INFLUENCE OF VERTICAL POROSITY ON WOVEN FABRIC AIR PERMEABILITY

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Abstract
Main aim of this paper is the search of suitable model that makes possible the prediction of air permeability of a woven fabric on the base of its constructional parameters (setts of warp and weft yarns, fineness of warp and weft yarns and a type of weave). This research is focused on experimental woven fabrics of a cotton type. The term of a vertical porosity is defined for the fabrics with non-plain type of weave. The new elliptical model of the vertical porosity is suggested and the influence of the vertical porosity on woven fabric air permeability is discussed and experimentally verified.
Key words: air permeability, horizontal porosity, vertical porosity, woven fabric, floats yarn

1. Introduction

A structure of textile materials is very complicated and very varied, while the structure is determinative for an air permeability of textile materials. A size of the pores in textile, a shape of the pores, their arrangement and frequency are decisive characteristics of a fabric with point of view air permeability. All of the methods, which lead to the determination or expression of a textile material porosity, include some simplifying assumptions. These assumptions introduce into result some inaccuracies. It is very difficult to find the optimal method that the most predicates about of textile properties such as for example air permeability.

A numbers of another porosity models were introduced. As basic constructional parameters are usually considered:

- D_O, D_U – are setts of warp yarns and sett of weft yarns respectively; in [1/m]
- T_O, T_U – are fineness of warp yarns and fineness of weft yarns respectively; in [tex]
- Type of weave

The fineness of yarns T [tex] is the parameter that is used for theoretical determination of equivalent yarn diameters d_O [m] and d_U [m]. Each type of a woven fabric can be described by using 4 pore types showed on fig. 1.

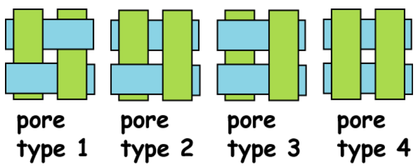


Figure 1. The unit cells for woven fabric

Most authors regard the shape difference between individual types of pore units, but not regard their mutual arrangement. Not only a count of the individual pore types but their mutual arrangement forms type of weave and it is very significant for the air permeability. In some models the woven fabric structure is in a simplified fashion describe as a 2-dimensional (the perpendicular projection of the yarns into the plane of fabric), in some models as a 3-dimensional (for example [1]). In some cases the 3-D structure of the pore unit cells is projected into plane of a fabric, but not in the perpendicular direction. Then it is possible classify as a modified 2-D model of porosity (for example [2]).

2. Define horizontal and vertical porosity

In this research two planes of a projection are use:

- The horizontal plane (= the plane of a woven fabric)
- The vertical plane (= the plane perpendicular to the plane of a woven fabric)

2.1 Horizontal porosity

The "classical" 2-D model of a woven fabric porosity describes the perpendicular projection of yarns into the plane of a fabric (similarly as fig. 1). According to this model it is possible calculated a part of an open area as:

$$P_{hor} = 1 - \left(d_O D_O + d_U D_U - d_O d_U D_O D_U\right) \tag{1}$$

Where d_O, d_U are diameters of a warp yarn, weft yarn respectively, and D_O, D_U are setts of warp yarns, weft yarns respectively. The graph (see fig. 2) shows the air permeability values of the one experimental fabrics set.

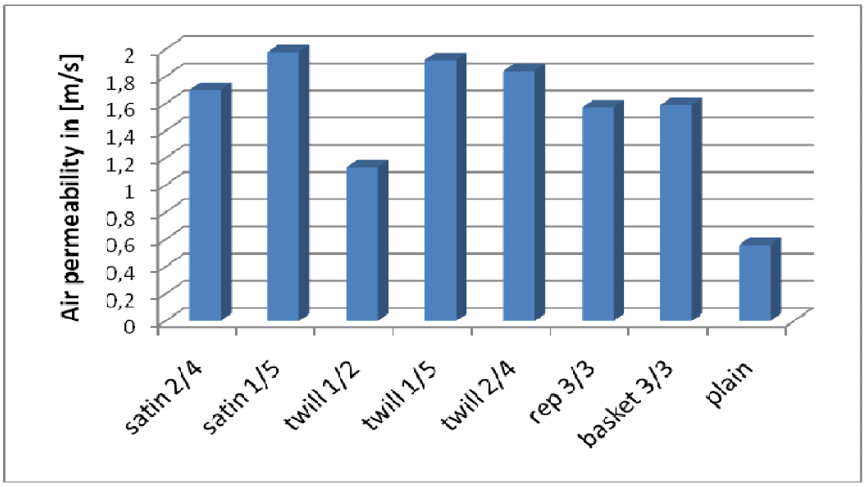
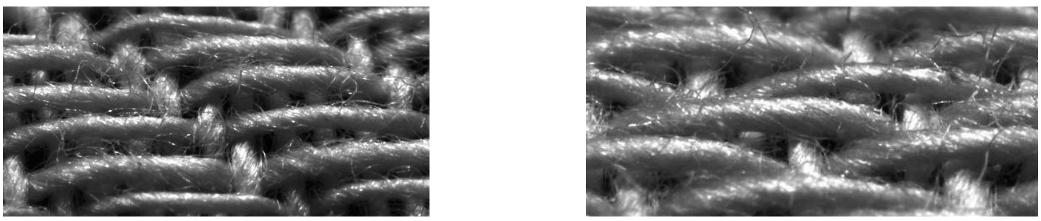


