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The Change of Air Permeability and Structure of Breathable-Coated Textile Materials after Cyclic Stretching

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In this article, the change of air permeability and structure of breathable-coated textile materials after cyclic stretching is discussed. The cyclic stretching test of woven cotton/polyester (PES) fabric with microporous polyurethane coating was done on the tensile testing machine Z005 (Zwick, Germany) by varying number of extension cycles and size of fixed elongation. The maximum number of stretching cycles was 420, and elongation varied in the range of 5 % – 25 %. The investigation of fabric was done both before mechanical treatment and fully relaxed (not less than 24 hours) after the cyclic stretching. Linear and logarithmic correlation analysis results, when researching the intensity of relationship between the parameters of cyclic stretching and air permeability, showed the sufficiently large values of coefficient of determination. It has been shown that an air permeability value after cyclic stretching increases depending on the increased number of stretching cycles and elongation. Comparison between the predictive and experimental values of air permeability has been carried out. The intensity of relationship between extension factors and the surface cover factor and this factor relationship with the air permeability of the fabric, are analyzed too. It has been concluded that the air permeability of the breathable-coated fabric is under the influence of the enlarged micropores in the coating structure.

Keywords: air permeability, cyclic stretching, breathable-coated fabric, correlation.

INTRODUCTION

Extensive research is being done worldwide to develop fabrics that provide comfort to wearer, while offering protection against foul weather. Breathable-coated fabrics designated for coats should have three main features: material should be permeable to water vapour, waterproof and windproof. In extremes of climatic conditions, the clothing should be windproof so that cold wind does not enter into the space between the skin and the clothing, dissipating the warm air in the vicinity of the skin [1]. Permeability to water vapour, waterproofness and windproofness are closely interrelated. The change of one property can cause the changes to the other two properties [2]. Resistance to wind penetration is usually assessed by measuring air permeability. The air permeability of textile fabrics is determined by the rate of flow of air passing perpendicularly through a given area of fabric is measured at a given pressure difference across the fabric test area over a given time period [3]. The main aim of the studies of an air permeability of textile materials is usually to find a relationship between an air permeability and structure of textiles. A textile structure is usually represented by its porosity [4]. Pores or voids spaces could be situated in the fibres, between fibres in the threads, and between warp and weft threads in the fabrics. The pores between warp and weft threads are also called the macropores [5]. The micropores coating contains very fine interconnected channels too [6]. The porosity has a very strong influence on uncoated textile materials air permeability. Air permeability is increased as pore size is increased [7–9].

The air permeability of coated fabrics is very low and this test is used for initial evaluation of breathable fabrics with porous coatings. During the mechanical treatment the breathable-coated fabric sustains deformations that are changing the pore size. The structure usually is damaged irreversible, and might be undesirable in apparel applications. The suitability of breathable-coated fabrics is usually thought of in terms of how many cyclic loads the fabric can withstand before damage of its structure and change of its properties. Only a small number of investigations could be found that analyze the effect of mechanical treatment to coated fabrics [10].

The current work presents the dependence of air permeability of breathable-coated fabric on cyclic stretching and change of structure.

MATERIALS AND METHODS OF INVESTIGATION

The woven 23 % cotton / 77 % polyester (PES) fabric with breathable microporous polyurethane coating was chosen for the research. The influence of the mechanical treatment on air permeability, the change of structure after cyclic stretching and the influence of the changed structure on air permeability has been investigated.

Before our research on the structure and air permeability change after cyclic stretching of breathable-coated fabric, we determined the initial basic structural parameters and mechanical properties of the material. These characteristics of breathable-coated fabric are presented in Table 1.

The tests determining two characteristics, i.e. breaking force and elongation at break, have been carried out according to the international standards ISO 13934-1 and ISO 1421 with a tensile testing machine Z005 (Zwick, Germany). All the tensile tests were performed at the crosshead speed of 100 mm/min. To shorten the rather long duration of each cyclic stretching, the standard distance between clamps has been diminished from 200 mm to 100 mm. Moreover, the consumption of material for testing was decreased about 33 %. The cyclic stretching

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Table 1. Initial details of breathable-coated fabric

Characteristic		Values
Mass per unit area, g/m^2		194
Diameter of yarns, mm (of outer woven fabric)	warp	0.17
	weft	0.25
Density, cm^{-1} (of outer woven fabric)	warp	43.0
	weft	22.5
Breaking force , N	at warp direction	886
	at weft direction	661
Elongation at break, %	at warp direction	38.7
	at weft direction	19.3

process of material was carried out by applying the fixed elongation method. The elongations along warp and weft directions were chosen different according to the initial properties (see Table 1) of the fabric. Specimens at warp direction were stretched up to 15 %, 20 % and 25 % and specimens at weft direction – 5 %, 10 % and 15 % for particular number of cycles. The results of fabric along warp direction at 30 % elongation have been emitted because the specimens were damaged after about 20 extension cycles.

