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Liquid moisture transport in knitted fabrics in relaxed and stretched state

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ABSTRACT

The aim of this work was to analyze the influence of stretch on liquid moisture transport through the knitted fabrics for T-shirts. Five variants of cotton and cotton blended fabrics were measured by means of the Moisture Management Tester. Measurements have been performed for samples in the unstretched state and samples stretched by 15%. To precisely stretch the fabrics, the MMT Stretch Fabric Fixture has been applied. The results have been analyzed statistically in order to assess the influence of stretch on the parameters characterizing the moisture transport through the fabrics.

Keywords
knitted fabrics,
underwear,
comfort,
moisture transport,
stretching

1 Introduction

The human body has a physiological feature of sweating in order to regulate its body heat due to a hot environment or intense exercise. Sweat is a fluid secreted by the glands under the skin, 99 percent of which is water and the remaining one percent is mineral salts. As the body temperature rises, the glands sweat and cool the body. Underwear and its materials play an important role in transporting and absorbing moisture from the human body and maintaining comfort for a long time. Generally, clothing is a barrier to the transport of heat and moisture from the human body to environment [1-3]. From the physiological comfort point of view, the main features of clothing and materials from which clothing is made of are the following [1,2]:

- thermal resistance,
- water-vapor resistance,
- liquid moisture transport, and
- air permeability.

Thermal resistance of clothing determines the heat exchange between the human body and the surrounding. It is very important from the point of view of thermal comfort of the clothing user [4, 5]. The higher the thermal resistance, the less heat is given away by the human body. The air permeability of clothing directly influences gas exchange between a human being and the surroundings and, in the same way, the physiological comfort of the clothing user. Due to this fact, air permeability is considered as one of the crucial comfort-related properties of clothing [6,7]. Water-vapour permeability of textile materials supports the moisture transfer from the human body skin through the textile layer into the environment [8]. This property is especially important while higher levels of activity and/or climatic conditions cause intensive sweating and the sweat must be rapidly managed by the clothing [9]. However, the water-vapour permeability or, connected with it, the water-vapour resistance are not sufficient to fully characterize the textile materials from the point of view of moisture transport because they consider only the transport of moisture in the form of vapour. During intense exercise or other activities, sweat in the form of vapour is not always fully evaporated. Excess sweat condenses on the surface of the human skin, giving an unpleasant feeling. Taking this into consideration, from the comfort point of view it is necessary to characterize the materials in two aspects: transfer of moisture in the form of vapour and in the form of liquid. Moisture transmission through textile materials in liquid and vapour forms are equally important.

Moisture transport in the liquid form is especially important for underwear and its material because the underwear adheres directly to the human skin and is in contact with the liquid sweat on the skin's surface. There are currently no requirements for undergarments used under protective clothing. Due to the fact that it is worn close to the body and that protective clothing could increase worker safety when exposed to hot factors, undergarments are very important elements of protective clothing [10]. Knitted fabrics currently available on the market show satisfactory biophysical properties in terms of their use in underwear worn in a hot microclimate. A problem arises from the fact that while usage the underwear material is constantly stretched during human movement. The underwear and also clothing made of knitted fabrics are usually stretched while wearing. The same situation occurs while wearing underwear and clothing containing elastomers. The stretching causes the changes of the fabrics' structure and in the same way the changes of the mechanism of liquid moisture transport in the fabrics. Last decade the Moisture Management Tester (SDL Atlas, US) was applied to evaluate in a complex way the textile materials from the point of view of their ability to transport liquid moisture [11,12]. However, currently published research works concerns the transport of liquid moisture in textile materials in relaxed (unstretched) state [13-16]. This measurement often does not reflect the actual conditions of moisture transport through the clothing material when stretched.

The aim of this study was to determine the effect of stretching on the moisture transport of knitted fabrics for underwear.

2 Materials and methods

Five types of cotton and cotton blends were selected for the study. The fabrics have the following characteristics (Table 1):

Table 1. Characteristic of the investigated knitted fabrics.

