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LIQUID MOISTURE TRANSPORT IN STRETCHED KNITTED FABRICS

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Abstract:

Transport of moisture is an important aspect of physiological comfort of clothing usage. The moisture originating from sweat can be in the form of vapour or liquid. Sweat in the form of liquid occurs, whereas the sweat in the form of vapour cannot be efficiently evaporated to the environment. For the stretchable fabrics, it is important to know the influence of stretching on their liquid moisture transport performance. The aim of the present work was to analyse the liquid moisture transport in knitted fabrics at varying degrees of stretch: 0, 15, 20 and 20%, and to assess the effect of stretch ratio on the ability of fabrics to transport the liquid moisture. Measurement was done using the M290 Moisture Management Tester supplemented with the MMT Stretch Fabric Fixture device. The obtained results confirmed that the stretching influences the values of the parameters characterizing the knitted fabrics from the point of view of their ability to transport liquid moisture.

Keywords:

Knitted fabrics, liquid moisture, stretching, physiological comfort, moisture management

1. Introduction

Transport of moisture is an important aspect of comfort of clothing usage. Sweating is the basic mechanism of the human body thermoregulation. Sweat is released as water vapour. Intensive sweating, in the absence of adequate evaporation of sweat, leads to its condensation on the human skin. In such a situation, to ensure physiological comfort, it is necessary to drain the condensed sweat through the material of the garment adjacent to the wearer's skin. Otherwise, it is observed that the condensed sweat is absorbed by underwear or clothing adhering to the skin, especially cotton which absorbs moisture well. In the last few years, this was considered as an advantage of cotton fibres and the materials made from them. However, a wet piece of clothing "sticks" to the skin, giving an unpleasant feeling of damp and cold. Advances in textile engineering have led to the development of innovative fibres and materials that wick sweat away from the skin to the outside of the garment while remaining dry itself. These are synthetic fibres, mainly polyester, and materials made of them: woven and knitted fabrics. There are many innovative fibre solutions designed for the transport of moisture. The term "moisture management fibres" is used more and more, and it characterizes this group of fibres very well. The general idea of the fibres with the "moisture management" function is the appropriate shaping of the fibres, enabling the maximum absorption of sweat and its rapid spread over the surface of the product, which ensures its rapid evaporation. On the surface of these fibres, there are channels that facilitate and direct a gas exchange between the human body and the environment. Additionally, the presence of external channels increases the specific surface area of the fibres, which intensifies the evaporation of moisture from the surface of the product. In addition, the shape of the fibres minimizes the contact of the product with the skin, which ensures greater comfort of usage compared to the standard products used in the same conditions. Among the numerous examples of fibres ensuring the transport of moisture, one can mention fibres such as Aqua-F, Aerocool, Coolmax, etc. [1].

Apart from the kind and shape of fibres applied in textile materials, the yarn construction and the structure of the fabrics, especially their compactness, influence the liquid moisture transport through them [2–5]. The shape and size of pores between threads and the pore distribution influence the liquid transport by different mechanisms. Nazir et al. [4] measured the interlock knitted fabrics of different stitch lengths knitted on double knit machine with 20 and 18 (needles per inch) gauge. They concluded that increase in knitting stitch length and decrease in knitting machine gauge result in decrease in the fabric mass per square metre and fabric density accompanied with increase in fabric thickness and porosity. In consequence, it was observed that the wetting time increased while the liquid moisture absorption rate, spreading speed (SS) and the maximum wetted radius decreased.

Öner et al. stated that liquid transport has decreased with increasing tightness, in general. Regarding the weave type it was observed that its effect was not as strong and significant as the factors such as raw materials and tightness [5].

Hu et al. [6] investigated the professional sportswear made of knitted fabrics. They also stated that the performance of the sportswear differs based on the structure and fibre composition of the fabrics from which they are made.

The aforementioned studies confirmed that the structure of the textile materials, especially their tightness, significantly influence the liquid moisture transport through them. In the majority of cases, the knitted fabrics are stretchable. Mostly the clothing made of knitted fabrics is worn close to the user skin and fit tightly to the user's body. In such a situation, the material of clothing is stretched out to a certain extent when used. Socks and some kinds of sportswear such as bike clothing, badminton clothing, fitness suits and many others are the examples of clothing worn in the stretched state [7,8]. Some kinds of daily use clothing are another example, especially the clothing and underwear made of elastane fibres.

