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Review on Cooling Enhancement of Different Shape Gas Turbine Ribbed Blade with Thermal Barrier Coating

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Abstract:Because of the severe working conditions of the TBCs, all of the following phenomena occur and interact with each other: diffusion, phase transformation, oxidation, creep deformation, radiation, thermal expansion, thermal conduction, fracture, fatigue and sintering. For the last decade, intensive researches have been concentrated on TBCS failure mechanism and advances of thermal insulation capability, and durability at higher temperature by discovering new materials, novel microstructures and progress of coating fabrication technologies, since the conventional yttrium-stabilized zirconia (YSZ) used under 1200 ^{o}C for long period.

***Keywords*—Barrier coating, cooling enhancement, gas turbine, heat transfer enhancement.**

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I. INTRODUCTION

Gas turbines are used for aircraft propulsion and in land-based power generationor industrial applications. Modern development in turbine-cooling technology plays important role in increasing the thermal efficiency and power output of advanced gas turbines. Various major factors affect thermal efficiency of a gas turbine plant or specific fuel consumption.

These include:(i) Increase in the turbine inlet temperature, called firing temperature. (ii) Reduction of cooling air usage. (iii) Improving components efficiencies. (iv) Enhancement of cycle [1].

The increase in turbine inlet temperature is limited in practice by the capability of the metal alloys used to make the turbine components (combustion liners, vanes, and blades). The component operating temperature must be maintained well below the material melting temperature. The turbine inlet temperature is an indication of gas turbine power output. It can be increased in three different ways:

(i) Development of cooling techniques.

(ii) The use of thermal barrier coatings.

(iii) The use of high performance materials.

Blades of gas turbine operate under severe stress conditions induced by high gas temperatures and high rotating speeds. There are three main methods of protecting the blades:

(i) Thermal barrier coatings (TBCs)

(ii) Internal cooling.

(iii) External cooling.

In general, gas turbine cooling is achieved by bleeding some relatively cool air from the compressor and using it inside the gas turbine blades to remove heat transferred into the blade from the hot mainstream. The cooling air flows through internal cooling passages inside the blade. These passages are specifically designed to maximize the heat transfer. In modern gas turbine blades, this is usually done by the use of contact area enhancers and turbulence promoters, such as ribs and pin-fins in the passages. Some of this cooling air is ejected onto the surface of the turbine blade to form an insulating film with the goal of reducing contact of the blade with the hot mainstream gas [2].

Many efforts worldwide were established to press the increase in the thrust to weight ratio of gas turbine engines in the aerospace industry field. To improve efficiency of combustion and reduce fuel consumption, gas turbine engine operating temperature can attain as high as 1350 C^{o}. Such a high operating temperature needs the use of many advanced structural materials, extensive cooling of components, and adoption of various coatings. Thermal barrier coatings (TBCs) have successfully been used in gas turbine engines for increasing operator temperature and improving efficiency of the engine. Over the past thirty years, a variety of TBCs materials and TBCs deposition techniques have been developed. Newly, nanostructured TBCs grow with the potential of commercial applications in various industries [3].

The heat transfer and pressure drop are strongly associated to the height of the rib. Though the ribs can be placed at different orientation, almost studies focus on the ribs placed orthogonally (at 90 degrees) to the mainstream flow. The rib size and the space between the two following ribs, the pitch has great importance [4].

This separated and reattached boundary layer results in the increased heat transfer coefficient of the ribbed channel. The rib induces secondary flow that further improves the heat transfer from the wall to the coolant. The rib also induces turbulent mixing in the passages which increases the flow velocity [4].

The repeated-rib surface can be classified as a "roughness" geometry, it may also be viewed as a problem in boundary layer separationand re-attachment. Note in figure (1.5) that when the rib spacing is large, the flow detaches and a recirculation zone develops downstream of the rib, and flow reattaches 6-8 rib heightsdownstream from the separation point. It is at this reattachment point that experimental measurements show the maximum heattransfer occurs effect of the channel aspect ratio and at p/e=10[5], [6].

