HEAT TRANSFER ENHANCEMENT USING CONCAVE AND RIBBED SURFACES IN LAMINAR FLOWS

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Abstract — In the present study, the heat transfer enhancement of laminar air flows over concave and ribbed surfaces have been investigated experimentally in a wind tunnel. The experiments were performed over a flat plate, a curved surface with a radius of 2.54 m in concave curvatures and a ribbed surface has a rib aspect ratio (the ratio of the rib width to the rib height)of 1.2 for the free stream velocity of 2 m/s. A constant-temperature hot wire anemometer and copper-constant thermocouples were used to the velocity and temperature measurements, respectively. The results show that the heat transfer rates are increased up to 60% by the concave and 175% by the ribbed surface comparing to the flat plate. It is noted that ribs give the higher heat transfer augmentation than concave surface.

Keywords — Heat Transfer Enhancement, Laminar Flow, Ribbed Surface, Concave Surface.

I. INTRODUCTION

The heat transfer enhancement by the ribbed and concave surfaces is of great importance for engineering applications such as turbine blades, heat exchangers, electronic cooling systems, biomedical devices and power plants.Therefore, there have been several previous investigations on the laminar flows over concave andribbed surfaces such as; Leung et al. [1] investigated experimentally the convective heat transfer and pressure-drop characteristics for laminar flows over rectangular ribs and recorded an increase of 133% with traverse rectangular ribs.Chen and Wang [2] carried out an experimental study on forced convective laminar and turbulent flow in a channel with blocks in tandem and they explained the effects of separation on flow and heat transfer characteristics.Kim and Anand [3] worked out numerical simulation of laminar and turbulent heat transfer in two-dimensional ribbed channel and reported that Nusseltnumber of block surfaces increased with increasing Reynolds number.Nakajima et al. [4] presented numerical results simulating a three-dimensional laminar separated flow and heat transfer around staggered surface-mounted rectangular blocks in a plane channel.Davalath and Bayazitoglu [5] solved the two-dimensional, conjugate heat transfer problem for laminar flow over an array of three obstacles and indicated that the heat flux distributions at the rear surfaces of blocks were much smaller than those at the front and top surfaces. On the other hand, Crane and Sabzvari [6], Umur [7], Thomann[8], Mayle et al. [9] and Simonich and Moffat [10] carried out a number of investigations over concave surfaces and showed that concave curvature caused higher Stanton number than flat plate values.

In this paper, the effect of the surface shapes on heat transfer enhancement was examined experimentally. The measurements were performed for the free stream velocities of2 m/s which correspond to the laminar flow case, the rib aspect ratio of 1.2and the concave surface radius of 2.54 m.

II. EXPERIMENTAL SET-UP AND METHOD

Experiments were performed in an open circuit and blowing-type, low-speed wind tunnel, as shown in Fig.1. The tunnel run by a 5.7 kW axial fan and has 30 m/s maximum velocity with a turbulent intensity of 0.7%. Air velocity was adjusted by a butterfly valve. Air passes through a metal duct having a length of 1.07m and a honey comb with a cross-sectional area of 0.305x0.305 m^2 to obtain smooth streamlines and to reduce turbulent level. After the honey comb, a nozzle that has 1.5:1 contraction ratio and 0.2x0.305 m^2 exit area was used to prevent boundary layer separations and accelerate flow. A straight duct of 0.4 m length was installed before the test section to eliminate the contractions effects of the nozzle and achieve smooth streamlines. The test section has an initial area of 0.2x0.305 m^2, length of 0.8 m and plexiglass side surface to provide full visibility of the flow area.

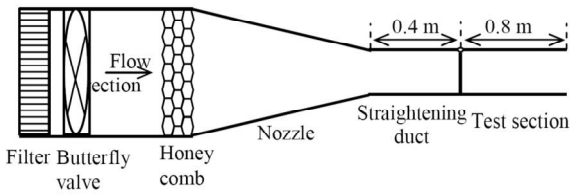


Fig. 1. Wind tunnel and test section.

