Breathability and Resistance to Water Penetration of Breathable-Coated Textiles after Cyclic Mechanical Treatments

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In this study, we have explored different aspects of wear-comfort, namely the breathability and resistance to water penetration properties of some breathable-coated fabrics that are used as outwear. The breathable-coated fabrics, i. e. the 100 % polyamide (PA) woven fabric coated with polyurethane (PU) and the three-ply laminate, consisting of an outer 100 % polyester (PES) woven fabric, an insider hydrophilic PU membrane and 100 % PES knitted lining, were tested. The variations of their properties by increasing number of stretching cycles and size of deformation were examined. The cyclic stretching test was done on the tensile testing machine Z005 (Germany). The maximum number of stretching cycles was 260, and elongation varied in the range of 15 % – 25 %. The kinetics of breathability and resistance to water penetration were examined. To determine the change of the above-mentioned properties of wear-comfort, the initial fabrics without mechanical treatment and the samples after cyclic mechanical treatments were measured. The test of water-vapour permeability was performed on a Sweating Guarded Hotplate M259b (England) and the resistance to water penetration was measured with a Shirley Hydrostatic Head Tester M018 (England). In the present study, we have attempted to show the dependences of resistance to water penetration of breathable-coated fabrics on cyclic stretching parameters. The polynomial regression equations and the coefficients of determination for relationships between number of stretching parameters and the resistance to water penetration were determined and analysed.
Keywords: breathable-coated fabric, cyclic stretching, waterproof, water-vapour permeability.

INTRODUCTION

Nowadays consumers are more and more interested in clothing assuring the wear comfort. Wear comfort is strongly connected with such properties of fabric as water-vapour permeability, air permeability and waterproofness. The definition of breathability is often being confused with water-vapour permeability, wind penetration or clothing's ability to wick liquid water away from the skin; all of these processes are also referred to as breathability but they depend on entirely different fabric properties [1 – 3]. The water-vapour permeability is a critical factor of wear comfort, especially in conditions that involve sweating. This property allows the fabrics to be water-vapour permeable, to have protection against wind and to be waterproof.

The water-vapour permeability of breathable-coated fabrics can be measured in several different methods determining with sweating guarded hotplate (skin model), cup method or inverted cup method. In several research works [2, 4 – 6] the above mentioned test methods have been compared. In these works it was concluded that the water-vapour permeability measured with different methods can't be compared directly due to different testing conditions, measurement parameters and units of measurements.

The air permeability of breathable-coated fabrics has to be zero or very low 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 [7, 8]. In previous our research [9], we have studied the influence of mechanical treatment on air permeability of breathable-coated fabrics and noted that the air permeability is increasing according to the growing number of stretching cycles. In the study [10], we have showed the mathematical dependences of air permeability of breathable-coated fabric on cyclic stretching parameters, and the proposition was formed that the air permeability has great influence under the microporosity of coating; meanwhile, the macroporosity of woven fabric has small influence on the air permeability.

Waterproofness is important property of the outer garment layer, and does not allow any penetration of water from outer side to the other [11, 12].

To insure two contradictory properties, i. e. breathability and waterproofing of fabric, material can be combined of some layers with different properties. A large variety of breathable fabrics, that have unique properties, is developed, and they may be categorised as closely woven fabrics, microporous membranes and coating, hydrophilic membranes and coating, combination of microporous and hydrophilic membranes and coating, use of retroreflective microbeads, smart breathable fabrics and fabrics based on biomimetics [1, 12 – 16]. The factors influencing the vapour regulation of these fabrics vary widely due to differences in underlying mechanism [1].

During the mechanical treatment the breathable-coated fabric sustains deformations that change the structure of material. The increase of air permeability and decrease of resistance to water penetration are undesirable indications of the wearing process and points the damage and unsuitability of garment.

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The recommendations to determine the change of resistance to water penetration of clothing with protection against rain after dry-cleaning and/or washing, abrasion, repeated flexing, and influence of fuel and oil are indicated in the European Standard EN 343 [17]. There is no indicated the determination of resistance to water penetration after cyclic stretching, which can damage the structure irreversible and change the main properties of breathable-coated fabrics.

In the present study, we attempted to show the dependence of breathability and resistance to water penetration of breathable-coated fabrics on cyclic stretching parameters.

