Fachtagung “Experimentelle Strömungsmechanik”
6. – 8. September 2016, Cottbus

Einfluss strukturierter Oberflächen auf das Strömungsverhalten in einem rechteckigen Kanal

Influence on flow behaviour inside a rectangular channel by patterned surface

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Schlagworte: Hexagonale Strukturen; Widerstandsreduktion ; LDA Messungen.
Keywords: Hexagonal Structures; Drag reduction; LDA Measurements

Abstract

Patterned steel sheets possess better material properties such as tensile strength and bending strength as compared to plain sheets. Due to their known advantages, a series of laboratory experiments has been carried out in the International Graduate School (IGS) at BTU Cottbus-Senftenberg to investigate hexagonal structured sheet surfaces ($k/d = 0.095$); where k is the depth of hexagonal structure and d is the equivalent diameter. In order to examine the possible application of structured sheets, aerodynamic properties and phenomena of structured plates need to be investigated: skin drag, pressure drag, vortex shedding, and boundary layers. In previous study projects, investigations were performed on the flow over structured surfaces (structured cylinders, plates and turbine blades). It was reported that the drag coefficient of the cylinder with patterns pressed outwards was found to be lower than the smooth cylinder by 65% Butt et al. 2013.While for the flat plate fig (2), the maximum reduction in shear stress coefficient was recorded for inwards structured surface of about 19% compared to the smooth surface Butt et al.2014.

In this paper, the experimental investigation for the channel flow is conducted for Reynolds number $Re = U_b\, d\, /\, \nu$ (using the bulk velocity U_b, channel half-width $d = D/2$) ranging from $1.09\text{x}10^4$ to $3.9\text{x}10^4$. The experiments are taken within the wind tunnel of the Department of Aerodynamics and Fluid Mechanics of the BTU Cottbus. The Gottingen-type wind tunnel was designed for good performance up to bulk velocity 50 m/s with background turbulence intensity less than 0.5% of the incident flow. Two parallel plates with a channel height D=50 mm are mounted in the test section of the wind tunnel. The sides of the channel were closed using transparent acrylic glass, to assure the access of the optical measurements to the channel, leading to span wise dimension 11,9 D. The stream wise length measures 22,4 D. Three strips of tripping device sandpapers were used to trigger the turbulent boundary layer at x/D=0.

All measurements were conducted in front and rear the tested sheets using the Laser-Doppler anemometry measuring the stream wise and wall normal velocity component. For computing the mean velocity of the local flow measurements at least 20000 samples were acquired at every measuring position.

A detailed study on the influence of the outwards and inwards facing structures onto the flow properties and phenomena is discussed within this paper.

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Introduction

A quest for drag reduction and hence fuel consumption has always provoked researchers to look for new ways to achieve their aim. Recently, there has been interest in using structure surfaces such as dimples for the purpose of turbulent drag reduction. Early efforts such as the experimental study of Alekseev et al. 1998 report significant drag reduction of up to 20% for dimpled surfaces compared to flat surfaces. However, more recent work such as that of Lienhart et al. 2008, who combined both experimental and numerical simulations, reports only small or no drag reduction for dimples in both open and internal boundary layers. No clear reason has been found for the conflict in such results, but the many parameters that affect the flow over dimples add much to the overall confusion, particularly since many of these parameters, such as the flow turbulence intensity, are often unreported. The flow over the dimples is influenced by a variety of the geometry and the flow parameters. Most significant of these parameters is the dimple depth, often non-dimensionalized by the dimple diameter. The effect of the dimple depth to diameter ratio has been well studied both experimentally Won et al. 2005, Burgess et al. 2005, Kovaleko et al. 2010, Ligrani et al. 2001, Kwon et al. 2011, Merbold et al. 2009 and numerically Isaev et al. 2003, Wang et al. 2006. Flow visualization Won et al. 2005, Burgess et al. 2005, Kovaleko et al. 2010, Ligrani et al. 2001, Kwon et al. 2011, Merbold et al. 2009, Isaev et al. 2003, Wang et al. 2006, Tay et al. 2014 show that dimples with depth to diameter ratios greater than 10% result in the generation of vertical and streamwise vortices. These vortices, which are sometimes periodic, greatly increase the mixing within the flow. The majority of these studies involve dimples in an internal flow environment such as in a channel or pipe. Numerous empirical relations have been proposed relating practically useful parameters such as friction factors with the dimple depth to diameter ratio, Reynolds number, inlet turbulence intensity, channel height, and even the channel aspect ratio Burgess et al. 2005, Mahmood et al. 2002, Ligrani et al. 2005, Isaev et al. 2010.

