Malgorzata Matusiak

Moisture Management Properties of Seersucker Woven Fabrics of Different Structure

DOI: 10.5604/01.3001.0013.0741

Lodz University of Technology, Faculty of Material Technologies and Textile Design, Institute of Architecture of Textiles,
Lodz, Poland
e-mail: malgorzata.matusiak@p.lodz.pl

Abstract
Moisture management is defined as the controlled movement of water vapour and liquid water (perspiration) from the surface of the skin to the atmosphere through the fabric. The ability of moisture transport is a very important feature of textile materials from the point of view of the physiological comfort of usage clothing made of these materials. Among the different textile materials (woven, knitted and nonwoven), seersucker woven fabric is considered as having good comfort-related properties. The fabrics are characterised by the occurrence of puckered and flat strips in the warp direction. The puckered effect generates air spaces between the body and the fabric, keeping the wearer cool in hot conditions as the puckered area holds the fabric away from the skin during usage. In the work presented, seersucker woven fabrics of different patterns of the puckered strips were investigated. The aim of the work was to analyse the relationship between the structure of seersucker fabrics and their moisture management properties. Measurement of the moisture transport properties of seersucker woven fabrics was made using a Moisture Management Tester M290, produced by SDL Atlas. Investigations performed showed that the properties of seersucker woven fabrics characterising their ability to transfer liquid moisture are different depending on the variant of the repeat of puckered strips.

Key words: *seersucker woven fabrics, physiological comfort, moisture management tester, overall moisture management capacity, wetting, absorption.*

Introduction

Clothing performance depends on many factors. The material composition and properties of the particular materials creating a clothing product are considered as some of the most important. Generally the properties of fabrics: knitted, woven and nonwoven are transferred to the clothing product and determine its properties and behaviour during usage. Due to this fact, an appropriate measurement and quality assessment of fabrics is crucial from the point of view of the material design of clothing. Nowadays comfort is the key element to be respected in clothing design and production [1]. Among the different categories of clothing comfort: thermophysiological, sensorial, garment fit and psychological comfort [2], the first is considered as the most important. Thermal or thermophysiological comfort is defined as the condition of the mind which expresses satisfaction with the thermal environment' [3]. Thermal resistance, water-vapour permeability and air permeability are regarded as the crucial comfort-related properties of textile materials [4, 5]. Thermal resistance is a decisive factor influencing the ability of fabrics to protect a human organism against excessive heat loss or overheating. The air permeability of fabrics and clothing directly influences gas exchange between a human being and the surroundings and, in the same way, the physiological comfort of the clothing user. And finally water-vapour permeability is connected with the diffusion of water-vapour molecules through the pores in textile materials [2]. The water-vapour permeability of textile materials supports moisture transfer from human body skin through the textile layer into the environment [6]. This property is especially important during higher levels of activity and/or when climatic conditions cause intensive sweating and the sweat must be rapidly managed by the clothing [7]. However, the water-vapour permeability or, connected with it, water-vapour resistance are not sufficient to fully characterise textile materials from the point of view of moisture transport because they consider only the transport of moisture in the form of vapour. From the comfort point of view, it is necessary to characterise materials in two aspects: the transfer of moisture in the form of vapour and in the form of liquid. Moisture transmission through textile material in liquid and vapour forms is equally important [8]. Wearing garments that transport moisture and evaporate it quickly actually enhances the human body's ability to cool itself [8].

In the last decade the term '*moisture management*' was introduced in the description of a textile material ensuring moisture transfer from human body skin to the environment. Moisture management can be defined as the controlled movement of water vapour and liquid water (perspiration) from the surface of the skin to the atmosphere through the fabric. This action prevents perspiration from remaining next to the skin [8]. The main aim of materials considered as moisture management fabrics is to make the skin feel dry. In order to achieve this, humidity released by the human body should be evaporated and transferred to the atmosphere as soon as possible.

Liquid moisture flow through textile materials is controlled by two processes: wetting and wicking. The term 'wetting' is usually used to describe the displacement of a solid-air interface with a solid-liquid interface [9]. It is the initial process in fluid spreading and is controlled by the surface energies of the solid and liquid involved [10]. Wettability is the potential of a surface to interact with liquids of specified characteristics [11]. According to Harnett and Mehta [12], wettability is the initial behaviour of a fabric, yarn, or fibre when brought into contact with a liquid. It also describes the interaction between the liquid and substrate prior to the wicking process.