In all the aforementioned studies and many others, an assessment of liquid moisture transport through the fabrics was done for the samples in the relaxed state. In the case of stretchable fabrics and clothing, such measurement does not reflect the real conditions in which the clothes are used and the actual phenomenon of liquid moisture transport through the structure of these materials during usage. Taking this into consideration, it is necessary to know how stretching the fabrics influences the liquid moisture transport through them.

The aim of the present work was to analyse the liquid moisture transport in knitted fabric at varying degrees of stretch and to assess the effect of stretch ratio on the ability of the fabric to transport the liquid moisture. The stretching of the investigated fabric has been performed using the MMT Stretch Fabric Fixture device (SDL Atlas Ltd, USA). It is a new device, which was introduced to the market in the second half of 2020. Any study based on the results obtained by usage of the MMT Stretch Fabric Fixture has not been published till now. Due to this fact, the device and procedure of sample preparation using it were presented in this study. Additionally, the aim of this work was to check the usefulness of the MMT Stretch Fabric Fixture device in the assessment of textile materials in the aspect of the liquid moisture transport ability, and to recognize potential limitations of usage of the device.

2. Materials and methods

In order to analyse the influence of stretching ratio on the liquid moisture transport in knitted fabrics, the measurements have been performed using the Moisture Management Tester. The interlock cotton knitted fabric was the object of the investigation. In the present investigations, only one knitted fabric was used, as the investigations are preliminary, exploratory tests in the field of application of the new device – the MMT Stretch Fabric Fixture. The fabric made of cotton was used, because the cotton fibres are commonly used in the textile materials designed for underwear, t-shirts, clothing for babies, i.e. clothing worn next to the user's skin. The knitted fabric was selected randomly from the cotton knitted fabrics for the aforementioned purposes. The basic properties of the investigated fabrics are presented in Table 1.

The parameters characterizing the liquid moisture transport in the fabric were measured using the M290 Moisture Management Tester manufactured by SDL Atlas Ltd according to the AASTCC standard [9–13]. The M290 MMT is an instrument designed to measure the dynamic liquid transport properties of textiles such as knitted and woven fabrics in the following three aspects [9,10]:

- 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 the outer surface of the fabric,
- spreading/drying rate – speed of liquid moisture spreading on the inner and outer surfaces of the fabric.

The device is controlled by PC and the MMT290 software. During the test a pre-defined amount of test solution (synthetic sweat) is introduced onto the upper side (skin side) of the fabric, and then the test solution is transferred onto the material in the following three directions [9]:

- spreading outwards on the upper (top) surface of the fabric,
- transferring through the fabric from the upper surface to the bottom surface,
- spreading outwards on the bottom surface of the fabric.

Measurement was performed in the following standard climatic conditions: 65 ± 5% RH and 20 ± 2°C ambient temperature. The following parameters have been determined:

- WTT, WTB – wetting time of top (T) surface and wetting time of bottom (B) surface (s),
- TAR, BAR – absorption rate of top (T) surface and absorption rate of bottom (B) surface (%/s),
- MWRT, MWRB – maximum wetted radius for top (T) surface and maximum wetted radius for bottom (B) surface (mm),
- TSS, BSS – spreading speed on top (T) surface and spreading speed on bottom (B) surface (mm/s),

Table 1. Characteristics of the investigated knitted fabrics

Parameter	Method of measurement	Unit	Value
Mass per square metre	PN-P-04613:1997	g m^{-2}	206
Thickness	PN-EN ISO 5084:1999	mm	0.88
Number of courses/cm	PN-EN 1471:2007	cm^{-1}	14.9
Number of wales/cm	PN-EN 1471:2007	cm^{-1}	11.7

- R – accumulative one-way transport index (–),
- OMMC – overall moisture management capacity (–).

The fabrics were measured in the relaxed state and stretched out to a certain extent.

While measuring the relaxed fabric, the samples are cut into 80 mm × 80 mm squares. According to the standard protocol in ref. [10], five repetitions of measurement are performed, and then the mean values of all determined parameters are calculated by the MMT software. The software also performs an assessment of fabric on the basis of the values of particular parameters giving a specific rating in the range from 1 (very poor) to 5 (excellent). On the basis of the values of measured parameters, the system distinguishes seven major types of fabrics:

- water proof,
- water repellent,
- slow absorbing and slow drying,
- fast absorbing and slow drying,
- fast absorbing and quick drying,
- water penetration fabric,
- moisture management fabric.

