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Multilayer Cotton Fabric Porosity and its Influence on Permeability Properties

Poroznost večplastnih bombažnih tkanin in njen vpliv na prepustnostne lastnosti

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Abstract

Apart from their soft feel and good water absorbency, cotton fabrics are also characterised by good heat conductivity, air permeability and breathing. By increasing the open surface of one-layer fabrics, their air and water vapour permeability, and heat conductivity should increase as well, whereas the protection against UV rays, on the other hand, which is especially important for summer clothes, decreases. The aim of the research was to establish the influence of multilayer cotton fabric constructions on the properties connected with porosity, i.e. thermal resistance, water vapour resistance, UV-light permeability and air permeability. One-layer, two-weft and double cotton fabric constructions were woven from white, blue and black yarn with fineness 8 × 2 tex, warp density 40 ends/cm and weft density 60 picks/cm, taking into consideration the colour distribution of yarns in the fabrics as well. The research results showed that the most optimal construction characterises multilayer two-weft and double fabrics. Among the studied fabrics, a positive correlation was established between the porosity of fabrics and their air permeability or ultraviolet protection factor (UPF), respectively, and a negative correlation between the porosity of fabrics and their heat or water vapour permeability, respectively. The correlation between the calculated number of pores of individual samples, as an important factor in porosity, and the studied permeability resistance properties (i.e. heat resistance, water vapour resistance, UV-light permeability and air permeability resistance) was higher than the correlation between the porosity of samples and the abovementioned permeability properties.
Keywords: multilayer fabrics, textile construction, air permeability, water vapour permeability, thermal resistance, UV-light permeability

Izvleček

Bombažne tkanine imajo poleg mehkega otipa in dobre vpojnosti tudi dobro toplotno prevodnost, prepustnost zraka in dihalnost. Z večanjem odprte površine enoplastnih tkanin se praviloma povečuje tudi njihova zračna prepustnost, prepustnost vodne pare in toplotna prevodnost, vendar se slabša zaščita pred UV-žarki, ki je pomembna zlasti za poletna oblačila. Namen raziskave je bil ugotoviti vpliv konstrukcije večplastnih bombažnih tkanin na lastnosti povezane s poroznostjo: toplotno upornost (R_{ct}), upor prehodu vodne pare (R_{et}), prepustnost za UV-žarke (UZF) in zračno prepustnost (ZP). V ta namen so bile iz bele, modre in črno obarvane preje, finoče 8 × 2 tex stkane dvovotkovne, dvojne in enoplastne bombažne tkanine v gostoti 40 niti/cm v smeri osnove in 60 niti v smeri votka, pri čemer je bila upoštevana tudi barvna razporeditev preje v tkaninah. Raziskava je pokazala, da imajo najoptimalnejšo konstrukcijo večslojne dvovotkovne in dvojne tkanine. Za raziskovane tkanine obstaja pozitivna korelacija med poroznostjo tkanin in njihovo zračno prepustnostjo oziroma faktorjem UZF ter negativna korelacija med poroznostjo tkanin in njihovo toplotno prevodnostjo oziroma prepustnostjo vodne pare. Korelacija med izračunanim številom por posameznih vzorcev, kot pomembnim dejavnikom poroznosti in raziskanimi prepustnostnimi lastnostmi (toplotno upornostjo, uporom prehodu vodne pare, prepustnostjo UV-žarkov in zračno prepustnostjo) je bila večja od korelacije med samo poroznostjo vzorcev in omenjenimi prepustnostnimi lastnosti.
Ključne besede: večplastne tkanine, konstrukcija tekstilij, zračna prepustnost, prepustnost vodne pare, toplotni upor, UV-prepustnost

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1 Introduction

Permeability properties are of utmost importance for certain technical textiles (e.g. used for filtration, drainage), as well as for textiles used in clothing where they contribute to the comfort of the wearer. The comfort of summer clothing depends especially on its ability to dissipate excess heat and water vapour, on the regulation of air permeability and at the same time on the protection against dangerous influence of UV-light.

The permeability of textiles depends on the type of the medium penetrating through them. The permeability properties of clothes need to be adjusted to specific weather conditions, which are changing in daily lives. In the summer, air, heat and water vapour permeability represent desirable properties of clothes, whereas the penetration of UV-light should be as low as possible. In the winter time, more emphasis is put especially on the ability of good thermal insulation of textiles. In the literature, textile permeability to UV-light is most commonly treated separately from other textile permeability characteristics (thermal conductivity, water vapour permeability, air permeability) [1–6].