Wicking is the spontaneous flow of a liquid in a porous substrate driven by capillary forces. As capillary forces are caused by wetting, wicking is a result of spontaneous wetting in a capillary system

Figure 1. *Moisture Management Tester M 290 by SDL Atlas.*

[10, 13]. Wicking can only occur when a liquid wets fibres assembled with capillary spaces between them. The resulting capillary forces drive the liquid into the capillary spaces [11, 13]. As the gaps between the individual fibres becomes thin, the force increases. Thus finer fibres will have smaller gaps and better humidity transport.

The transport of moisture through textile materials can be assessed using different tests. In the case of moisture in the form of water-vapour, the sweating guarded hot plate test called a "skin model" and Permetes are commonly used to determine the water-vapour resistance of textile materials. Both devices enable to conduct the test according to the standardised procedure [4, 5, 14, 15]. In order to assess the liquid transport trough fibrous materials, different tests are used, the most common being the contact angle method and vertical wicking test method [16].

In the last decade the Moisture Management Tester (SDL Atlas, US) has been applied to evaluate, in a complex way, textile materials from the point of view of their ability to transport liquid moisture (***Figure 1***). The Moisture Management Tester (MMT) is an instrument designed to measure the dynamic liquid transport properties of textiles, such as knitted and woven fabrics, in three aspects [17]:

- 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 to 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 a PC and MMT290 SOFTWARE. Measurement is performed for samples cut into 80 mm x 80 mm squares. For each fabric 5 repetitions of measurement are performed. 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 three directions [17]:

- spreading outward on the upper surface of the fabric,
- transferring through the fabric from the upper surface to the bottom surface,
- spreading outward on the bottom surface of the fabric.

Measurement is performed in standard climatic conditions: 65 ± 5% RH and ambient temperature 20 ± 2 °C. The device provides values of the following parameters:

- WT T – wetting time of top surface, s;
- WT B – wetting time of bottom surface, s;
- TAR – absorption rate of top surface, %/s;
- BAR – absorption rate of bottom surface, %/s;
- MWR_{top} – maximum wetted radius for top surface, mm;
- MWR_{botom} – maximum wetted radius for bottom surface, mm;
- TSS – spreading speed on top surface, mm/s;
- BSS – spreading speed on bottom surface, mm/s;
- R – accumulative one-way transport index;
- OMMC – overall moisture management capacity.

On the basis of the values of parameters measured, the system distinguishes seven major types of fabrics:

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

The fabric is considered as moisture management if it has the following properties: medium to fast wetting, medium to fast absorption, a large spread area on the bottom surface, fast spreading on the bottom surface, and good to excellent one-way transport of liquid.

The Moisture Management Tester can be applied to assess different textile materials: woven, knitted and nonwoven. However, the research work published till now have concerned mostly knitted fabrics.

Özdil et al. [18] assessed the moisture management properties of cotton knitted fabrics of single jersey structure. According to the results, the Authors stated that a higher twist coefficient of yarn results in a decrease in the absorption rate, spreading speed and maximum wetted radius as well as an increase in the wetting time of the fabrics. As the yarn gets finer, the maximum absorption rate, spreading speed and maximum wetted radius increase, whereas the wetting time of the fabrics decreases. According to the overall moisture management capacity (OMMC) values, even the yarn counts and yarn twist coefficients are different. All the cotton fabrics were classified into the same category and evaluated as good from the point of view of moisture management.

Öner et al. [19] investigated the effect of raw material, weave type and fabric tightness on the liquid absorption and transmission of knitted fabrics of different weaves made of cotton, viscose and polyester. They stated that polyester fabrics have higher OMMC values than cellulose-based fabrics. Regarding the effect of tightness, liquid transport decreased with increasing tightness. Weave types examined in this study do not have an effect as strong and significant as factors such as the raw material and tightness.
Sai Sangurai et al. [20] stated that the filament cross-section significantly affects the liquid transport ability of fabrics. In this study, it was found that fabrics with trilobal polyester filament have better liquid transportation properties than those with circular polyester filament [20].