The experiments were carried out over a flat, a ribbed and a concave surfacewhich have 0.24 mspanwise wide and 0.0008 m thick, as shown in Fig. 2. The streamwise distance (L) is 0.75 m in flat plate, 1.25 m in concave surfacewith a radius of 2.54 m and 0.45 m in ribbed surface. The ribbed surface with a sequence of 6 ribs has a rib height of 0.025 m and width of 0.03 m, a distance between ribs of 0.03 m and a distance up to the first rib of 0.06 m. These rib dimensions and numbers were chosen to obtain the same total surface area of the concave and flat surfaces. The experiments were performed over the all surface for the free stream velocity of 2 m/s.DANTEC digital constant temperature

anemometer along with model 55P11 probes, a traverse system and a calibration device were used for velocity and turbulent intensity measurements. All measurement was obtained at a sampling frequency of 2500 Hz and low-pass filter frequency of 1250 Hz.The chrome-nickel resistive wires were furnished on the backsides of the all copper surface to heat the surfaces and obtain the near constant heat flux condition. The wire knitting was regulated with a variable AC voltage controller and coated with silicon layer. The silicon layer was covered with fiberglass to achieve minimum the heat loss.The thermocouples were mounted on the bottom side of the surfaces and the free stream and wall temperatures were recorded by a copper-constant thermocouples and a data logger. The wall temperatures were obtained at streamwise x-locations of 0.06, 0.18, 0.3, 0.42, 0.54 and 0.66 m over the flat and concave surfaceand at interval of 15 mm in the streamwise direction on the ribbed surface.

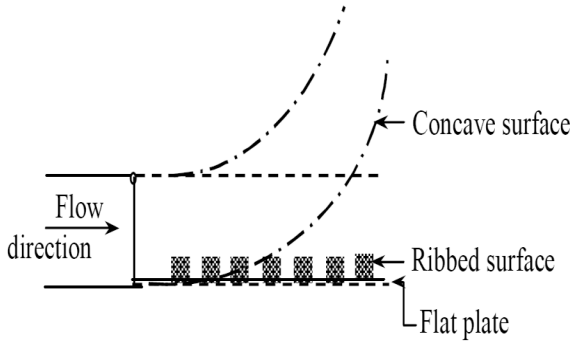


Fig. 2. Test section and heated surfaces assembly.

The convection heat loss was estimated from the difference between the flow-off $(q_o=V_oI_o/A)$ and flow-on $(q_f=V_fI_f/A)$ powers required to maintain locally constant wall temperature with and without flow, where V and I are the voltage and current values. The heat transfer coefficient and dimensionless wall temperature were calculated by $h=q/(T_w-T_0)$ and $\theta_w=(T_w-T_0)/(T_{in}-T_0)$, where $q=q_f-q_o$ and T_w,T_0 , *and* T_{in}refer to wall, free stream and inlet temperature, respectively. The corresponding experimental Stantonnumber were defined by St=h/ρUC_p, whereρ, U and C_p is density, free stream velocity and specific heat of fluid, respectively.

The maximum uncertainty in the calculation of Stanton number was estimated to be less than 3%, using the uncertainty estimation method of Kline and McClintock [11].

III. RESULTS AND DISCUSSION

The streamwise variation of the convective heat transfer coefficients over the flat and concave surfaceare shown in Fig. 3. The heat transfer coefficients decreased monotonically in the streamwise direction, as expected.The local heat transfer coefficients of the first and last measurement station over the concave surface were higher than those of flat plate by 22% and 78%, respectively.

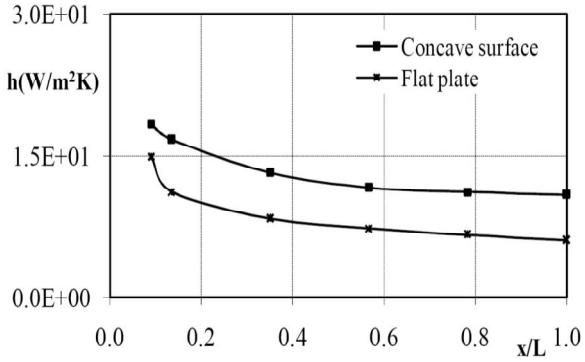


Fig.3.Streamwise variation of the heat transfer coefficient over the flat and concave surfaces.

