Modelling of arc attachment at the anode of high intensity transferred arcs

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Abstract: This paper is concerned with numerical studies of attachment mode of a high intensity argon arc. It is found that the adoption of chemical non-equilibrium model is helpful to obtain reasonable parameter distribution inside anode region and the transition processes of different arc attachment modes. The comparison of self-induced magnetic field distributions for different arc attachment modes demonstrate that the formation of anode jet is mainly due to the strong axial and radial Lorentz force above the anode surface.

Keywords: high intensity arc, anode region, diffuse and constricted attachment.

1. Introduction

It is well known that there exits two different types of stable arc attachment modes on the anode of high intensity transferred arc. As shown in Fig. 1, when the cathode jet is dominated, a strong plasma flow impinging on the anode surface. This will lead to the diffuse arc attachment mode on anode. However, when the arc constricts, the gas in the anode region is entrained radially into the arc and accelerated axially away from the anode, resulting in an anode jet [1]. Since the size and shape of the anode arc attachment determines the magnitude and the distribution of local heat fluxes at the anode and further determines integrity and lifetime of the anode, the study on the arc attachments continues to receive wide attention.

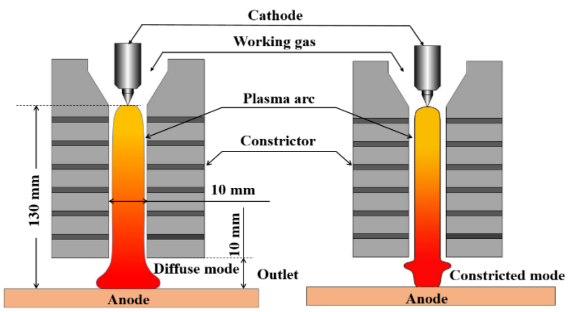

Fig. 1. Different anode attachments of wall stabilized arcs

As shown in Fig.1, the region between the exit of constricted tube and anode, *i.e.*, flow-affected region, is characterized by steep gradients of temperature and particle densities. Both the previous experimental and numerical studies show that the strong axial gradients in this region may cause substantial deviations from local thermodynamic equilibrium (LTE) and the steep gradients of particle densities and of the temperature may cause deviations from chemical equilibrium [2]. In order to accurately obtain the plasma parameter distributions in this anode region and further predict the arc behaviour, the attachment type, the numerical physical model should take into account the deviation from thermodynamic and chemical equilibrium.

In this study, a two-temperature and chemical nonequilibrium model is developed and then applied to simulate the high intensity arc in argon. In contrast to previous studies, the calculation domain includes the total arc region *i.e.*, the arc in both constricted tube and flow-affected region of anode. The transition processes from constricted to diffuse arc anode attachment are simulated self-consistently by changing the gas flow rates.

2. Modelling Approach

The high intensity transferred arcs under consideration are operated at a pressure of 1 atm. The structure and geometry of this device are the same as the wall-stabilized arc studied by Sanders and Pfender [3]. A DC arc is generated between a conical thoriated tungsten cathode tip, whose flattened part has a radius of 0.5 mm, and a flat copper anode with diameter of 50 mm. The total distance from the tip of the cathode to the end of the constrictor segment is 120 mm. The distance between the end of the constrictor segment and the anode surface is set to 10 mm.

The model is based on the following assumptions: (1) The arc in the anode region is steady, rotationally symmetric, and the flow is laminar. (2) Gravity, heat dissipation due to viscosity effects, and thermal diffusion are negligible. (3) The plasma is optically thin. (4) The plasma is assumed to be in chemical nonequilibrium and its composition considered in the discharge model include electrons, ground-state Ar atoms, electronically excited argon atoms in the 4s state, atomic ions Ar^+ and argon molecular ions.

The governing equations, including mass-averaged momentum equations, electron and heavy-particle energy conservation equations, species mass conservation equation, electrical potential equation, and magnetic vector potential equations, are solved simultaneously with appropriate boundary conditions for the field variables *u*, *v*, *T*, and species density. Thermodynamic and transport properties are calculated from the temperature, pressure and the composition at each position in the calculation domain for each iteration, until convergence is reached.