Woven fabrics have been measured in the range of their moisture transport properties rather rarely. Magnat et al. [21] reported that the moisture management capacity of denim fabrics is significantly affected by the types of weft yarns and washing treatments.

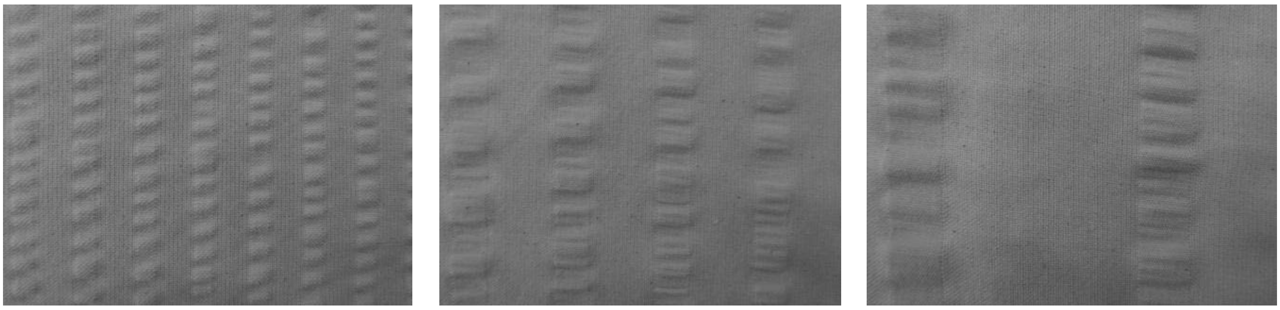

Figure 2. *Pictures of seersucker woven fabrics investigated.*

Çeven, et al. [22] investigated woven fabrics produced from linen (100%) and linen-polyester yarns (80% polyester and 20% linen) at different weft densities. They stated that the structural properties of fabrics such as the yarn type, yarn count, number of yarn folds, weft density as well as the fibre type and their content ratio influence the moisture management properties of the fabrics investigated.

The majority of works published till now have considered flat woven fabrics of basic (fundamental) or derivative weaves. Some problems can appear in the context of patterned weaves, especially woven fabrics classified as 3D or 2D + [23-25]. 3D woven fabrics can be manufactured by both 2D and 3D weaving. Depending on the way of manufacturing, the surface properties of 3D woven fabrics can be different. There are 3D fabrics with a smooth surface. Into this group some kinds of spacer fabrics and two-layer woven fabrics can be included [23, 26-28]. There are also 3D woven fabrics with a textured surface created from different elements such as plisse or pleated fabrics, terry fabrics, velvet fabrics, seersucker fabrics, etc. [26, 29]. Seersucker, also known as the crimp effect, is characterised by the presence of a three-dimensional (3D) wavy effect (puckered) and relatively flat sections, particularly in stripes [30, 31]. Typical seersucker woven fabrics are characterised by the occurrence of puckered and flat strips in the warp direction. Seersucker woven fabrics create an unconventional 3D woven structure which can influence the properties of the fabrics. Investigations carried out and published till now have concerned mostly the technology [28], structure assessment [3-34] or comfort related properties of seersucker fabrics, both woven and knitted [35]. Some researchers [36-39] reported that seersucker fabrics have good comfort properties because of the puckered structure. The puckered effect generates air spaces between the body and the fabric, keeping the wearer cool in hot conditions as the puckered area holds the fabric away from the skin during usage and facilitating air circulation. However, the thesis is not obvious and should be discussed, especially in the case of fabrics containing elastomeric yarns. The application of elastomeric yarn in the weft causes that the fabric fits closely to the user's body, which can impede heat and air exchange between the body and the surroundings [35]. There is a lack of investigations and publications aimed at analysis of the influence of the structure of seersucker woven fabrics and the pattern (repeat) of the seersucker effect on the liquid moisture transport ability of the fabrics.

The aim of work was to measure the moisture transport properties of cotton seersucker woven fabrics of different structure and to analyse the influence of the pattern of the seersucker effect on the results from the Moisture Management Tester.

Materials and methods

In the work presented, 3 variants of cotton seersucker woven fabrics were investigated. The fabrics were manufactured on the basis of the same warp sets made of 20 tex x 2 cotton yarn. The same yarn was applied as the weft.