In order to stretch the samples to a certain size, the MMT Stretch Fabric Fixture device (Figure 1) [14] was used. The round sample of 140 mm diameter is placed on the table of the device (Figure 2a) and then stretched to the percentage required (Figure 2b). The stretched sample is locked in the fabric clamp (Figure 3a). The excess fabric beyond the clamp circumference (Figure 3b) is trimmed. The sample prepared in such a way is placed in the M290 MMT test area (Figure 4).

Figure 1. MMT stretch fabric fixture device.

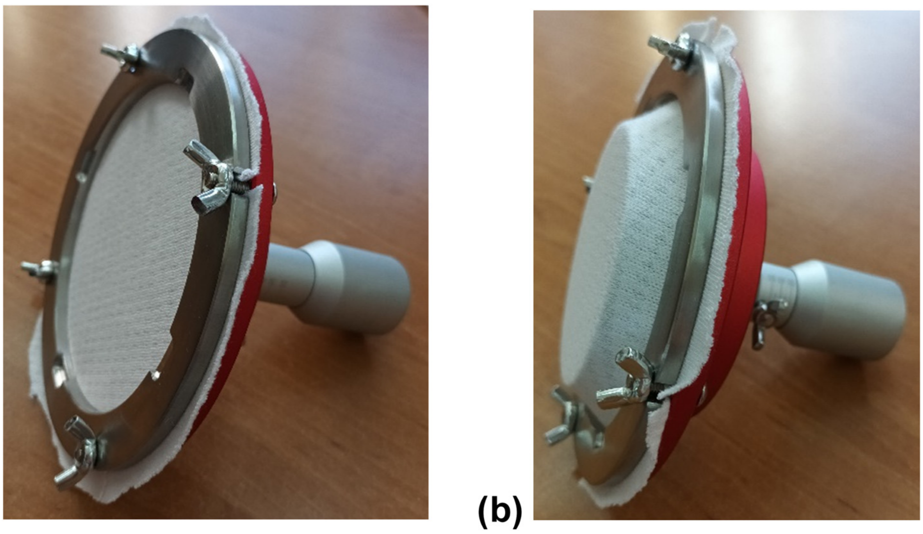
The samples have been stretched to three sizes: 15, 20 and 25%. The device can extend the fabric to different sizes from 15% to 50%, with each 5%. However, the structure of the investigated fabric and its tightness allow us to stretch it till 25% only. It should be mentioned here that in our other investigations (unpublished till now), different kinds of the knitted fabrics have been applied. Performed experiments showed that some of the fabrics can be stretched only to 15%, some others such as polar fabrics, due to their thickness, cannot be stretched using the MMT Stretch Fabric Fixture device even to 15%. These are some limitations of the device.

The multi-factor analysis of variance (ANOVA) available in the TIBC STATISTICA version 13.3 software was applied to analyse statistically the results.

3. Results and discussion

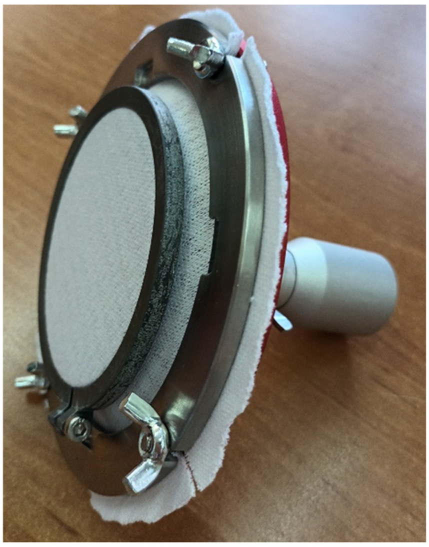
The results from the M290 MMT device are presented in Table 2.

