ISSN 1392–1320 MATERIALS SCIENCE (MEDŽIAGOTYRA). Vol. 18, No. 3. 2012

Influence of Shrinkage on Air and Water Vapour Permeability of Double-Layered Weft Knitted Fabrics

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crossref http://dx.doi.org/10.5755/j01.ms.18.3.2438

Received 16 June 2011; accepted 01 December 2011

Water vapour permeability and transport depends on the properties of the fibre and knitted fabric structure. It was designed double-layered fabrics knitted in plain plating pattern whose inner side was made from synthetic fibres the PES, PA, PP, and Coolmax® (tetra-channel fibres by DuPont) which do not absorb moisture and on the surface of the wear – natural cotton and bamboo fibres which have good absorption properties. In the present research it was established that the air permeability of all fabrics after washing and drying cycle decreased. It occurred because of the influence of shrinkage during washing and drying under the impact of moisture, heat, and mechanical action. After washing and drying cycle, the water vapour permeability of fabrics knitted from bamboo and synthetic yarns blend decreased predominantly and became similar to fabrics knitted from cotton and respective synthetic yarns blend. The water vapour permeability of fabrics knitted from cotton and synthetic yarns blend decreased significant less. Depending on the knitting structure, the most decrease of water vapour permeability was estimated to the plain plated fabrics.

Keywords: air permeability, water vapour permeability, shrinkage.

INTRODUCTION

Clothing comfort includes three main considerations: thermo-physiological, sensorial and psychological comfort [1, 2]. Thermo-physiological comfort has become an important parameter of clothing, especially designed for active leisure. Factors affecting the thermo-physiological comfort are numerous and they include heat exchange within clothing, air permeability, transfer and evaporation of moisture, and other.

Clothing must assist the body's thermal control function under changing physical loads in such a way that the body's thermal and moisture management is balanced and a microclimate is created near to the skin [3]. This physiological effect is extremely important, especially in the case of clothing for sports and active leisure. Items of clothing with poor thermo-physiological wear characteristics not only detract from well-being of the human but also impair his/her physical performance and may even act as a health hazard.

Human body produces heat continuously during all his/her activities because of metabolic processes. With greater physical exertion, and thus a greater level of heat generated by the body itself, heat transfer through the clothing is insufficient to compensate for the body's energy balance. Because of sweat, the body begin to feel cool through the evaporation of the sweat on the skin [3]. Naturally, the prerequisite for cooling is that this sweat can actually evaporate. Therefore, the clothing must always ensure a high level of moisture transmission and evaporation.

The air in the microclimate between the individual items of clothing also has a physiological function. When the body is at rest, this air in the microclimate contributes up to approximately 50 % to the effective thermal insulation properties of the clothing. When the body is in motion, approximately 30 % of the heat and moisture can be removed by air convection in the microclimate and air exchange via the clothing [3]. Air permeability being biophysical feature of textiles determines the ability of the air to flow through the fabric. Air permeability also depends on the finishing treatment [4, 5]. In sportswear, high air permeability is desirable.

Water vapour permeability is the ability to transmit vapour from the body. The ability of clothing to transport water vapour is an important determinant of physiological comfort [6, 7]. The sweat should be removed from the skin surface to the surface of fabric of the next-to-skin clothing. After the body has stopped sweating, the textile fabric should release the vapour held to the atmosphere in order to reduce the humidity on the surface of the skin.

Clothing for the leisure sports is difficult to design as far as the physiological requirements are concerned since these are often contradictory because of the differing climatic and activity conditions. It is not a simple task to optimize sportswear as regards thermo-physiological and sensorial comfort. On the other hand, leisure sports is characterised by the fact that maximum physical performance is not always achieved and the active phases are interspersed with rest phases [8 – 10]. In addition, the leisure sportsperson often wears his/her clothing several hours.

During the investigation, the double-layered weft knitted fabrics for leisure sports in order to make physiological and thermal comfort were designed. A typical double-layered construction of knitted fabrics includes the following elements [9]:

- One layer of knitted fabric made of conductive and diffusive yarns, which directly adjoins the body. Its role is to remove and transport sweat from the body in liquid and vapour forms.

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- Another layer of knitted fabric made of absorptive yarn, which is not in direct contact with the skin. The role of this layer is to keep the humidity far from the body and vaporise it to the environment.

Natural fibres, such as cotton, are hygroscopic and are, therefore, characterised by high absorption levels [10]. The absorbed moisture is bound in strongly and only released slowly. However, cotton fabrics hold absorbed water, and their moisture transfer property is not especially high during activity. This retention of water may, impair heat dissipation from the skin and post-activity evaporative cooling [8]. Synthetic fibres such as polyester, polypropylene, acrylic are not hygroscopic and therefore only absorb comparatively small amount of moisture. However, because of hydrophilic fibre surface they have a high moisture transfer rate. Synthetic fibre yarns improve the dimensional stability of knitted fabric. The combination of natural and synthetic fibre yarns is an optimal decision to design wear for leisure sports.