The fabrics were designed in such a way as to obtain puckered and flat strips in the warp direction of predetermined width. Three variants of the seersucker effect pattern were applied:

- variant 1 (V1) – width of puckered and flat strips, respectively: 5 mm and 8 mm,
- variant 2 (V2) – width of puckered and flat strips, respectively: 9 mm and 18 mm,
- variant 3 (V3) – width of puckered and flat strips, respectively: 11 mm and 41 mm.

The fabrics were finished by a tensionless method. The finishing process included washing, rinsing and drying. Because the fabrics were manufactured from 2 ply yarns, the warps did not have to be sized. Due to this fact, the desizing process was unnecessary.

Basic properties of the fabrics investigated are presented in ***Table 1***. The fabrics are characterised by a different mass per square metre, which is a consequence of the different repeat of the seersucker effect resulting in a different share of the puckered strips in the total area of the fabrics.

Table 1. *Basic structural properties of fabrics investigated.*

Parameter	Unit	Value		
		Variant V1	Variant V2	Variant V3
Weave – warp I	–	plain		
Weave – warp II	–	rep 2/2		
Warp density	cm^{-1}	13.8	13.7	12.8
Weft density	cm^{-1}	12.0	11.8	11.7
Mass per square metre	$g\ m^{-2}$	221.9	217.0	205.4
Take up – warp I	%	16.2	5.8	6.3
Take up – warp II	%	53.8	41.6	44.0
Take up – weft	%	14.7	14.8	15.3

Figure 3. Drop of water on the surface of grey seersucker woven fabric after the test of moisture management using the MMT.

Pictures of the fabrics investigated are presented in ***Figure 2***.

The fabrics were measured in the range of their moisture management properties. The measurement was performed using a Moisture Management Tester M 290 (***Figure 1***), made by SDL Atlas, according to the device manual based on the AATCC Method 195 -2011 [40].

On the basis of the results from the MMT device, statistical analysis was performed in order to analyse the influence of the pattern of the seersucker effect on the results of the moisture management test. The one-way AVOVA available in STATISTICA software was applied in the statistical analysis. In general, the purpose of the analysis of variance (ANOVA) is to test for significant differences between means. According to the software applied, the analysis is based on a comparison of the variance due to the between-group variability (called *Mean Square Effect*, or MS_{effect}) with the within-group variability (called *Mean Square Error*, or MS_{error}). The STATISTICA software compares these 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.

In the statistical analysis the variant of the seersucker effect (repeat of puckered strips) was applied as the main factor – an independent variable. The parameters from the MMT were taken as dependent variables.

Results and discussion

It should be mentioned here that grey fabrics were also objects of the investigation. However, tests performed using the MMT 290 device showed that the grey seersucker woven fabrics investigated do not transport moisture. For each variant of the grey fabrics, a drop of water was visible on the surface after the test (***Figure 3***). Liquid moisture had not spread on the fabric surface nor transferred from the top to the bottom surface . Due to this fact in further analysis only the results for the finished fabrics are presented.

Results of the measurement of moisture transport properties for the finished fabrics are presented in ***Tables 2*** and ***3***. The tables present the average values of parameters measured from individual results for 5 specimens.

Table 2. Average wetting time, absorption rate and maximal wetted radius of the seersucker woven fabrics investigated.

Sample		WT T	WT B	TAR	BAR	MWR_{top}	MWT_{bottom}
		s	s	%/s	%/s	mm	mm
V1	Mean	13.44	19.06	439.1	17.7	7.00	8.00
	SD	3.39	8.30	211.5	5.0	2.74	2.74
V2	Mean	10.95	13.46	146.4	26.6	13.00	12.00
	SD	3.44	11.12	73.9	7.4	2.74	2.74
V3	Mean	21.87	19.13	45.0	46.2	18.00	18.00
	SD	11.23	5.77	19.8	26.6	2.74	4.47

Table 3. Average spreading speed, accumulative one-way transport index and overall moisture management capacity of the seersucker woven fabrics investigated.

