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Mechanism of constriction in a high frequency pulsed welding arc plasma

Heng LIU [1], Mingxuan Yang [1], Bojin Qi [1]
[1] School of Mechanical Engineering and Automation, Beihang University
e-mail (speaker): lheng@buaa.edu.cn

High-frequency pulsed arc plasma has shown significant advantages in thermal processing, particularly in welding applications. It offers a higher degree of control over arc plasma energy distribution compared to conventional constant current arc plasmas, resulting in a more stable and constricted arc plasma that concentrates heat energy effectively. This concentration of energy helps narrow the heat-affected zone, improve weld bead contour, refine grains, reduce weld porosity, and optimize joint mechanical properties such as reducing residual stress and deformation, making it widely applicable in the manufacturing industry. Moreover, the ability to control the heat source through purely electronic means, without relying on gas mixing or mechanical adjustments, allows high-frequency pulsed arc plasmas to rival more complex plasma torches in heat concentration.[1,2]

To better understand and utilize these advantages, the phenomenon of arc plasma constriction in high-frequency pulsed welding arc plasmas has been investigated experimentally using the monochromatic imaging method (MIM) on arc plasmas generated with a thermionic electrode. Square pulses with a 50% duty cycle between 75 A and 125 A (average of 100 A) at frequencies of 1 kHz and 5 kHz were explored, with constant current arc plasmas of 75 A, 100 A, and 125 A used as references.

The observations revealed that the high-temperature region of the arc plasma (above 14,000 K) increases in volume during the pulse to sizes larger than those corresponding to the same pulse current in a steady state, while during the background current, the size of the hot regions is smaller than under the same constant current. The net increase in the average size of the most electrically conductive region draws current away from the less conductive periphery, contributing to the observed arc plasma constriction. Additionally, pulse frequencies from 1 kHz to 5 kHz have a significant effect on the thermal delay from the Joule region to the convection region, which plays a key role in the arc plasma constriction mechanism.

Figure 1 shows time-varying curves of plasma volume in different temperature profiles under different current parameters, revealing the expansion and contraction of the arc plasma. This work enhances the understanding of arc constriction, enabling more precise control of the welding heat source through electronic means, and is supported by the National Natural Science Foundation of China [Grant Nos. U20B2031, 51405007, 51675031], Beijing Natural Science Foundation [Grant Nos. 3202016, 3212008], and Fundamental Research Funds for the Central Universities of China, provides valuable insights into the control and optimization of high-frequency pulsed arc plasmas in thermal processing.

References

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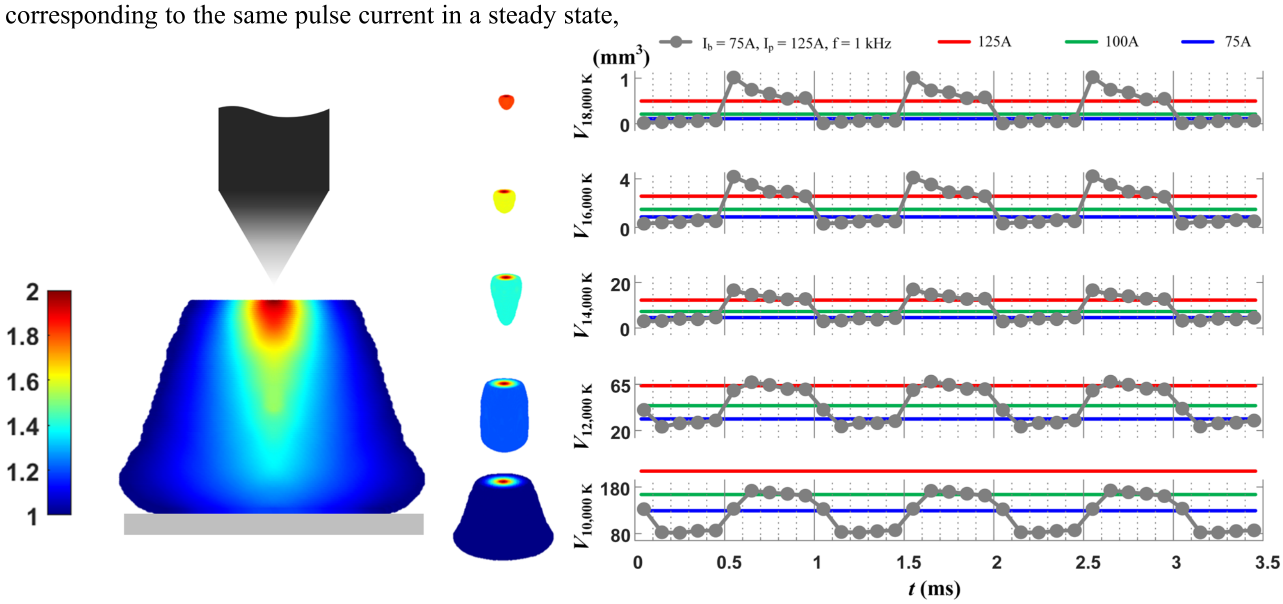

Figure 1. Time-varying curves of plasma volume in different temperature profiles under different current parameters