The aim of the research was to achieve the best permeability properties for summer clothing as possible by constructing two-layer fabrics. We strived for the highest thermal and water vapour resistance possible, and the best air permeability at simultaneous lowest textile permeability to UV-light. The research in this field has so far been conducted mainly on one-layer fabrics, taking into consideration the influence of altering various construction parameters, e.g. fibre composition, yarn fineness and density, and weave [8, 10, 11]. Since these studies have been performed on construction-wise very different samples (i.e. different mass per square unit, thickness and fabric porosity), it is impossible to establish the extent of the influence the textile construction had on the air, heat, water vapour and UV-light permeability. Therefore, we decided for the purpose of this research to make samples from the same yarn with the same density in warp and weft, the only difference being in weave. We produced two layered double-weft fabrics, where we put individual wefts into two levels, and two layered double fabrics, where we put individual warps and wefts into two levels, and one-layer fabrics.

2 Experimental

2.1 Materials

For the purpose of this research, we engineered and wove six different structures of cotton fabrics. The samples differed among each other in weave (number of layers), whereas the fineness of yarn in weft and warp (8 × 2 tex), the settings of coloured yarns in warp and weft, and the density of warp (40 ends/cm) and weft (60 picks/cm) stayed the same. We chose cotton yarn in blue colour for weft, and black and white yarn for warp with the sequence 1 : 1. All samples were woven on a laboratory loom

Table 1: Construction characteristics of samples and their labels

Sample	Weave	Fineness [tex]	Warp sequence [density: 40 ends/cm]	Weft sequence [density: 60 picks/cm]	Weft colour	Warp colour [black/ white]
1	One-layer: satin	8 × 2	1	1	blue	1 : 1
2	Two wefts: 8-end warp and 8-end weft satin	8 × 2	1	1 : 1	blue	1 : 1
3	Two wefts: 8-end satin and 2-stepped twill	8 × 2	1	2 : 1	blue	1 : 1
4	Double: 8-end satin	8 × 2	1 : 1	1 : 1	blue	1 : 1
5	Double: 8-end satin and 2-stepped twill	8 × 2	1 : 1	2 : 1	blue	1 : 1
6	Double: 8-end satin and 2-stepped twill	8 × 2	2 : 1	2 : 1	blue	1 : 1

Minifaber with a TIS jacquard mechanism. Table 1 includes sample labels and their basic construction parameters, and Figure 1 the technical schemes of samples.