Air permeability was measured for each specimen after full relaxation (not less than 24 hours) after cyclic stretching. Air permeability was measured using air permeability tester L14DR (Karl Schröder KG, Germany), as specified in ISO 9237 at pressure drop of 200 Pa.

The fabric cover factor shows the extent to which the two sets of threads in combination cover the area of the fabric. The research programme, regarding the evaluation of the cover factor change of outer woven fabric after mechanical treatment and the influence of the changed structure on air permeability, contained the following procedures and measurements. Firstly, the densities of woven fabric after various mechanical treatments were measured from digital views. The measured distance is 20 mm. The experimental set-up consists of a sample holder facing a binocular microscope Nikon SMZ 800 Achro 0,5× on which is mounted a PC-linked digital camera Nikon Coolpix 4500 to record the images of the textile material. METRIC 7.0 computer program was used for distance measurement. The accuracy of measurements is ±0.004 mm. Finally, the cover factor of each specimen was counted from the density at warp and weft directions and diameters of warp and weft yarns [11].

All the specimens of fabric were conditioned in a standard atmosphere of 65 % RH and 20 °C.

RESULTS AND DISCUSSION

In the present study we attempted to show the dependences of air permeability of breathable-coated fabric on cyclic stretching parameters. Also we studied the change of cover factor of outer woven fabric after various cyclic stretching. Then we investigated the dependence of the air permeability on the cover factor change of outer woven fabric.

The air permeability before mechanical treatment was zero; this result is in line with other studies [6, 12]. This value is assessed and evaluated when forming the linear regression equations. The results of the air permeability of breathable-coated fabric after different elongation at warp and weft directions are presented in Fig. 1 and Fig. 2, respectively. The linear regression equations and coefficient of determination between elongation and air permeability determined by the results of the tests are presented in Table 2. The coefficient values of elongation parameter of these equations increase as the chosen number of stretching cycles increases. This trend is applicable for all nine suggested equations. As expected, the correlation between elongation and air permeability is positive. The air permeability increases, increasing the elongation, due to the change of macropores and micropores of breathable-coated fabric. The theoretical analyse [4] supports this hypothesis also. The coefficient of variation of all specimens for this test ranged from 5 % to 15 %. We can see from Table 2 that

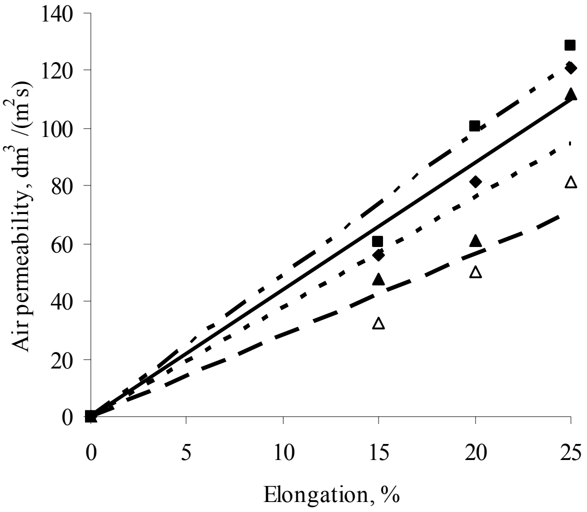

Fig. 1. The correlation between elongation at warp direction and air permeability of breathable-coated fabric: △ and — — after 100 stretching cycles, ▲ and – – – after 180 stretching cycles, ◆ and —— after 260 stretching cycles, ■ and — – – — after 420 stretching cycles