The main goal of this work is to investigate the influence of shrinkage, raw materials, and knitting structure on air and water vapour permeability of double-layered knits for leisure sports.

EXPERIMENTAL

Materials and methods. Investigations were carried out on the double-layered fabrics knitted in plain plating pattern and two types combined structure on a circular knitting machines in a gauge E22 from cotton and man-made bamboo yarns in outer layer and PP (polypropylene), PA (polyamide), PES (polyester), and Coolmax (tetra-channel fibres by DuPont) threads in inner layer. Overall, 16 particular variants of knits were investigated. The characteristics of tested knitted fabrics and values of shrinkage are presented in Table 1. The knitting structure of tested fabrics is presented in [11].

Note: the relative error δ of structure parameters measurement is less than 5 %.

All experiments were carried out in a standard atmosphere for testing according to the standard ISO 139:2005. Structure parameters of knitted samples were analysed according to the British Standard BS 5441:1998.

The area linear filling rate E was calculated according to the equation:

$$E = (l \cdot d)/(A \cdot B), \tag{1}$$

Table 1. Characteristics of tested knitted fabrics.

Sample code	Pattern	Linear density of yarns and percentage composition	Course density P_v, cm^{-1}	Wale density P_h, cm^{-1}	Loop length, l, mm	Shrinkage, %	
						Lengthwise, $\lambda_l \pm \Delta_l$	Transverse, $\lambda_t \pm \Delta_t$
LSI-1	Plain plating	Cotton, 20 tex, 71 % PA, 7.8; 29 %	24.5	12.5	2.84	1.75 ±0.03	–21.69±0.012
LSI-2	Plain plating	Cotton, 20 tex, 71 % Coolmax, 7.8; 29 %	24.5	12.5	2.79	0.56 ±0.021	–17.81±0.007
LSI-3	Plain plating	Cotton, 20 tex, 71 % PES, 8.3; 29 %	24.5	12.5	2.79	–0.11 ±0.004	–15.88 ±0.024
LSI-4	Plain plating	Cotton, 20 tex, 71 % PP, 8.4; 29 %	25	12	2.88	3.56 ±0.008	–19.44 ±0.012
LSII-1	Plain plating	Bamboo, 20 tex, 71 % PA, 7.8; 29 %	24	12.5	2.85	–5.88 ±0.03	–17.25 ±0.036
LSII-2	Plain plating	Bamboo, 20 tex, 71 % Coolmax, 7.8; 29%	24	12.5	2.81	–5.0 ±0.011	–17.81 ±0.049
LSII-3	Plain plating	Bamboo, 20 tex, 71% PES, 8.3; 29%	24	12.5	2.81	–5.38 ±0.021	–18.44 ±0.02
LSII-4	Plain plating	Bamboo, 20 tex, 71 % PP, 8.4; 29%	24.5	12	2.93	–1.38 ±0.014	–19.31 ±0.034
KI-1	Combined I (piquè)	Cotton, 20 tex, 71 % PA, 7.8; 29 %	16	12	3.11	–13.75 ±0.034	–12.88 ±0.032
KI-2	Combined I (piquè)	Cotton, 20 tex, 71 % Coolmax, 7.8; 29 %	16	12	3.10	–14.88 ±0.014	–6.50 ±0.047
KI-3	Combined I (piquè)	Cotton, 20 tex, 71 % PES, 8.3; 29%	16	12	3.10	–16.38 ±0.019	–4.69 ±0.036
KI-4	Combined I (piquè)	Cotton, 20 tex, 71% PP, 8.4; 29%	16	11	3.21	–13.88 ±0.023	–6.38 ±0.006
KII-1	Combined II	Cotton, 20 tex, 76% PA, 7.8; 24 %	15	11.5	3.24	–19.75 ±0.027	–13.31 ±0.035
KII-2	Combined II	Cotton, 20 tex, 76 % Coolmax, 7.8; 24 %	15	11.5	3.26	–15.38 ±0.016	–7.69 ±0.035
KII-3	Combined II	Cotton, 20 tex, 76 % PES, 8.3; 24 %	15	11.5	3.26	–13.63 ±0.014	–8.56 ±0.086
KII-4	Combined II	Cotton, 20 tex, 76 % PP, 8.4; 24 %	15	11	3.35	–15.38 ±0.014	–9.50 ±0.009

Δ – the absolute error.

where l is the experimentally found loop length (according to the British Standard BS 5441:1998), mm; d is the yarn diameter, mm; A is the wale spacing, mm; B is the course spacing, mm.