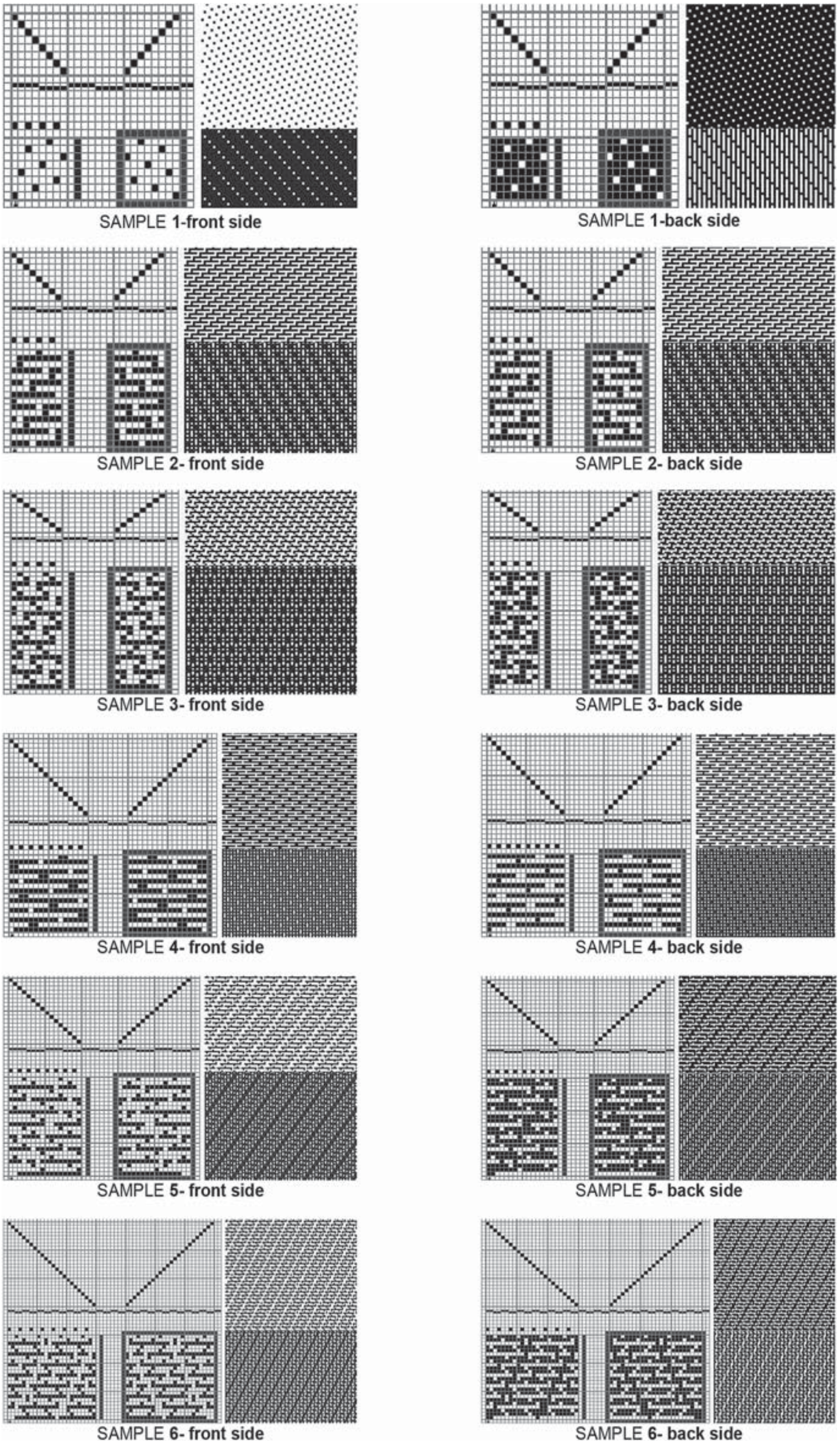

Figure 1: Demonstration of sample technical schemes from front and back sides (schemes were made in Arah-Weave program) [5, 12, 13]

2.2 Methods

In the research, we studied the following sample characteristics on both front and back sides:

– air permeability (*AP*) or air permeability resistance (1/*AP*), respectively, as the reciprocal value to air permeability through the fabric under certain conditions (m^2 s/l);

– thermal resistance, R_{ct}, (equation 1):

$$R_{ct} = (\overline{T}_k - T_z) \times \frac{A}{\phi_c} \quad (1),$$

where R_{ct} reprsents (total) thermal resistance of the clothing or garment system (m^2K/W), ϕ_c is dry heat flow (W), $\overline{T}_k$ is medium skin temperature (K), T_z is air temperature of surrounding environment (K) and A for the garment surface where the heat passes through (m^2) [7];

– water vapour resistance, R_{et}, is calculated with equation 2:

$$R_{et} = (\overline{p}_k - p_z) \times \frac{A}{\phi_e} \quad (2),$$

where R_{et} is (total) water vapour resistance of the garment (m^2Pa/W), ϕ_e for evaporative heat flow (W), $\overline{p}_k$ for medium partial water vapour pressure at skin temperature (Pa), p_z for water vapour pressure at air temperature (Pa) and A for the surface where the evaporative heat flow passes through (m^2) [7, 8];

– ultraviolet protection factor (*UPF*) (equation 3) indicates the effectiveness of a fabric at protecting human skin from ultraviolet radiation through the fabric:

$$UPF = \frac{\sum_{290\,nm}^{400\,nm} E(\lambda) \times \varepsilon(\lambda) \times \Delta\lambda}{\sum_{290\,nm}^{400\,nm} E(\lambda) \times \varepsilon(\lambda) \times T(\lambda) \times \Delta\lambda} \quad (3),$$

where $E(\lambda)$ represents solar spectral radiation ($Wm^{-2}nm^{-1}$), $\varepsilon(\lambda)$ is relative erythema effectiveness, $T(\lambda)$ is spectral transmittance of a sample at wavelength λ (%) and $\Delta\lambda$ a wavelength interval (nm) [9].

We measured the thickness and mass per square unit of the woven samples, and calculated the following two parameters:

– physical density (ρ_{fabric}) with equation 4:

$$\rho_{fabric} = \frac{M}{D \times 1000} \quad (4),$$

where ρ_{fabric} is physical density of a fabric (g/cm^3), M is mass per square unit (g/m^2) and D is thickness (mm) [10];

– fabric porosity (P) with equation 5:

$$P = \left(1 - \frac{\rho_{fabric}}{\rho_{material}}\right) \times 100 \quad (5),$$

where ρ_{fabric} is physical density of a fabric (g/cm^3), $\rho_{material}$ is fibre density (g/cm^3), and P is porosity (%). The value of 1.52 g/cm^3 was taken for the density of cotton fibres.

Apart from porosity, we also investigated the connection among individual porosity parameters (number, size and pore distribution in samples) and various types of resistance. The interdependence was studied between the number of pores or the number of estimated pore channels in the fabric, respectively, and the measured resistance. The number of macropores in a one-layer fabric and in double weft and double fabrics with the sequence 1 : 1 (weft and warp sequence) was calculated from the known densities of warp and weft. More effort was required at the calculation of the number of pores in double weft and double fabrics with the 2 : 1 sequences. Since a denser fabric generally represents a greater resistance to the transfer of media through it than a more loosely woven fabric, we conducted the calculation of the pore number of multilayer fabrics on their denser sides.

