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On the use of image processing techniques for the estimation of the porosity of textile fabrics

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***Abstract*—**This paper presents a novel approach to assessing textile porosity by the application of the image analysis techniques. The images of different types of sample fabrics, taken through a microscope when the fabric is placed over a constant light source, transfer the problem into the image analysis domain. Indeed, porosity can thus be expressed in terms of a brightness percentage index calculated on the digital microscope image. Furthermore, it is meaningful to compare the brightness percentage index with the air permeability and the tightness indices of each fabric type. We have experimentally shown that there exists an approximately linear relation between brightness percentage and air permeability indices.

***Keywords*—**Textile fabrics, porosity, air permeability, image analysis, light transmission.

I. Introduction

The introduction of image analysis techniques in textile industry and engineering enhances quality through the efficient use of metrology and control. There exists a body of research on the online quality control of woven fabric production, [1], as well as on mass reorganization of textile substrates under stress, [2], via optoelectronic techniques. Textile *porosity* and other related properties, such as air permeability or light transparency, have recently become the focal point of wide and intensive research activity, because of the steadily growing interest on technical textiles and composites.

Due to the complex and deformable structure and the non-uniform pore size distribution of textiles, it is somewhat difficult to reach a generalized porosity measure based on measuring the pore dimensions, or using the yarn diameter, etc. in order to calculate the air permeability of the fabric. The novelty of our approach is that we propose a method to estimate a general fabric porosity index not directly, but through the analogy between any such type of index and the air permeability index of a fabric. The latter, however, can be successfully measured via image processing techniques that calculate brightness indices of the fabric, exploiting light transmission properties of textiles.

Textiles are complex mechanical structures consisting of fibers. In the textile production process, the *yarn* is produced in the first step, by combining and paralleling fibers. This is the *spinning* process. Then, according to the intended use of the product, the planar construction known as the *fabric* is obtained, by knitting or weaving of the yarns in a variety of ways. In the knitting process, fabric is obtained by interlocking loops of yarn using needles or wires as shown in Fig. (1.a). Woven fabrics, on the other hand, are made of yarns interlaced in a regular order, which is the process of combining warp and weft yarns at 90^{o} angle to make a plane construction, as in Fig. (1.b). The integrity of the fabric is maintained by the mechanical interlocking of the fibers. Due to the loop formation, knitted fabrics are more flexible than woven fabrics and can be distorted quite easily. Woven fabrics are more stable than knitted fabrics but also quite deformable under stress.

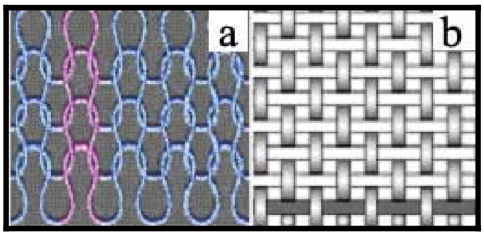

Fig. 1: Two major fabric types: (a) Knitted fabric, (b) Woven fabric.

II. Porosity of Textile Fabrics

The structure of a textile contains *pores* between the fibers and the yarns. It is quite clear that pore dimension and distribution is a function of the fabric geometry. The yarn diameter, surface formation techniques, number of yarn threads for woven fabrics (yarn density) and number of loop count for knitted fabrics per unit area are the main factors affecting the *porosity* of textiles. The porosity of a fabric is connected with certain important features of it, such as air permeability, water permeability, dyeing properties etc.

Thanks to their porous structure, textiles exhibit high fluid permeability. Fluid flow through textiles is a complex physical phenomenon, because of the fibrous and highly non-uniform organization of the structure and deformation. Nevertheless, fluid flow through a fabric is important in order to understand many of the physical and mechanical properties of it. Critical fabric functionalities, like the performance of parachute and sailcloth, efficiency of filtration, transportation of the moisture from body to environment, apparel comfort, thermal insulation properties, the rate of liquid penetration during wet processing

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and liquid removal during drying of fabrics, etc. depend on the permeability and consequently on the porosity of the textiles. When considering the fluid flow through textiles, the shape arrangement and size distribution of voids through which the fluid flows are of great importance. Fabric thickness and differential pressure between the two surfaces of a fabric are the other dominant factors that affect permeability. The pressure gradient through a textile is a function of viscosity, density, rate of the fluid flow and porosity, just as in the case of flow through a pipe, [3].