Symbol	Weave	Fiber composition	Thickness (mm)	Mass per unit area (g/m^2)	Number of courses/cm	Number of wales/cm
KF1	Single jersey	100% cotton	0.47	161.09	22	16
KF2	Rib stitch	100% cotton	0.61	138.59	17	12
KF3	Piqué	97% cotton, 3% elastan	1.27	198.44	12	10
KF4	Single jersey	95% cotton, 5% viscose	0.96	149.53	20	16
KF5	Single jersey	54% cotton, 46% polyester	1.32	205.47	16	11

Measurements were performed by means of the Moisture Management Tester (SDL Atlas) (Figure 1) [7-12] according to the procedure described in the AATCC Test Method 195-2011 [17].

Fig. 1 Moisture Management Tester

The M290 MMT is an instrument measuring the dynamic liquid transport properties of fabrics in the following aspects:

- absorption rate – moisture absorbing time for inner and outer surfaces of the fabric,
- one-way transport capability – one-way transfer of liquid moisture from the inner surface to outer surface of fabric,
- spreading/drying rate – speed of liquid moisture spreading on the inner and outer surfaces of fabric.

The instrument can calculate the following parameters:

- WTT, WTB – wetting time of top (T) and bottom (B) surface (s),
- TAR, BAR – absorption rate of top (T) and bottom (B) surface (%/s),
- MWRT, MWRB – maximum wetted radius for top (T) and bottom (B) surface (mm),
- TSS, BSS – spreading speed on top (T) and bottom (B) surface (mm/s),
- R – accumulative one-way transport index (-),
- OMMC – Overall Moisture Management Capacity (-).

The device cooperates with a PC and the MMT290 software. Measurements are performed for samples cut into 80 mm x 80 mm squares. For each fabric, 5 repetitions of the measurement are performed. The knitted fabrics were measured in the relaxed and stretched state.

In order to stretch the samples by a certain size, the MMT Stretch Fabric Fixture device was applied [18]. Round samples of 140 mm diameter are placed on the table of the device, stretched to the percentage required and next locked in the fabric clamp. The excess fabric beyond the clamp circumference is trimmed. The sample prepared in such a way is placed in the M290 MMT test area.

Fig. 2 MMT Stretch Fabric Fixture

The results of the measurements were analysed statistically using an ANOVA. For the statistical analysis, the TIBC Statistica version 13.3 software was applied.

3 Results and discussion

The results of measurement of liquid moisture transport through the investigated knitted fabrics in the relaxed state are presented in Tables 2 and 3.

Table 2. Results from the MMT M290 device for the relaxed knitted fabrics.

SYMBOL	WTT	WTB	TAR	BAR	MWRT	MWRB
	s	s	%/s	%/s	mm	mm
KF1	55.52	6.48	245.49	50.85	3	5
KF2	53.69	74.47	228.55	29.65	3	2
KF3	32.67	76.90	351.06	65.00	4	2
KF4	63.86	8.82	74.66	77.92	3	7
KF5	90.66	8.76	22.68	73.88	2	10

Table 3. Results from the MMT M290 device for the relaxed knitted fabrics. Continuation.

SYMBOL	TSS	BSS	R	OMMC
	mm/s	mm/s	%	-
KF1	0.24	0.80	424.31	0.41
KF2	0.32	0.32	-59.64	0.27
KF3	0.38	0.31	-370.50	0.18
KF4	0.12	0.95	913.70	0.71
KF5	0.08	2.05	1021.32	0.76

On the basis of the presented results it is clearly visible that the investigated knitted fabrics differ in the aspect of each determined parameter. For an assessment of the fabrics in the range of their ability to transport liquid moisture, the most important parameters are the following: R – accumulative one-way transport index, and OMMC – Overall Moisture Management Capacity. The accumulative one-way transport index R is calculated as the difference of the accumulative moisture content between two surfaces of the fabric: bottom and top in relation to the testing time [7]. A fabric with good accumulative one-way transport from the top (inner) fabric side to the outer side (high value of the parameter) offers good sweat management to the wearer. It is due to the fact that with high accumulative one-way transport index the fabric keeps the skin of the wearer dry due to transporting the perspiration towards the outer side of the fabric which is away from the skin. Positive and high values of the R parameter show that liquid sweat can be transferred from the skin to the outer surface easily and quickly [10].