The number of pores was calculated from the product of the density of warp and weft threads of the fabric denser side, namely for the one-layer sample 1 with equation 6:

$$n = d_o \times d_v \quad (6),$$

where n is number of pores, d_o is density of warp threads (ends/cm) and d_v is density of weft threads (pics/cm).

The number of pores for sample 2 was calculated with equation 7, for sample 3 with equation 8, for sample 4 with equation 9, for sample 5 with equation 10 and for sample 6 with equation 11:

$$n_{sample\ no.\ 2} = \frac{d_o \times d_v}{2} \quad (7),$$

$$n_{sample\ no.\ 3} = 2d_o \times \frac{d_v}{3} \quad (8),$$

$$n_{sample\ no.\ 4} = \frac{d_o}{2} \times \frac{d_v}{2} \quad (9),$$

$$n_{sample\ no.\ 5} = \frac{d_o}{2} \times \frac{2d_v}{3} \quad (10),$$

$$n_{sample\ no.\ 6} = \frac{2d_o}{3} \times \frac{2d_v}{3} \quad (11),$$

where n represents number of $pores_{(sample)}$, d_o is density of warp threads (ends/cm) and d_v is density of weft threads (picks/cm).

For sample 3, we additionally calculated the number of pores also with equation 6, which applies to one-layer fabrics.

The permeability properties of samples were measured in line with the ISO 9237:1995 (E) standard on an air permeability tester FX 3300 (Textest, Switzerland). Air permeability was measured on five different places on samples, on front and back side, at the pressure of 100 Pa.

Heat and water vapour resistance were measured on a Permetest instrument (Sensora Instruments and Consulting, Czech). To perform the measurements, we followed the manufacturer's instructions [4], which are in accordance with the standard ISO 11092.

The penetration of UV-light was measured in accordance with the standard SIST EN 13758-1:2002 on the apparatus Lambda 800, UV/VIS Spectrophotometer, PELA-1000 (PerkinElmer Inc, USA). The measurements were performed "in vitro", which enabled the measuring of permeability (T) and reflection (R), and the calculation of absorption (A) of ultraviolet radiation of samples. The values of UPF were calculated with equation 3.

The results were statistically processed with the method of linear correlation where we evaluated on the basis of correlation coefficients the interdependence between the construction (porosity, number of pores 1 and number of pores 2) and physical properties of samples (i.e. air permeability resistance, water vapour resistance, thermal resistance and UPF).

3 Results

The woven fabric samples were of approximately the same mass per square unit; however, they differed in thickness, physical density, porosity and the number of pores (Table 2). The number of

Table 2: Results of measuring construction parameters and physical characteristics of samples

Sample	Warp density [ends/cm]	Weft density [picks/cm]	Mass [g/m²]	Thickness [μm]	Density [g/cm³]	Porosity [%]	Number of pores 1	Number of pores 2
1	42.1	58.2	165.2	927	0.178	88.6	2450	2450
2	42.2	58.9	168.2	1022.5	0.165	89.4	1243	1243
3	42.1	58.5	172.9	932.5	0.186	88.1	1642[a]	2463[b]
4	41.4	59.6	165.5	1025	0.162	89.6	617	617
5	42.4	58.0	166.4	1034.5	0.162	89.6	820	820
6	42	60.0	167.9	1005.5	0.168	89.2	1120	1120

[a] Number of pores calculated with equation 8, [b] Number of pores calculated with equation 6

Table 3: Results of measuring thermal resistance (R_{ct}), water vapour resistance (R_{et}), UPF and air permeability resistance (1/AP) on front (F) and back (B) side of samples

Sample	R_{ct} – F [m²K/W]	R_{ct} – B [m²K/W]	R_{et} – F [m²Pa/W]	R_{et} – B [m²Pa/W]	*UPF* – F	*UPF* – B	*1/AP* – F [m²s/l]	*1/AP* – B [m²s/l]
1	0.02748	0.02773	1.42428	1.29535	205.51	158.32	0.00411	0.00426
2	0.03894	0.03259	1.69948	1.73933	63.01	66.92	0.00122	0.00121
3	0.03187	0.03074	1.51976	1.5928	92.4	86.17	0.00462	0.00483
4	0.04645	0.04268	2.06637	2.14774	97.74	102.37	0.00094	0.0009
5	0.03874	0.03949	1.54776	1.49723	81.36	74.03	0.00107	0.00109
6	0.04299	0.04484	1.78966	2.07643	101.04	88.54	0.00163	0.00187

Table 4: Calculated correlation coefficients between front and back sides of individual resistance values, and correlation coefficients between porosity, number of pores 1 and 2, and individual resistance values on front and back sides of samples

