Air permability of worsted fabrics

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REZUMAT – ABSTRACT

Permeabilitatea la aer a țesăturilor din fire pieptănate

Confortul reprezintă unul dintre cele mai importante aspecte ale îmbrăcămintei. Permeabilitatea la aer, una dintre caracteristicile de confort ale țesăturilor, depinde în principal de structura țesăturii, care poate fi descrisă prin legătură și densitatea firului. În acest studiu, au fost produse 16 mostre de țesături din fire pieptănate pentru îmbrăcăminte de iarnă, utilizând opt tipuri de legături implementate frecvent, împreună cu o desime de urzeală (28 fire de urzeală/cm) și două desimi de bătătură (25 și 28 fire de bătătură/cm). Suplimentar, un finisaj semi-mat a fost aplicat pe țesăturile brute. Rezultatele au arătat efectul legăturii, al desimii firelor de bătătură și al finisajului asupra permeabilității la aer a țesăturilor. Țesătura cu legătură diagonal 2/2, a cărei porozitate este cea mai mică, are cele mai scăzute proprietăți de permeabilitate la aer, de aceea este mai potrivită pentru a fi utilizată pentru confecționarea îmbrăcămintei de iarnă. Se observă că, în toate tipurile de legătură, o creștere a desimii firelor de bătătură a determinat scăderea permeabilității la aer și a valorilor de porozitate. Procedeul de finisare duce, de asemenea, la scăderea porozității, reducând astfel proprietatea de permeabilitate la aer.

Cuvinte-cheie: permeabilitatea la aer, țesături din fire pieptănate, țesături, legătură, densitatea firului, porozitate

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Comfort is one of the most important aspects of clothing. Air permeability, one of the comfort charectaristics of fabrics, depends mainly on the fabric structure, which can be described by weave and yarn density. In this study, 16 worsted woven fabric samples were produced for winter clothing using eight frequently implemented weave types together with one warp density (28 ends/cm) and two weft densities (25 and 28 picks/cm). Additonally, semi-dull finish was applied on raw fabrics. Results revealed the effect of weave, weft yarn density and finishing process on air permeability of woven fabrics. 2/2 twill woven fabric, whose porosity is the lowest, have the lowest air permeability properties, therefore it is more convenient for winter clothing. It is observed that in all weave types, an increase at weft setting caused to decrease in air permeability and porosity values. Finishing process also leads to decreasesin porosity thereby to decrease air permeability property.

Keywords: air permeability, worsted fabrics, woven fabrics, weave, yarn density, porosity

INTRODUCTION

Air permeability, which is an important factor in clothing comfort, is an essential characteristic of apparel fabrics. In summer, the transfer of heat and sweat from human body to the atmosphere depends mainly on the permeability of the clothing material; therefore, a highly permeable material is preferable. However, the winter clothing should be less permeable to protect the human body from the cold weather. The effects of various fabric and test parameters on the air permeability of fabrics have been studied by many researchers.

Behera, Ishtiaque, and Chand measured air permeability of plain and twill fabrics [1]. They observed that plain fabric is more permeable to air than twill fabric. Almetwally and Mourad investigated the effect weave structures on the air permeability properties of cotton/spandex woven fabrics [2]. They observed that the order of fabric air permeability is as follows: plain > satin > twill. Zupin, Hladnik and Dimitrovski investigated the air permeability of 36 samples in nine different weave types and four different densities [3]. From this analysis it was found that samples woven in plain weave had nearly 25% higher air permeability than the samples woven in twill weave at the same density of the woven fabrics and also warp and weft densities strongly influenced the air permeability of woven fabrics. Vimal produced a series of woven fabrics differing only in weave structures and having the common count and fabric sett from three types of doubled yarns, namely compact/compact, conventional/conventional and compact/conventional [4]. Among the parameters, thickness exerted a strong influence on the air resistance. Buyukbayraktar investigated the effects of bagging deformation of the fabric to the air permeability performance [5]. She observed that weave type determined the air permeabilityresults of deformed fabrics when all other structuralparameters were same.

