Determination of the pore size of woven structures through image analysis

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Abstract: The paper presents an experimental procedure developed for determination of the pore size, shape and distribution in a single layer woven fabric, for the construction of a virtual model to be incorporated in a future CFD software package. The procedure is based on non-destructive observation and analysis of woven samples. 14 different samples of gray fabrics of 100 % cotton in plain and twill weaves are investigated. The results obtained allow the creation of reality more realistic virtual model of the woven structure, and theoretical investigation of its porosity and permeability through computer simulation.

Keywords: Woven fabrics • Pore size • Porosity • CFD • Image analysis • Non-destructive analysis

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1. Introduction

In the recent decade extensive research has been performed worldwide on fabrics that provide comfort to wearer, being at the same time a protection barrier against outdoor and indoor environmental conditions. The thermal comfort of clothing and textiles is strongly related to fabrics' air permeability, water-vapour permeability, and waterproofness [1]. On the other hand, these three characteristics are dependent on the porosity and the internal structure of the fabrics [2–4].

The use of computational fluid dynamics (CFD) for numerical modeling of the permeability of textile structures can reduce to a minimum or even eliminate the sample weaving. To develop an adequate virtual model, however, different problems have to be overcome. These problems are related with the geometry of the yarn interaction, the proper grid generation, etc. [5].

Several studies were oriented to the investigation of the porous structure of woven fabrics. The reason is that the woven structure, while compared to knitted or nonwoven structures, has the most exactly determined inner geometry, which can be compared to a tube-like porous structure [6]. Dubroski (2000) [7] has developed a three-factor analytical model to determine the volume porosity of woven fabrics and later on the same author presented a geometrical model of the porosity of woven structures, based on the basic characteristics of a fabric: i.e., linear density, weave factor, and relative fabric density [8]. Volume porosity was used in the paper of Militky et al. (2010) [9] to predict the air permeability of 27 of plain woven samples with constant warp density and changeable weft settings. Though several studies have treated the pores
as cylinders with a permanent cross-section over all its length [6, 10–12], the pore size and shape are completely uneven. The same is valid for the pore distribution in the woven fabric [13].

The application of a CFD code for simulation of the air permeability of woven fabrics requires the microstructure of the pores between the threads and pore distribution to be known [14]. The virtual model of a woven structure is relatively easy to be built by using the pre-processor of the CFD code or other graphical software. However, the research studies in textiles usually present complicated and time-consuming methodologies, which increase the price of the CFD simulation. Therefore the aim of this study is to present a method, based on image analysis, which is faster and particularly appropriate for use in CFD software. Both shape and size of the interyarn pores are determined and analyzed. The results obtained allow the creation of closer to the reality virtual model of the woven structure and theoretical investigation of its porosity and permeability through computer simulation.

2. Porosity of the woven structures

Porosity or the volume of the pores is the main characteristic responsible for the air permeability of the woven structures. It determines the comfort of apparel, the thermal insulation efficiency, and the precision of the filter media or the barrier fabric performance.

Woven fabrics are characterized by their hierarchical structure. Generally, this structure consists of two components: yarns, and fibers, which form the yarns. The hierarchical structure of the fabrics makes the problem of the air-permeability simulation quite complex. The air (or any kind of fluid) does not move only between the threads, in the interstices, but also between the fibers in the yarns. Only in the case of fabrics made of monofilaments does the air permeability depend only on the interstices between the threads.

Fig. 1 illustrates the motion of fluid flow with velocity $u_0$ and flow rate $Q_0$ through a screen of a porous woven structure. Part of the flow moves with velocity $u_1$ through the interstices between the threads and it is determined by the porosity of the fabric. However, a percentage of the flow with velocity $u_2$ penetrates through the threads (being staple fiber yarns or polyfilaments), which form the fabric. It is not possible to estimate directly this interrelation via standard measurements. Modelling of the fabric structure, however, could be a useful tool to simulate the influence of the threads parameters and fabric structure on the air permeability.

To apply CFD tools for numerical simulation of the flow through a woven sample, a reliable geometrical model of the fabric has to be built. It requires the following parameters of the fabric to be known: size and shape of the pores in the fabric and their distribution in the fabric area, fabric thickness, flow velocity through the sample, etc. Fig. 2 shows as an illustration the incorporation of a woven sample of 6 warp and 6 weft threads in a computational domain for CFD prediction of the flow through the sample. Fluent 6.3 CFD software is used for building the grid and only the domain and the computational grid (tetrahedron type with local refinement in the zone of the pores) are shown.

The most frequently used method for description of the porosity of woven structures is to use the fabric geometry and its parameters like count of the warp and weft yarns (or their diameter), yarn density in warp and weft direction (yarn density), etc. Therefore the permeability of a single textile layer can be theoretically and experim-