Charac-teristic	R_{ct} – F	R_{ct} – B	R_{et} – F	R_{et} – B	UPF – F	UPF – B	1/AP – F	1/AP – B	Porosity	Number of pores 1	Number of pores 2
R_{ct} – F	–	0.90	–	–	–	–	–	–	0.78	–0.92	–0.92
R_{ct} – B	0.90	–	–	–	–	–	–	–	0.68	–0.83	–0.84
R_{et} – F	–	–	–	0.94	–	–	–	–	0.59	–0.74	–0.74
R_{et} – B	–	–	0.94	–	–	–	–	–	0.47	–0.71	–0.66
UPF – F	–	–	–	–	–	0.98	–	–	–0.43	0.79	0.58
UPF – B	–	–	–	–	0.98	–	–	–	–0.39	0.71	0.52
1/AP – F	–	–	–	–	–	–	–	0.99	–0.98	0.84	0.98
1/AP – B	–	–	–	–	–	–	0.99	–	–0.98	0.84	0.97
Porosity	0.78	0.68	0.59	0.47	–0.43	–0.39	–0.98	–0.98	–	–	–
Number of pores 1	–0.92	–0.83	–0.74	–0.71	0.79	0.71	0.84	0.84	–	–	–
Number of pores 2	–0.92	–0.84	–0.74	–0.66	0.58	0.52	0.98	0.97	–	–	–

pores refers to the number of pore channels among the intertwined warps and wefts. As mentioned before, the number of pores for two-layer fabrics was calculated according to the number of pores of the denser layer (Table 2, number of pores 1). In line with the fact that sample 3 was treated as a one-layer sample, we calculated the number of pores using equation 6. For the purpose of statistical correlation, we formed another group of measurements and labelled it as number of pores 2 (Table 2), where we used the assumption that sample 3 is one layered, since weft density was insufficient to put all wefts in the position of the second layer weft. We decided not to increase the density as we wanted to preserve total production comparability (costs and time) among samples.

The results of measuring individual resistance and UPF values of samples, measured on the front and back sides, are listed in Table 3.

Table 4 contains the correlation coefficients of linear correlation among individual measured sample characteristics.

4 Discussion

4.1 Analysis of construction parameters

The samples included in the study differed in structure and weave. Sample 1 was a one-layer fabric with maximum density in weft. Samples 2 and 3 were double weft fabrics with the sequences 1 : 1 and 2 : 1. Consequently, we expected samples 2 and 3 to have greater thickness and lower physical density. The anticipated values were achieved by sample 2, but not sample 3, which was even thinner and had higher density than sample 1. The sequence 2 : 1 was chosen due to a higher cover factor of the fabric. As it can be seen in Table 1, the measured thickness of sample 2 was only by about 10% higher than of samples 1 and 3 (according to our expectations, it should be at least twice as thick since the wefts were positioned one above another).

One reason for the latter is that the wefts in sample 1 got due to extremely high density deformed perpendicularly (normal) to the fabric plain. In the cases of lower density of wefts, the deformation of warp and weft yarns usually takes place in the fabric plane direction, consequently decreasing fabric thickness.

Another reason for the resulting difference arises from the weaving process, where we pull the fabric after each pick. Usually, the fabric is pulled for the length of each pick after every second weft, setting half the density. The wefts are this way not positioned as defined in theory, i.e. one above another, but they take the position which is partly characteristic of one-layer fabrics, especially if the chosen weft density does not suffice. A similar situation was also at sample 4, where both weft and warp systems in the sequence 1 : 1 should theoretically be one above another [5]. Furthermore, samples 5 and 6 had only by about 10% higher thickness, which explains that the structure of all samples was similar enough and that the difference in the values of physical density was minimal.

4.2 Analysis of colour differences

The colour of samples plays an important role in establishing the level of UV-light protection; thus, the positioning of colour combinations of yarn in the fabric construction is of the essence. Samples included in the research also differed among each other in the position of coloured yarns. The biggest difference between the front and the back was shown at sample 1. Whereas on the front, cotton weft yarns in blue colour prevailed, the back had black and white warp yarns. Sample 2 was the only double-sided sample with weft yarns in blue dominating on both the front and back, while warp yarns remained mainly in the middle. Sample 3 had in comparison with the back side a denser front side with two weft yarns in blue, whereas only one weft was on the back side. Sample 4 had a combination of blue weft and white warp on the front, and of blue weft and black warp on the back side. The front of samples 5 and 6 was denser than the back, with weft yarns prevailing on both sides.