(a)

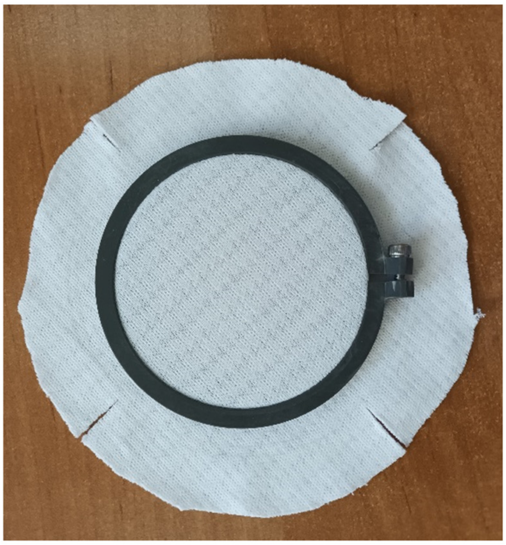


(b)

Figure 2. Preparation of the stretched sample using the MMT Stretch Fabric Fixture device: (a) sample placed on the table of the device and (b) sample stretched to the percentage required.



(a)



(b)

Figure 3. Preparation of the stretched sample using the MMT Stretch Fabric Fixture device: (a) sample locked in the clamp and (b) sample in the clamp with the excess fabric beyond the clamp circumference.

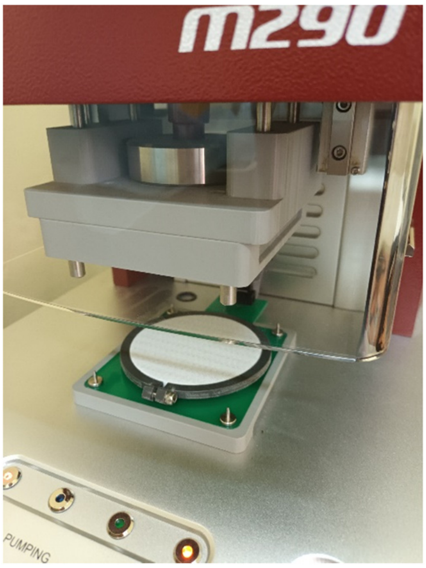


Figure 4. The stretched fabric sample placed in the MMT device.

It is clearly seen that stretching changes the properties characterizing the ability of knitted fabric to transport the liquid moisture. The wetting time increases due to the stretching of the fabric (Figure 5). Higher stretch causes higher wetting time. For the fabric in relaxed state, the wetting time for the top and bottom surfaces is at the same level, ca. 5 s. With an increase in the stretch percentage, the disproportion between the WTT and the WTB increases. WTT increases drastically. It means that at higher stretching percentage the top surface wets significantly slower. WTB also increases due to stretching but the increase is much smaller than that for the top surface. The significant increase in the WTT can be explained by the fact that when stretching the fabric, the pores between yarns became larger. It causes the testing solution to move more quickly from the top surface to the bottom surface through the open pores due to the gravity. Some amount of the testing solution goes directly to the bottom sensor causing less amount of the testing solution to remain in the fabric structure, which is absorbed by the fibres or spread on the fabric surfaces. Unfortunately, it is impossible to

Table 2. Results from the MMT for the relaxed and stretched samples

Parameter	Unit	Relaxed	Stretched 15%	Stretched 20%	Stretched 25%
WTT	s	5.32	16.25	31.39	45.56
WTB	s	5.41	6.25	11.59	10.87
TAR	%/s	54.62	46.05	16.18	71.93
BAR	%/s	61.93	64.17	136.74	285.72
MWRT	mm	18	15	14	11
MWRB	mm	18	13	12	12
SST	mm/s	2.34	0.93	0.61	0.49
SSB	mm/s	2.42	1.142	1.09	1.58
R	—	20.99	179.78	290.72	636.88
OMMC	—	0.26	0.55	0.49	0.725

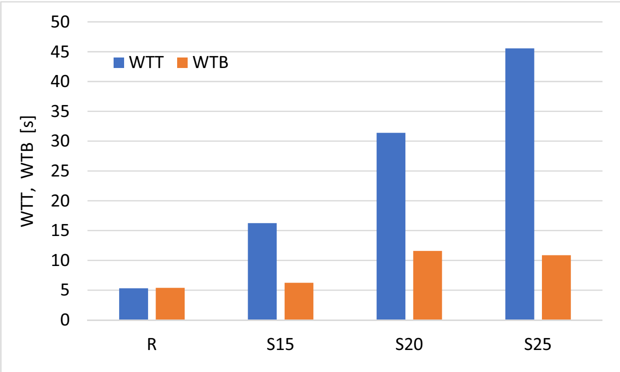


Figure 5. Wetting time for the top and bottom surfaces: R – relaxed sample, S15 – sample stretched 15%, S20 – sample stretched 20% and S25 – sample stretched 25%.

determine the amount of testing solution remaining in the bottom sensor surface.

