Experimental study of DC arc plasma jet impinging on material surface in a rarefied gas wind tunnel

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Abstract: A rarefied gas wind tunnel has been applied to generate high-enthalpy DC arc plasma jet flows with maximum velocity greater than 6000 m/s. The impinging test of high-enthalpy flow on four kinds of material pieces of stainless steel, copper, aluminium and molybdenum have been conducted with different working conditions. The surface morphology of these test pieces after being impinged by the high-enthalpy flow have been analysed.

Keywords: rarefied wind tunnel, high-enthalpy plasma jet flow, surface morphology.

1. Introduction

In recent years, an important research area of space technology is the long-term maintenance of satellites and other spacecraft in low earth orbit (LEO) or ultra-low earth orbit (150km or below) due to the important usage in military and civilian fields. Nevertheless, owing to the existence of the relatively high density atmosphere in this region, the sputtering of the high-speed particles on the wall material and aerodynamic heating problem are important factors that might shorten the lifetime of a spacecraft. On the high-speed flight orbit of a spacecraft, the ambient gas contains complex components, such as oxygen atom and nitrogen atom with strong chemical activity, which have chemical corrosion effects on the wall materials of the spacecraft. In addition, the spacecraft has a high relative velocity relative to the environmental molecules, and the impact energy of the molecules reaches 5eV or even higher, which can cause surface sputtering of the wall material. Wall material damage will affect the long-term flight of the spacecraft, and it is necessary to carry out experimental study on the interactions between high-speed molecular flow and wall materials.

In this study, a rarefied gas wind tunnel, which can ground-based simulate the real rarefied gas environment at an altitude of ~100 km, has been applied to generate the high-enthalpy plasma jet flow, and four different test pieces of stainless steel, copper, aluminium and molybdenum have been used to conduct the impinging test. The surface morphology of these materials after being impinged by high-enthalpy plasma jet flow at different working conditions have been analysed.

2. Experimental setup

The impinging test was performed in a rarefied gas wind tunnel located at Institute of Mechanics, CAS, and the schematic diagram of the experimental system is shown in Fig. 1. The wind tunnel is mainly composed of an arcjet thruster with its DC power supply system, gas feeding system, and cooling water system, a test vacuum chamber of 2.5m in diameter and 6m in length, and a vacuum pump system with pumping speed of 54000 L/s for nitrogen. The ultimate vacuum of the test chamber is 10^{-4}Pa.

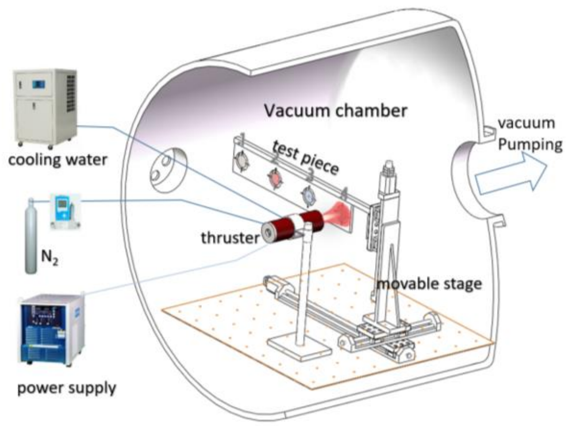

Fig. 1 The schematic of the rarefied gas wind tunnel

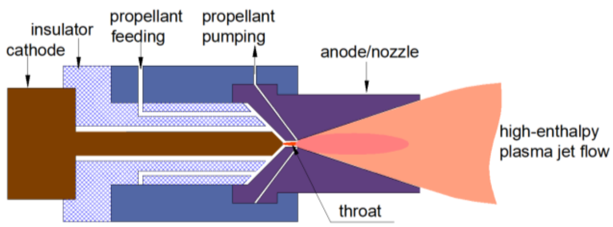

Fig. 2 The schematic diagram of the arcjet thruster

The schematic diagram of the arcjet thruster is shown in fig. 2, which mainly consists of an anode/nozzle, a cathode and the insulator part. The nozzle structure was specially designed in order to pumping out the low-enthalpy propellant gas within the nozzle boundary layer, and producing high-enthalpy plasma jet flow with maximum velocity greater than 6000 m/s [1]. The divergent part of the anode/nozzle has a conical shape with a half angle of 20°, throat diameter of 1.4 mm, and area expansion ratio of 330. In this study, nitrogen is chosen as the working gas, and the gas flow rate is 4L/min, the arc power is 2kW.