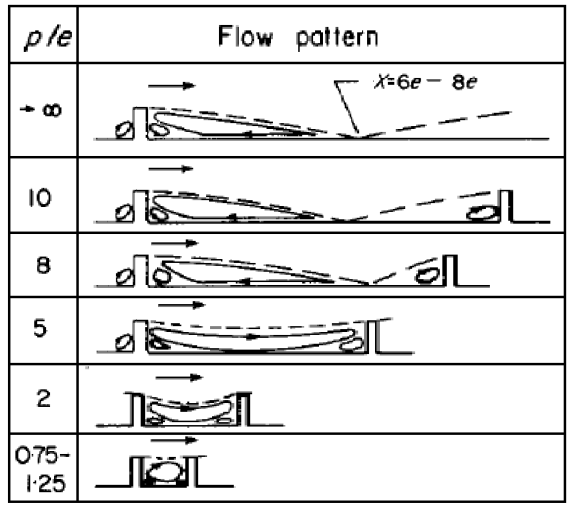

Fig. 1. Flow pertains as a function of x [7]

II.THERMAL BARRIER COATINGS (TBCs)IN GAS TURBINES

Blade usually coated with thermal barrier utilized for protecting the components of the super alloy from the stream hot gas in the gas turbine used in marine propulsion, power generation, and aircraft propulsion. As shown in figure (1.6) a usual engine of gas turbine and the (TBCS) coated turbine blade. The persistent necessary for increasing efficiency of a gas turbine has pushed the inlet temperature of the turbine to be higher. For instance, a temperature in commercial aircraft and land-based power generation gas turbine engines reach to (1500 °C), and of rocket hot sections and fighting aircraft turbines can reach (1600 °C) [8]. Clearly, a melting point of nickel-based super-alloys which are nearly (1300 °C). To raise the turbine inlet temperature, it can be done chiefly by three important developments:

- Technology of airfoil cooling.
- High-performance materials.
- Thermal barrier coating [9].

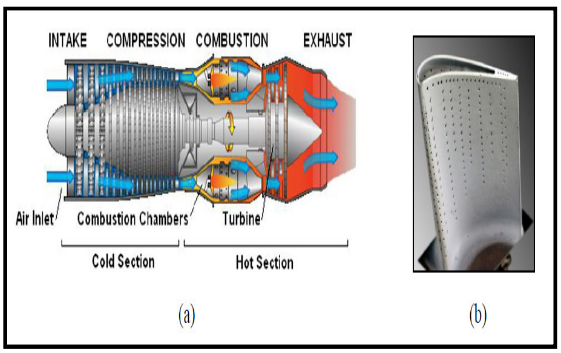

Fig. 2 (a) Gas turbine engine [10]; (b) TBCS coated turbine blade [3]

Although composites of ceramic matrix are promising turbine materials, they are still below their immature stage, and in the foreseeable future, no materials can compensate nickel-base super alloys as the turbine materials. With the well-developed air cooling design, the internal parts air cooling combined with the external film cooling can decrease the metal temperature up to 200-300 °C [11]. However, it reduces the engine efficiency by fuel consumed to pump and compress the cooling air through cooling passages and increase the complication and engines manufacture cost by fabricating internal passages within the airfoils and holes or slots for cooling gas ejected out to the external surface of the turbine vanes or blades [12]. Thermal barrier coatings (TBCs) can reduce the metal surface temperature up to 100-200 °C and protect the components of super alloy from the hot gas corrosion and erosion, thus increase the energy efficiency and durability of the gas turbine engines. Therefore, extensive studies have been focused to improve the TBCs properties.

Few researches focus on thermal radiation properties of conventional YSZ TBCs and improvements of coating reflectance through the design of multilayer structured TBCs and control of fabrication parameters [13]. Few other researches focus on radiation properties of new TBCS materials.