MATERIALS AND METHODS OF INVESTIGATION

Two different types of breathable-coated fabrics made of different materials were used for the experiments. These fabrics are: three-ply laminate (sample A), consisting of 100 % polyester (PES) outer fabric, an insider hydrophilic polyurethane (PU) membrane and 100 % PES knitted lining; 100 % polyamide (PA) woven fabric with PU microporous coating on a back side (sample B). The specifications of fabrics are listed in Table 1.

Table 1. Characteristics of breathable-coated fabrics

Characteristic		Sample A	Sample B
Mass per unit area, g/m^2		262	86
Weave of outer fabric		plain	plain
Knitting structure of lining		single jersey	–
Density, cm^{-1} (of outer woven fabric)	warp weft	33.3 22.5	40.8 32.5
Density, cm^{-1} (of knitted lining)	courses wales	6.7 6.7	– –
Breaking force, N	at warp direction at weft direction	1165 794	627 258
Elongation at break, %	at warp direction at weft direction	58.5 39.5	32.9 30.3

The cyclic stretching has been carried out with a tensile testing machine Z005 (Zwick, Germany). All the tensile tests were performed at the crosshead speed of 100 mm/min. The distance between clamps was 200 mm. The cyclic stretching process of material was carried out by applying the fixed elongation method. Specimens were stretched up to elongation (ε) 15 %, 20 % and 25 % for particular number of stretching cycles (n). The following values of n were used: 100, 180 and 260.

The measurement of water-vapour resistance (R_{et}) under steady state conditions have been carried out according to the International Standard ISO 11092 [18] with Sweating Guarded Hotplate M259b (SDL International Ltd., England). Before testing, the specimens were conditioned for a minimum of 24 h at a temperature 35 °C and relative humidity 40 % [18] in Controlled Humidity Test Chamber (JCI, UK). During the test temperature of measuring unit and air temperature in the test enclosure were 35 °C with a relative humidity of 40 %. The air speed was hold at 1 m/s. The test specimens were placed so that they lie flat across the measuring body towards the measuring unit.

Water-vapour permeability (W_d) was calculated [18]:

$$W_d = \frac{1}{R_{et} \cdot \phi T_m}, \tag{1}$$

where: $\phi\, T_m$ is the latent heat of vaporization of water at the temperature T_m of the measuring unit in (Wh)/g; R_{et} is the water-vapour resistance in (m^{2}Pa)/W.

A hydrostatic pressure method according to [19] for determining the resistance of fabrics to water penetration at a constant rate of increase of pressure was applied. The test was performed on a Shirley Hydrostatic Head Tester M018 (SDL International Ltd., England). The outer side of breathable-coated fabric was placed in contact with water during evaluation. Rate of water column rise was 60 cm/min. The hydrostatic pressure (H) at which water penetrates the fabric at the first place was observed. The accuracy of measurement is ±2 cm.

All the specimens used for the tensile tests and measurement of resistance to water penetration were conditioned, and the tests were carried out in a standard atmosphere of 65 % ±2 % RH and 20 °C ±2 °C.

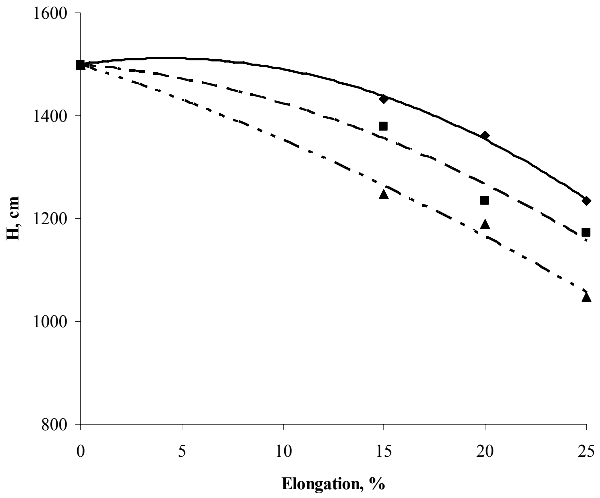
RESULTS AND DISCUSSION

In the first part of our research we have studied the effect of the cyclic stretching on breathability of breathable-coated fabrics. The initial water-vapour resistance was measured, and water-vapour permeability was estimated. These results confirmed that both tested materials behave well and satisfy the needs, for which they are designed. These results are in line with other studies [1, 6, 20]. In this case, water-vapour can penetrate through the membrane due to non-activated diffusion and drift away. The initial values of water-vapour permeability before and after mechanical treatment are presented in Table 2.