Opposite tendencies are observed for the absorption rate. In the case of the bottom surface, the value of this parameter (BAR) increases significantly with the increase in stretch percentage. For the relaxed fabric, the BAR is 61.93%/s, and for the fabric stretched to the 25%, the BAR is 285.72%. The results of the BAR parameters confirmed that due to the fabric stretching the testing solution goes quickly to the bottom surface, which is rapidly absorbed by the surface. For the top surface, first the value of the TAR parameter decreases from the relaxed state (54.62%/s) to the 20% stretching (16.18%/2). It is in agreement with the WTT results. For the sample stretched to the 25%, the value of the TAR parameter increases drastically (71.93%/2 – Figure 6). It can be caused by the fact that at the 25% level of stretching the bottom surface absorbs a large amount of the testing solution. Due to the high saturation of the bottom surface, some of the liquid moisture is captured and absorbed by the upper surface of the knitted fabric. It is only an assumption. However, this phenomenon needs further investigations.

The maximum wetted radius is also changed by stretching the sample (Figure 7). Here, it should be mentioned that due to the anisotropy of the textile materials the liquid is not spread evenly in all directions. It means that the wet spot is usually non-circular, irregular in shape (Figure 8). Thus, the maximum wetted

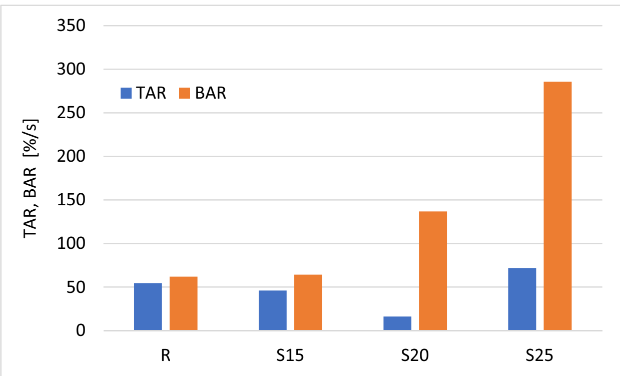


Figure 6. Absorption rate for the top and bottom surfaces: R – relaxed sample, S15 – sample stretched 15%, S20 – sample stretched 20% and S25 – sample stretched 25%.

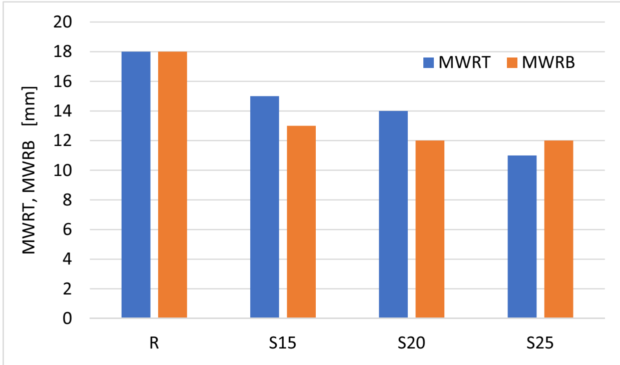


Figure 7. Maximum wetted radius for the top and bottom surfaces: R – relaxed sample, S15 – sample stretched 15%, S20 – sample stretched 20% and S25 – sample stretched 25%.

radius means the radius of the circular sensor furthest from the central point to which the test fluid is tapped.

For both surfaces, the radius decreases with the increase in the stretching percentage (Figure 7). It means that while stretching the sample the synthetic sweat is more rapidly transferred from the top surface to the bottom surface and at the same time the spreading of the liquid on both surfaces is slower and spatially limited. It is difficult to assess this phenomenon. With the increase in the stretching percentage, it was observed that liquid moves very quickly from the top surface to the bottom surface due to the gravity and then the liquid accumulates on the surface of the lower sensor. Hence, at the 25% stretching the wet spot was very small (Figure 9). Probably, some amount of the liquid is on the surface of the bottom sensor. As it was mentioned earlier, there is not any possibility to assess this amount now.

