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18th Australasian Fluid Mechanics Conference: An experimental study of knitted fabrics used in elite sports

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Abstract

It is important to measure the aerodynamic properties (drag and lift) contributed by fabric in order to design aerodynamically efficient sports garments for higher speed sports. The primary objective of this study is to investigate the aerodynamic properties of fabric over a range of Reynolds numbers varied by speeds. Specially developed cylindrical methodology was used to quantify the effects of aerodynamic properties and fabrics' surface parameters. The study was undertaken experimentally in a wind tunnel environment for a range of five commercial knitted fabrics used in speed sports. Additionally, the electron microscopic analysis was undertaken to study the fabric physical parameters. A correlation between the surface parameter from microscopic studies and the aerodynamic properties of knitted fabric with different roughness was established. The findings indicated that the aerodynamic properties are dependent the fabric's surface structure, and hence can be optimised.

Keywords: Sports fabrics, aerodynamic properties, Reynolds number, wind tunnel, microstructure analysis.

Introduction

Science and technology can play an important role in achieving better outcomes in speed sports. In speed sports, aerodynamics is considered to be one of the decisive factors in the winning margins and elite sports competitions. Wearing sport garment is believed to cause elite athlete to record faster times than other garments. The aerodynamic resistance was acquired at different speeds relevant to high speed sports. Therefore, aerodynamics has become an important factor for increasing demands of high performance in modern speed sports. The surface texture and the corresponding air permeability of speed sports fabrics can potentially exhibit subtle, yet significant influences on drag and flow transitions. Surface roughness is an important parameter for aerodynamic properties due to the transitional properties at the boundary layer. Sports fabrics represent a wide spectrum of surface topologies and wide boundary layer behaviours. Appreciation of aerodynamic behaviour of surface texture, seam and fastener placement, and air permeability of sport garments can provide much needed advantages [1-3].

In recent years, there have been considerable research and studies conducted to evaluate the surface roughness of sports garments [1, 4, 5]. Kyle and Brownlie [2, 6], carrying out systematic wind tunnel studies of drag and flow transitions utilizing both mannequins with athletic apparel and cloth-covered cylinders. Oggiano [1], Chowdhury et al. [3] and Moria et al. [7] carried out experimental studies of different sports fabrics using specially developed cylindrical methodology. These studies showed that the cylinder surface covered with fabrics exhibited less aerodynamic drag than the smooth surfaced cylinder. This has been attributed by the surface morphology of the fabrics. Hence, it is not clear how a speed sport can minimize the aerodynamic drag. The primary aim of this paper is to report a study which was undertaken to understand the aerodynamic behaviour of five knitted fabrics used in speed sports under a range of speeds alone with electron microscopic analysis in order to correlate the aerodynamic properties with their physical parameters (i.e., surface roughness).

Methodology

With a view to obtain precise information on both the drag and aerodynamic lift characteristics of commercial available knitted fabrics, a 90 mm diameter and 220 mm length cylinder was manufactured. The cylinder was made of PVC material and used some filler to make it structurally rigid. The cylinder was vertically supported on a six-components transducer (type JR-3) had a sensitivity of 0.05% over a range of 0 to 200 N. The aerodynamic forces and their moments were measured for a range of Reynolds numbers based on cylinder diameter and varied wind tunnel air speeds (from 30 km/h to 140 km/h with an increment of 10 km/h). Each test was conducted as a function of speed sport fabric.

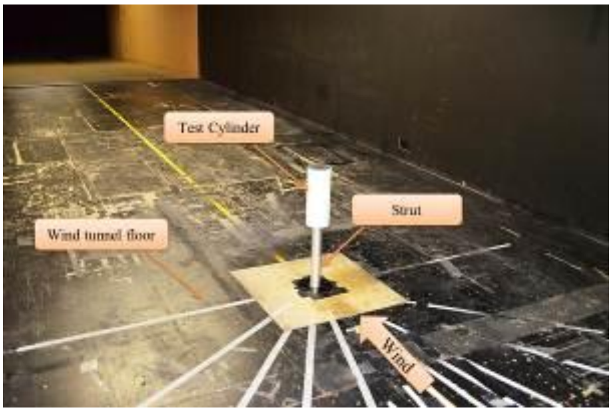


Figure 1. Experimental arrangement of the cylinder geometry in RMIT industrial wind tunnel.