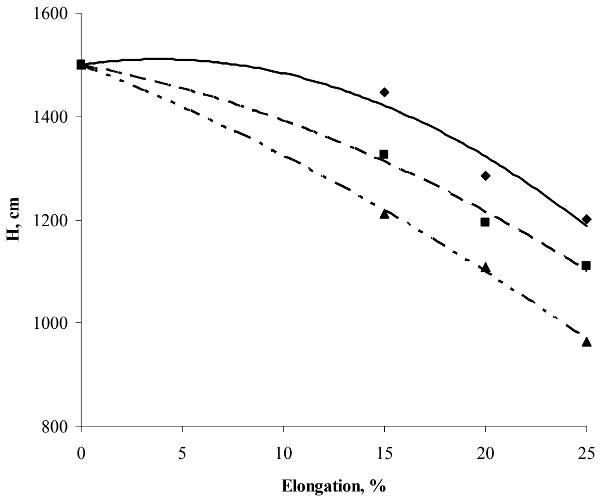
Table 2. Water-vapour permeability of tested breathable-coated fabrics

Code of sample	Water-vapour permeability, g/(m^2 h Pa)		
	Initial value	Value after 260 stretching cycles at elongation of 25 %	
		after stretching at warp direction	after stretching at weft direction
A	0.138	0.166	0.162
B	0.112	0.178	0.167

To find out the effect of cyclic stretching on breathability property of breathable-coated fabrics, water-vapour permeability was measured after maximum treatment applied in this research, i. e. after 260 stretching cycles and elongation of 25 %. The results (Table 2) demonstrate that the water-vapour permeability increases compared with the initial level. The increase of water-vapour permeability is desirable indication, because it increases the comfort level of wear but the estimated results alert that the structure is damaged. The increase of water-vapour permeability after 260 stretching cycles and elongation of 25 % is due to the more open structure, which is more accessible for the additional water-vapour permeability. This proposition corresponds well with Jassal et al. [11]. In this study, it was noted, that the increase of water-vapour permeability may be due to higher number of micropores and/or the higher hydrophilicity of the coating. The change of water-vapour permeability after above mentioned treatment is more remarkable for sample B comparing with sample A. It can be asserted, that in this case the tree-ply structure of sample A is more stable and it changes less than the structure of sample B. However, water-vapour permeability values are close for both investigated samples, even after maximum treatment. Therefore, there is no aim to analyse the change of water-vapour permeability after every applied treatment, because the values will be in the margins of error.



a



b

Fig. 1. The dependence of resistance to water penetration on elongation at warp direction (a) and weft direction (b) of sample A: ◆ and —— after 100 stretching cycles, ■ and — — after 180 stretching cycles, ▲ and — – – after 260 stretching cycles

In the second part of the current research to establish the influence of elongation and number of stretching cycles on resistance of water penetration, hydrostatic pressure tests were conducted with both types of samples. Firstly, we analysed the effect of elongation on the resistance to water penetration of breathable-coated fabrics. The resistance to water penetration before mechanical treatment was very high, i. e. 1500 cm for sample A, and 1386 cm – for sample B, and they are suitable for outwear apparel, as recorded in references [1, 11]. Figure 1 shows the resistance to water penetration of sample A as a function of elongation in warp and weft directions. Similar graphs produced for sample B are shown in Figure 2. The resistance to water penetration of samples A and B decreases as the elongation increases, thus showing agreement with the results of water-vapour permeability discussed above. Comparing the data from Figures 1 and 2, the values of resistance to water penetration for both samples have the same trends. For sample A the resistance to water penetration varies in the range from 1500 cm to 1047 cm when stretched in warp direction. The values from 1500 cm to 964 cm were observed after stretching at weft direction. Due to low tensile stability of sample B, this sample shows a much bigger change in resistance to water penetration than sample A. The resistance to water penetration of sample B was in the range from 1386 cm to 560 cm at warp direction, and this index varied from initial level till 784 cm after stretching at weft direction.

The polynomial regression equations and the coefficients of determination between number of stretching cycles and resistance to water penetration determined by the results of the tests are given in Tables 3 and 4. We have found that lines of the best fit are given by a second-degree polynomial. As it can be seen, the values of coefficient of determination show very strong dependence between elongation and resistance to water penetration. So, the obtained polynomial regression equations can be used for prediction of the change of resistance to water penetration when fixed number of stretching cycles and variable elongation is known.