In the case of the investigated fabrics, three of them (KF1, KF4 and KF5) are characterized by high values of the R parameter. According to the classification presented in the MMT manual [7], the fabric can be classified as excellent (R > 400). In the case of the fabrics KF2 and KF3, the R parameter value is negative. This means that they are classified as very poor. Both fabrics are characterized by very high values of the WTB parameter. This is a wetting time of the bottom surface. High values of this parameter mean that the bottom surface of the fabric is wetting very slowly and at the same time, evaporation of sweat from the outer surface of the fabric is limited.

The value of the OMMC parameter is calculated using the formula presented in the AATCC Test Method 195-2011 [13]. The OMMC calculation is based on the absorption rate for the bottom surface, the spreading speed for the bottom surface and the one-way transport capability at appropriate weights of mentioned parameters. The value of the OMMC can be in the range from 0 to 1. Higher values of the OMMC parameter mean better liquid moister management capacity. The OMMC results are in agreement with the R values. The lowest values of the OMMC parameter were stated for the fabrics KF2 and KF3. On the basis of the OMMC values, the KF2 fabric can be classified as poor, whereas the fabric KF3 as very poor from the point of view of the liquid moisture measurement.

The results from the MMT for the stretched knitted fabrics are presented in Tables 4 and 5.

Table 4. Results from the MMT M290 device for the stretched knitted fabrics.

SYMBOL	WTT	WTB	TAR	BAR	MWRT	MWRB
	s	s	%/s	%/s	mm	mm
KF1	97.42	29.18	28.92	57.05	1	4
KF2	120.00	6.12	0.00	67.06	0	7
KF3	79.21	8.24	196.80	83.07	2	5
KF4	120.00	8.09	0.00	145.16	0	9
KF5	76.68	13.82	15.04	172.57	2	10

Table 5. Results from the MMT M290 device for the stretched knitted fabrics. Continuation.

SYMBOL	TSS	BSS	R	OMMC
	mm/s	mm/s	%	-
KF1	0.47	0.60	690.39	0.54
KF2	0.00	1.6.	1091.92	0.72
KF3	0.11	0.73	644.93	0.50
KF4	0.00	2.09	1177.25	0.80
KF5	0.20	2.29	963.93	0.77

As we can see, the values of particular parameters characterizing the liquid moisture transport through the stretched fabrics are quite different than that for the relaxed (unstretched) fabrics. The ability of the KF2 and KF3 fabrics to transport liquid moisture was significantly improved due to their stretching. Improvement was also observed for the rest of fabrics, but the differences are not as large as that observed for the fabrics KF2 and KF3. After stretching, the fabric KF2 shows much better ability to transport liquid moisture than the fabric KF1, whereas the same fabrics in relaxed state have been assessed in the opposite manner.

The influence of the fabric type and stretching on the liquid moisture transport through the investigated knitted fabrics was assessed using the analysis of variance (ANOVA). The purpose of the ANOVA is to test for significant differences between means. The analysis is based on a comparison of the variance due to the between-groups variability (called Mean Square Effect, or MSeffect) with the within-group variability (called Mean Square Error, or MSerror). The software compares those two estimates of variance via the F test, which tests whether the ratio of the two variance estimates is significantly greater than 1. These latter variance components are then tested for statistical significance, at the significance level 0.05. Statistical analysis confirmed that in the case of all parameters (except BAR – absorption rate for the bottom surface), stretching significantly influenced the values of the parameters determined by the MMTM290 device (Fig. 3-5).