The air permeability tests of the investigated double-layered knitted fabrics were provided according to the standard EN ISO 9237:1997, using the head area of 10 cm^2 and pressure difference of 100 Pa. 10 tests per sample were performed. The air permeability R was determined according to the following equation:

$$R = \frac{D}{A} \cdot 167, \ \text{dm}^3/(\text{m}^2\text{s}), \tag{2}$$

where D is the average of air flow rate, dm^3/min; A is the the operative area of sample equal to 10 cm^2.

The rate of moisture vapour transfer was measured using a cup method. Samples with diameter of 10 cm were kept on the round cup containing water of 40 °C temperature in controlled conditions (air temperature of 25 °C and relative humidity of 50 %) for the duration of 1 hour. 5 tests per sample were performed. The water vapour permeability W was determined according to the following equation:

$$W = \frac{M_W}{A \cdot t}, \ \text{mg}/(\text{m}^2\text{h}), \tag{3}$$

where M_W is the mass of water evaporated from the cup, mg; A is the operative area of sample, m^2; t is the time of water mass M_W evaporation, h.

The air and water vapour permeability after washing and drying of tested fabrics (according to the standard ISO 26330:1993) was measured and the influence of fabric shrinkage on air and water vapour permeability was estimated.

The shrinkage value λ was determined by the following equation (according to the washing standard ISO 26330:1993):

$$\lambda = \frac{L - L_0}{L_0} \cdot 100\,\%, \tag{4}$$

where L_0 is the dimension of sample before washing and drying; L is the dimension of sample after washing and drying.

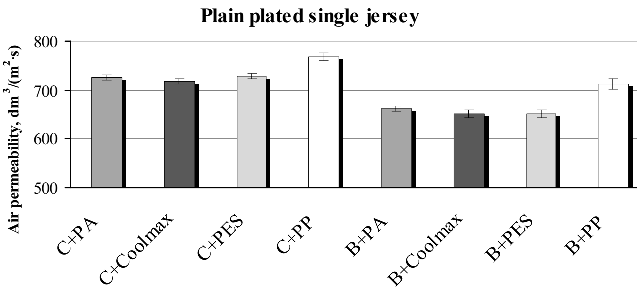
RESULTS AND DISCUSSION

The influence of fibre composition on air permeability and water vapour permeability of double-layered knits for leisure sports was investigated in this work.

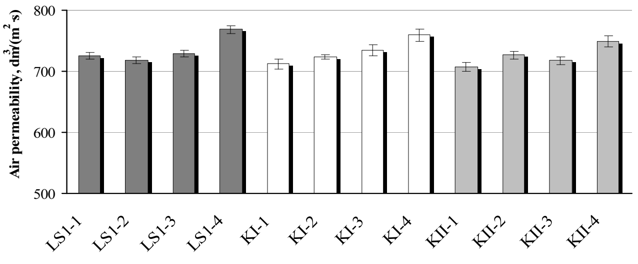
The values of air and water vapour permeability of original knitted fabrics are presented in [11]. The results presented in [11] show that air and water vapour permeability strongly depend on the raw material and knitting structure of investigated double-layered knitted fabrics. The correlation of water vapour permeability on air permeability of investigated double-layered knitted fabrics was not found, because water vapour permeability depends on the structure of knits not in the same order as air permeability.

After washing, analysed plain plated knitted fabrics *LSI* and *LSII* have shrunk in the transverse (wale) direction (approx. 19 %), which indicates that the density of loops in the fabrics has increased (Table 1). The fabrics with combined structures *KI* and *KII* have shrunk in the transverse direction approximately twice as less value. The plain plated fabrics *LSII* with bamboo plating yarn shrunk in the lengthwise (course) direction approximately to 5 % ÷ 6 %, whereas the plain plated fabrics *LSI* with cotton plating yarn extended approximately to 1 % ÷ 3 %. The fabrics with combined structure shrunk in the lengthwise direction in approx. 14 % ÷ 19 %.

The air permeability of all fabrics after washing and drying cycle decreased (Fig. 1). It occurred because of the influence of shrinkage during washing and drying under the impact of moisture, heat, and mechanical action [18]. Interestingly, that air permeability of fabrics knitted from bamboo and synthetic yarns combination decreased most of all, and they had (60 – 70) dm^3/(m^{2}s) worse air permeability than fabrics knitted from cotton and synthetic yarns blend in the same pattern (Fig. 1, a). The shrinkage values of bamboo fabrics *LSII* were the highest (Table 1): 6.38 % ÷ 9.09 % in longitudinal direction, and 1.14 % ÷ 2.04 % in transverse direction. It goes to show the influence of washing and drying on change of air permeability of fabrics (as stated in [5]). Meanwhile, the air permeability of fabrics knitted from cotton (or bamboo) and PP yarns composition in all investigated knitting structures (*LSI-4*, *LSII-4*, *KI-4*, *KII-4*) after washing and drying cycle remained the best (Fig. 1, b).