For an efficient economic use of structured sheets, a state financed Graduate class named ‘Destrukt’ was established. The graduate class was divided into 9 different disciplines to investigate the various aspects of structured sheets as following: Laser processing Sasse et al. 2012, Acoustic Langhof et al. 2013, Aerodynamics Butt et al. 2013, 2014, Corrosion surfaces Kornienko et al. 2011, FE simulation, Design parameters, Production and logistic processes, and Light weight steel manufacturing. The present study focuses on the effect of passive hexagonal structures smooth rounded edges and depth to diameter ratios of 9.5% to investigate the influence of the hexagonal structures on the flow experimentally in a channel flow.

Experimental Setup

The experimental investigation for the channel flow is conducted for Reynolds number Re = U_b d / v (using bulk velocity U_b, channel half-width d = D/2) ranging from 1.09 x 10^4 to 3.9 x 10^4 in wind tunnel of the aerodynamics and fluid mechanics department as shown in fig.(1). The wind tunnel, Gottingen type, was designed for good performance up to bulk velocity 50 m/s with background turbulence intensity less than 0.5% of the incident flow and equipped with a cooling system to fix the temperature at about 20°c. Two parallel plates with channel height 50mm are mounted in the test section of the wind tunnel. The sides of the channel were closed using transparent acrylic glass leading to span wise dimension at 11,9 D. The stream wise length measures 22,4 D. Three strips of tripping device sandpapers were used to trigger the turbulent boundary layer as in fig (3). The Upper and lower plates are equipped with a wide pocket served as a platform for the structured sheets to be investigated. The test sheets of similar width as the upper and lower plates and smaller length were placed in the

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pocket of the plates and fixed with the help of fixing elements on both sides. The surface of the test sheet was set flush to the surface of the plates to avoid stepping and hence any local separation of the flow as shown in fig.(2). All measurements were conducted in front and rear the tested sheets as shown in fig (3) using the Laser-Doppler anemometry. For computing the mean velocity of the local flow measurements at least 20000 samples were acquired at every measuring position. Also pressure gradients are calculated from static pressure measurements using 16 pressure taps along the channel to establish the effect of the dimples on drag in the channel flow. All pressure measurement points are connected to pressure scanner (PSI 9116 Ethernet Pressure Scanner) provided with sixteen channels for simultaneous pressure readings. For each test Reynolds number, the pressure gradient dp/dx was deduced by a linear fit of the measured pressure data. The location and dimensions of the pressure taps are given in Fig.(4). At each x-position there were three pressure taps installed which allowed, prior to the final tests, to check the consistency of the readings as well as the two dimensionality of the flow.

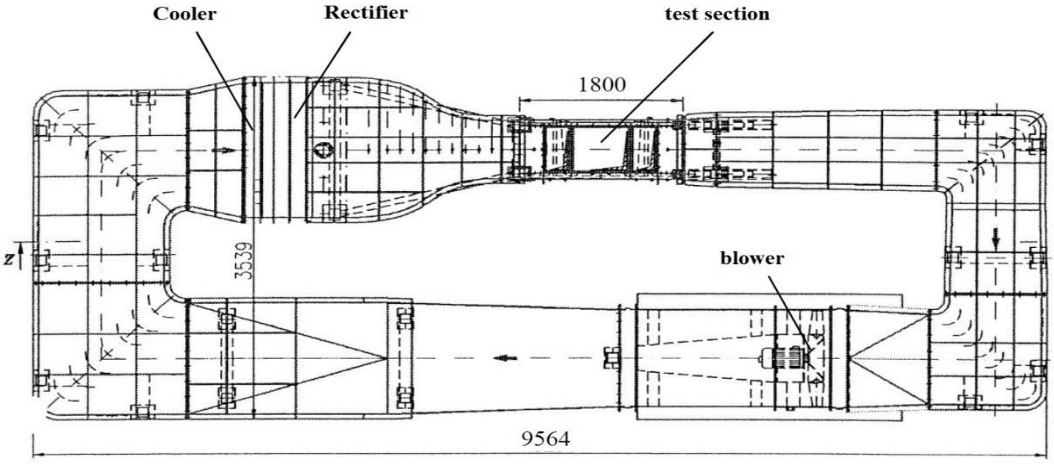

Fig. 1: Sketch for the Gottingen wind tunnel in LAS.

