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Experimental study on film cooling performance of imperfect holes

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Abstract An experimental study is made to investigate the film cooling performance of imperfect holes due to in-hole blockage over a flat plate. A specifically pyramid-shaped element is used to simulate the in-hole blockage. Six in-hole blockage orientations (such as leading-inlet, leading-middle, leading-exit, trailing-inlet, trailing-middle and trailing-exit) and four blocking ratios (ranging from 0.1 to 0.4) are taken into considerations. Based on the experimental results, the influences of in-hole blockage on the film cooling effectiveness and discharge coefficient under typical blowing ratios are analyzed. It is confirmed that the in-hole blockage results in a reduction of discharge coefficient related to the perfect film cooling holes, especially for the leading-exit and trailing-inlet orientations with a big blocking ratio. However, in the view of film cooling effectiveness, the in-hole blockage shows complicated affecting roles. In general, except for the leading-exit orientation, the in-hole blockages produce detrimental influence on the film cooling effectiveness.

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1. Introduction

Film cooling plays an important role on protecting the hot-section components from overheating. In the real applications, the initially designed perfect film holes may be partially obstructed by fine particulate matter due to foreign ingestion and combustion production.[1–3] In addition, the film-hole imperfections may also be resulted from thermal barrier coating spallation as well as imperfect manufacturing.[4,5]

It is well known that the geometric shape of film cooling holes is an important factor affecting film cooling behaviors. A lot of efforts have been devoted to the film cooling enhancement in past decades by actively optimizing the film-hole shape.[6–12] These shaped film-holes are properly designed to mitigate the detrimental effect of large-scale kidney vortices generated from a conventional film cooling hole. Differing from the shaped holes designed actively in the view of enhancing film cooling effectiveness, however, the alteration of initially designed film-hole caused by some uncontrolled reasons, such as particulate deposition, thermal barrier coating

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spallation and manufacturing inaccuracy, etc., is generally undesirable. In order to illustrate the influences of film-hole imperfection on the film cooling performance, some investigations were carried out experimentally[4,5,13–16] or numerically.[17–19] As the imperfections inside the film cooling holes are caused randomly with vast possibilities of blockage shapes as well as deposition orientations, some simplified configurations for simulating the in-hole blockage were presented, such as half torus, carving round rods and pyramid-shaped elements, etc. Of particular significance was that the affecting roles of film-hole imperfection on the film cooling behaviors illustrated by different researchers were found to be non-consistent, tightly dependent on the in-hole blockage orientations and blocking ratios. Due to the diversity of in-hole blockages and complexity of affecting roles, the knowledge about the film cooling performance of imperfect holes need further illustration.

To address this issue, a series of experiments are conducted in the present investigation to study the effects of in-hole blockages on a row of holes film cooling over a flat plate.

2. Experimental procedures

The experimental setup is schematically shown in Fig. 1, the same as that used by Yang and Zhang[11] which consists basically of three main parts: the primary flow or mainstream supply passage, the secondary flow or coolant supply passage, and the test section.

The primary flow and secondary flow are supplied by two independent air compressors. Both flows are measured and adjusted by respective flow-meter and valve. In the primary flow supply passage, an electric heater is used for air heating. The test section has a constant rectangular cross-section (180 mm in width and 100 mm in height). Consequently, the primary inlet velocity (u_∞) is controlled at 20 m/s approximately. The temperature of primary flow (T_∞) is measured by a temperature probe. In the current tests, the temperature of primary flow is 85 °C approximately.