Figure 2. Air permeability of the woven fabrics with the same : T_O=20 [tex], T_U=20 [tex], D_O=26 [1/cm], D_U=26 [1/cm] and with the different type of weave

The constructional parameters of the fabrics are the same (used material, T_O, T_U, D_O, D_U), but types of weave are different. It is evident, that the values of the horizontal porosity P_{hor} are the same, but the air permeability values are different.

2.2 Vertical pore

The term "vertical pore" includes the space in the woven fabric that is filling up by air (=pore). This pore forms in the place of the longer non-interlaced parts of yarns between warp and weft yarns in the vertical direction (see fig. 3). The vertical porosity is very important with point of view the woven fabric air permeability.



a **b**

Figure 3. Photos of the experimental fabrics (a – twill 1/5, b – satin 1/5) under of the angle 45°

2.3 Elliptical model of the vertical pore

An elliptical model of the vertical pore was suggested. This model describes one vertical pore respective its projection to the vertical plane (the plane perpendicular to the plane of a woven fabric) as a half of ellipse. The basic geometry of this vertical pore model is introduced on the fig. 4.

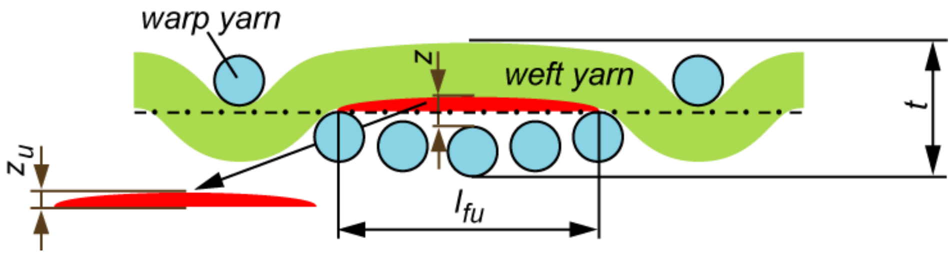


Figure 4. The 2-D elliptical model of the vertical pore in the woven fabric (the cross-section through woven fabric along the weft yarn)

The area of the one vertical pore that is created under weft yarn is:

$$E_{U1} = \frac{1}{2}\pi * l_{fU} * z_U \tag{2}$$

where l_{fU} is a length of the floats (non-interlaced) weft yarn:

$$l_{fU} = \frac{1}{D_O} * p_{lU} \tag{3}$$

where p_{lU} is a number of the non-interlaced segments in this floats yarn. The number of these floats weft yarns in one pattern repeat is p_{fU} and a number of pattern repeat in 1 cm^2 is calculated as:

$$p_S = \frac{D_O D_U}{n_{SO} n_{SU}} \tag{4}$$

where D_O [1/cm], D_U [1/cm] are setts of warp yarns and sett of weft yarns respectively and n_{SO}, n_{SU} are a numbers of warp and weft yarns in a pattern repeat respectively. The total area of the all vertical pore cross sections under weft yarns in the 1 cm^2 is possible calculated as:

$$E_U = \frac{\pi}{2} \frac{p_{lU}}{D_O} z_U p_{fU} \frac{D_O D_U}{n_{SO} n_{SU}} \tag{5}$$

The value E_U is necessary quantified for each type (respective length) of floats yarn in the case that different types of the floats yarns (for example twill 2/4, twill 3/4) are in the pattern repeat. According to the same process it is possible calculated the total area of the warp vertical pores E_O.