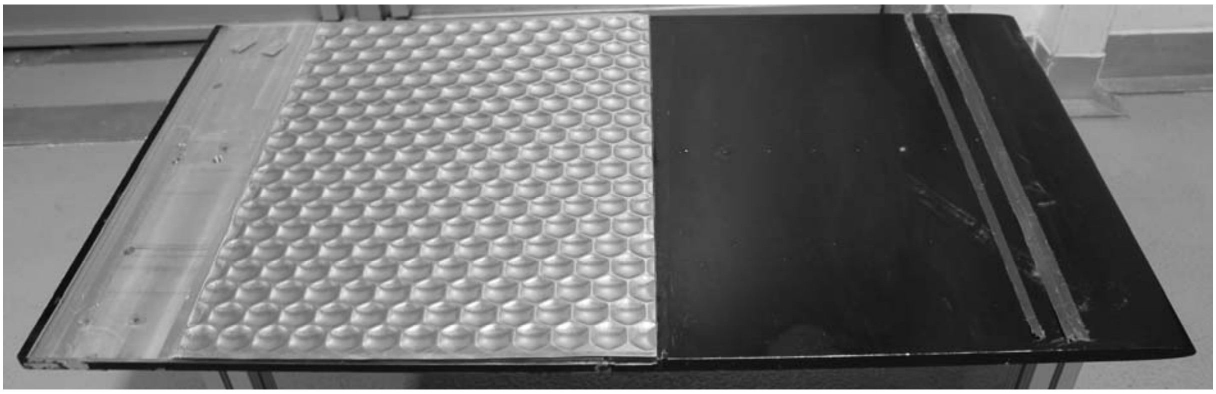

Fig. 2: Structured sheet plate fixed over the lower flat plate. Second plate is mounted above with separation distance of 50mm.

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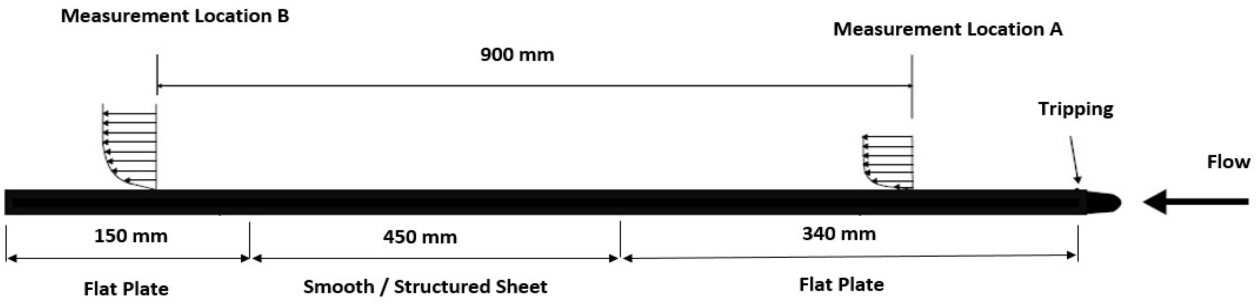

Fig. 3: Sketch for lower plate showing measurement locations.