Table 3. The polynomial regression equations and correlation between elongation and resistance to water penetration (sample A)

Direction	Number of stretching cycles	Polynomial regression equation	Coefficient of determination
Warp	100	$H = -0.635\varepsilon^2 + 5.3723\varepsilon + 1500$	0.99
	180	$H = -0.4086\varepsilon^2 - 3.4745\varepsilon + 1500$	0.97
	260	$H = -0.1997\varepsilon^2 - 12.746\varepsilon + 1500$	0.99
Weft	100	$H = -0.726\varepsilon^2 + 5.6332\varepsilon + 1500$	0.96
	180	$H = -0.3452\varepsilon^2 - 7.3155\varepsilon + 1500$	0.99
	260	$H = -0.2513\varepsilon^2 - 15.004\varepsilon + 1500$	0.99
H – resistance to water penetration, ε – elongation			

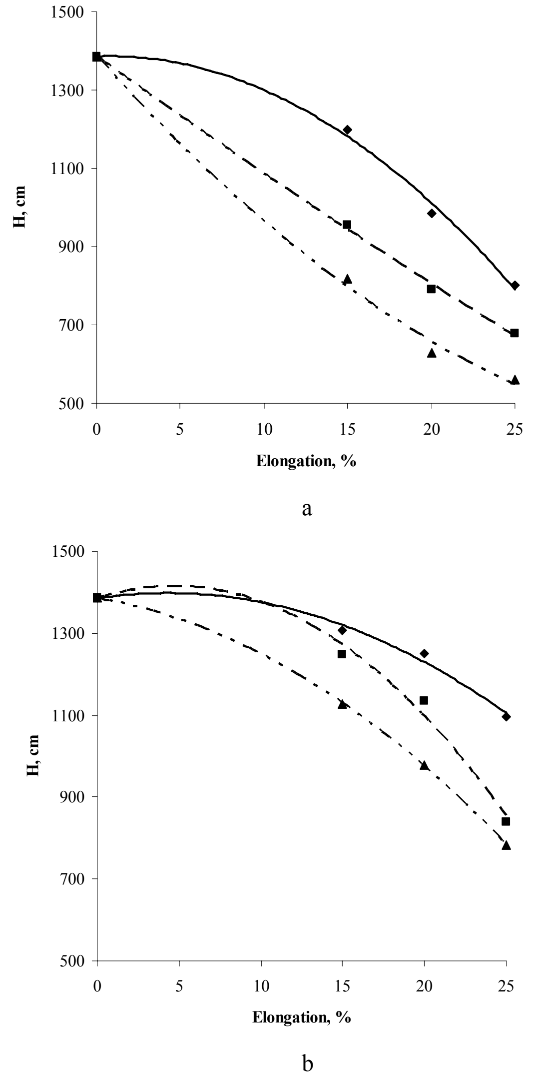


Fig. 2. The dependence of resistance to water penetration on elongation at warp direction (a) and weft direction (b) of sample B: ◆ and —— after 100 stretching cycles; ■ and — — after 180 stretching cycles; ▲ and — – – after 260 stretching cycles

Table 4. The polynomial regression equations and correlation between elongation and resistance to water penetration (sample B)

Direction	Number of stretching cycles	Polynomial regression equation	Coefficient of determination
Warp	100	$H = -1.0099\varepsilon^2 + 1.477\varepsilon + 1386$	0.99
	180	$H = 0.0902\varepsilon^2 - 30.812\varepsilon + 1386$	0.99
	260	$H = 0.5749\varepsilon^2 - 47.894\varepsilon + 1386$	0.99
Weft	100	$H = -0.6828\varepsilon^2 + 5.849\varepsilon + 1386$	0.98
	180	$H = -1.362\varepsilon^2 + 12.8\varepsilon + 1386$	0.99
	260	$H = -0.6947\varepsilon^2 - 6.6737\varepsilon + 1386$	1.00
H – resistance to water penetration, ε – elongation			