4.3 Analysis of thermal resistance (R_{ct}), water vapour resistance (R_{et}), UPF values and air permeability resistance (1/AP)

The results of measuring thermal resistance (R_{ct}), water vapour resistance (R_{et}), UPF values and air permeability resistance (*1/AP*) of cotton fabrics included in the research are demonstrated in Figure 2, which shows the difference between the one-layer and multilayer samples. Samples 1 and 3 acted similarly

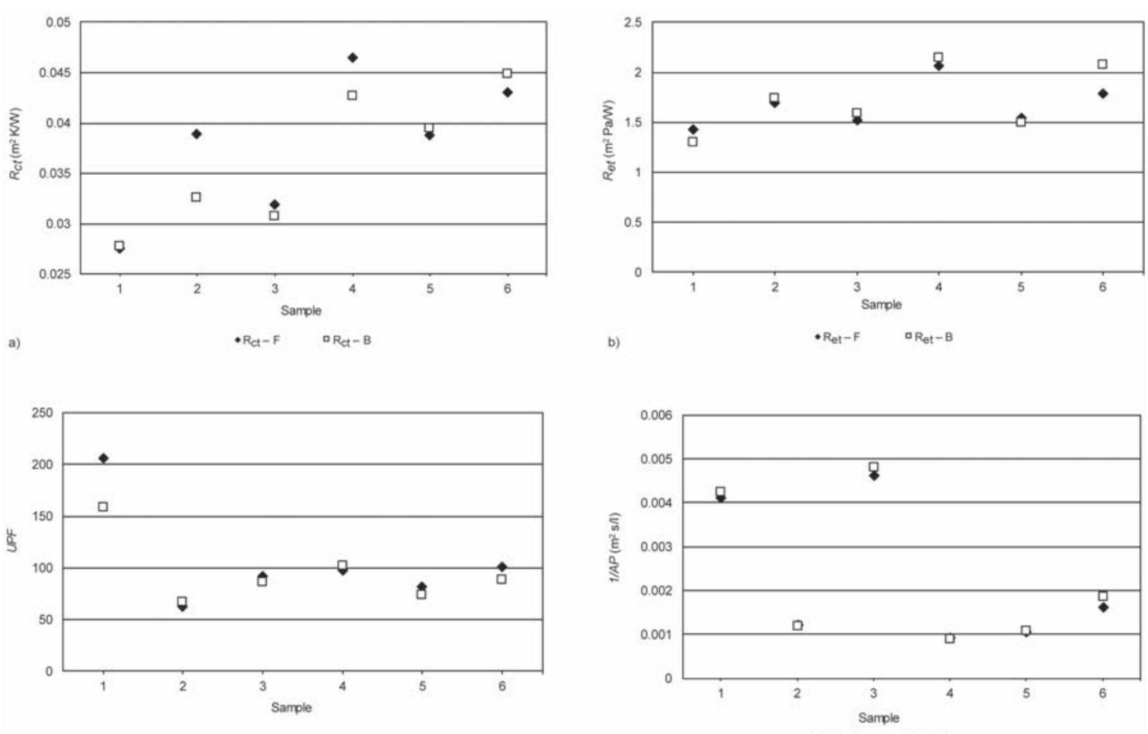

Figure 2: Demonstration of a) thermal resistance, b) water vapour resistance, c) UV-light resistance and d) air permeability resistance

regarding air permeability resistance, but differently at the results of measuring UPF, where the dominant role was taken over by the colours on the front and back sides of the fabric, and the direction of yarn deformation at sample 1. The differences were very obvious at the results of air permeability and thermal resistance. The air permeability resistance of samples 1 and 3 was in comparison with the rest of multilayer samples by about 4 times larger. The differences among all samples in the case of thermal resistance were approximately double if comparing one- and multilayer fabrics. The greatest differences between the front and back side were shown when measuring thermal and water vapour resistance. This leads to the conclusion that the structure of samples, especially when one side is denser than the other, strongly influences the abovementioned characteristics. There were no differences between the front and back side of samples regarding air permeability resistance. Concerning the UPF values, differences occurred only at samples 1 and 6, where the influence of yarn colour was shown.

4.4 Influence of porosity on thermal resistance (R_{ct}), water vapour resistance (R_{et}), UPF values and air permeability resistance (1/AP)

The correlation coefficients of thermal resistance (R_{ct}), water vapour resistance (R_{et}), UPF values and air permeability resistance (*1/AP*), and porosity point to a high level of correlation between the front and back side of samples (Table 4). The correlation coefficient was larger than 0.9 in all cases. The biggest correlation (i.e. 0.99) was shown between the front and back side at air permeability resistance, then at UV-light resistance, followed by water vapour resistance and thermal resistance. This clearly points to the fact that positioning yarn into various layers in the construction (i.e. multilayer fabrics) does not affect air permeability resistance, meaning that the air permeability resistance stays approximately the same regardless of the differences in the density of individual layers in multilayer fabrics.

The most important role at achieving good UPF is played by the fabric structure. The correlation coefficient between the UPF values on the front and back sides of individual samples was high at all samples, despite the fact that the absolute values varied (especially at sample 1, where the colour differences were the greatest).