The z_U [cm], z_O [cm] are values of the weft and warp yarn deflection respectively (≈ the length of by ellipse axis). This parameter is not constructional parameter of woven fabric. For experimental fabrics it is possible value $z = z_O + z_U$ approximately consider as:

$$z = t - (d_O + d_U) \tag{6}$$

where t [cm] is fabric thickness, d_O [cm] and d_U [cm] are diameters of warp and weft yarns respectively. The fabric thickness must be measured under minimum pressure of jaw measuring apparatus. In the case air permeability prediction it is possible the fabric thickness calculated as [3]:

$$t = \left[(d_O + d_U) + \left[\frac{d_O + d_U}{2} e_1 - \frac{d_O + d_U}{2} (1 - e_1) \right] \right] f^m \beta \tag{7}$$

where f^m is interlacing coefficient, *e1* is warp waviness, β is yarn compression in fabric cross section. This equation has been verified only for 100% cotton woven fabrics.

2.4 Vertical porosity

The term porosity of woven fabric expresses the part of the total volume or surface that is not in woven fabric filled by fibres. The porosity is considered as a complement to the filling of a woven fabric. In the classical 2-D construction of the horizontal porosity (see 2.1), the porosity is defined as a complement to the woven fabric cover factor and a surface projection of the pore is related to the area of the unit cell of a woven fabric. In the case of the 2-D vertical porosity it is not completely clear. The neighbouring pores are not adjacent in the plane of projection. In this contribution the total area (respective the reference area for one vertical pore) is considered according to figure 5.

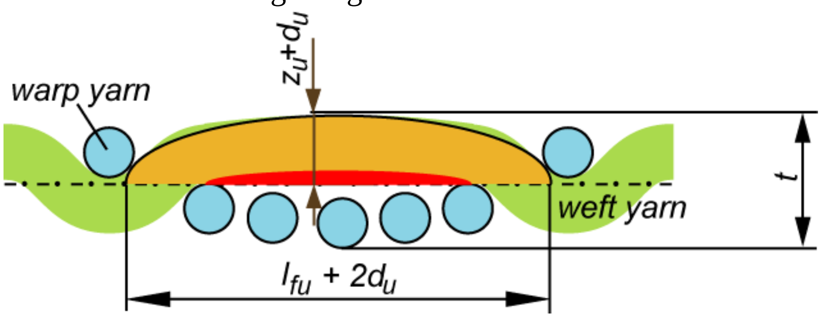


Figure 5. The model of the reference area for one vertical pore

The total area of the projection of one flotage is considered as a half ellipse, whose axis are simply expressed as:

$$a_U = l_{fU} + 2d_U \tag{8}$$
$$b_U = z_U + d_U \tag{9}$$

The total area of the projection of the warp yarn flotages on 1 cm^2 is:

$$S_{FU} = \frac{\pi}{2} \left(\frac{p_{lU}}{D_O} + 2d_U \right) (z_U + d_U) p_{fU} \frac{D_O D_U}{n_{SO} n_{SU}} \tag{10}$$

The total area of the projection of the weft yarn flotages on 1 cm^2 is calculated according to equation (10) with the substitution of index U→O. The value S_{FU} is necessary quantified for each type (respective length) of floats yarn in the case that different types of the floats yarns are in the pattern repeat. The vertical porosity is then possible calculated as:

$$P_{ver} = \frac{E_O + E_U}{S_{FO} + S_{FU}} \qquad (11)$$

3. Experimental part

For the experiment were used 4 sets of the woven fabrics, whose parameters are listed in the table 1 (total of 32 fabrics). Consequently, the setts of warp and weft yarns were not completely uniform, the values D_O, D_U fluctuate ± around the desire value. The values horizontal and vertical porosity were calculated and the experimental values of air permeability were measured (using digital instrument FX 3300) for all woven fabrics.

