Numerical Simulation of Effect of Various Rib Configurations on Enhancing Heat Transfer of Matrix Cooling Channel

Seok Min Choi, Minho Bang, Seuong Yun Kim, Hyungmin Lee, Won-Gu Joo, Hyung Hee Cho

Abstract**—**The matrix cooling channel was used for gas turbine blade cooling passage. The matrix cooling structure is useful for the structure stability however the cooling performance of internal cooling channel was not enough for cooling. Therefore, we designed the rib configurations in the matrix cooling channel to enhance the cooling performance. The numerical simulation was conducted to analyze cooling performance of rib configured matrix cooling channel. Three different rib configurations were used which are vertical rib, angled rib and c-type rib. Three configurations were adopted in two positions of matrix cooling channel which is one fourth and three fourth of channel. The result shows that downstream rib has much higher cooling performance than upstream rib. Furthermore, the angled rib in the channel has much higher cooling performance than vertical rib. This is because; the angled rib improves the swirl effect of matrix cooling channel more effectively. The friction factor was increased with the installation of rib. However, the thermal performance was increased with the installation of rib in the matrix cooling channel.

Keywords**—**Matrix cooling, rib, heat transfer, gas turbine.

I. Introduction

TURBINE inlet temperature has been increased for gas turbine efficiency and power. The gas turbine hot components such as combustor, vane and blade are exposed to harsh conditions. Thus, the efficiency of cooling performance in such hot components becomes important. Many cooling methods such as impingement cooling, internal passage cooling and film cooling were adopted on the turbine blade. The matrix cooling is one of the internal passage cooling methods which are used for several gas turbines. The matrix cooling method was designed to not only cool the gas turbine, but also increase the structural safety of turbine blade. For this region, many researchers developed the efficiency of matrix cooling channel.

Bunker [1] compared the effect of sub-channel shapes by experiments. He provided the local heat transfer distribution in the matrix cooling channel. Acharya et al. [2] conducted experiments in matrix cooling channel in rotating condition. They found out that matrix cooling channel can provide the thermal performance as similar to rib turbulators. Su et al. [3] investigated the heat transfer in turbine blade with matrix cooling channel by numerical simulation. They concluded that the matrix cooling contributes a uniform temperature distribution on turbine blade. Saha et al. [4] measured the heat transfer and pressure drop in trailing edge with matrix cooling channel. They found out that the matrix cooling channel has higher thermal performance than the pin-fin array cooling. Oh et al. [5] measured the local heat transfer distribution and friction loss in matrix cooling channel. They found out that the thermal performance factor changed little with various rotation numbers. Hagari et al. [6] compared the rib inclinations of matrix cooling channel. They found out that 68° rib inclination has 30% higher heat transfer than 41° rib inclination. Carcasci et al. [7] measured the heat transfer and pressure loss in matrix cooling channel with various geometries. They concluded that lower sub-channel height has lower thermal performance because of higher pressure losses. Luan et al. [8], [9] compared the effect of sub-channel width and angle of matrix cooling channel. They found out that thermal performance decreases with increasing sub-channel wall angle. They also conducted large eddy simulation of matrix cooling channel. They compared the results of numerical simulation and experimental data. Bu et al. [10] optimized the thermal performance of matrix cooling channel with various rib angles. They concluded that the sub-channel angle, width, height should be considered for optimizing the thermal performance of matrix cooling. Gillespie et al. [11] carried out experiments in trapezoidal shaped matrix cooling channel. They found out that matrix cooling channel is useful for increasing heat transfer but uniformity is poor. Deng et al. [12] found out that the slotted matrix cooling channel has higher heat transfer than regular matrix cooling channel.

Many researchers conducted numerical simulations and experiments in matrix cooling channel, however, they mainly focused on the existing parameters. From those researches, there exist lower heat transfer distribution regions on the matrix cooling channel. Therefore, we suggest the various rib configurations on the matrix cooling channel to increase the heat transfer on the lower region. Various rib configurations were compared to increase the heat transfer in matrix cooling channel.

II. Numerical Simulation Method

The matrix cooling channel with various rib configurations were modeled by the CATIA. The width and height of matrix cooling channel were 120 mm and 48 mm. The matrix cooling channel has eight sub-channels. The width and height of sub-channel was the same as 24 mm. Therefore the hydraulic

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diameter of sub-channel was 24 mm. The length of channel was 368 mm. The detailed geometry of matrix cooling channel was originated from [5].