The differences were already more noticeable at water vapour resistance and even more at thermal resistance. This can be explained by the difference in sample structures and in the density of individual layers, respectively. If during the measurements, water vapour and heat penetrate first through a less dense layer of the fabric, the resistances are going to be bigger due to the trapped insulating air between the body and the denser fabric layer, and vice versa. Table 4 offers the calculated correlation between sample porosity and measured resistances. The highest negative correlation existed between porosity and air permeability resistance, i.e. about –0.98. The correlation coefficient between thermal resistance and porosity was 0.78 on the front and 0.68 on the back side, while it was between water vapour resistance and porosity 0.59 on the front side and 0.47 on the back side. The differences between the correlation coefficients of porosity on the front and back side confirm the explanations in the previous paragraph about the influence the fabric construction has on individual resistances. The lowest correlation values were obtained at the measurements between porosity and UPF on the front and back sample sides. Porosity itself does not influence UPF dominantly, but the fact whether a fabric structure is open or closed (transparency) does influence UPF in connection with the chosen yarn colour.

The fact is that porosity varied among samples only by about 2%, whereas permeability or permeability resistance varied by a lot more. This confirms the theory that porosity on its own, despite easily determined, in many cases does not suffice to determine UV-light permeability of a fabric. The latter has also been confirmed by the research of other authors [11], where in a fabric structure which is closed enough yarn colour takes the leading role in the permeability of UV-light.

The last two rows in Table 4 show the influence of the number of pores on the denser side of samples on the measured permeability resistance properties. In almost all cases, at the number of pores 1 and 2 from Table 2, a greater correlation was shown between the number of pores and the measured permeability resistance properties than between porosity and measured resistances.

Between the number of pores 1 and UPF, a higher coefficient of linear correlation was calculated compared to the number of pores 2 and UPF (Table 4). The coefficient of linear correlation between air