Table 1. Konstructional parameters of experimental woven fabrics

20 tex (warp yarns and weft yarns)		**45 tex** (warp yarns and weft yarns)	
100%CO	65%PP/35%CO	100%CO	65%PP/35%CO
D_O ± 26 [1/cm]	D_O ± 26 [1/cm]	D_O ± 18 [1/cm]	D_O ± 18 [1/cm]
D_U ± 26 [1/cm]	D_U ± 26 [1/cm]	D_U ± 18 [1/cm]	D_U ± 18 [1/cm]
Type of weave: P, A2/4, A1/5, K 1/2, K1/5, K2/4, R3/3, P3/3			

The figure 6 shows the relationship between porosity and air permeability values for one set of the woven fabrics (100%CO, 20 tex). As a result of the fluctuating values D_O, D_U the values of horizontal porosity P_{hor} fluctuate too. It is evident the high degree of dependence between the values of vertical fabric porosity and values of air permeability (R^2=0,83). If the woven fabrics with the Panama weave and the rep weave were exclude, was R^2=0,96. These woven fabrics have significantly uneven the horizontal inter-yarns pores (see figure 8).

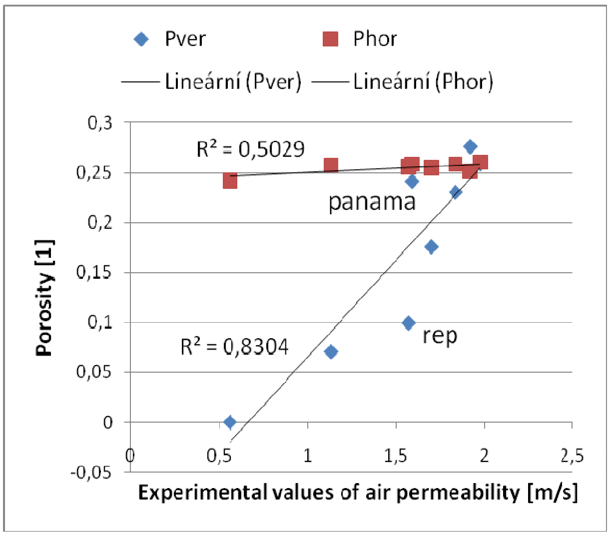


Figure 6. Correlation between porosity (horizontal and vertical) and air permeability values - data of woven fabrics 20 tex, 100%CO, all type of weave

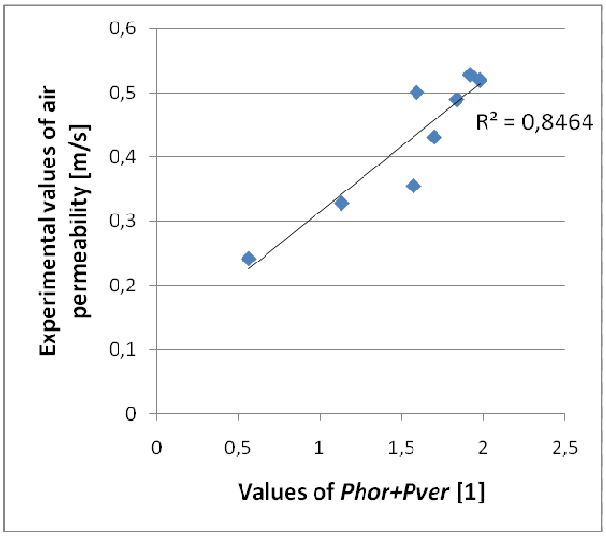


Figure 7. Correlation between air permeability values and values of P_{hor}+ P_{ver} – data of woven fabrics 20 tex, 100%CO, all type of weave

It is clear that both horizontal and vertical porosity have a significant effect on the air permeability of the woven fabric. An intensity of this influence is not the same for all fabrics. Figure 7 shows the relationship between air permeability and porosity of the tested fabrics as:

$$AP \approx function\left(P_{hor} + P_{ver}\right) \quad (12)$$

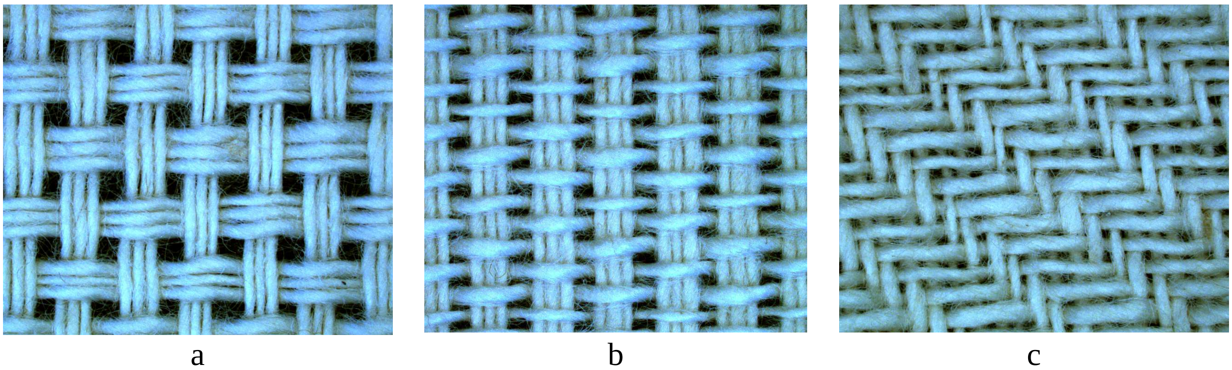


Figure 8. Photos of the experimental fabrics (a – Panama, b – rep, c – twill 2/4)

Figures 9, 10 and 8-a show for example the woven fabric with the Panama weave. Figure 9 shows non-real (ideal) structure of this fabric with steady D_O, D_U. Such a structure implies the calculation of horizontal porosity (see equation (1)). Figure 10 shows the real structure of this fabric with unequal distribution of the warp and weft yarns.

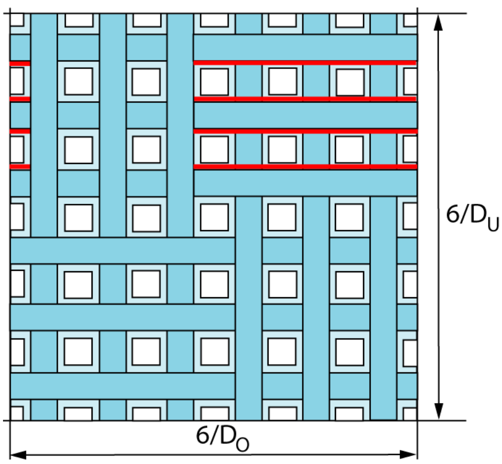


Figure 9. Schema of the Panama woven fabric with the non-real structure (setts of yarns are regular)

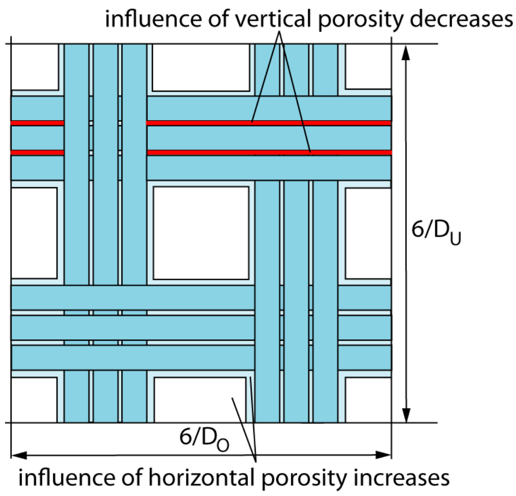


Figure 10. Schema of the Panama woven fabric with the real structure (setts of yarns are irregular)

The inter-yarn pores have not completely clear boundaries in the case of using the staple yarns. Some kind of "gray area" around the yarns should be considered with point of view the air permeability. This gray area reduces the air permeability of a fabric due to the increase hydraulic losses (due to a hairiness of yarns). Then, if the size of some inter-yarn pores is smaller than a dimension of the gray area (see fig. 9 and 10), the air permeability of this woven fabric increases.

On the other hand, the influence of the vertical porosity decreases due to the close location of the neighbouring vertical pores (see fig. 9 and 10). The air permeability decreases too. The different effect of the vertical porosity is in the case of type of weaves A 1/5 and K 1/5 due to

the different placement of the vertical pores. This phenomenon was discussed already in [4 or 5].
Figure 11 shows the relationship between the air permeability values and the porosity of the tested fabrics as:

$$AP \approx function\left(h * P_{hor} + v * P_{ver}\right) \qquad (13)$$

where parameters *h* and *v* are set according to table 2.