Sample		TSS	BSS	R	OMMC
		mm/s	mm/s	–	–
V1	Mean	0.41	0.33	-445.4	0.02
	SD	0.09	0.11	284.8	0.01
V2	Mean	0.61	0.71	-70.2	0.10
	SD	0.19	0.44	115.3	0.07
V3	Mean	0.78	0.80	-18.8	0.22
	SD	0.28	0.22	256.6	0.20

The results of selected parameters are presented in the graphs below (***Figure 4-9***). On the basis of the results obtained, it was stated that the seersucker woven fabrics investigated differ from each other in the range of their parameters related to liquid moisture transport. The highest wetting time was stated for fabric V3, and the lowest for the V2 fabric variant, for both the top and bottom surfaces (***Figure 4***).

Another situation is observed for the absorption rate. In the case of the top surface, the highest absorption rate was stated for the V1 fabric variant. The absorption rate shows a decreasing tendency, starting from the V1 variant, then V2, and finally the V3 fabric variant. The opposite tendency is observed for the bottom surface. The absorption rate increases in the direction from the V1 variant to V3 variant (***Figure 5***).

The lowest value of the maximum wetted radius occurred for the V1 fabric variant, and the highest for the V3 variant (***Figure 6***). The same tendency was stated for the spreading speed (***Figure 7***). In the case of both parameters, there are visible differences between the top and bottom surfaces for the V1 and V2 fabric variants. In the case of the V3 seersucker fabric, the values of the maximum wetted radius and spreading speed for the top and bottom surfaces are almost the same.

Values of the accumulative one-way transport index are negative for all fabric variants investigated. This parameter is a measure of the difference between the areas of the liquid moisture content curves of the bottom and top surfaces of a specimen with respect to time [17, 21]. A negative value of the R index means that the area below the U_{top} curve is bigger than that below the U_{bottom} curve.

The classification of fabrics according to the value of the accumulative one-way transport index is as follows:
- excellent > 400
- very good – from 200 to 400,
- good – from 100 – to 200
- poor – from -50 to 100,
- very poor < – 50.

A fabric with good accumulative one-way transport from the inner fabric side to the outer (high value of the parameter) offers good sweat management to the wearer. This is due to the fact that with a high accumulative one-way transport

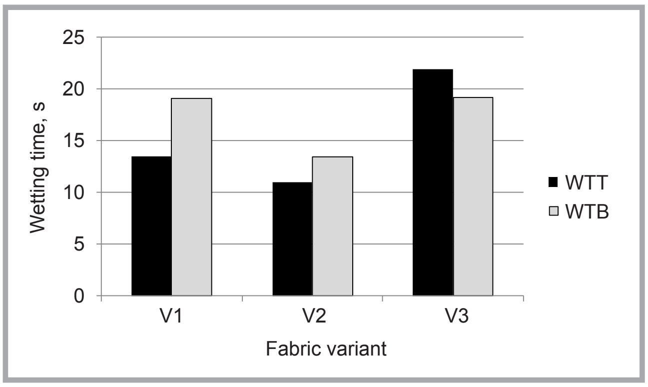

Figure 4. *Wetting time of top and bottom surfaces of seersucker woven fabrics.*

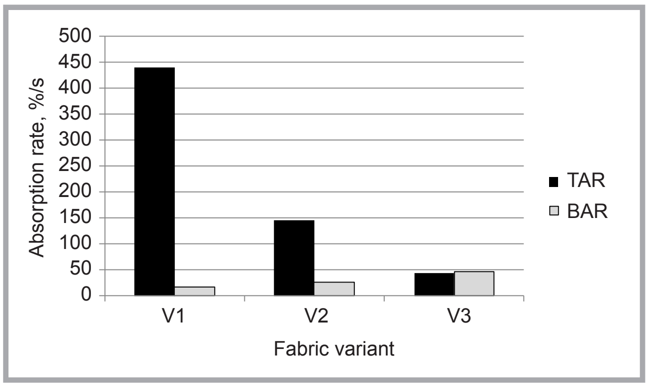

Figure 5. *Absorption rate of top and bottom surfaces of seersucker woven fabrics.*