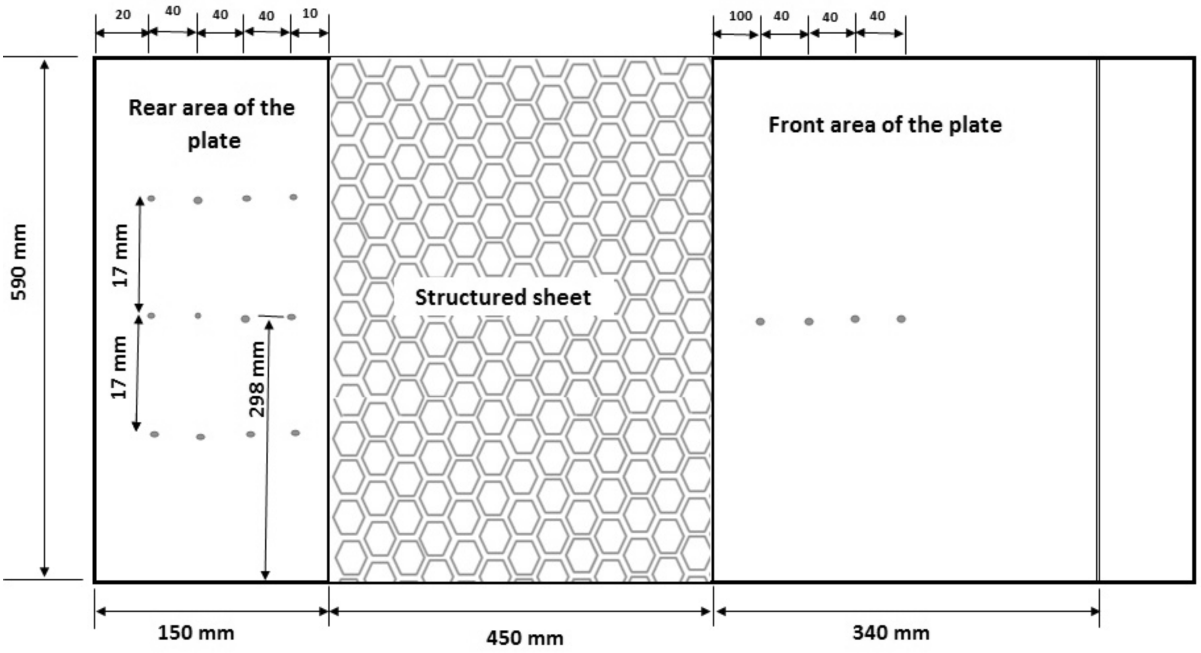

Fig. 4: Sketch for upper plate showing pressure taps locations.

Channel Validation

In order to validate the velocity profile measurements, a Large Eddy Simulations have been performed for the same Reynolds numbers. A Comparison of the Experimental profiles and the LES as well as Direct numerical simulations by Moser et al. 1999 are shown in Fig. 5 and 6 for a turbulent plane channel flow at Re = Ub d / v = 10935 and Re T = 590 is used. This test case has several advantages with smooth walls the flow is homogeneous in streamwise and spanwise directions. This allows to use periodic boundary conditions in both directions and thus avoids the definition of appropriate inflow and outflow boundary conditions.

The experimental results show an agreement with the direct numerical simulation data (DNS) as shown fig. (5, 6), for Re H =10900 for both of the logarithmic profile and the turbulent Intensity.

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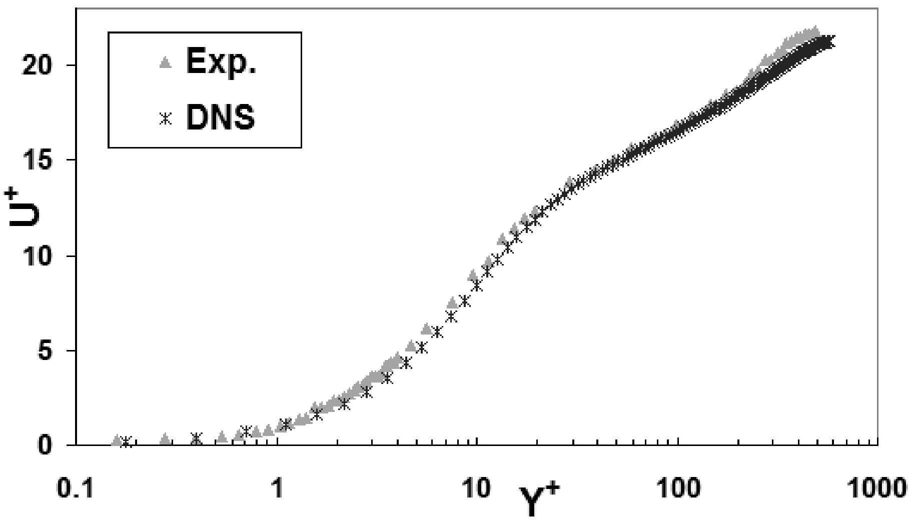

Fig. 5: Comparison of logarithmic velocity profiles and DNS data measured at measurement location B and Re $_H$= 10900.