The question is: what while real clothing usage? In the majority of cases, the clothing material is oriented vertically [15]. Due to this fact, the gravity acts parallel to the material surface. The MMT device and procedure do not allow us to assess the liquid moisture transport in vertically oriented materials. In the case of the MMT measurement procedure, there is horizontal wicking. However, this procedure does not reflect real conditions of clothing usage. The orientation of the human skin surface

Figure 8. An example of wet spot on the fabric surface after measurement using the MMT.

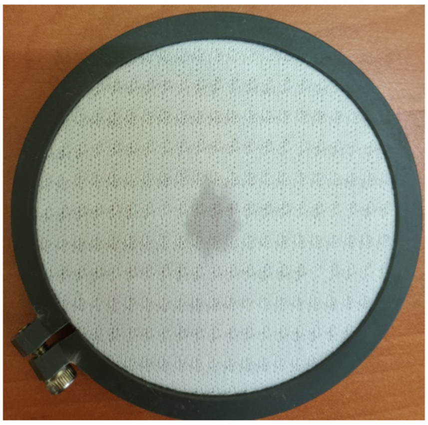


Figure 9. An example of wet spot on the fabric surface at 25% stretching after measurement using the MMT.

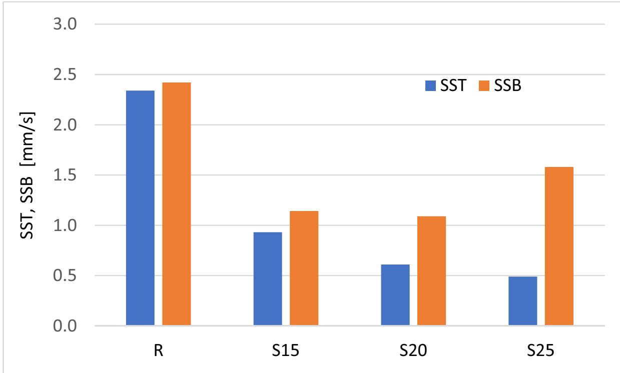


Figure 10. Maximum wetted radius for the top and bottom surfaces: R – relaxed sample, S15 – sample stretched 15%, S20 – sample stretched 20% and S25 – sample stretched 25%.

differs based on the place on the human body and changes during body movement. Sometimes, it has a vertical orientation. The drop of liquid is placed on the vertically oriented surface. In some other cases, the orientation of skin surface is horizontal and/or inclined at a certain angle to the vertical. Surface of clothing covering the human body usually has the same orientation as the orientation of human skin surface covered by clothing. Due to this fact, using the MMT device it is possible to assess and to compare the textile materials in different aspects of the liquid moisture transport. However, this method does not allow the assessment of the behaviour of these materials in real or close to real conditions of usage of the garment. Limited spreading of the testing solution on both surfaces due to the stretching is reflected in values of the SS parameters. For the relaxed samples, the SS is the highest (Figure 10). According to the instrument manual [9], it can be assessed as medium. For the stretched samples due to the loosening of the fabric structure, the liquid spreading is significantly limited, especially on the top surface. Due to the fact that it is difficult to tell where the liquid can be accumulated in real conditions for vertically oriented clothing material, an assessment of the phenomenon from the physiological comfort point of view is difficult.

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 [9]. A fabric with good accumulative one-way transport from the inner (top) 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 by 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 [16].

The value of the R parameter increases with an increase in the stretching percentage (Figure 11). Based on this parameter the knitted fabric can be assessed as follows [9]:

- relaxed sample – poor,
- 15% stretch – good,
- 20% stretch – very good,
- 25% stretch – excellent.

The value of the OMMC parameter is calculated using the formula presented in the AATCC Test Method 195-2011 [10]. The OMMC calculation is based on the absorption rate of the bottom surface, the SS of the bottom surface and the one-way transport capability at appropriate weights of the mentioned parameters. The value of the OMMC can be in the range of 0–1. Higher value of the OMMC parameter means better liquid moisture management capacity. In the case of the investigated knitted fabric, its stretching caused change of the OMMC parameter from 0.26 to 0.725 (Table 2) and at the same time the change of fabric grading according to this parameter from poor to very good.

Statistical analysis using the ANOVA confirmed that an influence of the stretching percentage on the values of the majority of parameters provided by the MMT device is statistically significant at the significance level of 0.05. It includes the BAR, the MWRB, the SST, the SSB, the R and the OMMC. In two cases, the TAR and the MWRT, the influence of stretching was statistically insignificant.