The arcjet thruster was mounted on a fixed holder, and the test pieces support, which was mounted on a three-dimensional moveable stage driven by stepping motors, was set perpendicular to the jet flow axis. The distance between the thruster nozzle exit and the test piece was set to be 100mm. For the impinging test, the first test piece stayed in the plasma jet flow centre for 30s, then moved out quickly through the movable stage, and the second test piece was quickly moved into the jet flow centre, the process repeated until the fourth test piece completed the jet impact. Fig. 3 shows the photos of the experimental process. A profile measurement microscope of model VK-X1000 has been used to observe the surface morphology of the test pieces.

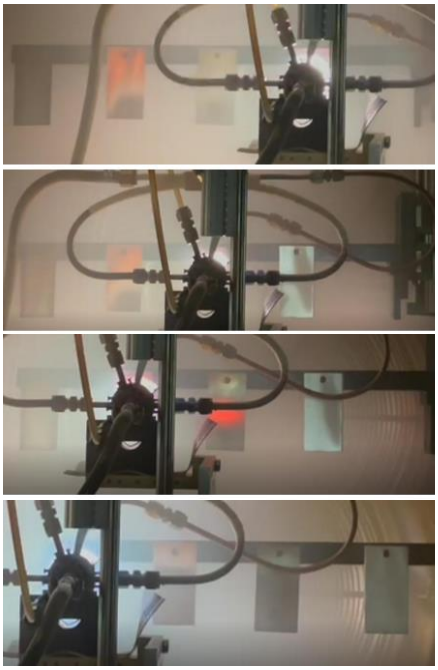

Fig. 3 Photos of the experimental process.

3. Results and discussions

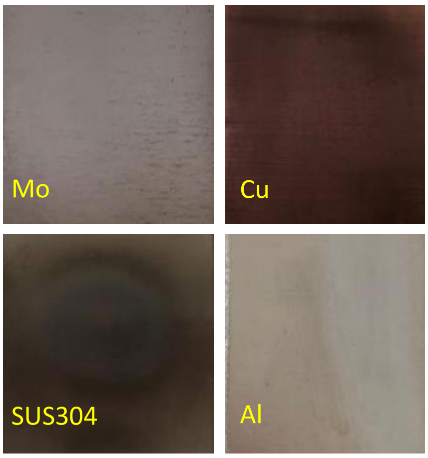

Fig. 4 Photos of the test pieces after impinging test

Fig.4 shows photos of four test pieces after being impinged by the high-enthalpy plasma jet flow. It is seen that the surface of the stainless steel has the most obvious ablation trance, while for molybdenum test piece, it is almost no ablation trace, which might be related to the low thermal conductivity of stainless steel, the high melting point and high thermal conductivity of molybdenum.

Fig. 5 illustrates the preliminary results of the surface micromorphology of aluminium test piece before and after impinging test. Although there is no obvious difference from the ordinary digital photos, the results of microscope observation show than the roughness and uniformity of the aluminium piece after jet impact exhibit greatly difference from those before jet impact.

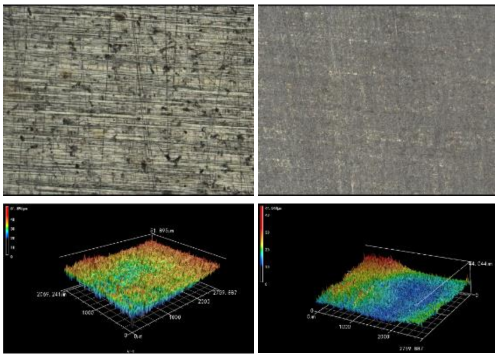

Fig. 5 Surface micromorphology of Al piece before (left) and after (right) impinging test

4. Conclusion

In this study, a rarefied gas wind tunnel has been applied to generate high-enthalpy plasma jet flows. The impinging test of high-enthalpy flow on four kinds of material pieces of stainless steel, copper, aluminium and molybdenum have been conducted, and the surface of the stainless steel has the most obvious ablation trance after jet impact, while for molybdenum test piece, it is almost no ablation trace. It might be related to the low thermal conductivity of stainless steel, the high melting point and high thermal conductivity of molybdenum.

5. Acknowlegments

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6. Acknowledgments

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