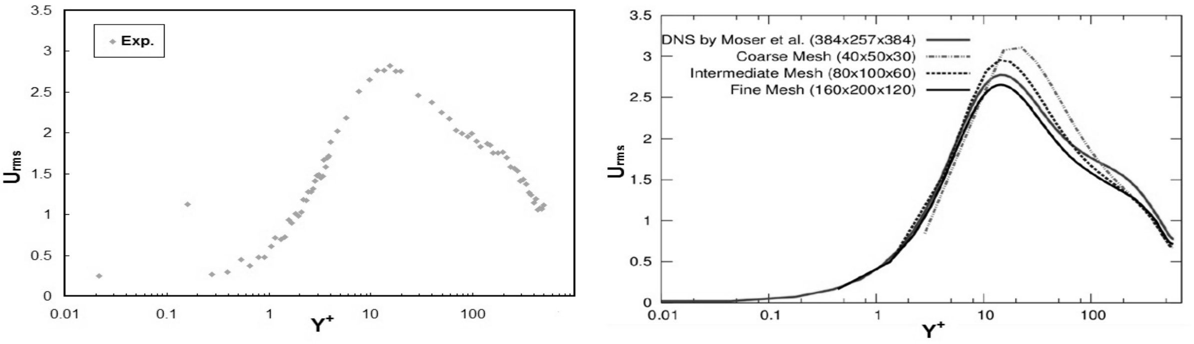

Fig. 6: Comparison of axial turbulence intensity with DNS data measured at measurement location B and Re $_H$= 10900.

Results and conclusions

The velocity profile measured at the measurement location B (rear of the tested sheets) plotted in fig (7) for both the smooth and negative surfaces. At Re $_H$ = 10900 , there is an agreement for the behavior of the flow at the buffer layer of the boundary layer .While the change occurs in the overlap region as the shear velocity (u_t) start to decrease for the negative surface more than for the smooth surface . The same behavior can be noticed in the axial turbulence intensity plot, as both surfaces are similar at the buffer region and in the overlap region another peak appears indicating to an increase of turbulent intensity for the negative surface due to the large scale vortices. This leads to a decrease of the pressure gradient losses for negative surface more than for the smooth surface as shown in fig (9).

By increasing Re $_H$ to be 19800, the shear velocity decreased more as shown in fig. (8) and a higher peak appears too. On the other hand the pressure gradient losses increased for the negative surface. This is due to the wall-shear stresses decrease within the hexagonal structure, leading to a very small recirculation region at the falling edge .However, at the downstream edge of the hexagonal structure, where the fluid flow leaves the surface depression again, large values of the wall-shear stress are found. Also, it is obvious that the hexagonal structure lead to a modified pressure distribution compared with the case of a smooth wall. At both upstream and downstream regions of the hexagonal structure, where the flow either enters or leaves the surface depression, the pressure is slightly decreased. However, more important is the observation that the pressure increases on the rising edge of the hexagonal structure yielding a contribution to the overall drag.

Further investigations will be done for different channel widths to investigate the influence of the channel height to the structure depth ratio on the flow.