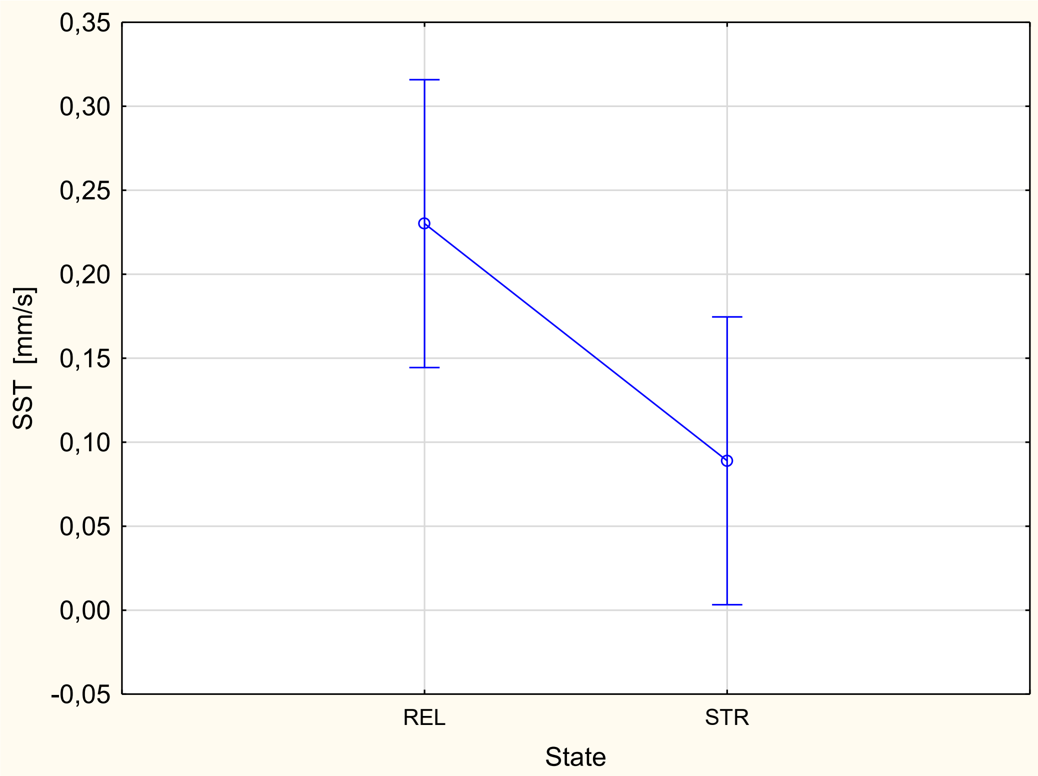

Fig. 3 Influence of stretching on the spreading speed on the top surface: REL – in relaxed state, STR – stretched.