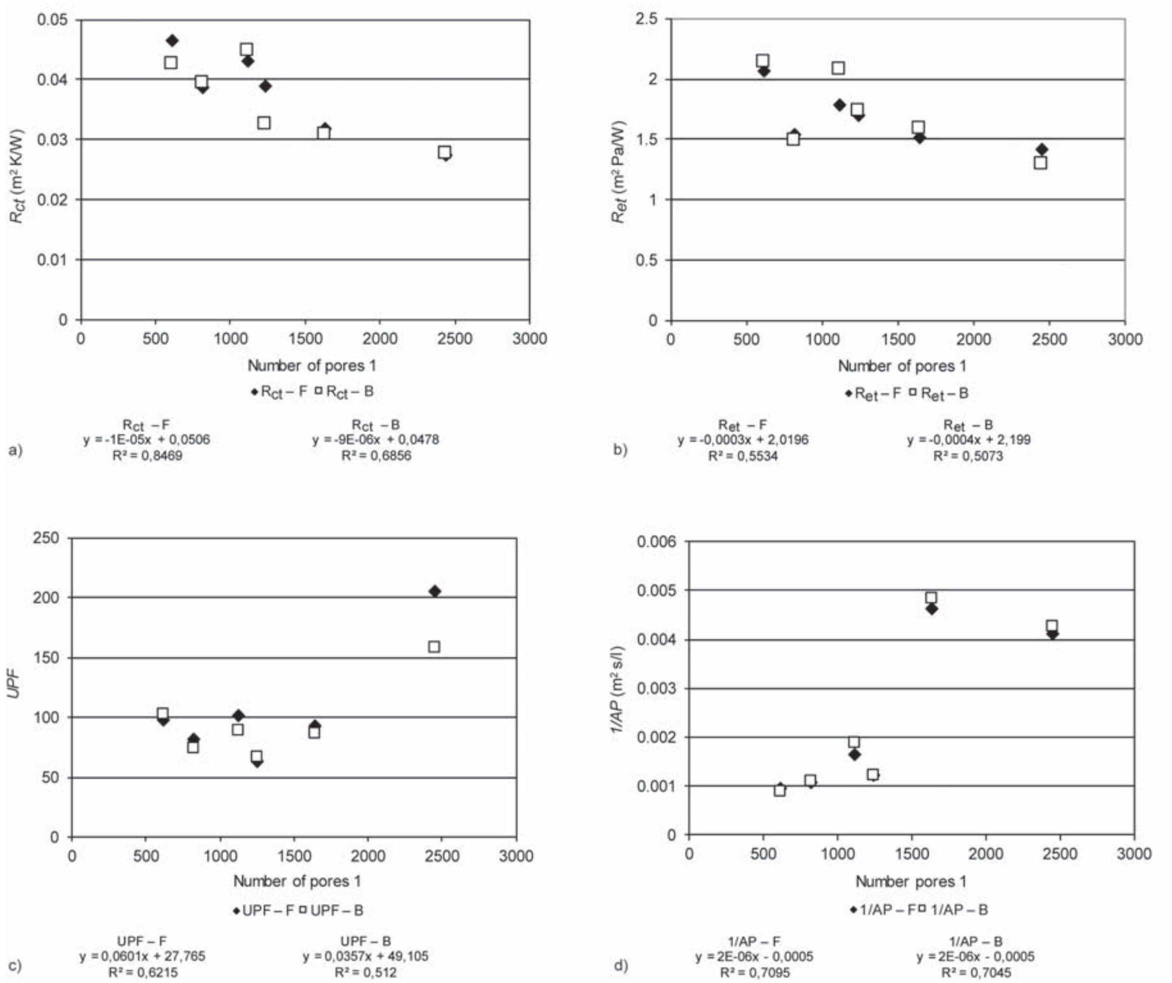

Figure 3: Dependence of thermal resistance (a), water vapour resistance (b), UV-light resistance (c) and air permeability resistance (d) from number of pores 1 on front and back sample sides and corresponding regression equations

permeability resistance and the number of pores 1 or number of pores 2, respectively, amounted to 0.84 or 0.97/0.98, respectively (Table 4). This means that the denser side of the fabric is of greater importance for UPF, while the thinner side is more important for air permeability resistance

The results show that there were no substantial differences between the front and back side of samples at air permeability resistance, not even in the colour of used yarns. This clearly points to the air permeability being dependant only on the porosity of samples and the structure of pores.

The correlation between the calculated porosity (calculated from the mass per square unit and thickness) and air permeability resistance was high. In both cases (porosity vs air permeability resistance on the front and back side), it amounted to more than 0.98 and the correlation of air permeability resistance between the front and back side to 0.99.

The results showed that air permeability resistance changed with the fabric structure (about 4 times among samples 1, 3 and 4). Putting yarns into two levels within the same warp or weft increased air permeability and decreased the physical density of samples. Using the sequence 2 : 1 in weft diminished the air permeability in two-level/layer samples.

Samples differed minimally among each other (by up to 2%) regarding porosity, while the differences were more noticeable in the air permeability resistance (Table 3). Again, this demonstrates that the air permeability resistance primarily depends on the number and diameter of air channels in samples.

Despite the porosity of samples not differing substantially, the correlation coefficient between the number of pores and air permeability resistance was high enough to lead to the conclusion that a greater number of pores (consequently smaller in diameter) corresponds to a greater air permeability resistance.

4 Conclusion

Based on the research of permeability properties of one- and multilayer structures, we can make some conclusions for the fabrics which are closed and non-transparent enough.

The analysed resistance properties of samples differently correlate with porosity and porosity parameters. Porosity positively correlates with thermal resistance and water vapour resistance, and negatively with air permeability resistance and UPF. This means that the samples with more pore channels in a fairly closed structure ensure better thermal insulation and better water vapour resistance. In contrast, samples with more air spaces also have worse UPF and air permeability resistance.

We came to an important, new conclusion regarding the pore sizes in a fabric. Thermal resistance and water vapour resistance negatively correlate with the number of pores, or better with the number of air channels in a fabric, and positively with UPF and air permeability resistance. A small number of pore channels mean their larger volume in a fairly closed fabric structure. In consequence, air and UV-light penetrate more easily through larger pore channels (smaller number of larger pores). At the same time, heat and water vapour will penetrate through the material and smaller pores more easily.

The latter was confirmed by the number of pores which differ among samples 1–4 and some permeability resistances (e.g. air permeability resistance and UV-light resistance), which are also within approximately the same range.

When the structure of multilayer fabrics contains two differently dense layers, the dominant role regarding resistance properties is as expected played by the denser fabric layer, which was in fact used in determining the number of pores. This causes differences between the thermal and water vapour resistance measured on the front and back side of samples. The measured results correlate better in all cases with the number of pores of the denser layer.

The research results showed that while all samples boasted of excellent UPF (+50), only four of them achieved excellent air permeability at the same time.

The air permeability of double weave with the sequence 1 : 1 was by more than four times greater than the air permeability of a satin fabric and of a double weft fabric with the sequence 2 : 1 (in weft). Thermal resistance did not show such dependence on sample structures and at water vapour resistance, the dependence was even smaller. These findings confirmed our expectations that apart from porosity, fibre composition influences the thermal resistance of a fabric, the influence being even greater at water vapour resistance and absorption properties. Air permeability resistance is influenced only by porosity (sample structure), since there are no significant differences in the results between the front and back side. The differences are bigger at other resistance properties, especially at sample 1 (UPF due to applied colour), samples 3 and 6 (water vapour resistance due to different density of fabric layers).

The presented research clearly shows a relatively wide spectrum of possibilities to regulate the permeability resistance properties with a fabric construction which is closed enough and non-transparent, produced with comparable production costs.

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