As mentioned earlier, the RMIT Industrial Wind Tunnel was used to measure the aerodynamic properties of sport fabrics. The tunnel is a closed return circuit wind tunnel with a turntable to simulate the cross wind effects. The maximum speed of the tunnel is approximately 150 kilometres per hour (km/h). The rectangular test section dimensions are 3 meters wide, 2 meters high and 9 meters long, and the tunnel's cross sectional area is 6 square meters. An isometric view of RMIT Industrial Wind is shown in Figure 2. The tunnel was calibrated before and after conducting the experiments and air speeds inside the wind tunnel were measured with a modified National Physical Laboratory (NPL) ellipsoidal head Pitot-Static tube (located at the entry of the test section) which was connected through flexible tubing with the Baratron® pressure sensor made by MKS Instruments, USA. The cylinder was connected through a mounting sting with the JR3 multi-axis load cell, also commonly known as a 6 degree-of-freedom force-torque sensor made by JR3. The sensor was used to measure all three forces (drag, lift and side forces) and three moments (yaw, pitch and roll moments) at a time. Each set of data was recorded three times for 30 seconds time average with a frequency of 20 Hz ensuring electrical interference is minimised. Multiple snaps were collected at each speed tested and the results were averaged for minimising the further possible errors in the experimental raw data. Fabric to be tested was wrapped onto the cylinder and joined together by creating a seam which was placed at the rear of the cylinder (e.g., 180° orientation) to minimise the effect of seam on aerodynamic properties (see Moria et al [7]). Further details about the wind tunnel can be found in Alam et al. [10].

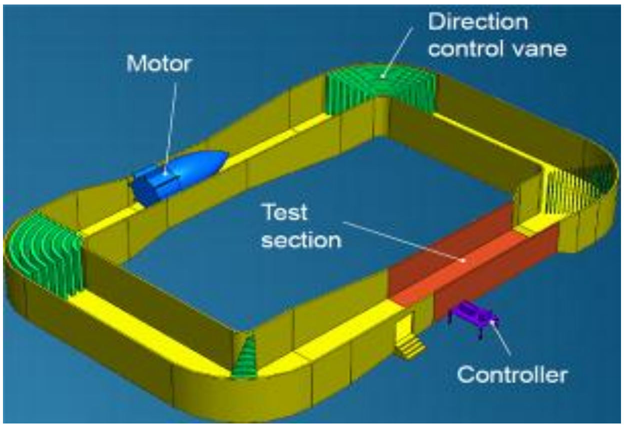


Figure 2. Isometric view of RMIT Industrial Wind Tunnel

To study the effect of surface texture on the aerodynamic properties, five different knitted fabrics were selected. The wind tunnel was used to measure the aerodynamic properties and the KESFB4-A, Kato Tech Co. Ltd. evaluation system was used to measure the fabric surface properties. Figure 3 shows the experimental setup for the textile surface roughness measurement. Details about the KESFB4-A machine and measurement technique can be found in Troynikov et al. [8]. Moreover, Table 1 shows the fabric materials and their compositions.