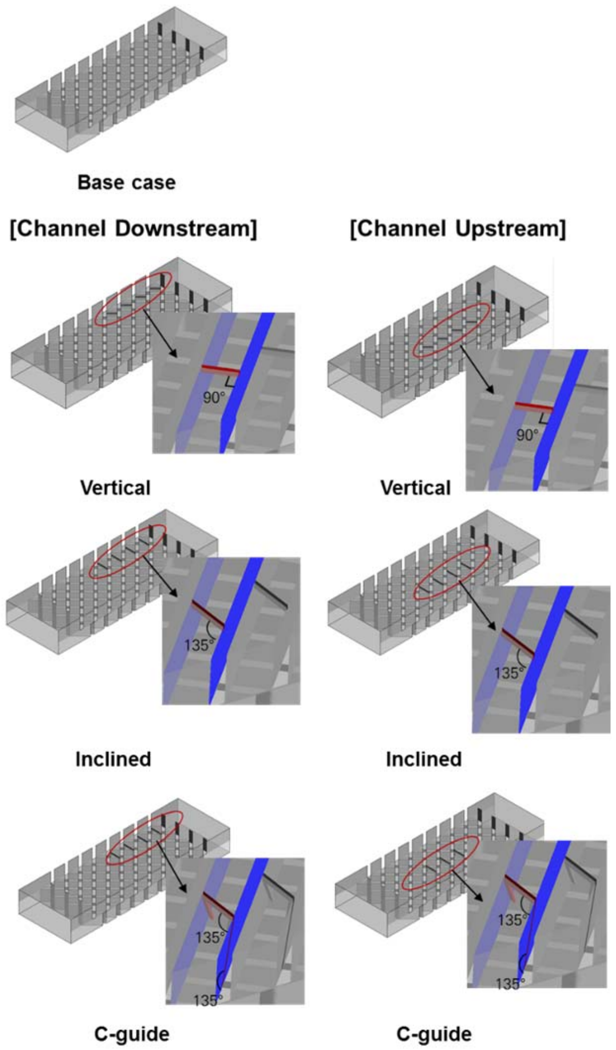

Fig. 1 Geometries of various rib configurations in matrix cooling channel

Six different matrix cooling channels with rib configurations were compared in this paper. The configurations of matrix cooling channel were shown in Fig. 1. The matrix cooling was categorized into two parts: Channel upstream and channel downstream. The ribs were located at 1/4 of channel in channel upstream cases and 3/4 of channel in channel downstream cases. Three different shapes of ribs were compared. Vertical, inclined, C-guide ribs were compared. The height of the ribs is 2.4 mm which is 1/10 of sub-channel height. The vertical rib case has the 90 degree angle of attack and inclined rib case has the 135 degree angle of attack. The C-guide also has the 135 degree angle of attack; however, the ribs are positioned not only on the bottom but also on the both side of the channel. Therefore the six matrix cooling channels with ribs and without matrix cooling channel were compared by numerical simulation.

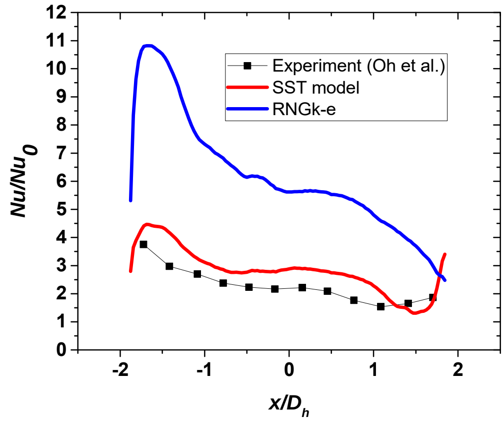

Fig. 2 Validation of local heat transfer distribution

The numerical simulation was conducted by the ANSYS ver.15 CFX. The mesh grid test was conducted between 5 and 15 million. We concluded that 10 million meshes were enough to predict the flow and heat transfer characteristics. The validation of numerical simulation was shown in Fig. 2. We concluded that the shear stress transport (SST) turbulence model was suitable. Therefore, the comparisons of seven matrix cooling channel were conducted by SST turbulence model. The constant mass flow rate condition was set on the channel inlet. The sub-channel Reynolds number was 10,500 in each case. The temperature of inlet air was 25 ℃. The average pressure of 1 atm was set at outlet. The constant temperature was set on both leading edge and trailing edge wall with 30℃. The y+ of wall was below 1 which is suitable for predicting the heat transfer characteristics.