Umair et al. produced six different woven samples on air jet loom with two different weave designs (i.e. 3/1 twill and plain), three different picking sequences (i.e. single pick insertion (SPI), double pick insertion (DPI) and three pick insertion (3PI)) [6]. They found that fabrics woven in plain weave design and with simultaneous 3PI gave significantly better air permeability as compared to twill woven fabrics and those with double or SPI. Turan and Okur examined the effect of different weft settings on air permeability and porosity [7]. They observed that in all weave types (plain, 2/2 twill, 3/1 twill) an increase at weft setting caused decrease in air permeability and porosity values. Çay and Tarakçıoğlu dried thirty woven fabrics with different porosities by vacuum extraction method [8]. Due to the increase of the warp and weft yarn density, the air permeability of the fabrics decreased. Basal, Mecit, Duran and Ilgaz produced woven fabrics at three weft densities [9]. They observed that at high weft densities airpermeability was low. Oğulata and Mezarcioz carried out on seven woven samples (one panama weave, six plain woven) in different warp and weft densities [10]. They observed that if a fabric has very high porosity, it can be assumed that it is permeable.

Lolaki, Shanbeh and Borhani investigated the effect of fabric structural parameters of double-face woven fabrics [11]. Results revealedthe effect of kind of porous yarn, hole size of hollow yarn, and weft density on air permeability and moisturetransfer of woven fabrics. Angelova et al. prepared 14 systems of fabrics, used for the production of outerwear clothing for protection from cold, on the basis of 16 single textile macrostructures: 14 woven and two non-wovens [12]. They observed that the air permeability of the single layer decreased with the increment of its thickness and mass perunit area, while the higher porosity had a positive effect on the transfer of air. Urbas, Kostanjšek and Dimitrovski wove six different structures of woven cotton fabrics – one-layer fabric, double-weft fabrics and double fabrics [13]. They found that air permeability is only the function of porosity of samples and their pore structure.Mahbub et al. investigated the air permeabilities of plain woven Kevlar/wool and Kevlar ballistic fabrics [14]. They observed that the Kevlar/wool fabric has higher airpermeability and optical porosity than Kevlar fabric.

Önder, Kalaoğlu and Özipek examined ten samples varying in raw materials, yam production methods, and fabric construction [15]. They observed that polyester and yarn type significantly affected fabric air permeability.

The studies in literature focused on fabrics woven with basic weaves such as plain, twill, satin. However matt (basket), herringbone and diced weaves and worsted woven fabrics have not been investigated. The aim of this study was to investigate the effects of fabric structural parameters and finishing process on the air permeability of the commonly used clothing worsted fabrics. In this regard, an experimental study has been carried out and then, the effects of the parameters were detected firstly by graphics formed by obtained data and secondly by analysis of variance.

THEORETICAL

Since textiles are discontinuous materials, being produced from macroscopic sub-elements such as fibres and filaments, they have void spaces or pores and therefore finite porosities [16]. Hseih defines porosity as [17]

$$\varepsilon = 1 - \frac{\rho_a}{\rho_b} \qquad (1)$$

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

The pores of a fabric can be classified as pores between the yarns and the pores within the yarns between the fibres (micro voids). The dimensions of the pores between the yarns are directly affected by the yarn density and yarn thickness. By the increasing of the yarn density, the dimensions of the pores become smaller, thus the permeability decreases [18–19]. The dimensions of pores within the yarns between the fibres (micro voids) are generally affected by fibre fineness, yarn count, yarn twist and crimp, and also the deformation and flattening of the yarns. During the air flow, air tends to pass through the largest pore. For loose fabrics, air mainly passes through the pores between the yarns due to the large pore dimensions; however, a dominant air flow through the yarns between the fibres can occur in the case of dense fabrics that have very small pores between the yarns [20]. The resistance of the fabric to air is very high in dense fabrics, so air passes through all the voids. According to the fabric structure, a great variation on the amount of the air flow and the air flow paths can be possible.

MATERIALS AND METHOD

Materials

In this research sixteen types of worsted fabric samples were woven by DORNIER modified loom with rapier picking mechanism. Nm 80/2 staple fiber of 45/55% WO/PES blend worsted yarn in blackcolor was used. Weave patterns are shown in figure 1. While warp setting on the loom of was 28 cm^{-1}, weft settings on the reed were 25 and 28 cm^{-1}. Semi-dull finish was applied on fabric samples in singeing, rinsing, mini stenter, foulard and decofast machines, respectively. Face of fabrics was singed with the passing speed of 110 m/min. The temperature of blanket was 80 °C. Internal pressure was 14 mbar. And then, fabrics were rinsed at 50 °C with the speed of 20 m/min in rinsing machine. They were fixed thermally at 190 °C with the speed of 2 m/min in mini stenter. And later, they were treated with the silicone solution, whose concentration was 40 g/l, in foulard. Lastly, they were applied decatizing treatment at cylinder pressure of 3 bar and felt pressure of 0.2 bar with the speed of 18 m/min in decofast.