Permeability of the fabrics can be theoretically and experimentally expressed as the porosity or structure of the porous medium, using parameters such as number of capillaries, averaged pore diameter, etc., [4].

Fluid flow through a porous structure can be described by the relationship of Darcy's law,

$$B = \frac{\mu \cdot t \cdot \nu}{\Delta P} \tag{1}$$

where μ denotes the viscosity of the fluid, t the thickness of the fabric, ν the velocity of the fluid and ΔP the pressure drop across the fabric. B is considered as a constant for the relationship between ν and ΔP and is called the permeability of the fabric. The value for B will depend on the type of porous media and the pore geometry, [5].

Following the reasoning that the void content in a porous media is a primary factor of the media permeability, the Kozeny-Carman equation was developed to provide a description of fluid flow based on the filtration properties. One form of this equation, [6], is the following:

$$B = \frac{1}{K_0 S_0^2} \frac{\varepsilon^3}{(1-\varepsilon)^2} \tag{2}$$

where K_0 is the Kozeny constant, S_0 is shape factor and ε denotes the porosity.

Porosity is defined as the ratio of the projected geometrical area of the opening across the material to the total area of the material. It is also defined as the ratio of the void to the total volume. Hseih in [7] defines porosity as:

$$\varepsilon = 1 - \frac{\rho_a}{\rho_b}, \tag{3}$$

where ρ_a is the fabric density (g/cm^3) and ρ_b is the fiber density (g/cm^3). Fabric density is calculated by dividing the fabric weight per unit area, by fabric thickness.

Porosity can also be calculated from the projected geometrical area of the opening across the material,

$$\varepsilon = \frac{open\ pore\ area}{total\ area} = \frac{P_1 . P_2}{(P_1 + d_1)(P_2 + d_2)} \tag{4}$$

where

P_1 = distance between warp threads,

P_2 = distance between weft threads,

d_1 = diameter of the warp yarn,

d_2 = diameter of the weft yarn.

The main problem in the calculation of porosity is deformation, unevenness and irregular pore size distribution of the textile structures. Neither the distance between yarns nor the diameter of the yarn is uniform; moreover, the thickness is practically never constant across a fabric. Therefore, existing porosity calculation methods that depend on the shape characteristics of the fabric, such as those mentioned earlier in this section, are not useful for estimating the air permeability in practice.

III. Experimental Part

In the experimental part of this study, a set of plain woven cotton fabrics are examined, in order to estimate the porosity of every fabric type through the respective measured air permeability. Fabric types differ in warp and weft yarn count per unit area. The grayscale images of the sample fabrics, taken through a microscope under which we have placed a fixed and constant light source, are used to transfer the porosity estimation into a numerical, image processing task. The digital images are processed to enhance contrast and equalize their histogram. In each enhanced image, the degree of brightness is calculated from a circular pixel area, centered on the light source coordinates. The brightness value thus obtained is the proposed estimate of porosity and it is also compared with the air permeability values.

TABLE I
PROPERTIES AND AIR PERMEABILITY VALUES OF SAMPLES

Sample No:	Warp yarn count per cm	Weft yarn count per cm	Air permeability (cm^3/cm^{2}s)
1	54	20	45,74
2	54	25	27,02
3	54	30	15,68
4	54	35	8,756
5	54	40	4,366
6	54	45	2,9
7	57	20	47,94
8	57	25	27,52
9	57	30	14,84
10	57	35	8,99
11	57	40	3,976
12	57	45	2,684
13	60	20	33,98
14	60	25	17,01
15	60	30	9,754
16	60	35	4,558
17	60	40	2,116
18	60	45	1,698
19	63	20	27,68
20	63	25	15,24
21	63	30	7,226
22	63	35	3,222
23	63	40	1,888
24	63	42	1,608
25	66	20	27,28
26	66	25	14,42
27	66	30	6,898
28	66	35	3,186
29	66	40	1,648
30	66	42	1,372

We have tested thirty (30) woven fabrics to determine the air permeability values. The supplier of the fabrics was Gökhan Tekstil A.Ş., based in Denizli, Turkey. The yarns were made of cotton fibers and the bonding type of each sample was plain. The weft yarn count (Ne40) and the warp yarn count (Ne50) per cm differ in each fabric.

