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DETERMINATION OF POROSITY OF TEXTILES WITH AN UNEVEN PORE SIZE

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Abstract

The research studies in the porosity of textile macrostructures have always been relevant, but they have undergone significant progress with the development of optical devices and computer facilities. The main reason for this continuous interest is the strong correlation between textile porosity and the transfer of heat, fluids, and matter. Adequate porosity determination is needed for estimation of the influence of the macrostructure's parameters on the transfer abilities of the textiles and their adequate design.

The present study aims to experimentally determine the porosity of textile macrostructures with uneven pores, using image analysis. Microscopic images of seven fabrics were converted to binary images, and the pore content was assessed. The results were verified with a classical method for the determination of porosity of woven macrostructures. The obtained results show a very good correlation with the theoretical porosity of woven macrostructures. The proposed image analysis can be used for the determination of porosity of other types of textile macrostructures with uneven pore size.

Key words: porosity, uneven pores, textile macrostructures, image processing

Introduction. The porosity of the macrostructure defines the heat and mass transfer processes through the textile [1–3]. Several investigations were dedicated to the assessment of the porosity of woven textiles: both theoretical [4–7] and experimental studies [8–10]. The main reason is that the structure of woven fabrics, unlike that of the knitted and nonwoven textiles, is the most accurate and arranged

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like a tubular porous structure. Most of the studies have treated the pores between the yarns as cylinders with constant cross-section [11, 12], but the size of the pores between warp and weft threads, as well as their shape, are uneven. The same is valid for the distribution of the pores within the macrostructure [13].

The determination of the porosity of textiles with uneven pore size is critical as the known geometrical models cannot be applied. At the same time, air permeability, heat transfer, moisture transfer strongly depend on porosity [14–16]. Porosity data are needed for simulations as well when a proper virtual model of the textile layer has to be created [15, 17]. Adequate porosity determination is also needed for estimation of the influence of the macrostructure parameters on the transfer abilities of the textiles and their adequate design [14, 15, 18].

Methods for direct measurements, based on pore area determination, have been developed [17], but the experimental work is time-consuming and tedious. Zhu and Li [18] used the fractal method, but it cannot be applied if the pore size of the textile is uneven. Oğulata [19] applied air-permeability measurements to experimentally determine the pore size of knitted fabrics, where pores have uneven geometry. However, the method cannot be applied for textile macrostructures with big pores, as the flow resistance of the macrostructure is zero or tends to zero. A sophisticated method for vertical porosity measurement was presented by Havlová [20], but it is needed for woven and knitted textiles from staple yarns and is unnecessary for technical textiles with uneven pores, made of tapes or ribbons.

The present study deals with the determination of the porosity of a non-uniform porous textile structure. The method is based on the processing of microscopic images and can be applied to all types of textile macrostructures: woven, nonwoven, and knitted. The method has been verified with a classical geometric approach to determine the porosity of textile structures.

Material and methods. ***Materials.*** Seven samples of woven fabrics of 100% cotton were selected. The first reason for their selection was that the textiles, woven by using spun yarns, have uneven pore size. The second reason was that a classical geometric approach for the porosity determination of woven textiles exists, and it is widely accepted and used.

Table 1 summarizes the basic characteristics of the textile samples (arranged by both fabric weight and weave patterns). The linear density of both warp and weft yarns was determined before weaving, following ISO 7211-2:1984. Both the weight of the samples and the warp and weft density were also measured, in accordance with BDS EN 12127:2000 and ISO 2060:2019 international standards.

Methodology. A methodology, based on a non-destructive analysis for determination of the size of the pores in a woven macrostructure, was developed and applied. A digital microscope Optika DM-15 with a built-in digital camera was used to make the pictures. Twenty pictures were taken for each sample or a total of 140 images. The resolution of the images was 300 dpi with 256 greyscale level.