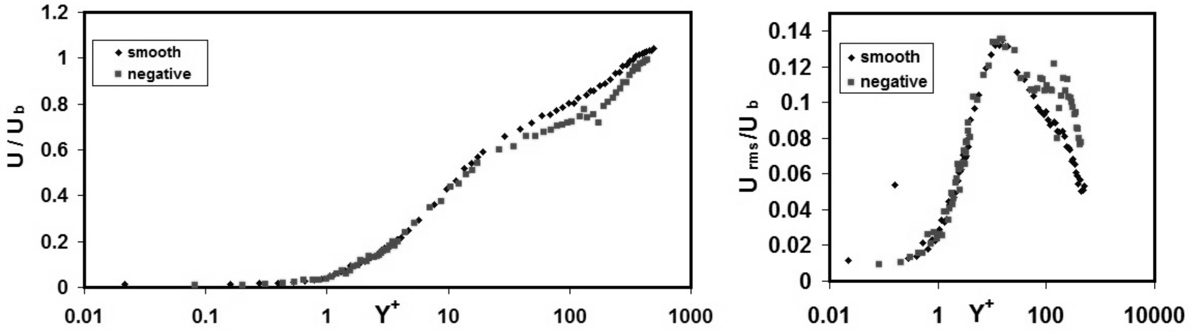

Fig. 7: Logarithmic velocity profiles and axial turbulence intensity measured at measurement location B and Re $_H$= 10900 for both smooth and negative surfaces. U and U rms are normalized using U_b.

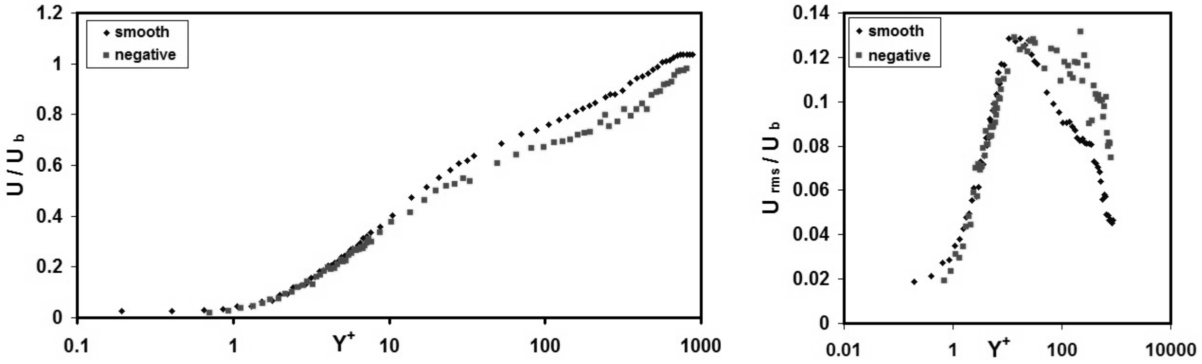

Fig. 8: Logarithmic velocity profiles and axial turbulence intensity measured at measurement location B and Re $_H$= 19800 for both smooth and negative surfaces. U and U rms are normalized using U_b .

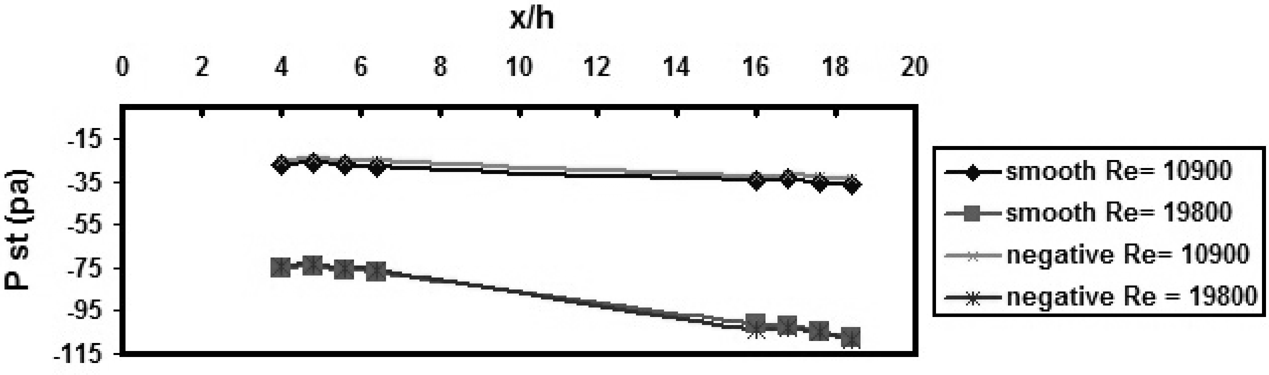

Fig. 9: Pressure gradient losses measured along the upper plate of the channel for both smooth and negative surfaces.

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