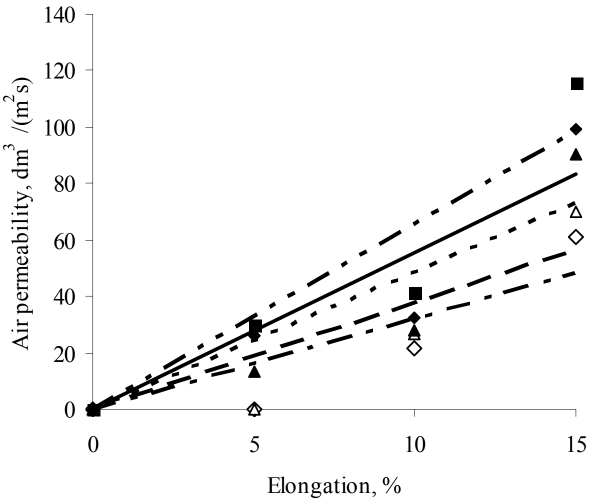

Fig. 2. The correlation between elongation at weft direction and air permeability of breathable-coated fabric: ◇ and — – — after 20 stretching cycles, △ and — — after 100 stretching cycles, ▲ and – – – after 180 stretching cycles, ◆ and —— after 260 stretching cycles, ■ and — – – — after 420 stretching cycles

Table 2. The linear regression equations and correlation between elongation and air permeability

Direction	Number of stretching cycles	Linear regression equation	Coefficient of determination
Warp	100	$Q = 2.8234\ \varepsilon$	0.93
	180	$Q = 3.7862\ \varepsilon$	0.90
	260	$Q = 4.3955\ \varepsilon$	0.97
	420	$Q = 4.9138\ \varepsilon$	0.98
Weft	20	$Q = 3.2176\ \varepsilon$	0.78
	100	$Q = 3.7694\ \varepsilon$	0.80
	180	$Q = 4.8579\ \varepsilon$	0.82
	260	$Q = 5.5651\ \varepsilon$	0.85
	420	$Q = 6.5651\ \varepsilon$	0.88

Q – air permeability, ε – elongation.

for all tested samples after various number of cyclic stretching the coefficient of determination varies in rather close limits and their values are large. So, the influence of different elongation on air permeability is significant because the coefficient of determination ranges from 0.78 to 0.98.

The obtained linear regression equations help to predict the change of air permeability when the number of stretching cycles and fixed elongation is known. This possibility was checked in one chosen point, i. e. at warp direction after 180 stretching cycles and for elongation of 12 %. Judging from the values of experimental and predictive air permeability, it seems that both results are in rather good agreement. The difference between these values is 11.8 %.

In our research, we also determined the influence of the second parameter, i. e. number of stretching cycles on air permeability, when size of deformation is fixed. The logarithmic dependences of air permeability on the number of stretching cycles at warp and weft directions are presented in Fig. 3 and Fig. 4, respectively. The correlation between number of stretching cycles and air permeability is positive too, as it was for correlation with different elongation. The air permeability increases, increasing the number of stretching cycles, due to the change of material structure. Proposition corresponds well with Chen et al. conclusions [10].

The logarithmic regression equations and coefficient of determination between number of stretching cycles and air permeability are presented in Table 3. The dependence of air permeability on number of stretching cycles along warp and weft directions is good and values of coefficient of determination fluctuated in the range from 0.67 to 0.95 except the case, when elongation was 5 %. The first three points are zero or very close to zero and distort the coefficient of determination.

We additionally studied the change of cover factor of outer woven fabric after various cyclic stretching. The cover factor was estimated according to the measurements of densities from taken digital views. The initial cover factor of woven fabric was 88.4 %. The cover factor after various mechanical treatments has changed very little, i. e. in the margin of error. The difference between maximum and minimum values of cover factor was only 1.6 %.

The values of coefficient of determination between number of stretching cycles and cover factor are presented in Table 4. In this case, the possibility to apply the exponential regression was verified. In the second approach, the linear regression was used to study the relationship between elongation and cover factor. The values of coefficient of determination are given in Table 5. These values of coefficients show that the cover factor has not marked dependence on studied mechanical treatments. The possible reason of this dependence is the influence of coating, which makes the outer woven fabric more stabile as recorded in reference [10]. Besides that the density of woven fabric during the stretching process is decreasing at one direction and increasing at other direction of yarns. Therefore, the increase of one parameter and decrease of other may eliminate the changes of cover factor.

Finally, we investigated the dependence of the air permeability on the cover factor change of outer woven fabric. In this case, the coefficient of determination of this

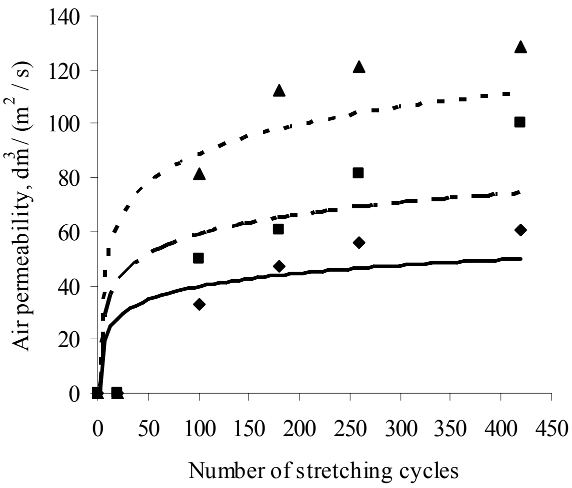

Fig. 3. The dependence of air permeability on number of stretching cycles along warp direction: ◆ and —— 15 % fixed elongation, ■ and — — 20 % fixed elongation, ▲ and – – – 25 % fixed elongation