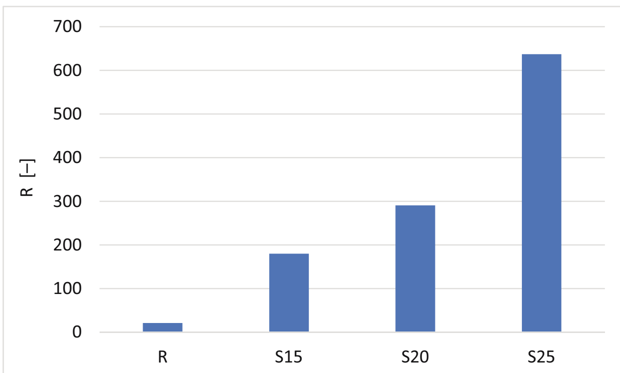


Figure 11. Accumulative one-way transport index: R – relaxed sample, S15 – sample stretched 15%, S20 – sample stretched 20% and S25 – sample stretched 25%.

On the basis of the measurement results, the M290 MMT software classifies the measured fabrics to appropriate types from the water proof till the moisture management fabric. It characterizes the fabric performance from the point of view of the liquid moisture transport. The results of classification are as follows:

- relaxed sample – fast absorbing and quick drying fabric,
- 15% stretch – moisture management fabric,
- 20% stretch – water penetration fabric,
- 25% stretch – water penetration fabric.

The aforementioned classification takes into account the spreading of the liquid on both fabric surfaces. The fabric is classified as moisture management when it is characterized by: medium to fast wetting, medium to fast absorption, large spread area at bottom surface, fast spreading at bottom surface and good to excellent one-way transport.

The performed investigations showed that the 15% stretching of the investigated fabric ensured the best performance from the point of view of liquid moisture management. Further stretching to 20 and 25% did not improve the performance of the fabric. It is due to significant loosening of the structure of fabric causing a penetration of the fabric by testing solution. In such a situation, it is difficult to assess where the excess liquid moisture is accumulated when the fabric is vertically oriented, i.e. in real conditions of clothing usage.

4. Conclusions

The transport of liquid moisture through the clothing is very important from the point of view of the physiological comfort, especially in the case of clothing adherent to the human skin and/or underwear. The Moisture Management Tester provides the values of ten parameters characterizing the fabrics from the point of view of the liquid moisture transport.

In the case of clothing made of the stretchable materials, such as knitted fabrics, the measurement of the liquid moisture transport through the fabrics in the relaxed/unstretched form is insufficient to characterize the clothing performance while usage. The Moisture Management Tester together with the MMT Stretch Fabric Fixture makes it possible to assess the liquid moisture transport through the fabrics in the stretched form, i.e. in the form in which they are usually worn.

The performed investigations confirmed that the stretching percentage influences the performance of the knitted fabrics from the point of view of the liquid moisture transport. In the majority of cases, the influence of stretch percentage on the values of parameters determined by the MMT device is statistically significant at the significance level of 0.05.

The obtained results showed that the relationship between the stretch percentage and the values of the parameters characterizing the liquid moisture transport in the fabrics is not linear.

The ability of knitted fabrics to transport the liquid moisture is a complex issue, as it concerns several parallel phenomena: absorption of liquid by the fibrous material, spreading the liquid on the top surface, spreading the liquid on the bottom surface and transport of the liquid from the top to the bottom surface.

In the case of the investigated knitted fabric, stretching above 15% did not improve the ability of the fabric to manage the liquid moisture.

The performed investigations showed some limitations of measurement using the MMT Stretch Fabric Fixture device. First of all, the stretching to the 50% is rather impossible for clothing materials. Probably, the hosiery and slimming underwear can be stretched to this level.

Thicker fabrics such as polar fabrics are difficult to stretch using the MMT Stretch Fabric Fixture device, especially to lock in the clamp.

The application of the MMT Stretch Fabric Fixture device to stretching the woven fabrics is rather limited due to usually low stretch ability of the woven fabrics.

The stretching of the fabrics changes the structure of the measured specimen. In order to assess the influence of the change of fabric structural parameters on the liquid moisture transport properties, it is necessary to perform further investigations including the deep structural examination of the samples both relaxed and stretched. It will be the object of further investigations.

Conflict of interest: The authors state no conflict of interest.

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