III. LITERATURE REVIEW

VeyselOzceyhan [14] performed numerical search for examine heat transfer augmentation in the tube fitted with a ring having triangular cross sectional ribs. Three various thicknesses for rib were taken for a numerical analysis. Working fluid used was air and applied uniform heat flux. steady heat flux was applied to the outer surface of the wall of a tube. Reynolds number of this search was ranging from $8\times10^3$to 36×10^3. ANSYS -FLUENT 6.1 was utilized such as Numerical calculations and standard (k–ε) turbulence model had been successfully administered to these models. results showed that the greatest overall improvement ratio was (1.34)achieved for (e/D) =0.75.

K. Yongsiri [15] performed numerical investigation for enhanced heat transfer on turbulent flow through a rectangular channel which roughened by inclined discrete ribs. Numerical results of turbulent flow and heat transfer in a channelfitted with inclined detached ribs was displayed the research, Reynolds number was varying from 4×10^3 to 24×10^3. The pressure loss, heat transfer, and thermal performance for using ribs of various attacking angles(θ) for 0^o, 15^o, 30^o, 45^o, 60^o, 75^o, 105^o, 120^o, 135^o, $150^o$and 165^o,were investigated and compared with rib of angle(θ) of 90^o. From computational results, it was found that, the influence of attack angle is trivial when Reynolds number was low, differently, when Reynolds number was high the ribs with $\theta=60^o$ and 120^owould be more effective in thermal performance and heat transfer which are bigger than the provided with another angle.

ArkanAltaie et al. [16] performed a numerical study of heat transfer enhancement in a circular tube with rectangular opened rings. Numerically investigated, forced convection with turbulent flow of cooling air with a velocity of (10 m/s) in a tube of steel with 0.5 m long and 30 mm in diameter with 15 mm thickness, the outside surface of the tube has a constant temperature of 1400,1200 and 1000 k . Combination k-ε model was used in simulating turbulence by program ANSYS FLUENT 14.5. Tube fitted with open ring having a rectangular cross-section and p/e=10. It was found that fitting ribs inside tube would be increase heat transfer as compared with smooth tube and increase the thermal performance.

`PriyankLohiya[17] has performed anumerical investigation for the influence of change rib height friction factor and heat transfer in a square channel roughened with inclined ribs having a gap. Researcher focuses on the experimental study of forced convection heat transfer and friction factor (pressure drop) characteristics of a ribbed surface with different rib height of separate inclined ribs. Inclined ribs with a gap were fixed on the bottom and top wall of the square channel. Reynolds number ranged from 5,000 to 40,000, relative roughness pitch (p/e) was 10. The influence of height to hydraulic diameter ratio of five ribs on heat transfer with regard to Nusselt number and friction factor. The results showed that varying (e/D_h) affect on friction factor were studied, and on Nusselt number. The best heat transfer and thermal performance reach (2.18).

Surah Kumar [18] Studied the influence of secondary flow as a result of the existence of ribs in heat transfer. This was accomplished by casting two type of v-shape continuous repeated and broken in the square passage in the core of the blade. Two different combinations of 600 V and Broken 600 V ribs in the passage were studied. Researcher get data about average Nusselt number into the ribbed channel for Reynolds Number of 56000. Large Eddy Simulation was accomplished on the continuous and Broken V arrangements to analyze the flow model inside the channel. The results pointed out that ribs were essentially responsible to vortex generation and improvement in hat transfer.

Deepak Kumar Patel [19] performed numerical investigation for the three dimensional simulations for study fluid flow characteristics and heat transfer of a rectangular channel employing ANSYS-CFX. characteristics of heat transfer was investigated for Reynolds numbers varying from (8×10^3 to 18×10^3). It was created Model geometry in CATIA V5 R20, then meshed, analyzed and post processed utilizing ANSYS CFX software. Heat transfer characteristics and Fluid flow of various rib shapes were simulated and the results obtained using k–ω model. the rectangular channel had AR, channel length,D_h and (p/e) was 5, 550 mm,66 mm,10, respectively. Three models of the rectangular channel had been modeled with a bottom section of the channel was provided by the aluminum plate, this plate was roughened with three various ribs configuration. Other surface of the aluminum plate was kept with steady heat flux (1000) W/m^2. The reasonable variation was observed in the heat transfer simulation data of various ribs shape. The researcher noticed that there was a notable variation in friction factor, heat transfer rate, friction factor ratio, Nusselt number ratio and the thermal performance factor, and it was found that that the change on rib configuration fixed in the rectangular channel could improve the heat transfer rate.