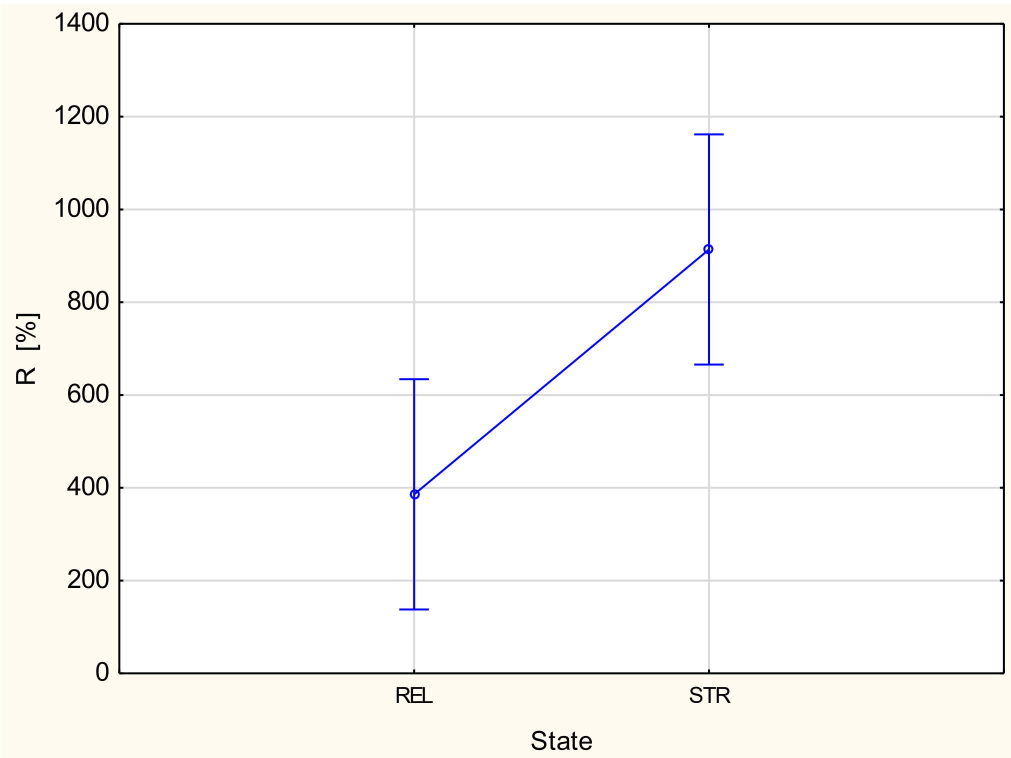

Fig. 4 Influence of stretching on the accumulative one-way transport index R: REL – in relaxed state, STR – stretched.

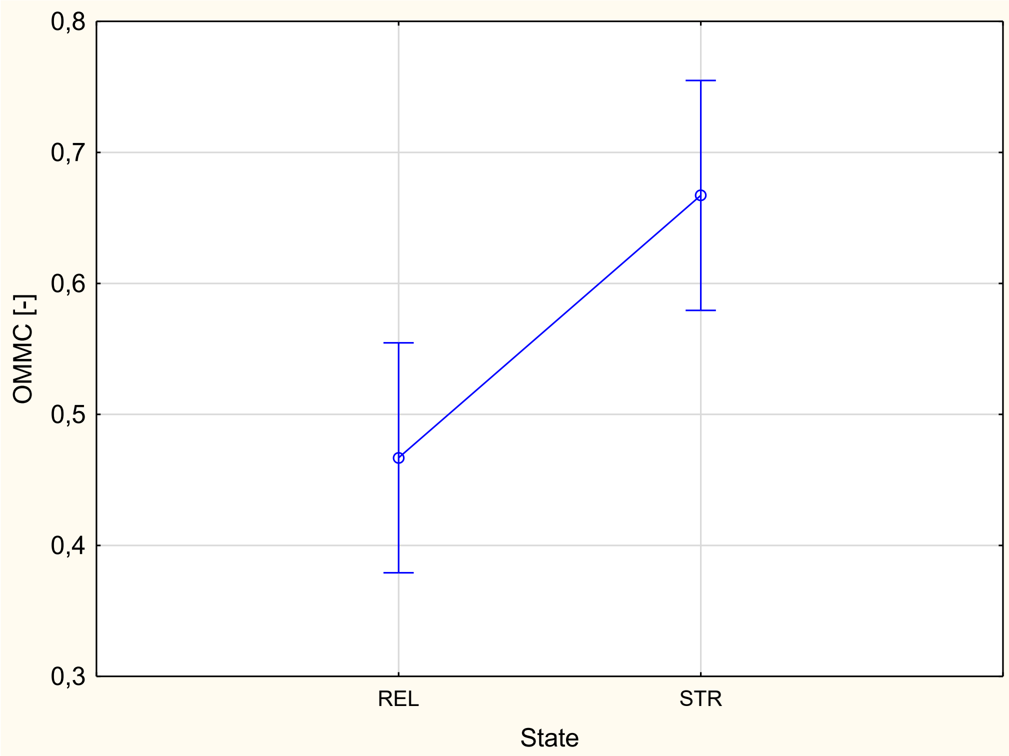

Fig. 5 Influence of stretching on the overall moisture management capacity OMMC: REL – in relaxed state, STR – stretched.

In the case of the fabric type, the statistically significant influence on the parameters characterizing the liquid moisture transport was stated for the following parameters: TAR – absorption rate for the top surface (Fig. 6), SSB – spreading speed for the bottom surface (Fig. 7), MWRB – maximum wetted radius for the bottom surface, R – accumulative one-way transport index, and OMMC – overall moisture management capacity.