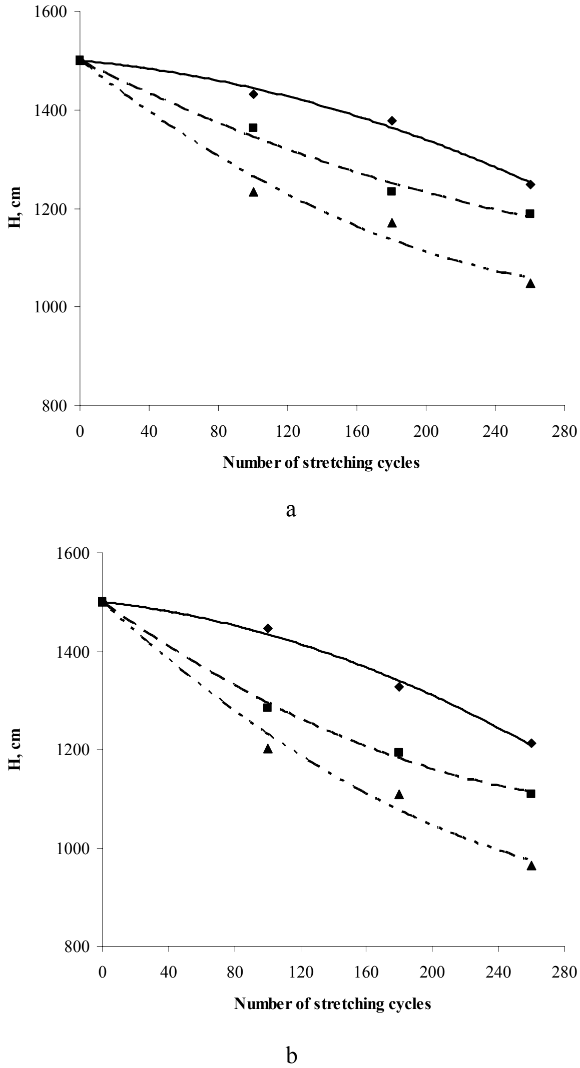


Fig. 3. The dependence of resistance to water penetration on number of stretching cycles at warp direction (a) and weft direction (b) of sample A: ◆ and —— 15 % fixed elongation; ■ and — — 20 % fixed elongation; ▲ and — – – 25 % fixed elongation

Table 5. The polynomial regression equations and correlation between number of stretching cycles and resistance to water penetration (sample A)

Direction	Elongation, %	Polynomial regression equation	Coefficient of determination
Warp	15	$H = 0.00246n^2 - 0.3103n + 1500$	0.99
	20	$H = 0.002n^2 - 1.739n + 1500$	0.99
	25	$H = 0.0041n^2 - 2.7532n + 1500$	0.98
Weft	15	$H = -0.0029n^2 - 0.3618n + 1500$	0.99
	20	$H = 0.0035n^2 - 2.3954n + 1500$	0.99
	25	$H = 0.0042n^2 - 3.0985n + 1500$	0.99
H – resistance to water penetration, n – number of stretching cycles			

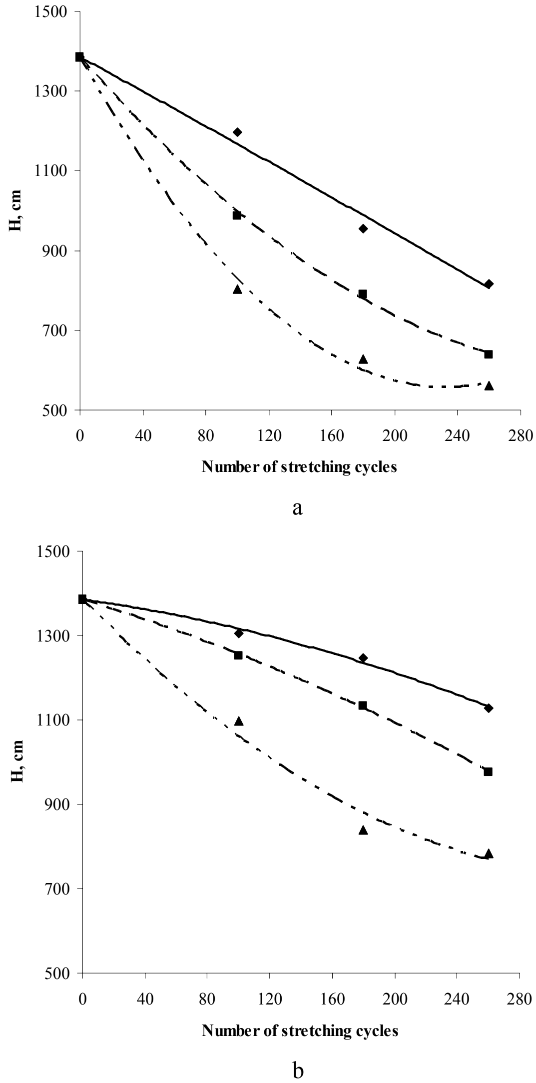


Fig. 4. The dependence of resistance to water penetration on number of stretching cycles at warp direction (a) and weft direction (b) of sample B: ◆ and —— 15 % fixed elongation, ■ and — — 20 % fixed elongation, ▲ and — – – 25 % fixed elongation