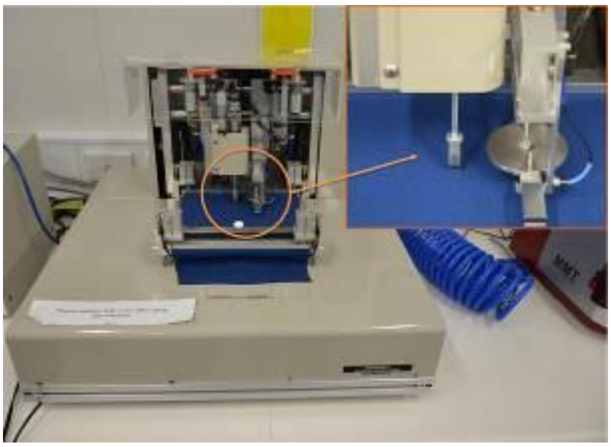


Figure 3. Experimental setup for fabric surface roughness measurements

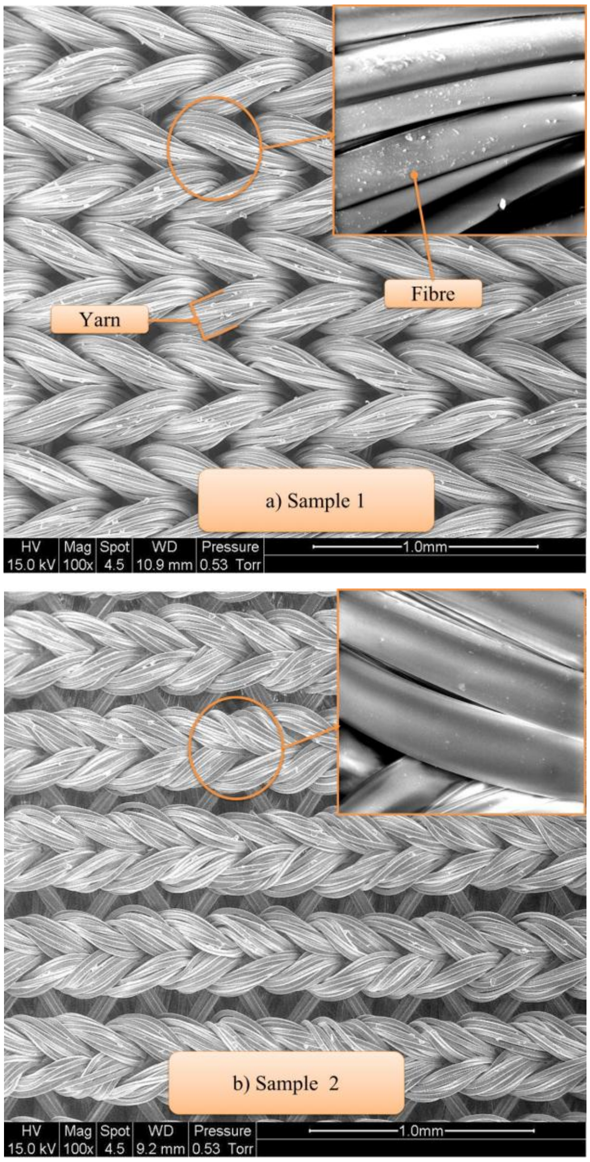
Fabric No.	Fabric Composition	Fabric Thickness, mm
1	92% Polyester & 8% Spandex	0.40
2	85% Nylon & 15 %Spandex	0.60
3	95% Polyester & 5% Spandex	0.65
4	50% Nylon, 45% Polyester & 5% Spandex	0.5
5	80 % Nylon & 20 % Spandex	0.55

Table 1. Material composition for speed sport fabrics.

Results and Discussion

Microstructural Analysis

Yarn and fibre size, and stitch pattern define the surface morphology of the fabric. However, the optical images did not provide detailed information of the surface parameter including the yarn and fibre sizes, and knitting stitch pattern. Hence, a scanning electron microscope (SEM) was used at 100 and 3000 times magnification to reveal in detail the fabric surface parameters. Figure 4, shows the SEM image for the five knitted fabric used in this study. Moreover, Table 2 shows the fabric characterization with SEM image.