III. Results and Discussions

Fig. 3 shows the streamlines of matrix cooling channel without rib case. The matrix cooling channel has eight sub-channels. They were divided into two parts where four sub-channels were located in upper side and other four sub-channels were located in down side of channel. In Fig. 3 the down sides of sub-channels were shown to analyze the flow characteristics easily. The swirling flow and impinging flow were two main flow characteristics in matrix cooling channel. As the first sub-channel flow met the wall in the lower side at x/D_h=3.5, the flow turned to the upper side of sub-channel. Therefore, the impinging flow occurred from down side to upper side of sub-channel. After that the flow passed through the upper side sub-channel. While the flow passed through the upper side of sub-channel, the flows of lower side sub-channels passed. Those upper side and lower side of flows passed perpendicularly. The lower side of flow inflicted the shear stress on the upper side of flow. Therefore, the swirling flow was promoted in upper side of sub-channels. These same phenomena were also shown in the lower side of sub-channels when the upper side of flow impinged to the lower side of sub-channels.

Fig. 4 shows the streamlines of flow with different rib configurations. Firstly, we compared the streamlines between channel downstream and channel upstream. The swirling flow in upstream channel was shown more clearly than downstream channel in each case. Especially, the inclined and C-guide cases showed more swirling flows in upstream channel cases. This is because, the rib configurations has 135 degree angle of attack to accelerate the swirling flow.