Air permeability (cm^3/cm^2s) was measured via the standard BS5636 method, using the Shirley FX 3300-5 air permeability tester. For each one of the 30 fabric types, we repeated this measurement on five (5) samples, thus obtaining a body of (30 x 50=) 150 measurements. Fabric properties and respective air permeability values are given in Table I.

The images of the sample fabrics were taken through a Zeiss microscope, under which was placed a constant light source. A Sony polaroid microscope camera took the pictures, in order to calculate the light transparency. When the fabrics are white, not only the pores but the fibers also are relatively permeable to light. In order to obtain the light transparency only for pores, we dyed the samples to a black color. Sample pictures of the lighted fabric images are presented in Fig. (2). We took five (5) pictures from each fabric type.

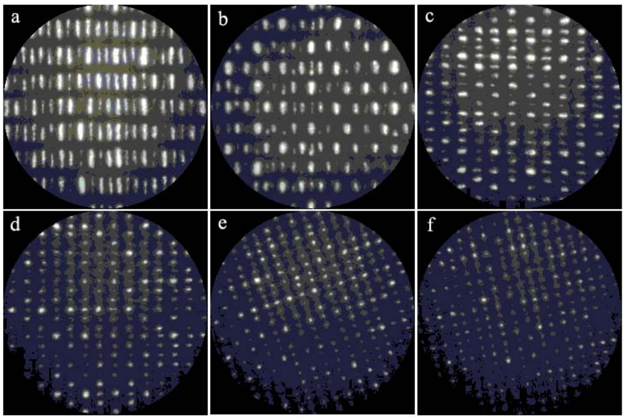

Fig. 2: Pictures of six sample fabric types. (a) Sample no:1, (b) sample no:2, (c) sample no:3, (d) sample no:4, (e) sample no:5, (d) sample no:6.

The next step is to enhance and process the images, which was done using the MATLAB software on a computer. As the images taken were colored, we converted them to grayscale. After processing of the images, the values obtained using MATLAB for

(i) the average illumination and
(ii) the average percent illumination

of each sample were correlated to the air permeability results of the same fabric types.

IV. Results and Discussion

In Figs. (3) and (4) are shown the two image brightness indices (illumination and percent illumination, respectively) calculated using the proposed image processing method for the 30 different fabrics examined. As it can be seen, the two indices portray fully analogous results; percentage values, however, are preferable, as they render results independent of a variety of experimental setup parameters.

As it is can be seen in Figs. (3) and (4), light transparency of the looser fabrics (in the upper position on the graph) is higher than that of the tighter fabrics (in the lower position on the graph), because of the bigger pore dimensions. It is clearly seen that pore dimensions are highly variable across fabrics, thus making it difficult to estimate the porosity of the fabrics via measuring the pore dimensions or yarn diameter through a microscope. Moreover, this procedure is time consuming and sensitive. On the contrary by taking pictures of back lighted fabrics and applying image processing of the digital images thus obtained, one can have objective results on porosity estimation while keeping the practical procedure efficient and simple.

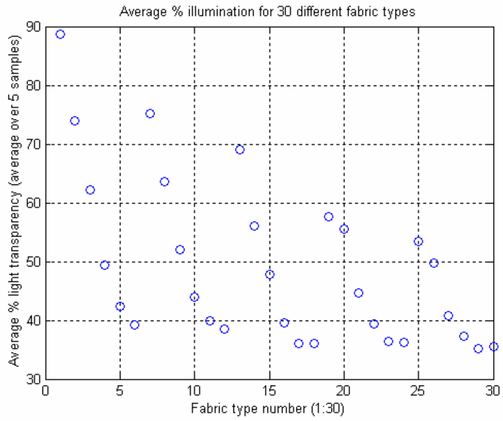

Fig. 3: Average percent illumination count for the thirty fabric types examined. Each value represents the mean of five experiments.