3. Modelling Results

In this study, the arc current is set to be 60 A. Working gas flow rate is varying in the range 1-15 l min^{-1}. In order to focus on the parameter distributions inside flow affected region, only part of computation domain are presented. Figure 2 presents the distribution of heavy-species temperature and gas flow direction for input gas flow rates of 1 l min^{-1}, 2 l min^{-1} and 15 l min^{-1}, respectively. It can be found that at the small input gas flow rate, the arc–anode attachment is constricted. With the increase of input gas flow rate, the arc anode attachment is become diffuse. If we take a closer look on the gas flow direction of plasma, a stagnation layer may be found between the cathode jet and anode jet. When the cathode jet is dominated, a strong plasma flow directly impinges on the anode surface. The anode jet cannot be formed in this situation. However, with the decrease of the input gas flow rate, the anode jet increases, and then pushes the stagnation layer moving upward. The location of this stagnation layer mainly depends on the relative strength of cathode and anode jets.

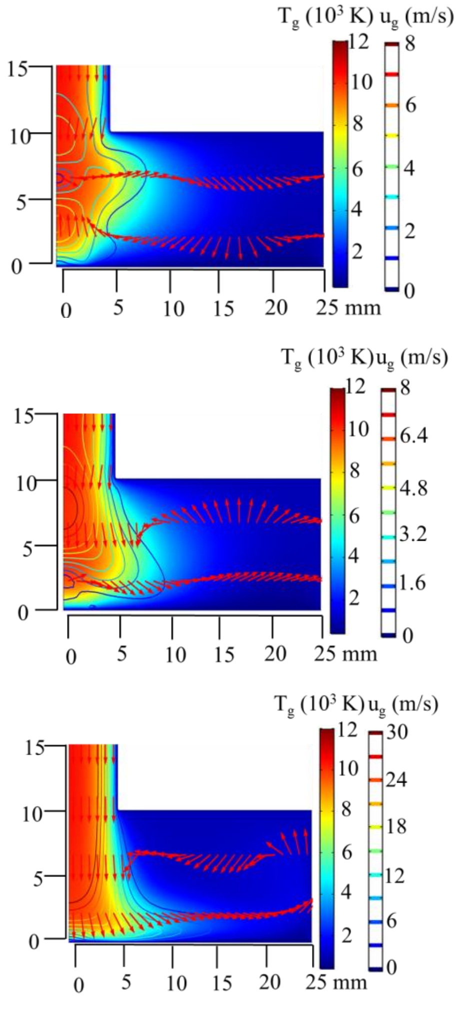

Fig. 2. Distribution of heavy-species temperature, gas velocity and flow direction (red arrows) for the different arc–anode attachments at an arc current of 60 A and input gas flow rates of 1 l min^{-1}, 2 l min^{-1} and 15 l min^{-1}.

The temperature distribution for a diffuse arc attachment shows the well-known bell shape, while the gas temperature distribution in a constricted arc attachment exhibits an inverted bell shape due to the increase of distance from the stagnation layer to the anode. Moreover, the low heavy-species temperature layer near the anode becomes thicker with the decrease of input gas flow rate.

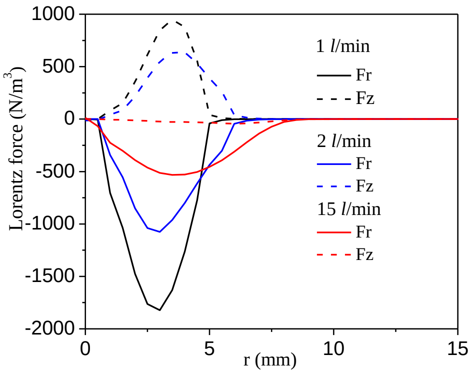

Fig. 3. Radial distributions of radial and axial Lorentz force at a distance of 2 mm above the anode .

Based on the analysis above, it can be inferred that the formation of anode jet is important for the constricted arc attachment. Therefore, it's very interesting to explore the reason for the generation of anode jet. It can be seen from the Fig.3 that for the case with the low input gas flow rate, which corresponds to the constricted arc attachment, the peak values of axial and radial Lorentz force are much larger than those of high input gas flow rates, which correspond to the diffuse arc attachment. The differences for the radial distributions of self-induced magnetic field corresponding are caused by the differences of current density distribution to different arc attachment modes. Therefore, obtaining a reasonable current density inside anode region is curial to analyze the arc attachment mechanism.

4. Conclusions

The transition process between the different arc–anode attachment modes has been investigated by changing the gas flow rate. It is found that the location of stagnation layer mainly depends on the relative strength of cathode and anode jets. The results show that the peak values of axial and radial Lorentz force for constricted arc attachment are much larger than those of the diffuse arc attachment.

Acknowledgments

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5. References

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