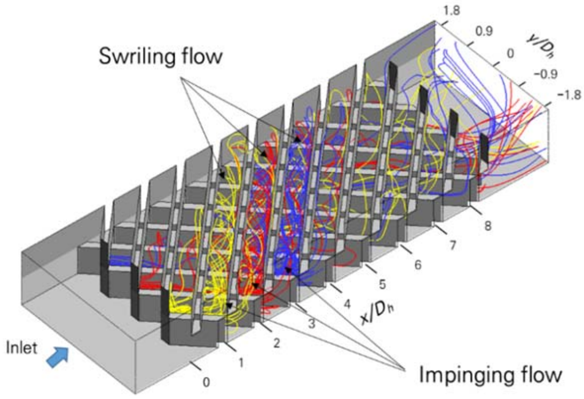

Fig. 3 Streamline of base case

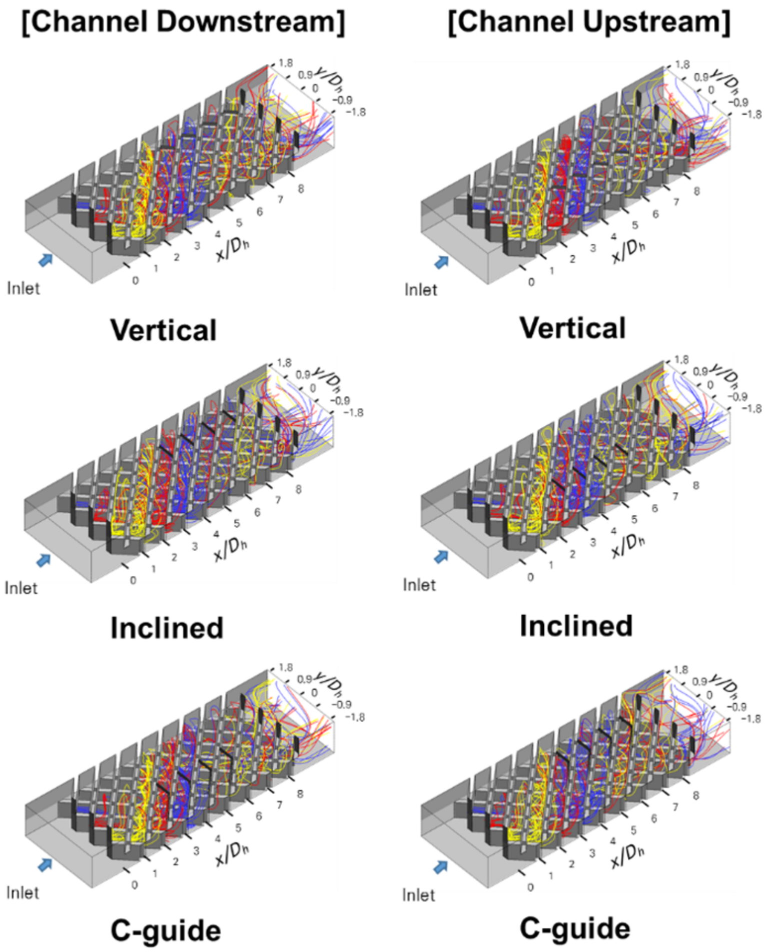

Fig. 4 Streamline of various rib configurations channels

Fig. 5 shows the local heat transfer distribution on the leading edge surface. In base case, the lower heat transfer region was shown at $3 < x/Dh < 8$, $0.5 < y/Dh < 1.3$. The swirling flow in each sub channel developed in that region which causes low heat transfer. For this region, we installed the various ribs in that region. The increased amount of heat transfer is C-guide, inclined, vertical in order. The vertical rib has angle of attack 90° which disturbs the occurrence of swirling flow. The vertical rib only has the effect of rib. The inclined rib has angle of attack 135° which helps the occurrence of swirling flow. Therefore, the vertical rib has not only effect of rib but also encouraging occurrence of swirling flow. The C-guide rib also has angle of attack 135° on leading edge and both side wall. The increased amount is the highest due to this region. These similar phenomena are shown in channel upstream cases. In base case, the lower heat transfer region was also shown at $2 < x/Dh < 6$, $-1.3 < y/Dh < -0.5$. In that region, the impinging flow was not fully developed to the swirling flow in sub-channels. We also installed various rib in that region to increase heat transfer. The similar phenomenon was shown in that region. Therefore, the increased amount of heat transfer is C-guide, inclined, vertical, in order.

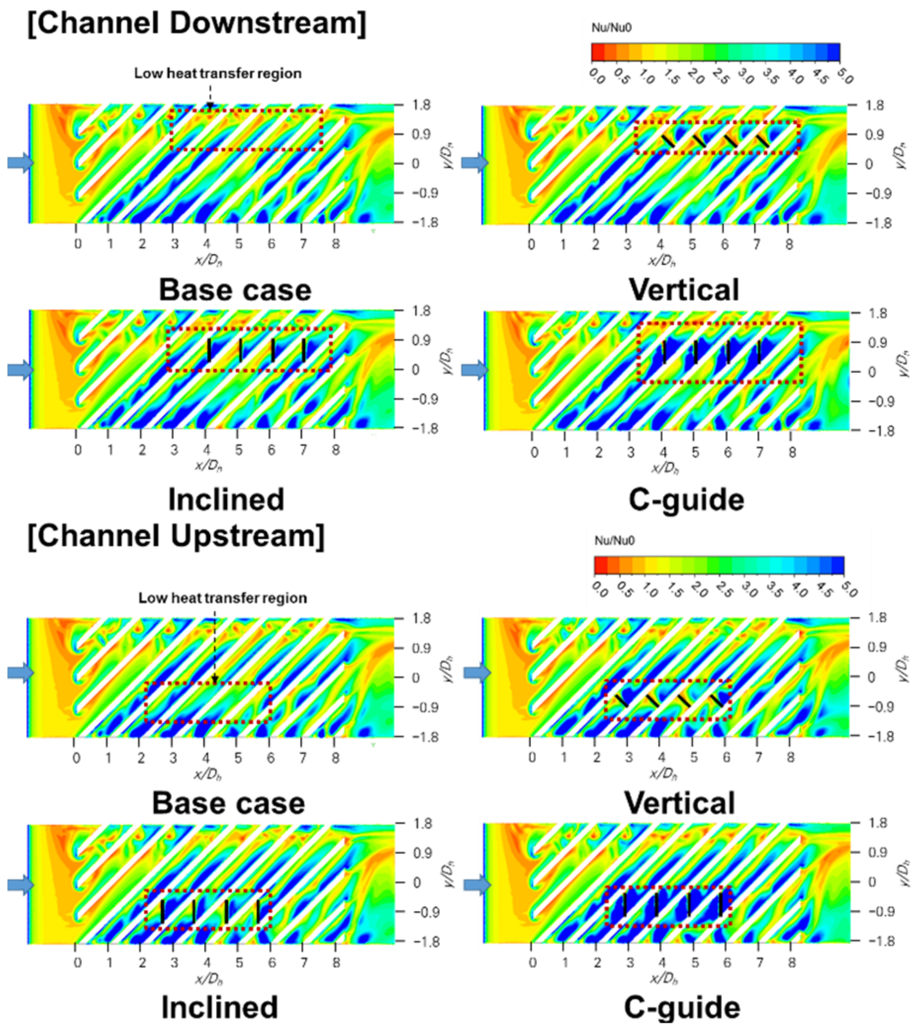

Fig. 5 Local heat transfer distribution of various rib configurations channels

IV. Conclusion

In this study, the numerical simulations were carried out to compare the effect of various rib configurations in matrix cooling channel. The C-guide, inclined and vertical ribs increased the heat transfer on the surface. Therefore, installing various rib configurations in matrix cooling channel is helpful to increase the heat transfer.

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