Fabric samples were coded according to finishing, their weave pattern and weft densitiesas in table 1. While the letter in each fabric code represents finishing, numbers represent weave patterns and weft yarn densities. Plain, 2/1 twill, 2/2 twill, 5 end sateen, 2/2 matt and 2/1 herringbone weaves are square

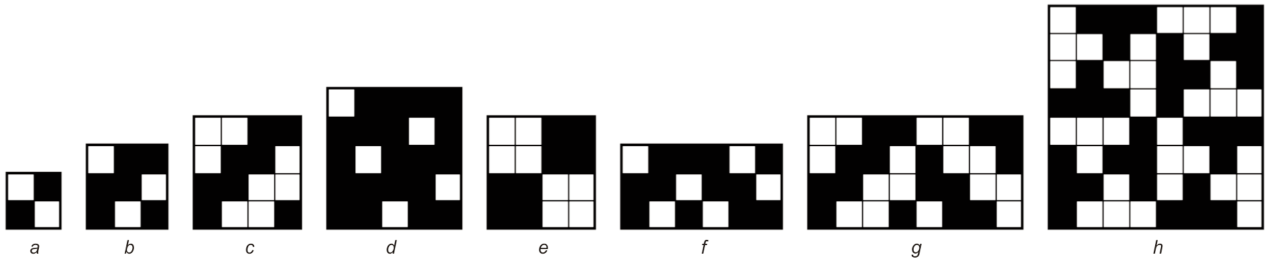

Fig. 1. Weave patterns used in experimental

Table 1

Fabri code	Finishing	Weave	Warp setting on the loom (cm^{-1})	Weft setting on the reed (cm^{-1})	The weave interlacing coefficient	Thickness (mm)	Mass per unit area (g/m^2)	Porosity (ε)
A1	Raw fabric	Plain	28	25	1	0.34	158.5	0.32
A2	Raw fabric	Plain		28		0.36	167.4	0.28
A3	Raw fabric	2/1 Twill	28	25	0.67	0.45	163.9	0.24
A4	Raw fabric	2/1 Twill		28		0.47	172.8	0.20
A5	Raw fabric	2/2 Twill	28	25	0.5	0.40	161.3	0.22
A6	Raw fabric	2/2 Twill		28		0.42	169.5	0.19
A7	Raw fabric	5 End sateen	28	25	0.4	0.38	160.2	0.18
A8	Raw fabric	5 End sateen		28		0.41	170.1	0.14
A9	Raw fabric	2/2 Matt	28	25	0.5	0,36	159.1	0.20
A10	Raw fabric	2/2 Matt		28		0.38	168.3	0.17
A11	Raw fabric	2/1 Herringbone	28	25	1.5	0.44	163.5	0.26
A12	Raw fabric	2/1 Herringbone		28		0.46	172.2	0.23
A13	Raw fabric	2/2 Herringbone	28	25	0.625	0.41	161.8	0.30
A14	Raw fabric	2/2 Herringbone		28		0.43	169.7	0.26
A15	Raw fabric	Diced weave	28	25	0.625	0.42	162.4	0,28
A16	Raw fabric	Diced weave		28		0.44	172.1	0.25
B1	Finished fabric	Plain	28	25	1	0.36	153.7	0.29
B2	Finished fabric	Plain		28		0.38	162.6	0.25
B3	Finished fabric	2/1 Twill	28	25	0.67	0.47	158.7	0.20
B4	Finished fabric	2/1 Twill		28		0.49	149.6	0.17
B5	Finished fabric	2/2 Twill	28	25	0.5	0.42	156.5	0.19
B6	Finished fabric	2/2 Twill		28		0.44	148.6	0.16
B7	Finished fabric	5 End sateen	28	25	0.4	0.40	155.3	0.15
B8	Finished fabric	5 End sateen		28		0.43	145.6	0.10
B9	Finished fabric	2/2 Matt	28	25	0.5	0,38	154.2	0.17
B10	Finished fabric	2/2 Matt		28		0.40	145.7	0.14
B11	Finished fabric	2/1 Herringbone	28	25	1.5	0.46	158.4	0.23
B12	Finished fabric	2/1 Herringbone		28		0.48	150.3	0.20
B13	Finished fabric	2/2 Herringbone	28	25	0.625	0.43	156.7	0.26
B14	Finished fabric	2/2 Herringbone		28		0.45	148.9	0.23
B15	Finished fabric	Diced weave	28	25	0.625	0.44	157.6	0.25
B16	Finished fabric	Diced weave		28		0.46	147.5	0.22

weaves, so the number of each warp and weft yarn interlacing is equal to each other, namely the average yarn interlacing is equal to number of yarn interlacing. The weave interlacing coefficient, defined by Galcerán was calculated by equation 2 [21]

$$KL = \frac{i}{w_1 \times w_2} \quad (2)$$

where i is the number of interlacing points in weave repeat, w_1 – the number of ends in weave repeat, w_2 – the number of picks in weave repeat.