Table 1

Structural data of the samples

Sample No	Fabric weight, g/m^2	Fabric density, threads/dm		Linear density, tex		Weave pattern
		Warp, D_{wa}	Weft, D_{wf}	Warp, t_{wa}	Weft, t_{wa}	
1	89	176	124	28	28	plain
2	118	272	218	20	25	plain
3	138	270	266	25	25	plain
4	201	258	238	36	36	plain
5	184	383	338	28	28	twill 2/1
6	202	386	226	30	36	twill 3/1
7	219	376	216	36	36	twill 2/1

The grey scale image was consequently converted to a binary form, using 100 as a threshold of the image intensity, as it was found that the binary versions of the microscopic images did not change significantly up to this threshold value.

The number of pixels in the whole picture was compared to the number of pixels in the pores. Twenty measurements were performed on the twenty images for each sample. Two parameters were determined: the whole number of pixels and the number of black pixels that correspond to the pores in the samples. The porosity P (%) was calculated as:

$$P = \frac{n_p}{N} 100, \ \%, \tag{1}$$

where n_p is the number of black pixels of the pores, and N is the total number of the pixels.

The porosity P can be calculated via the measurement of the pixels of the textile matter (the white pixels). In this case, the porosity of the sample is:

$$P = \left(1 - \frac{n_t}{N}\right) 100, \ \%, \tag{2}$$

where n_t is the number of white pixels that correspond to the textile matter.

The measurement of the black pixels from the twenty images was used for calculation of the average value of the pixels in the pores, their dispersion and variation coefficient. The porosity for each sample was determined following equation (1) and using the average value of pores black pixels.

The obtained values were compared with the theoretically determined porosity of each sample P_t. A well-known geometrical method was used, where the theoretical porosity P_t of a woven macrostructure is determined as:

$$P_t = 100 - (E_{wa} + E_{wf} - 0.01 E_{wa} E_{wf}), \tag{3}$$

where E_{wa} and E_{wf} are the warp and weft cover factors of the woven macrostructure, respectively.

The warp and weft cover factors are calculated using the measured warp density D_{wa} and weft density D_{wf} of the samples, as well as the linear density of the warp threads Tt_{wa} and the linear density of the weft threads Tt_{wf}, tex, namely:

$$E_{wa} = k_f D_{wa} \sqrt{\frac{Tt_{wa}}{1000}}, \ \% \tag{4}$$

and

$$E_{wf} = k_f D_{wf} \sqrt{\frac{Tt_{wf}}{1000}}, \ \%, \tag{5}$$

where k_f is a coefficient that depends on the material.

To compare the porosity determined by image processing and the theoretical porosity calculated from eq. (3), the relative error was used:

$$Er = \frac{(P_t - P)}{P_t} 100, \ \%. \tag{6}$$

Results and discussion. Figure 1 presents the microscopic pictures of the textile samples (4 times enlargement) and their binary images.

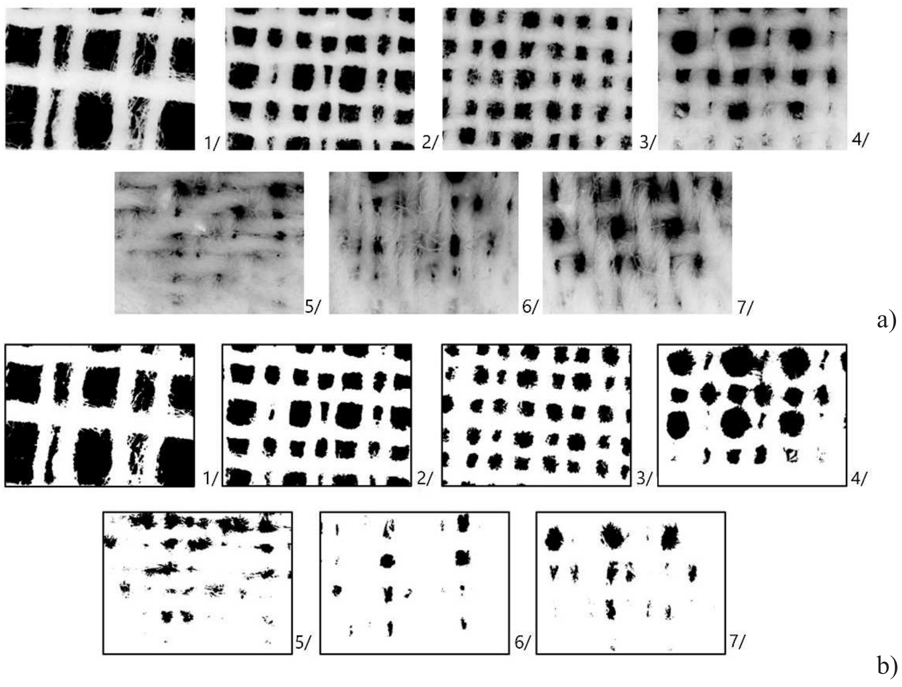

Fig. 1. The investigated textile macrostructures: a) microscopic pictures; b) binary images