ArkanAltaie and Mohammad J. Kadham [20] performed numerical study of heat transfer characteristics of horizontal square channel 500 mm long using internal square-circle ribs of 7.5x7.5mm cross section ribs spacing =75 mm, with air as the working fluid. Reynolds number = 34.267×10^3 was taken. The steel channel (ASM4120) was subjected to different constant surrounding hot air temperatures (673, 773 and 873 K). Heat transfer was enhanced by (ΔT=9, 13 and 15 K) for using ribs at constant surrounding airtemperature of (673, 773 and 873 K), respectively. Increases surrounding hot air temperature increases coolant air temperature at the channel center line. Increases surrounding hot air temperature having no effect on coolant air velocity. Using ribs enhances fluctuation in coolant air velocity and thus enhances heat transfer rate. All studies where carried out using workbench program Fluent14.5 by using K-ε model.

J.C.HAN [21] studied the compounding effect of using different attack angles of rib and channel aspect ratio on heat transfer coefficient distribution in a rectangular channel. Where the ribs fixed on the upper and lower side of the channel, air flowed with $Re=10*10^3$ to $60*10^3$, attack angle of the rib was varying from 30 to 90, and the aspect ratio was raging from 1 to 4. Result found that the effect of varying attack angle was slightly in the channel with aspect ratio (2).Thermal performance was changing from 1.05 to 1.85 depending on the attack angle and channel aspect ratio. Semi-empirical friction heat transfer and heat transfer correlations had been obtained for an account for rib spacing, rib angle, channel aspect ratio, Reynolds number, and rib height. The results could be utilized in the designing channel of the blade of the gas turbine.

M. Amro[22] performed an experimental investigation of the heat transfers in a triangular channel having rounded edge which roughened with ribs as a model that simulates the passage in the blade of gas Turbine. To measure the heat transfer, it was used the method of A transient liquid crystal. Reynolds numbers vary between5 $\times 10^4$5 $\times 10^4$ and. it had been found from results that the ribs of 60^o were better than the ribs of 45^o in heat transfer and with this ribs of 60o were had high friction factors. The enhancements of overall heat transfer depend on the rib and also structure rib angle.

SachinBaraskar et al. [23] presented an experiment research of friction factor properties and heat transfer of fixing ribs on one wall of the rectangular channel, the aspect ratio of channel equal to 8, the ribs were with and without gap, ribs spacing to height (p/e) =10,heat transfer and friction properties of this ribbed channel have been compared to the smooth channel with similar condition. The influence of rib has been studied for a range of Reynolds numbers from 5×10^3 to 14×10^3. The best enhancement in friction factor and the Nusselt number was perceived to be 2.85 and 2.57 times of that of the smooth channel, respectively.

UmeshPotdar et al. [24] presented an experimental work in the stationary square channel with V-shaped and 45°inclined arc of circle rib turbulators to find the thermal and hydraulic performance. Ribs were fitted on opposite walls, the heat transfer coefficient and frictional factor were calculated. Stationary channel with aspect ratio one (W/H=1) was considered in the analysis. The thermal and hydraulic performance was measured by calculating the Nusselt number and frictional factor. Square ribs (w/e = 1) were considered as the baseline configuration. Rib geometries involved three rib height-to-channel hydraulic diameter ratios (blockage ratios) of 0.083, 0.125 and 0.167, as well as rib spacing (pitch to height ratio) is 10. The heat transfer performance for the channel was calculated with Reynolds numbers range from $45x10^3$ to $75x10^3$. The results obtained for the channel with different ribs configuration proved that the increase in rib width increases the thermal performance of the channels. The optimal cooling configuration was obtained by combined effect of rib width, rib spacing and flow parameters.