Table 2

Weave pattern	The warp yarn interlacing coefficient	The weft yarn interlacing coefficient
Herringbone	0.5	0.75-0.5
Diced	0.5-0.75	0.5-0.75

On the other hand, 2/2 Herringbone and diced weaves are not square unit weaves. Moreover, in 2/2 Herringbone, single numbered weft yarns interlace in different way from even numbered weft yarns, namely it has two different weft yarn interlacing coefficients as given in table 2. Besides, in diced weave, the single numbered warp and weft yarn interlacing coefficients are different from even numbered warp and weft yarn interlacing coefficients, calculated by equation 3;

$$yic_{1/2} = \frac{i_{1/2}}{w_{1/2}} \quad (3)$$

where $i_{1/2}$ is the number of warp or weft interlacing points in weave repeat, $w_{2/1}$ – the number of picks or ends in weave repeat.

Methods

Measurements and air permeability tests were conducted on the fabrics in Physical Testing Laboratory of in-house. The fabric samples were conditioned at standard atmosphere conditions (20 ± 2 °C, % 65 ± 2 relative humidity) for 24 hours in Physical Testing Laboratories.

Determination of fabric properties

Fabric thickness is measured by R&B Cloth Thickness Tester in compliance with EN ISO 5084 [22]. Mass per unit area of samples was determined according to EN 12127 [23]. The specifications of fabric samples are given in table 1.

Air permeability test

Air permeability was measured in accordance with EN ISO 9237:1995 (24), by the Tex-Test air permeability tester (FX3300, Switzerland), where the air permeability is expressed as the quantity of air in cubic centimeters, passing through a square centimeter of fabric per second ($cm^3/sec \cdot cm^2$). The air permeability tests were made for a test pressure drop of 100 Pa (20 cm^2 test area). The average of five measurements was used for comparison. The air permeability tester is shown in figure 2.

Fig. 2. Air permeability tester

Statistical evaluation

Air permeability test results were evaluated statistically by ANOVA according the General Linear Model with SPSS 15.0 software package. In order to analyse the effect of weave and weft yarn density, multivariate analysis was made for the two groups of fabrics: one including fabrics which were not applied any finishing process, the other including fabrics applied finishing process. Significance degrees (p), which were obtained from ANOVA, were compared with significance level (α) of 0.05. The effect, whose significance degree was lower than 0.05, was interpreted as statistically important.

Besides, the effect of finishing on air permeability of fabrics was evaluated by t-tests for raw-finished fabrics. t-tests were done by MATLAB 6.5 with significance level (α) of 0.05 also. Hypothesis of h_0 was defined that averages were equal. If h, the calculated value, was equal to 1, h_0 would be ignored, namely; the difference between the air permeability test results is statistically important.

Results and discussions

Air permeability of WO/PES worsted fabrics before and after finishing is shown in figure 3. From the figures, it was observed that the air permeability of fabric samples change according to finishing, weave pattern and weft density. Air permeability of fabrics that were not applied any finishing process are higher than those of fabrics that were applied finishing process. This is due to the fact that when the finishing process is applied on fabric, yarns swell with liquor and shrink, the density of fabrics increase. Therefore the prosity of raw fabrics are higher than finished fabrics.

The samples A1, A2 whose weaves are plain weave have the highest air permeability property. This is because of the fact that plain weave have the highest weave interlacing coefficient, namely the number of interlacing is the most frequent one in that each yarn goes once over and next under the intersecting yarn and this prevent intersecting yarns stand besides, so porosity of the plain is the highest. The samples A9, A10, A7 and A8 whose weaves are 2/2 matt and 5 end sateen weaves have higher air permeability properties than other samples. Although the calculated porosity of 2/2 matt is low, the matt weave has the less interlacing coefficient than 2/1 twill, 2/1 herringbone, 2/2 herringbone and diced weaves.The floating pairs of matt weaves get close to each other, this increase the porosity of the matt weave. And also, 5 end sateen weave there are warp yarn floats passing