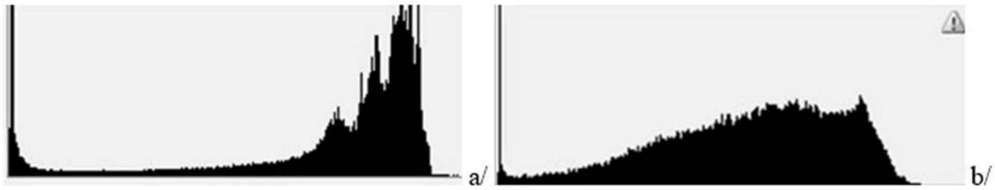

Fig. 2. Histograms of the binary images: a) Sample 1; b) Sample 7

Figure 2 compares the histograms of the binary images of the most porous Sample 1 (light-weighted fabric) and Sample 7 (the heaviest fabric, supposing to be the less porous). The graphs of the histograms clearly show that Sample 1 (Fig. 2a) lets more light to pass through the pores between the yarns, compared to Sample 2 (Fig. 2b).

The results from the image processing are shown in Table 2. Four values were determined for each sample: the total amount of pixels in each image, average amount, standard deviation, and variation coefficient of the black pixels.

The variation coefficient of the determined black pixels is under 5% for all samples except for Samples 5 and 7. A reason for Sample 7 is that this is the most tightly woven macrostructure, and the appearance of a pore with bigger area influences sizably the amount of the black pixels. The last could also explain the high relative error for Sample 7.

The other values that need comments are the relative errors for Samples 1 and 5. The measured on the binary images porosity of Sample 1 is 5.6% lower than the theoretically determined porosity, which leads to 11.78% relative error. Sample 1 has the most porous macrostructure. It is possible that the applied threshold for the binary image is a bit low and covers part of the pore pixels. The same could be the reason for the higher error of Sample 7: the threshold to be a bit high and covers part of the textile matter pixels. In any case, the results show that further estimation of the threshold influence has to be done. As for the error

Table 2

Results from the image processing

Sample No	All pixels	Pore pixels			Porosity P, %	Theoretical porosity P_t, %	Error Er, %
		average	standard deviation	variation coefficient, %			
1	120000	50771	1453.6	2.86	42.31	47.96	11.78
2	120000	35205	1505.1	4.28	29.34	30.24	2.98
3	120000	29036	858.2	2.96	24.2	23.94	1.09
4	120000	21766	784.5	3.60	18.14	17.31	4.79
5	120000	13519	753.7	5.57	11.27	13.05	13.64
6	120000	10884	444.3	4.08	9.06	8.88	2.03
7	120000	7971	834.9	10.47	6.64	7.23	8.16

of Sample 7, it could be partly due to the higher variation coefficient of the black pixels' measurement and partly – due to threshold conversion used in the binary image.

Despite the amplitude of the relative error, it can be concluded that the method for measurement of the porosity of textile macrostructures with uneven pores gives very good results. The method is fast and requires a high-resolution digital camera (with or without a microscope) and software for image processing. The main advantage of the method is that it can be applied for any textile macrostructure: woven, nonwoven, or knitted. For comparison, the theoretical calculation of the porosity (eq. (3)) can be applied only in the case of woven macrostructures and requires time-consuming measurement of the linear density of the warp and weft threads, as well as the determination of the warp and weft density.

Conclusions. A method for determination of porosity of textiles with irregular shape of the pores is presented, based on the processing of binary images of textile layers with woven macrostructure. The experimental results are very close to the calculated theoretical porosity based on a widely used geometrical model.