Shailesh et al. [25] performed an experimental investigation for ribs which have no gaps and ribs having gaps with (p/e) =10, (e/Dh) =0.06 and two attacking angles (60^o and 90^o), Re= $5x10^3$ to $40x10^3$. The thermal heat transfer performance of continues and discontinuous ribs with (d/w) =0.2 and g/e=1 was investigated under the same conditions, the results of friction factor ratio and heat transfer were obtained from the ribbed channel were compared with the channel without ribs. From the results it was found that the performance of inclined ribs is best than the transverse ribs with and without gaps. The best case of thermo hydraulic performance was found to be the case of inclined ribs with gaps at Re=5000 and it was about (2.03).

Heeyoon Chung [26] has performed an experimental investigation of the influence of channel aspect ratio and an intersecting rib on performance in rectangular channels with two angled ribs and three channel aspect ratio from 1 to 4.The researcher used three channel having the same hydraulic diameter (D_h=40mm) but different in channel aspect ratio (AR=1,2, and 4) . The Reynold number range from 10000 to 20000 In a rib-roughened channel with angled ribs, the results show that intersecting rib raised the thermal efficiency for every case, despite the channel aspect ratios and Reynolds numbers and the effect of the intersecting rib was strongest for AR = 2.0.

Srivastava and alt. [27] has performed an experimental study for the influence of attack angle on the forced convection heat transfer and friction factor of the ribbed channel. The square channel (AR=1) was ribbed on its bottom and the top wall with the square-shaped rib as V-rib and having a gap on its length. The attack rib angle (α) was increased from 300 to 750, the ratio of width(W) to the height of the channel (W/H) was 1, relative roughness pitch (p/e) was 10. The flow rate of air corresponded of Reynolds number (Re) was ranged from $5\times 10^3$to 40×10^3. The pressure drop and heat transfers of different configurations was manifested in the form of friction factor and Nusselt number. The result showed that the changed the attack angle has an effect on friction factor and Nusselt number. The highest enhancement of friction factor (f) and Nusselt number (Nu) were 8.1 and 4.7 times that of the smooth channel, respectively. As the results, the highest performance of 2.6 times that of smooth channel, was given for broken V-shaped ribs with attack angle flow as 60^o .

Sebastian Ruck[28]has performed an experimental investigation for heat transfer measurements to examine the thermal-hydraulics in the square, round-edged ribbed channel (p/e = 10), the ribs fixed on one wall at Reynolds numbers from 50000 to 250000. Three variously shaped ribs were investigated: transverse ribs, Transverse ribs with square cross sections and, upstream directed 60° V-shaped ribs with round-edged rib front and rear surfaces the thermal performance, Friction factors, roughness functions, and ratios ofNusselt number, were manifested. the upstream directed V-shaped ribs having the highest thermal performance and best heat transfer.

Mohammad et al.[29] presented numerical predictions of a three dimensional flow and heat transfer for a rotating two-pass rectangular channel with 45^{o} rib turbulators and channel aspect ratio of 2:1. The rib height to hydraulic diameter ratio (e/D_h) was 0.094, and the rib spacing to height ratio (P/e) was 10. Two channel orientations were studied: ß=90^{o} and 135^{o} corresponding to the mid portion and the trailing edge regions of a turbine blade, respectively. Researchers investigated the effect of the channel aspect ratio and the channel orientation on the nature of the flow and heat transfer enhancement. A multi block Reynolds-averaged Navier-Stokes (RANS) model was employed in conjunction with a near wall second moment turbulence closure. The convective transport equations for momentum, energy, and turbulence quantities were solved in curvilinear, body-fitted coordinates using the finite-analytic method. The numerical results compared reasonably well with experimental data for both stationary and rotating rectangular channels with rib turbulators at Reynolds number of 10,000.