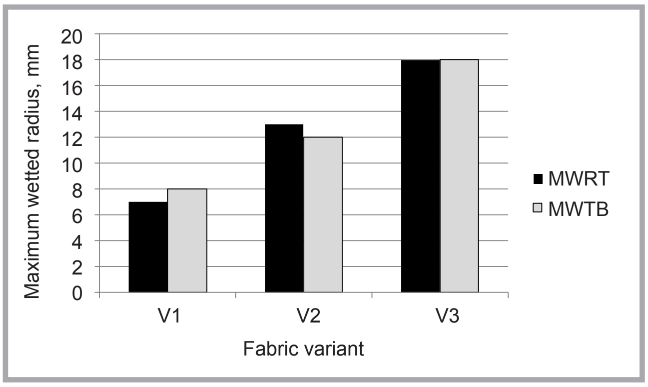

Figure 6. *Maximum wetted radius of top and bottom surfaces of seersucker woven fabrics*

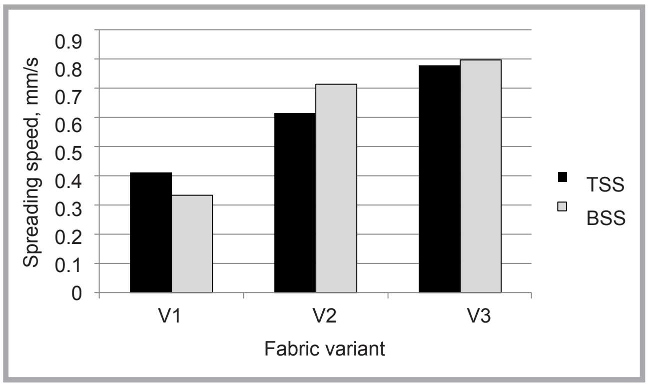

Figure 7. *Spreading speed on top and bottom surfaces of seersucker woven fabrics.*

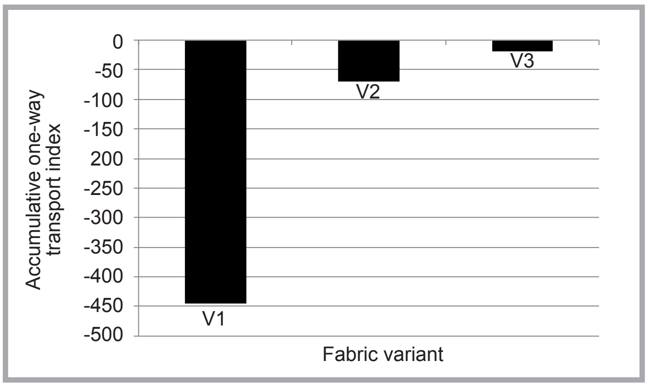

Figure 8. *Accumulative one-way transport index of seersucker woven fabrics.*

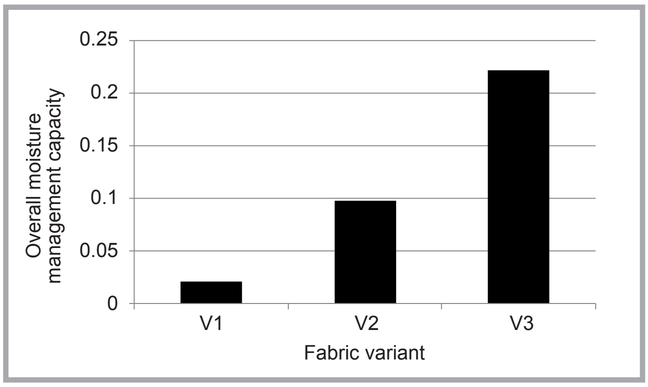

Figure 9. *Overall moisture management capacity of seersucker woven fabrics.*

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 [21].

In the case of the fabrics investigated, all of them are assessed according to the MMT results as not satisfactory from the point of view of moisture transport away from the skin side of the fabric to the outer surface (***Figure 8***). The V3 fabric variant is classified as "poor", whereas the V1 and V2 variants are classified as "very poor", which is surprising taking into consideration the very good hygienic properties of cotton fabrics reported in many scientific publications. Additionally, taking into account the structure of seersucker woven fabrics, they are considered as fabrics ensuring physiological comfort due to their ability to ensure human body ventilation [35]. This is true because the presence of puckered strips on the fabric surface causes that they do not adhere human skin to the whole fabric surface, due to which air and moisture in the form of water vapour can be easily removed and exchanged. The results obtained show that in the case of the liquid moisture, the performance of cotton seersucker fabrics is not as good as was expected.