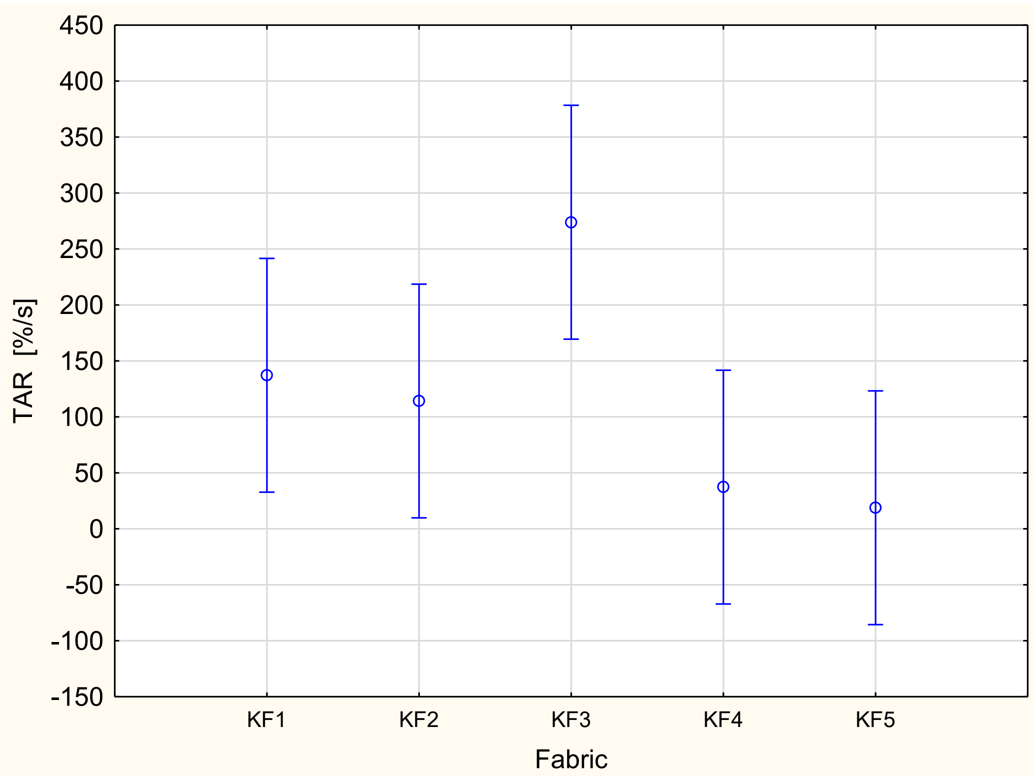

Fig. 6 Influence of fabric type on the absorption rate for the top surface.