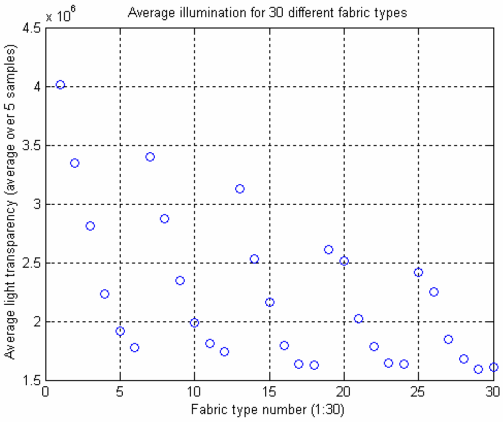

Fig. 4: Average illumination count for the thirty fabric types examined. Each value represents the mean of five experiments.

Loose fabrics, due to the reduced number of bonding points of the yarns per unit area, are more deformable. Consequently, the pore size distribution shows a great variability. On the contrary, tight fabrics have a more stable structure and the pore size distribution does not vary significantly across fabric types.

An interesting result of the set of experiments performed is shown in Fig. (5). Indeed, there exists a clear relation between the brightness percentage and the tightness index of a fabric. The latter we obtain by multiplying the weft and warp yarn counts per cm. However, deviations appear because of the deformation and unevenness of the loose fabrics.

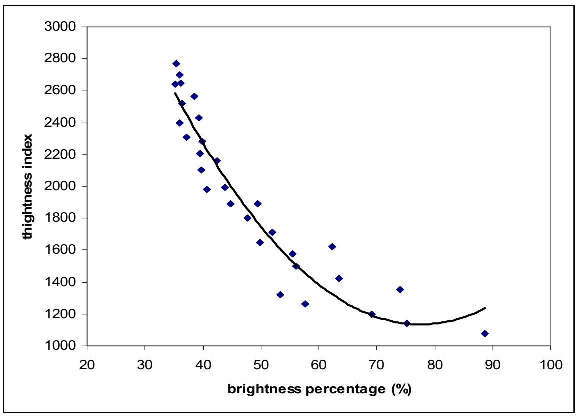

Fig. 5: Relation between brightness percentage and tightness index (weft yarn count x warp yarn count per cm) and fitted curve.

Due to the increase of the warp and weft count per unit area, the air permeability of the fabrics decreases, as shown in Table I, because the dimensions of the pores the air should go through are getting smaller, when moving from loose fabrics towards tight fabrics. For tight fabrics the resistance to air flow is higher than for loose fabrics.

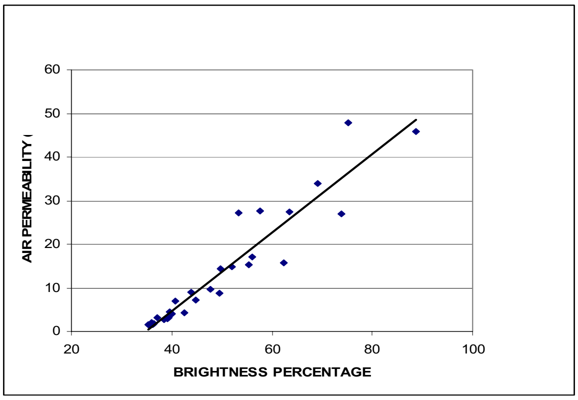

Fig. 6: Relation between air permeability and brightness percentage, with fitted line.

It is obvious that the higher the air permeability, the higher the light transparency. As shown in Fig. (6), there exists an approximately *linear* relationship between brightness and air permeability of fabrics. For loose fabrics, again, deviations from the fitted trend line appear, because of the deformations and their highly non-uniform structure.

V. Conclusion

In this research work we have focused on the application of image processing to the problem of estimation of the porosity of textile fabrics. Intuitively, light transmission increases with porosity but decreases with fabric tightness (increased warp and weft yarn counts). The numerical indices obtained experimentally from the images of all fabric samples tested, have a polynomial relation with the fabric tightness index (warp yarn count x weft yarn count) and a linear relationship with air permeability; however, for looser fabrics there arise deviations from the trend line or from the fitted curve. Because loose fabrics have bigger pores, the mobility of the yarns is quite higher than that of tight fabrics; consequently they are more deformable. In view of the above observation we can conclude that the proposed method gives more reliable estimates of the porosity index for tight fabrics. Furthermore, it has the advantages of being objective and practically simple and efficient.

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