a



b

Fig. 1. The influence of shrinkage on value of air permeability of knits (marked as in Table 1)

After assessing the influence of knitting structure on air permeability of fabrics after washing and drying cycle, it can be seen in Fig. 1, b, that the results of fabrics knitted in various structures from the same yarns are very similar and vary in the limits of error. However, after assessing the influence of shrinkage on change of air permeability, it can be stated that the air permeability of fabrics knitted in plain plated single jersey structure *LSI* decreased most (from 106 dm^3/(m^{2}s) to 135 dm^3/(m^{2}s), depending on the fibre composition). Whereas the air permeability of fabrics knitted in combined structures *KI* and *KII* decreased twice as less (from 40 $dm^3/(m^2s)$ to 67 $dm^3/(m^2s)$, depending on the fibre composition).

After washing and drying cycle, the water vapour permeability of fabrics knitted from bamboo and synthetic yarns blend decreased predominantly – in $(1100 \div 1300)$ $mg/(m^2h)$ (as presented in Fig. 2, a) – and became similar to fabrics knitted from cotton and respective synthetic yarns blend. The water vapour permeability of fabrics knitted from cotton and synthetic yarns blend decreased noticeably less – about $(100 \div 400)$ $mg/(m^2h)$ (except fabrics knitted from cotton and PP yarns blend; after washing and drying, water vapour permeability of those decreased just in $(10 \div 30)$ $mg/(m^2h)$, i. e. in the margins of error). The most decrease of water vapour permeability $(200 \div 400$ $mg/(m^2h))$ was estimated to the plain plated fabrics. The results presented in Fig. 2, b, demonstrate that the best water vapour permeability after washing and drying remains fabrics knitted in combined patterns *KI* and *KII*.

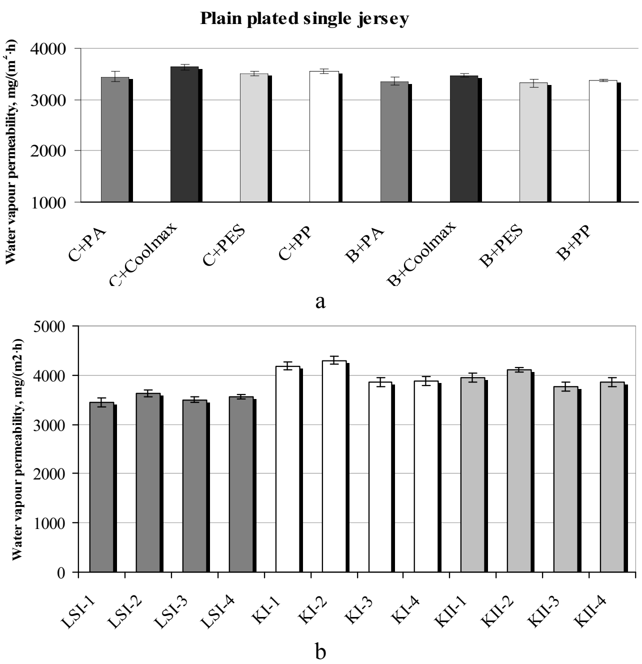


Fig. 2. The influence of shrinkage on value of water vapour permeability of knits (marked as in Table 1)

It all goes to show the influence of fibre composition of fabric (especially of natural derivation fibres), knitting structure and washing and drying (shrinkage) on water vapour permeability of knitted fabrics.

CONCLUSIONS

- The air and water vapour permeability strongly depend on the raw material and knitting structure of investigated double-layered knitted fabrics. However, water vapour permeability depends on the structure of knits not in the same order as air permeability.
- After washing and drying, all investigated knitted fabrics shrunk in both (lengthwise and transverse) directions, which indicates that the density of loops in the fabrics has increased.
- Because of increasing of loops density and decreasing of porosity of the fabrics, their air permeability decreased. The air permeability of fabrics knitted from bamboo and synthetic yarns blend decreased most of all.
- After washing and drying, the air permeability of fabrics knitted in plain plated single jersey structure decreased most, whereas the air permeability of fabrics knitted in combined structures decreased twice as less.
- After washing and drying cycle, the water vapour permeability of fabrics knitted from bamboo and synthetic yarns composition decreased predominantly and became similar to fabrics knitted from cotton and respective synthetic yarns blend.
- Depending on the knitting structure, the most decrease of water vapour permeability was estimated to the plain plated fabrics.

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Presented at the 20th International Baltic Conference "Materials Engineering 2011" (Kaunas, Lithuania, October 27–28, 2011)