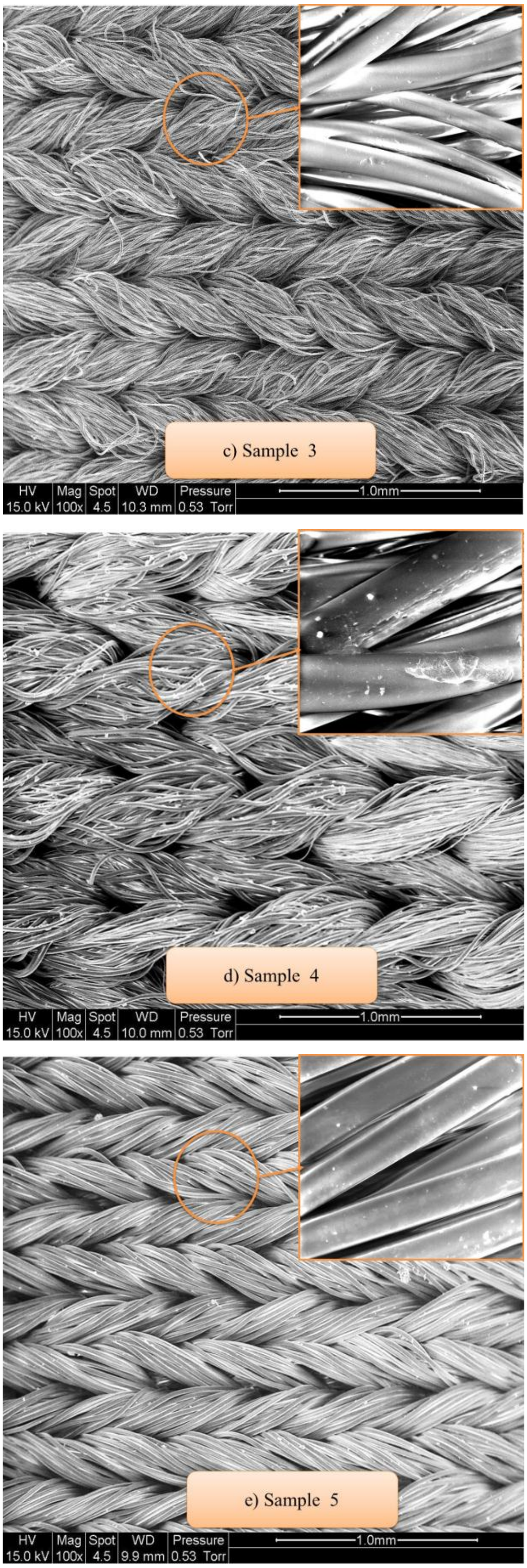


Figure 4. Scanning electron microscope (SEM) image for the five knitted fabric used in this study.

Fabric No.	Yarn Size (µm)	Fibre Size (µm)	Stitch Pattern
1	138	16.67	Circular Loop
2	114	21.11	V-shaped
3	184	11.99	Circular Loop
4	246	18.33	V-shaped
5	146	24.22	V-shaped

Table 2. Fabrics characterization with SEM image.

Aerodynamic Analysis

In this paper, only drag force (F_D) and its dimensionless quantity drag coefficient (C_D) are presented. The C_D was calculated by using the following formula:

$$C_D = F_D/0.5\rho V^2 A \qquad (1)$$

Where F_D, V, ρ and A are the drag force, wind speed, air density and cylinder's projected frontal area respectively. Also another dimensionless quantity the Reynolds number (Re) is defined as:

$$Re = \rho V d/\mu \qquad (2)$$

Where, d and µ are the diameter of the cylinder and absolute air viscosity respectively. The drag versus wind speeds and the C_D as a function of Re for a range of sport speed knitted fabrics are presented in Figures 5 to 6. In order to compare the results of fabrics, the drag force and dimensionless parameter C_D of the bar cylinder were also shown in all figures. Figure 5 shows that drag for the smooth cylinder is continuously increasing without any abrupt changes as expected. However, a sudden drop forces in between 70 and 90 km/h speeds is evident for all the samples tested.

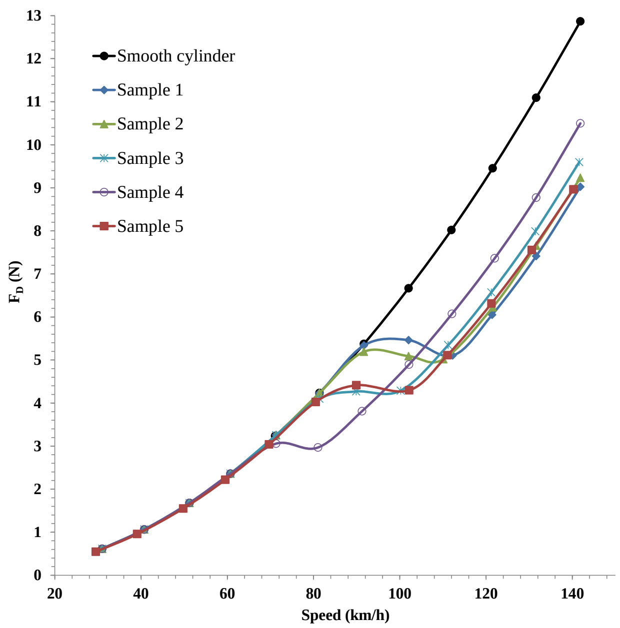


Figure 5. F_D variation with speeds

The C_D variation with Re is shown in Figure 6 clearly indicates that Sample 4 has undergone early transition from laminar to turbulent flow regimes at low speed (60km/h) compared to other samples. Sample 3 and 5 have undergo a similar transition that occurs at slightly higher Re. further delayed transition is seen for Samples 1 & 2 (transition starts at 90 km/h and ends at 110 km/h for sample 1 and start at 80 km/h and end at 110 km/h for sample 2). However, once the transition occurs, the C_D values become significantly lower.