Mi-Ae Moon[30] presented an experimental and numerical investigation to estimate performances for heat transfer of different rib shapes .The friction loss and heat transfer performance forribbed rectangular channels with an assortment of rib configurations which had been analyzed by employing equations of 3D Reynolds averaged Naiver Stokes. Researchers made numerical simulations for sixteen different shapes: isosceles triangular, inverse right angle triangular, fan shaped, right angle triangular, house shaped, square, reverse pentagonal, reverse cut trapezoidal, pentagonal, cut trapezoidal, reverse right angle trapezoidal, reverse boot shaped, right angle trapezoidal, boot shaped, semicircular ribs, and isosceles trapezoidal. The proportion of width, height, and pitch of the rib to the hydraulic diameter of channel were established to, 0.047, 0.047 and, 10 respectively. The spezialeSarkargatski pressure–strain model with the Reynolds-stress model were utilized to analyze the turbulence. Under the same conditions, it was validated results of computations of the area-averaged Nusselt number by comparison to the experimental data. The influence of the ratio of rib pitch to the width and Reynolds number on the performances of different ribs were additionally studied for Re=5000 to 50000 and pitch to the width from 5 to 10. The result shows that the best performance heat transfer with a pressure drop was the boot shaped rib.

Hasan Jorumt[31] presented an experimental and numerical investigation of the heat transfer properties of a circular 500 mm long pipe using internal ribs in six cases: rings of different heights, open ring, spiral square ribs, spiral slot, ring of same heights and square ribs (namely: 1,2,3,4,5, and 6). The seventh case was a pipe without ribs for pitch =100 mm, coolant air enters the test section at 300 K with constant surface temperatures (573, 873, and 1173 K) and Re=31170. The heat transfer coefficient enhancement for internal ribs was higher than that for plain pipe for the same conditions. The results showed that using rings with different heights removed more heat than the other cases compared with smooth tube. The obtained numerical results were compared with the experimental and revealed a good agreement, as follows: 2.2 %, 6.3 %, 2.34 %, 3.64 %, 4.22 %, and 2.7 % for cases 1, 2, 3, 4, 5, and 6, respectively. These results were all compared with case 7 (smooth tube).

F. L. Rashid [32] presented an experimental and numerical investigation for the heat transfer of a circular 500 mm long tube using internal ribs in eight cases. these cases include helical ribs with square cross section, helical ribs with rectangular cross section, rings, helical ribs with triangular cross section, rings (letter G shape), rings with middle arm, open rings (letter C shape) and rings with triple arms. These cases were called case: 1, 2, 3, 4, 5, 6, 7 and 8 for pitch =85 mm. Coolant air enters the test section at 300 K. The test section was kept with constant surface temperatures: 673, 773, 873 and 973 K, and different Reynolds numbers; Re=24.253×10^3, 26.119×10^3 and 27.984×10^3. The heat transfer coefficient enhancement for internal ribs was higher than that for smooth tube for the same conditions. The results showed that using rings with different heights removed more heat than the other cases compared with smooth tube. The obtained numerical results were compared with the experimental ones and showed a deviation of: 2.1, 2, 2.4, 2.2, 1.2, 1.6, 1.8, 2.4 % for cases 1 ,2 ,3 ,4 ,5 ,6 ,7 and 8, respectively. These results were all compared with case 9 (smooth tube).

Peter Forsyth[33] presented an experimental and numerical research of improvement and combination of heat transfer and aerodynamicflows in a model internal coolingchannel fitted with ribs for giving view to the secondary flows development. To measure localflow features in a series of experiments. The researcher fixed Static instrumentation at theend of a long smooth passage and used where ribs wereincrease added upstream by utilizing a hybrid transient liquid crystal technique, here develops experiment turnaround time and permits greater-resolution of distributions of heat transfer coefficient to be gained. The composite distribution of heat transfer coefficient of the passage is stated: prominently, the behavior is governed by the development of the secondary flow in the passage throughout. Examination data of the aerodynamic and heat transfer were together compared to numerical simulations developed employing a commercial computational fluid dynamics solver. It was possible to examine the veracity of the underlying assumptions of the experimental strategy via conducting numbers of simulations. The result captures develop strength and size of the vertical structure in the secondary flow. The local flow field was shown to be strongly coupled to increase of the heat transfer coefficient. Although the numerical simulations failure to catch few enhancements on the smooth and ribbed surfaces. In general, by comparing the numerical and experimental data, there is a good consensus in heat transfer coefficient prophecy.