The streamwise variation of the convective heat transfer coefficients over the flat and ribbed surface are also given in Fig. 4. The local Stanton numbers were bigger than those of flat surface 85% on the first and 50% on the last cavities, and increased up to 200% on the first and 150% on the last ribs. The maximum heat transfer coefficients were obtained at the beginning corners of the first rib due to the strong accelerating and impact effects, and then decreased in the subsequent ribs. The St of the cavities lower than those of the ribs due to the recirculation region, adverse pressure gradient and insulation from main flow, but still higher than the flat plate values.

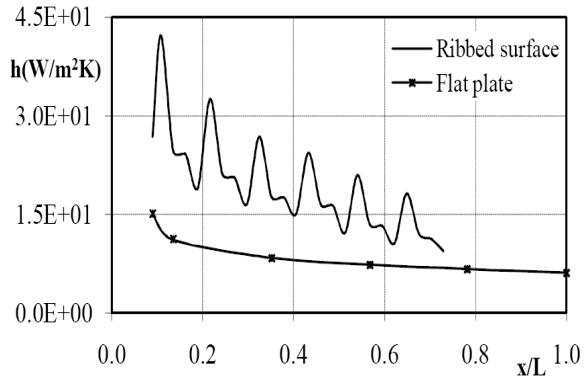


Fig. 4.Streamwise variation of the heat transfer coefficient over the flat and ribbed surfaces.

The dimensionless wall temperatures and Stanton numbers in streamwisedirection which showed reverse distribution in laminar flow near zero pressure gradient flow are given in Figures 5 and 6, respectively. The St values of the flat surface were found 78% and 50% below the concave and ribbed values at the exit of the surfaces, respectively. The concave curvature increased the average St values by 60% due to the thinner boundary layer and higher skin friction coefficient, comparing the flat plate values. The ribbed surface raised the average St by 175% due to higher fluid mixing and turbulence

level. The concave and ribbed surface destabilized the flow and enhanced heat transfer.

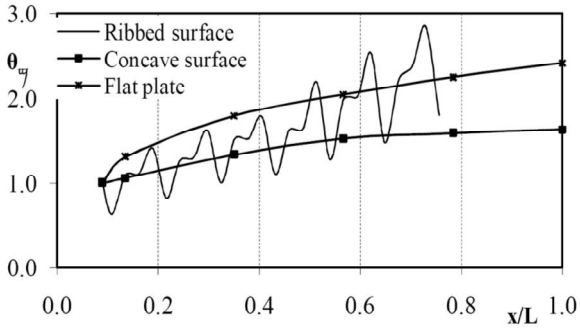


Fig. 5.Dimensionless wall temperatures over flat, concave and ribbed surfaces.

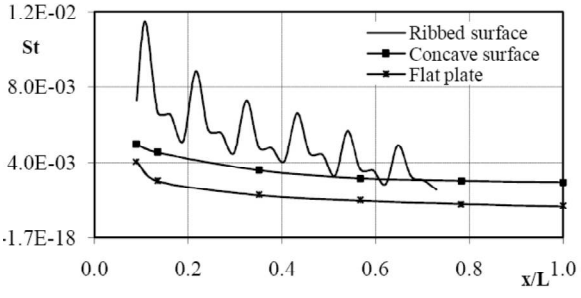


Fig. 6.Streamwise variations of Stanton numbers over flat, concave and ribbed surfaces.

CONCLUSION

The effects of the surface shapes on heat transfer enhancement for the free stream velocity of 2 m/shave been experimentally studied. The concave curvature and presence of the ribs effectively enhanced the heat transfer performance, comparing to the flat plate. The heat transfer enhancement ratios of the ribbed surface were bigger than those of the concave surface. The maximum heat transfer were obtained at the front corner of the first rib and then decreased in the subsequent ribs.The heat transfer values of the cavities of ribs were smaller than those of the top faces of theribs, but still bigger than the flat plate values. The average Stanton numbers of the concave and ribbed surface were higher than those of the flat surface by 60% and 175%, respectively.

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