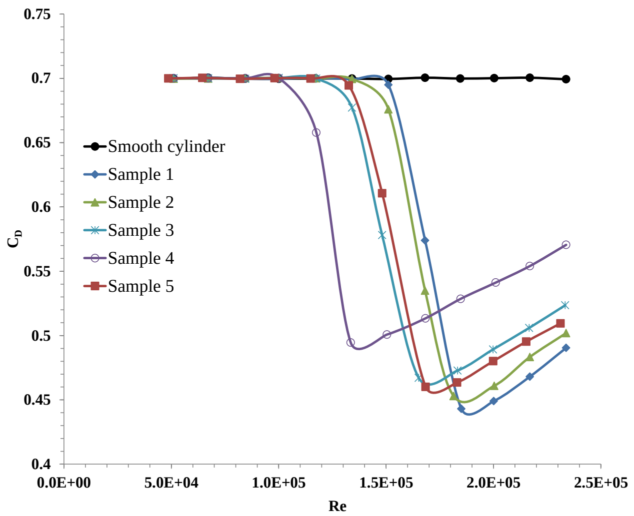


Figure 6. C_D variation with Re

It can be seen from the fabric surface roughness measurements and aerodynamic tests that, with an increase of surface roughness as shown in Figure 7, the magnitude of C_{Dmin} value increases, agreeing with findings of Bearman and Harvey [9] which examined the surface roughness of solid cylinders. Also, with a decrease of relative roughness, the magnitude of C_{Dmin} value decreases as indicated previously (e.g., Achenbach [5]). At the same time, the critical Re at the C_{Dmin} decreases with increasing the surface roughness (see Figure 8).

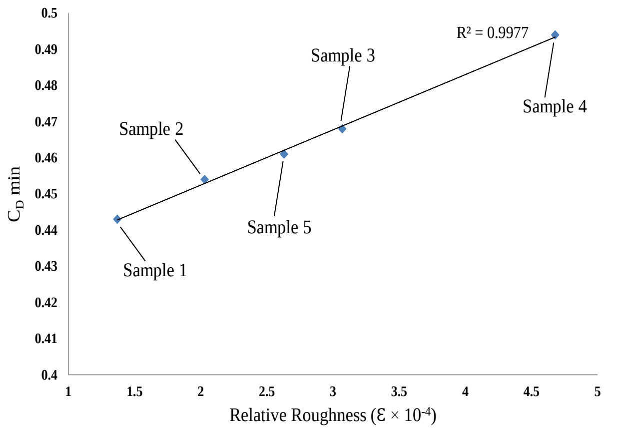


Figure 7. The minimum drag coefficient (C_{Dmin}) variation with relative roughness (ε).

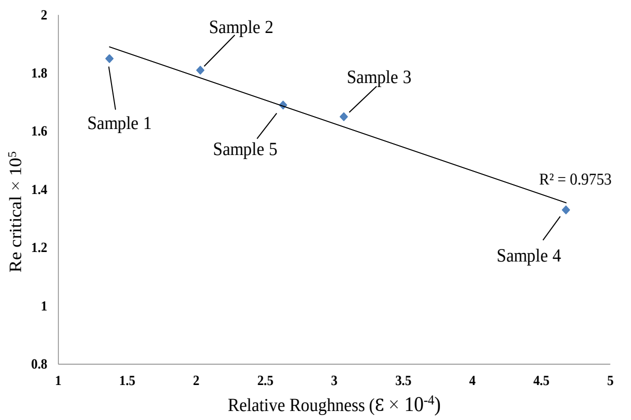


Figure 8. Critical Reynolds number ($Re_{critical}$) variation with relative roughness (ε).

Conclusions

The following conclusions were made based on the experimental study presented here:

- The amount of drag generated by the tested sports fabrics is significantly lower compared to the smoother surface.
- The aerodynamic drag of the tested fabrics is directly dependent on the surface roughness.
- The surface roughness can be utilised to maximise aerodynamic benefit for various speed range.
- Right selection of speed sport fabric for the elite athletes is utmost important for achieving aerodynamic advantages.

Acknowledgments

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