HasanKahtan[34]presented an experimental and numerical study for the effect of using circular rib in rectangular channel on flow and heat transfer. The researcher used ribs to enhance the cooling of gas turbine blade. The boundary condition of the work was that the air cooling was at 300 k and the hot air surrounding was 400 ^{o}C, the Reynold number of the air was (7901), and the dimension of the channel was (30x60 mm) cross section and the long of the channel was 500 mm the circular ribs with p/e=10. ANSYS FLUENNT 14.1 was used to found the Result.results were obtained for thermal performance factor, temperature distribution of the coolant air at centerline of the channel, the temperature of inner wall surface of the channel, and velocity, temperature distribution contours. The better result was found for the ribs with fins.

Arkan Al Taie[35] presented an experimental work on TBC on gas turbine blade at turbine inlet temperatures 973, 1073 and 1173 K. The researcher used six TBC systems. Researcher found that C-YPSZ was the best insulator. However, blades coated with Zirconia suffered loss near the edges, and the two alumina based systems were lost more than a blade. It was demonstrated that thickness of 0.3 mm of C-YPSZ increased the surface temperature by 250 K and decreased metal temperature by 270 K for the turbine entry temperature of 1673 K. Metal temperature reduction was 310 K for a coating thickness of 0.5 mm.

Arai and Suidzu [36] devised a cooling system for the applications gas turbine which had an important advantage by decreasing the quantity of coolant air and rising cooling efficiency. The porous ceramic coating was improved with a spraying plasma process, and the characteristics of the porous coating material, so as thermal conductivity, and adhesion strength were measured. The composite of polyester and (8 wt.%) yttrium-stabilized-zirconia was used as the coating material. It was shown that the porous ceramic coating has superior permeability for cooling gas. The strong adherence of porous coating was low at only 20% associated with the thermal barrier coating used in current gas turbine blades. A simulation test of hot gas flow around the gas turbine blade proved the remarkable decrease of the coating surface temperature by the mechanism of transpiration cooling.

OrhanAydin [37] investigated the electiveness of a new thermal barrier coating material. The model consists of two concentric cylinders with high temperature gas flow in the annular space and with low temperature liquid in the inner cylinder whose exterior surface is coated with thermal barrier coating material having high emissivity. The new coating material, which was developed by the Noritake Co. Ltd., is silica-based glass ceramic. A control volume approach is used for gas and liquid flows, while surface energy balance is used for the surfaces of the inner and outer cylinders. Results obtained for the new coating material are compared with those obtained for the materials with lower emissivity and zero emissivity, that is, the case in which radiation effect is neglected. It is disclosed that a gas turbine blade coated with the new thermal barrier coating material, glass-ceramic, results in higher heat transfer rates, which in turn enhance power output.

Researchers [38-73] designed and built an experimental rig to simulate conditions in the gas turbine blade cooling. it was presented the effect of using different rib geometries fitted in different channel shapes and found the fluid flow and heat transfer characteristics. The coolant air flow velocity seems to be accelerated and decelerated through the channel in the presence of ribs, so it was shown that the thermal performance factor along the duct is larger than 1, this is due to the fact that the ribs create turbulent conditions and increasing thermal surface area, and thus increasing heat transfer coefficient than the smooth channel.

IV. CONCLUSION

With continuous improving, the TBCs working temperature and the thermal radiation is playing more and more significant role in the total heat transfer because of its fourth power dependence on temperature. It is necessary to implement various cooling methods, so the turbine blades survive in the path of the hot gases. Simply passing coolant air through the airfoils does not provide adequate cooling; therefore, it is necessary to implement techniques that will further enhance the heat transfer from the airfoil walls. The internal heat transfer can be enhanced with jet impingement, pin-fin cooling and internal passages lined with turbulence promoters. The heat transfer distribution in cooling channels with turbulators has been studied for many years because a number of factors combine to affect the heat transfer.

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