In consequence, the overall moisture management capacity of the fabrics in-

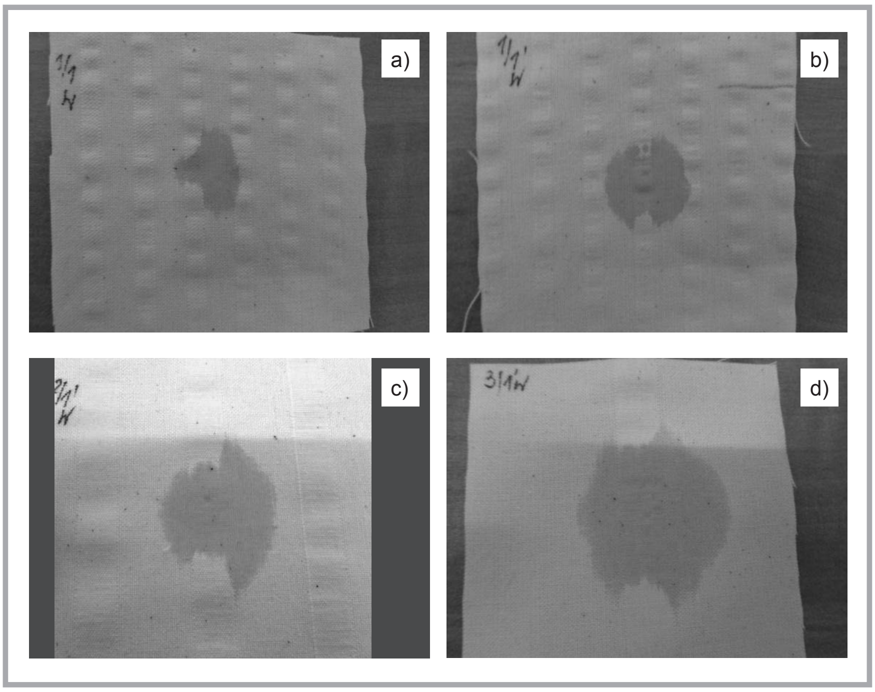

Figure 10. *Pictures of samples after the MMT test: a, b) the V1 fabric variant, c) the V2 fabric variant, d) the V3 fabric variant.*

vestigated was also assessed as not being high (***Figure 9***).

The value of OMMC is calculated using the formula presented in AATCC Test Method 195-2011. Generally the OMMC is based on the absorption rate for the bottom surface, the spreading speed for the bottom surface and the one-way transport capability. The weights of the parameters mentioned above were established based on human perception studies. According to the test method description, the one-way transport capability is twice as important as the absorption rate and spreading speed [40]. However, the authors of the method suggest that the weights should be adjusted according to the relative importance of these three indices based on the type of fabric and end use of the product. Perhaps the weights of particular parameters included in the formula of the OMMC should be established specially for seersucker woven fabrics taking into account their specific structure and surface topography. Seersucker woven fabric does not adhere to human skin on its whole surface due to its puckered surface topography. It influences the comfort sensation. Some amount of liquid moisture is kept away from the human skin, although it is absorbed by the fabric and is present in its structure. It would be advisable to perform an investigation aimed at the establishment of the weights of particular indices included in the OMC parameter formula for seersucker woven fabrics or other fabrics of developed topography of the surface. However, it needs utility trials and an assessment of the subjective feeling of subjects during usage of clothing made of such kinds of fabrics – fabrics of 3D structure and puckered surface.

In order to assess the significance of the relationships between the pattern of the seersucker effect and the liquid moisture transport parameters, ANOVA statistical analysis was performed.

Results of AVOVA are presented in ***Tables 4***. In the software applied, interpretation of the results is the following:

- when $p \leq 0.05$ – there is a statistically significant difference between within-group and between-group variability,
- when $p > 0.05$ – the difference between within-group and between-group variability is statistically insignificant.

In the ***Table 4*** the effects statistically significant at the level of significance $p = 0.05$ are highlighted in bold italics.