As the threshold determines the image segmentation and can influence the porosity, calculated by eq. (2), a future work is foreseen on this topic. A relationship between the geometric structure of textiles with known porosity and the threshold for the binary conversion of their images will be searched.

The method allows fast and accurate measurement of porosity and can be successfully applied for the determination of porosity of more complicated textile macrostructures as knitted and nonwovens.

REFERENCES

[1] Daukantiene V., A. Skarulskiene (2005) Wear and hygienic properties of cotton velvet fabrics light industry–Fibrous materials, In: Proceedings of Radom International Scientific Conference Radom, Poland, 355–358.

[2] Wilbik-Halgas B., R. Danych, B. Wiecek, K. Kowalski (2006) Air and water vapour permeability in double-layered knitted fabrics with different raw materials, FIBRES and TEXTILES in Eastern Europe, **14**(3), 77.

[3] Havlová, M., J. Špánková (2017) Porosity of Knitted Fabrics in the Aspect of Air Permeability-Discussion of Selected Assumptions, Fibres & Textiles in Eastern Europe, **25**(3(123)), 86–91.

[4] Love L. (1954) Graphical relationships in cloth geometry for plain, twill, and sateen weaves, Textile Research Journal, **24**(12), 1073–1083.

[5] Hamilton J. B. (1964) 7—A general system of woven-fabric geometry, Journal of the Textile Institute Transactions, **55**(1), T66–T82.

[6] Peirce F. T., J. R. Womersley (1978) Cloth geometry, Textile Institute.

[7] Seyam A., A. El-Shiekh (1994) Mechanics of woven fabrics: Part IV: Critical review of fabric degree of tightness and its applications, Textile research journal, **64**(11), 653–662.
[8] Dubrovski P. D. (2000) Volume porosity of woven fabrics, Textile research journal, **70**(10), 915–919.
[9] Jakšić D., N. Jakšić (2007) Assessment of porosity of flat textile fabrics, Textile research journal, **77**(2), 105–110.
[10] Zupin Ž., A. Hladnik, K. Dimitrovski (2012) Prediction of one-layer woven fabrics air permeability using porosity parameters, Textile Research Journal, **82**(2), 117–128.
[11] Kulichenko A. V., L. V. Langenhove (1992) The resistance to flow transmission of porous materials, Journal of the Textile Institute, **83**(1), 127–132.
[12] Xu G., F. Wang (2005) Prediction of the permeability of woven fabrics, Journal of Industrial Textiles, **34**(4), 243–254.
[13] Çay A., S. Vassiliadis, M. Rangoussi (2004) On the use of image processing techniques for the estimation of the porosity of textile fabrics, International Journal of Signal Processing, **1**(1), 51–54.
[14] Neves S. F., J. B. L. M. Campos, T. S. Mayor (2015) On the determination of parameters required for numerical studies of heat and mass transfer through textiles–Methodologies and experimental procedures, International Journal of Heat and Mass Transfer, **81**, 272–282.
[15] Puszkarz A. K., I. Krucicska (2018) Modeling of Air Permeability of Knitted Fabric Using the Computational Fluid Dynamics, Autex Research Journal, **18**(4), 364–376.
[16] Malik S. A., R. T. Kocaman, T. Gereke, D. Aibibu, C. Cherif (2018) Prediction of the Porosity of Barrier Woven Fabrics with Respect to Material, Construction and Processing Parameters and Its Relation with Air Permeability, Fibres & Textiles in Eastern Europe, **26**(3(129)), 71–79.
[17] Angelova R. (2012) Determination of the pore size of woven structures through image analysis, Open Engineering, **2**(1), 129–135.
[18] Zhu F., K. Li (2010) Determining effective thermal conductivity of fabrics by using fractal method, International Journal of Thermophysics, **31**(3), 612–619.
[19] Oğulata R. T., S. Mavruz (2010) Investigation of porosity and air permeability values of plain knitted fabrics, Fibers & Textiles in Eastern Europe, **18**(5), 71–75.
[20] Havlová M. (2014) Model of vertical porosity occurring in woven fabrics and its effect on air permeability, Fibres & Textiles in Eastern Europe, **22**(4(106)), 58–63.

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