Table 2. Parameters *h* and *v* for the set of fabrics 100%CO, 20 tex

Type of weave	A 2/4	A 1/5	K 1/2	K 1/5	K 2/4	R 3/3	P 3/3	P
h	1	1	1	1	1	1,25	1,25	1
v	1	1	1	0,9	1	1	0,4	1

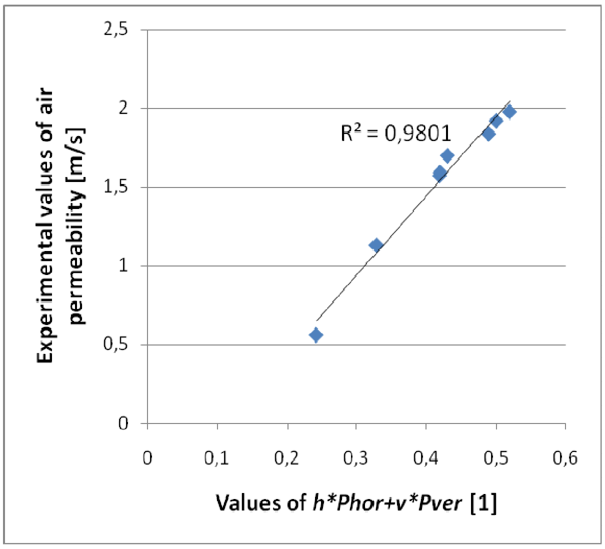


Figure 11. Correlation between air permeability values and values of $h*P_{hor}+ v*P_{ver}$ – data of woven fabrics 20 tex, 100%CO, all type of weave

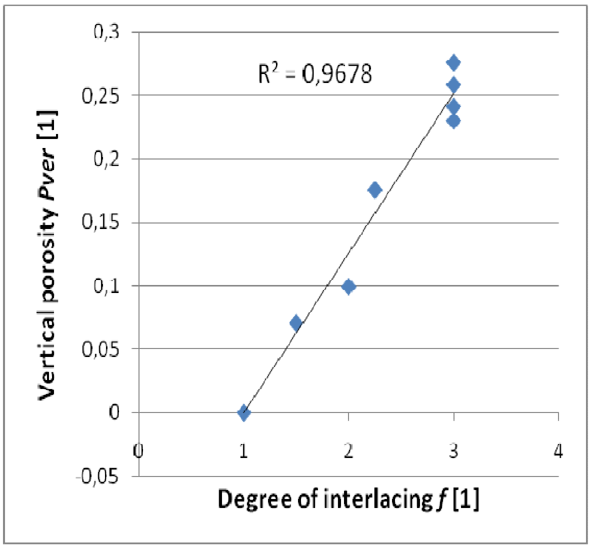


Figure 12. Correlation between vertical porosity and degree of interlacing – data of woven fabrics 20 tex, 100% CO, all type of weave

4. Conclusion

This paper shows the importance of the vertical porosity of a woven fabric for the theoretical assessment of the air permeability. It was designed the 2-dimensional elliptical model of the vertical pores and this model was applied to the experimental fabrics. It is clear that both horizontal and vertical porosity have a significant effect on the air permeability of the woven fabric, but the intensity of this influence is not the same for all fabrics. Some of the most important aspects that determine the influence of horizontal and vertical porosity to the air permeability were discussed. The correlation of the tested dependence in the form of relationship (13) is high, but it should be noted that the used fabrics were made with the same constructional parameters (sets of warp and weft yarns, with the same fineness of warp and weft yarns, with the same fibres). The values of the parameters *h* and *v* are significantly affected by the constructional parameters of the woven fabric. It can be expected that values of the parameters *h* and *v* will be greatly variable in the dependence on the constructional parameters of specific woven fabric (respective group of fabrics). It was also verified for other fabrics used in this experiment.

5. References

1. Lu, W.M. – Tung, K. L. – Hwang, K. J., *Textile Research Journal*, Fluid Flow Through basic Weaves of Monofilament Filter Cloth, 66 (5). 311 – 323 (1996).
2. Gooijer, H.: *Flow Resistance of Textile Materials*. Thesis UT Enschede. 1998. ISBN 90-36511240.
3. Kolčavová – Sirková, B., *Systém projektování textilních struktur. Část 2 "příze – tkanina"*. VCT, TU Liberec 2004.
4. Havrdová, M., *Vlákna a textil*, Air permeability and a structure of woven fabrics, 10 (2) 86-90 (2003).
5. Havrdová, M., *Příspěvek k hodnocení prodyšnosti oděvních tkanin*. Disertační práce. Liberec 2004.

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