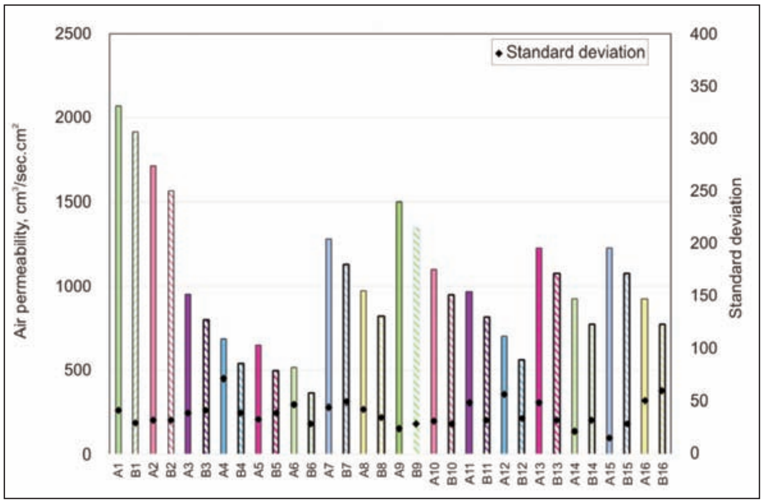

Fig. 3. Air permeability of raw and finished fabrics

over four weft yarns, these longer yarn floats move away from each other easily by air pressure applied during air permeability test, namely porosity of 5 end sateen fabric increased during the test, the calculated porosity of 5 end sateen is low though. The air permeability of samples A13 and A14 whose weaves are 2/2 herringbone weave are approximately equal to those of samples A15 and A16 whose weaves are diced weave. Because the weave interlacing coefficients and warp and weft yarn interlacing coefficients of these weaves are equal to each other. Additionally, the air permeability of samples A11 and A12 whose weaves are 2/1 herringbone weave are approximately equal to those of samples A3 and A4 whose weaves are 2/1 twill weave. This is due to the fact that the weave interlacing of 2/1 herringbone weave is equal to that of 2/1 twill weave.

When compared binary groups of (A1, A2), (A3, A4), (A5, A6), (A7, A8), (A9, A10), (A11, A12), (A13, A14), (A15, A16) within them, the air permeability of the fabrics decreases, as shown in figure 3, due to the increase of the weft yarn density. Because the dimensions of the pores through which the air would pass are getting smaller, when moving from loose fabrics towards dense fabrics. For dense fabrics, the resistance to air flow is higher than for loose fabrics.

When compared binary groups of (A1, B1), (A2, B2), (A3, B3), (A4, B4), (A5, B5), (A6, B6), (A7, B7), (A8, B8), namely when the finishing process was applied on fabric, wihtin them, air permeability of fabrics decreases. This due to the facts that yarns swell with liquor and shrink, density of fabrics increased, and thereby porosity and air permeability of fabrics decrease.

The variance analysis showed that both the effects of weave and weft density on air permeability of the raw and finished fabrics are statistically significant, getting the p-values of (0.002) and (0.042) respectively. The results of t-test confirmed that the air permeability changed with the finishing process, having the h-values of (1) for the raw-finished fabrics.

CONCLUSIONS

This paper presents a comprehensive experimental study, conducted on a series of raw and finished worsted woven fabric samples, which are used for production of outerwear clothing for protection from cold, with commonly used weaves. With the least air permeability, 2/2 twill woven fabric can be preferred for the winter clothing to protect the human body from the cold weather.

Results indicate that the permeability and pore size are strongly related to each other. If a fabric has very high porosity, it can be assumed that it is permeable. So the factors that change the porosity such as weave pattern, weft yarn density and finishing also affect the permeability properties of fabrics. Oğulata and Mezarcioz (10), Lolaki, Shanbeh and Borhani (11), Angelova et al. (12) and Urbas, Kostanjšek and Dimitrovski (13) reached similar results.

The structural properties of weaves such as the weave interlacing coefficient, namely the density of interlacing points as for plain weave, arrangement of yarns side by side as in 2/2 matt weave are factors that increase the porosity of fabrics, so increase their air permeability's. Long length of warp yarn floats in 5 end sateen cause to increase air permeability. Due to the least weave interlacing coefficient, 2/2 twill fabric has the least air permeability values. Behera, Ishtiaque, and Chand (1), Almetwally and Mourad (2), Zupin, Hladnik and Dimitrovski (3) and Umair et al. (6) obtained similar results for plain, sateen and twill weaves.

When the number of yarns per unit area increased, the pores between the yarns become smaller, and then air permeability of tight fabrics decreased. Buyukbayraktar [5], Turan and Okur (7) and Çay and Tarakçıoğlu (8) reached the same result.

It is observed that porosity and air permeability of finished fabrics decreased, because the density of finished fabrics increased as a result of yarn swelling with liquer and yarn shrinkage.

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