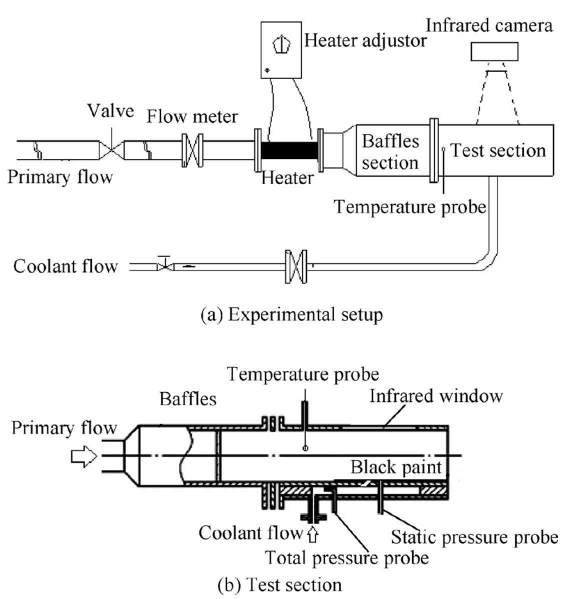

Fig. 1 Schematic of computational model.

The secondary flow plenum has a height of 18 mm. Its inlet is located at 90 mm ahead of the film-hole outlet and its end is located at 30 mm down the film-hole outlet. A row of perfect cylindrical holes with the same inclination angle (α) of 35° and diameter (d) of 6 mm is selected as the baseline case. Nine holes are involved in a single row with a fixed hole-to-hole spacing pitch of 3d. The temperature (T_c) and total pressure (p_c^*) of secondary flow are measured by a temperature probe and a total pressure probe respectively. Both probes are placed inside the coolant plenum. Besides, a static pressure probe is located immediately down the film hole to measure the exiting static pressure of coolant flow (p_c).

Considering that a practical in-hole blockage is randomly distributed around the hole and the deposition generally has a bigger base and a smaller top, the specifically pyramid-shaped element numerically investigated by Pan et al.[19] is selected as the in-hole obstruction in the present study. Six representative deposition locations are determined according to their orientations, as seen in Fig. 2. The film-protected plate is made of a bakelite plate, which has a thermal conductivity of about 0.15 W/(m·K). All the pyramid-shaped elements occupy one-third of film-hole length. For the blockage deposited in vicinity of film-hole inlet or exit, the apex of in-hole blockage is located at the corresponding inlet plane or exit plane. While for the blockage deposited at the middle of film-hole, the apex of in-hole blockage is located at the middle plane. The in-hole blockage blocking ratio (B) is defined according to this specified cross-sectional plane where the apex of in-hole blockage is located, as seen in Eq. (1).

$$B = \frac{4A_{\mathrm{b,section}}\sin\alpha}{\pi d^2} \tag{1}$$

where $A_{\mathrm{b,\ section}}$ is the cross-sectional area of blockage at the cross-sectional plane where the apex is located. In this cross-sectional plane, the obstruction of the in-hole blockage inside the film cooling hole is the maximum.

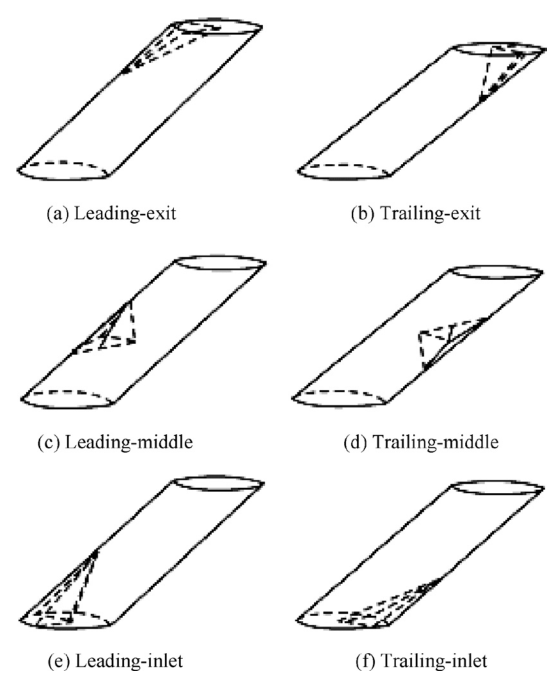

Fig. 2 Schematic of in-hole blockage.

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