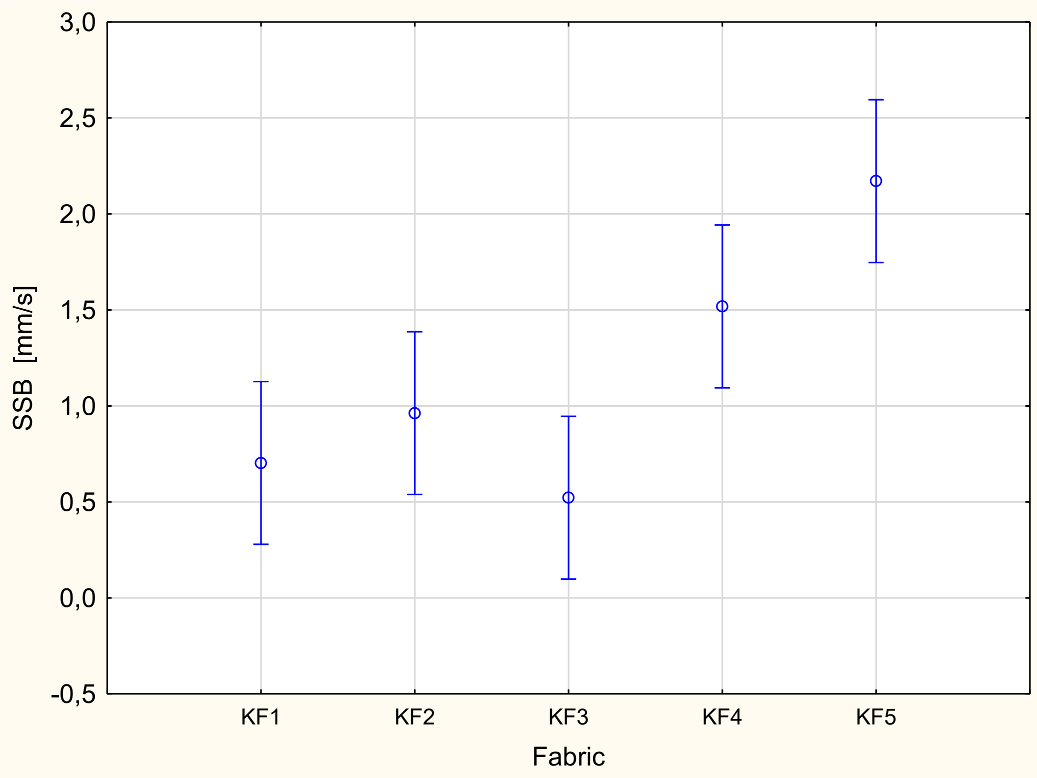

Fig. 7 Influence of fabric type on the spreading speed for the bottom surface.

For two parameters (WTB – wetting time for the bottom surface and MWRB – maximum wetted radius for the bottom surface), a statistically significant interaction was observed between two independent variables: fabric type and stretching (Fig. 8, 9). This means that influence of one independent factor (for instance fabric type) changes the influence of a second independent factor (stretching).

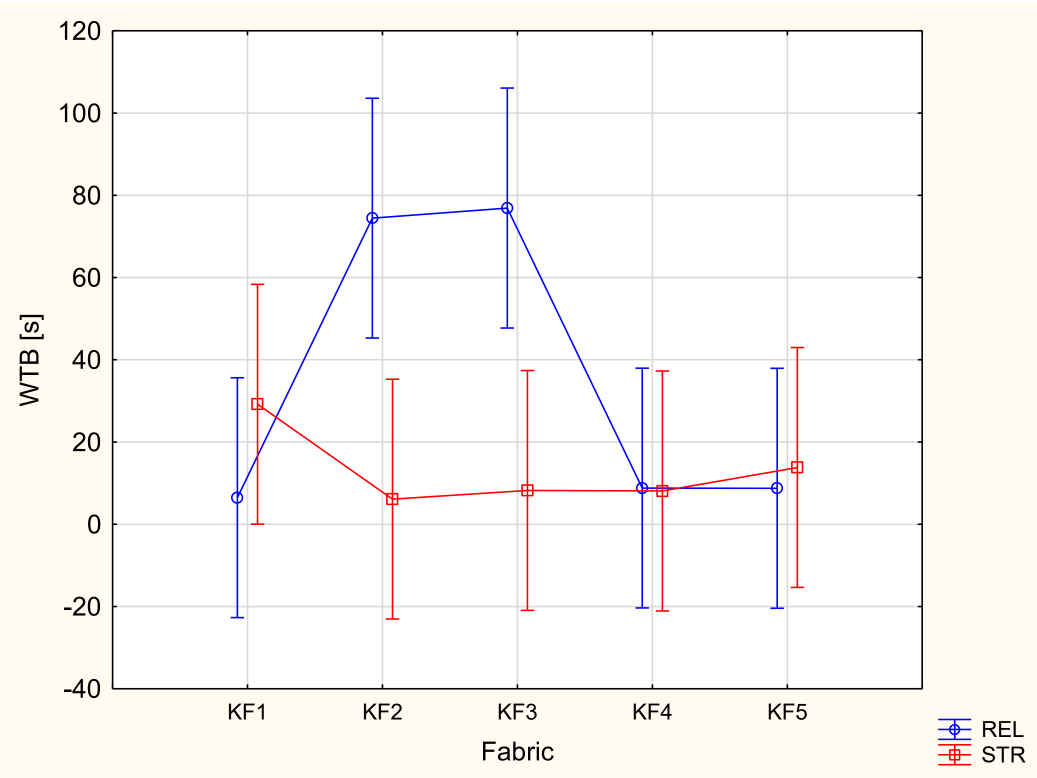

Fig. 8 Influence of stretching and fabric type on the wetting time for the bottom surface: REL – in relaxed state, STR – stretched.