Table 6. The polynomial regression equations and correlation between number of stretching cycles and resistance to water penetration (sample B)

Direction	Elongation, %	Polynomial regression equation	Coefficient of determination
Warp	15	$H = 0.0003n^2 - 2.1578n + 1386$	0.98
	20	$H = 0.0064n^2 - 4.5309n + 1386$	0.99
	25	$H = 0.0153n^2 - 7.1219n + 1386$	0.99
Weft	15	$H = -0.0018n^2 - 0.5204n + 1386$	0.99
	20	$H = -0.0017n^2 - 1.1314n + 1386$	0.99
	25	$H = 0.0055n^2 - 3.8032n + 1386$	0.99
H – resistance to water penetration, n – number of stretching cycles			

We have also determined the influence of second parameter, i. e. number of stretching cycles on resistance to water penetration. In this case, the size of elongation was at fixed level. We have plotted graphs of resistance to water penetration versus number of stretching cycles at warp and weft directions for both tested fabrics, and these results are shown in Figures 3 and 4. As it can be seen, the lowest resistance to water penetration is shown by the sample B after 260 stretching cycles and elongation of 25 %. From the results presented in Figures 3 and 4 it is also evident that the dependences between the resistance to water penetration and number of stretching cycles are significant. According to the character of presented values of resistance to water penetration (Figures 3 and 4) it may by assumed that the resistance to water penetration of both samples can be described by the polynomial regression equations of second order. The equations and coefficients of determination between elongation and resistance to water penetration determined by the results of the tests are given in Tables 5 and 6. It is also evident that the values of coefficient of determination show very strong dependence between number of stretching cycles and resistance to water penetration.

From the practical point of view, important scientific results were obtained for investigation of different relationships of resistance of water penetration of breathable-coated fabrics after some combinations of stretching parameters. As it can be seen from Figures 1 to 4, the rather equal values of resistance to water penetration after different effect of mechanical treatment were observed. We have noticed some groups of combinations of stretching parameters, where the water penetration values were close or almost the same. We have ascribed to the first group the combinations that are after 100 stretching cycles and elongation of 25 %; after 180 of stretching cycles and elongation of 20 % and after 260 of stretching cycles and elongation of 15 %. The second group may be composed of treatments after 100 stretching cycles and elongation of 20 % and after 260 stretching cycles and elongation of 15 %. To estimate the intensity of influence of each stretching parameter, the further analysis is needed.

CONCLUSIONS

To summarize, we can see from the experiments reported in this paper that the dependence of water-vapour permeability and resistance to water penetration of tested breathable-coated fabrics (samples A and B) on cyclic stretching exist.

The values of water-vapour permeability were found to increase with increase of deformation parameters and demonstrate that structure of breathable-coated fabrics is changed and damaged irreversible. The values of water-vapour permeability increased from 0.138 g/(m^2 h Pa) to 0.166 g/(m^2 h Pa) of sample A after 260 stretching cycles and elongation of 25 %. The change of water-vapour permeability value of sample B after maximum treatment applied in this research was 0.066 g/(m^2 h Pa).

The resistance to water penetration of samples was shown as a polynomial function of stretching parameters. We can see, that the resistance to water penetration of samples A and B decreases as the values of stretching parameters increase. Thus, this result is in agreement with the results of water-vapour permeability and that structure of samples is damaged.

Due to low tensile stability of sample B, this sample shows a much bigger change in resistance to water penetration than sample A.

The values of coefficient of determination show very strong dependence between stretching parameters and resistance to water penetration, i. e. R^2 varies in the range of 0.96 – 1.00.

We have noticed that after some different effects of stretching, the values of resistance to water penetration were close or almost the same. It follows, that the similar effect of stretching to resistance to water penetration can be observed by changing the number of stretching cycles or size of elongation in various ways.

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