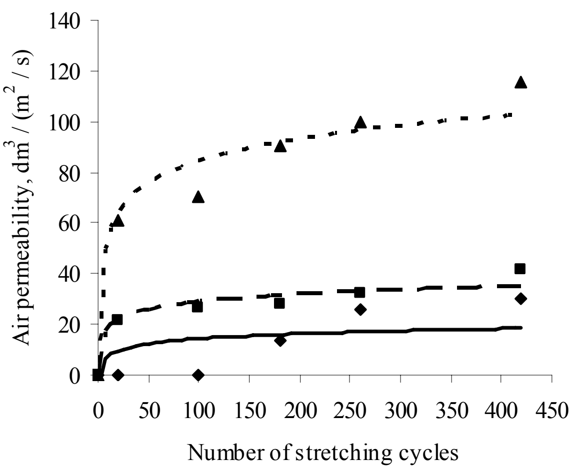

Fig. 4. The dependence of air permeability on number of stretching cycles along weft direction: ◆ and —— 5 % fixed elongation, ■ and — — 10 % fixed elongation, ▲ and – – – 15 % fixed elongation

Table 3. The logarithmic regression equations and correlation between number of stretching cycles and air permeability

Direction	Elongation, %	Logarithmic regression equation	Coefficient of determination
Warp	15	$Q = 7.2104 \ln (n) + 6.3362$	0.69
	20	$Q = 10.873 \ln (n) + 8.8241$	0.67
	25	$Q = 15.975 \ln (n) + 15.137$	0.70
Weft	5	$Q = 2.8757 \ln (n) + 1.0866$	0.43
	10	$Q = 4.3374 \ln (n) + 9.0614$	0.94
	15	$Q = 12.743 \ln (n) + 25.798$	0.95

Q – air permeability, n – number of stretching cycles.

Table 4. The coefficient of determination between number of stretching cycles and cover factor

Direction	Elongation, %	Coefficient of determination
Warp	15	0.23
	20	0.14
	25	0.02
Weft	5	0.84
	10	0.97
	15	0.14

Table 5. The coefficient of determination between elongation and cover factor

Direction	Number of stretching cycles	Coefficient of determination
Warp	20	0.15
	100	0.23
	180	0.27
	260	0.37
	420	0.34
Weft	20	0.60
	100	0.73
	180	0.73
	260	0.84
	420	0.91

dependence shows that the linear correlation between cover factor of outer woven fabric and air permeability does not exist. The value of coefficient of determination is 0.28. So, the air permeability of breathable-coated fabric has very small influence under the macroporosity. As the result goes a proposition that air permeability has great influence under the microporosity of the coating. We can expect that microporosity of the polyurethane coating after various cyclic stretching is damaged irreversible.

CONCLUSIONS

The change of air permeability and structure of cotton / PES breathable-coated textile material after cyclic stretching was studied by applying the correlation analysis and different types of regression equations.

1. The air permeability of tested fabric during the mechanical treatment increases from zero to 128 $dm^3/(m^2/s)$. The permeability rises, increasing the elongation and number of stretching cycles. To show these trends of the permeability, the linear and logarithmic regression equations have been proposed. The coefficient of determination between elongation and air permeability varies in the range of 0.78 – 0.98. This coefficient between number of stretching cycles and air permeability ranges from 0.67 to 0.95 except the case, when elongation was 5 %. In this case, the first three points distorted the coefficient of determination.

2. The cover factor of outer woven fabric after different mechanical treatment varies only 1.6 %. It is due to the coating on the backside, which leads to a more dimensionally stable fabric structure. The marked correlation between cyclic stretching parameters and cover factor does not exist. The coefficient of determination varies between 0.14 and 0.97.

3. The correlation between outer fabric cover factor and air permeability is shown to be very weak. As the result of this trend goes a proposition that air permeability of breathable woven fabric with microporous polyurethane coating is under the influence of the change microporosity of coating, meanwhile the macropores have small influence to air permeability.

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