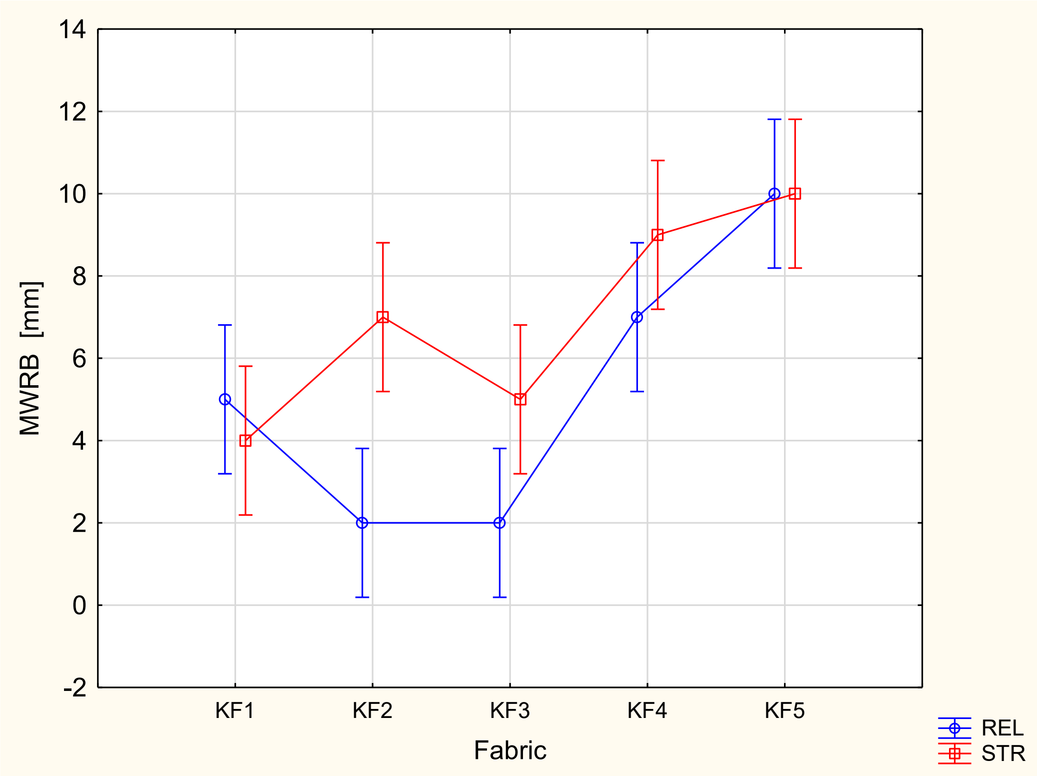

Fig. 9 Influence of stretching and fabric type on the maximum wetted radius for the bottom surface: REL – in relaxed state, STR – stretched.

4 Conclusions

As a result of the performed investigations and processing the test results, the following conclusions can be drawn:

- Underwear material is in direct contact with the human body and it is the first step in transporting sweat and moisture from the skin, so special attention should be paid to the choice of materials,
- when wearing underwear, its material is constantly stretched; due to this fact it is necessary to know how the stretching changes the ability of the fabrics to transport liquid moisture,
- stretching the knitted fabrics changes their texture and geometric structure what influences the moisture transport,
- in the case of the investigated knitted fabrics, stretching the samples by 15 % caused significant improvement of their moisture management ability.

Author Contributions

M. Matusiak: conceptualization, methodology, co-writing – original draft preparation, visualization, supervision; O. Sukhbat: investigation, data curation, statistical analysis, visualization, co-writing – original draft preparation. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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