown in **Fig. 1**. One compartment consists of 4 electrodes. These 4 electrodes were configurated by diode-rectified anode and cathode as well as AC electrodes. Electrode positioned at A and C have the role of AC electrode, where A and C correspond to negative-positive cycle and positive-negative cycle, respectively. Diode-rectified electrodes are located as B and D positions. Electrode of B have the role of anode, while that of D works as cathode. Planar thermal plasma jet was successfully generated owing to this unique configuration of electrode with diode-rectification technique.

The schematic diagram of the diode-rectified AC arc is shown in **Fig. 2**. Graphite rods with 6 mm in diameter were used as electrodes. Two electrode compartments and neutral electrodes at both ends were arrayed in a single line. The distance between each electrode without neutral electrode is fixed 10 mm. The distance between the neutral electrode and the adjacent electrode are adjusted at 5 mm to equalize the electric field between all adjacent electrodes at no load.

Typical condition for plasma generation is as follows; Arc current: 70 A, power: 10 kW, argon flow rate as electrode shield gas: 3.0-8.0 L/min. A high-speed camera synchronized with an oscilloscope was used to observe the plasma jet generated under atmospheric pressure from the front of the equipment. The frame rate of the high-speed camera was set at 10,000fps.

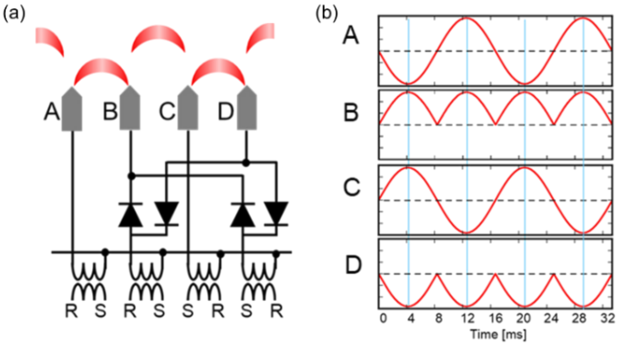

Fig. 1 (a) Conceptual diagram of diode-rectified AC Arc and (b) ideal current waveform of each electrode.

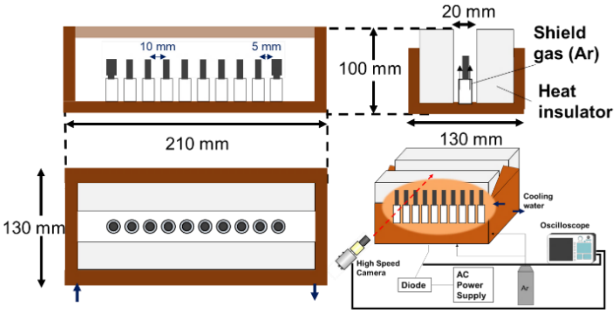

Fig. 2 Schematic image of diode-rectified AC arc.

3. Results and Discussion

Figure 3(a) shows a representative high-speed snapshot at 70 A of arc current with 5 L/min of the gas flow rate per electrode. The existence probability distributions of plasma jets and arcs are summarized in **Fig. 3(b) and (c)**, respectively. Four central electrodes was focused on to eliminate edge effect on the plasma jet characteristics. The images were analysed by integrating for 10 AC cycles. The existence probability of unity corresponds to the position where plasma jet is always existed, while zero corresponds to the position where no plasma jet exists. Obtained result suggested a horizontally long plasma jet with planar shape was generated.

Figure 4 shows the horizontally-averaged existence probabilities of the plasma jet in vertical direction with different gas flow rates. An increase of the gas flow rate decreased the existence probability values of the plasma jet. This is because the increase in gas flow rate increases the gas velocity, resulting in the surrounding air entrainment into the plasma jet. As a result, plasma jet length becomes shorter. In contrast, the existence probability is higher at 8 L/min of gas flow rate than that at 5 L/min. This is due to existing arcs at nozzle exit.

Figure 5 shows the existence probability values of arcs in vertical direction with different gas flow rates. Increasing the gas flow rate decreased the existence probability values of arcs. This is due to the increase in arc length caused by the increase in gas drag due to the increase in gas flow rate.

The existence probability values of the plasma jet and its coefficient of variation (CV) at the height of Z = 5 mm where the material is processed for each gas flow rate are shown in **Fig. 6**. The CV value decreases as the gas flow rate increases. This means that increasing the gas flow rate can generate a highly uniform plasma jet in the horizontal direction.

4. Conclusion

The plasma jet fluctuation in diode-rectified AC arc system were successfully clarified by the high-speed camera synchronized with an oscilloscope. Planar thermal plasma generation in horizontal direction was confirmed. Obtained results indicate that the plasma jet can be controlled by the shield gas. The diode-rectified AC arc is a promising thermal plasma generation technique that is attractive and innovative thermal plasma processing.

5. References

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6. Acknowledgements

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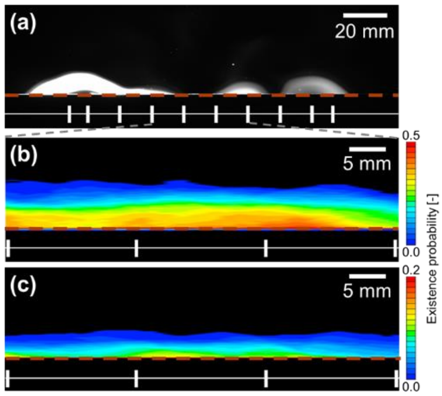

Fig. 3 (a) Representative high-speed snapshots, (b) counter maps of plasma jet existence probability, and (c) counter maps of arc existence probability: shield gas of 5 L/min.

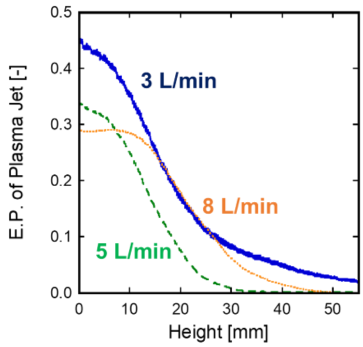

Fig. 4 Existence probability values of the plasma jet with different shield gas flow rates.

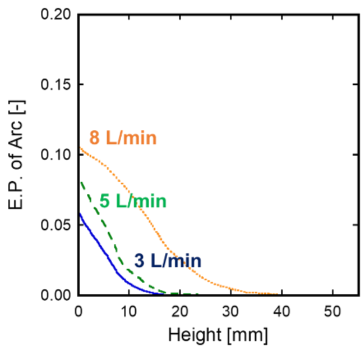

Fig. 5 Existence probability values of arcs with different shield gas flow rates.

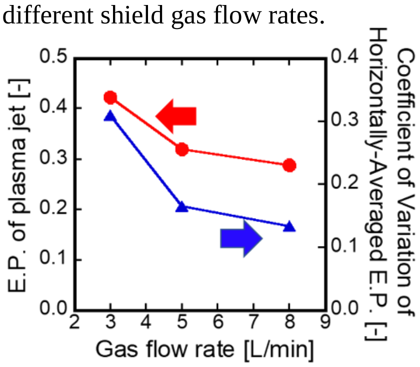

Fig. 6 Effect of the shield gas flow rate on existence probability of plasma jet and its coefficient of variation at Z=5 mm.