The results of statistical analysis show that there is a statistically significant influence of the repeat of the seersucker effect on the majority of parameters characterising the liquid moisture transport properties of the seersucker woven fabrics investigated. The repeat of the seersucker effect of the cotton seersucker woven fabric influences the following parameters in a statistically significant way:

- absorption rate of top surface,
- absorption rate of bottom surface,
- maximum wetted radius for top surface,
- maximum wetted radius for bottom surface,
- spreading speed on top surface,
- accumulative one-way transport index.

Figure 10 presents pictures of the test samples taken directly after the MMT test. It is clearly seen that the spreading pattern (shape of the wet surface of the sample) is noncircular. Due to this fact the parameter 'maximum wetted radius' should be considered as an imaginary term.

In the case of seersucker woven fabrics, the spreading pattern is irregular. Moreover we can see differences between the shapes of the wet surface placed on the flat and puckered strips of the fabrics. In all cases it was stated that in the warp direction the range of the wet spot on the

Table 4. *Results of ANOVA for the moisture management properties of the seersucker woven fabrics investigated.* ***Legend:*** *MS_{efect} – mean square of effect expressing between-group variability, MS_{error} – mean square of error expressing within-group variability, df – degree of freedom, F – variable of F distribution.*

	df_{effect}	MS_{effect}	df_{error}	MS_{error}	F	p
WT T	2	163.56	12	49.84	3.28	0.0730
WT B	2	52.92	12	75.34	0.70	0.5146
TAR	***2***	***209411.40***	***12***	***16860.20***	***12.42***	***0.0012***
BAR	***2***	***1065.06***	***12***	***262.47***	***4.05***	***0.0451***
MWR T	***2***	***151.67***	***12***	***7.50***	***20.22***	***0.0001***
MWR B	***2***	***126.67***	***12***	***11.67***	***10.86***	***0.0020***
SS T	***2***	***0.17***	***12***	***0.041***	***4.13***	***0.0432***
SS B	2	0.30	12	0.08	3.61	0.0593
R	***2***	***271141.30***	***12***	***53431.31***	***5.07***	***0.0253***
OMMC	2	0.05	12	0.02	3.41	0.0673

flat surface of seersucker woven fabrics is bigger than that of the wet spot on the puckered surface. It allows to assume that the puckered strips in the seersucker woven fabrics investigated disturb the spreading of liquid moisture in the warp direction of the fabric.

Pictures for the V1 variant (***Figure 10.a*** and ***10.b***) suggest that the puckered strips also disturb the spreading of liquid moisture on the top surface in the weft direction. In this fabric variant the repeat of the puckered strips, i.e. the distance between the puckered strips, is the lowest. Due to this fact, during the MMT test the liquid moisture can reach the edge of the next puckered strip sooner than in the V2 and V3 fabric variants and can be stopped by it. It should be mentioned here that the samples were cut in such a way that the puckered strip was in the centre of the sample, causing that the drops of the test solution delivered by the pump drip centrically onto the puckered strip of the specimen tested.

Clothing made of seersucker woven fabrics is in contact with human skin in the places of puckered strips. It means that liquid sweat released by human skin is firstly picked up by the fabric in places created by the puckered strips, which was the reason that samples for testing by means of the Moisture Management Tester were cut in the way described above.

However, investigations were also performed in the form of an assessment of the influence of the way of sample cutting on the results from the Moisture Management Tester. In the case of seersucker woven fabrics and other patterned fabrics, this aspect seems to be very important for the correct assessment of fabrics from the point of view of their ability to transfer liquid moisture. The results will be presented in the next article.

Due to the rather unsatisfactory assessment of the seersucker woven fabrics in the aspect of their liquid moisture management, the fabrics were also measured after washing by means of the Moisture Management Tester, which is advised by the Authors of the test method [40]. One washing cycle was used, and next drying in a free state. The fabrics were not pressed because the advantage of seersucker woven fabrics is that they do not have to be . Results obtained for the washed fabrics are significantly better than for those before washing. ***Figure 11*** presents values of the overall moisture management capacity of the fabrics before and after washing. Improvement is observed for all variants of fabrics investigated. They are still classified as "poor" in the aspect of the liquid moisture management. However, the value of the OMMC parameter for each variant is much higher after washing than before.

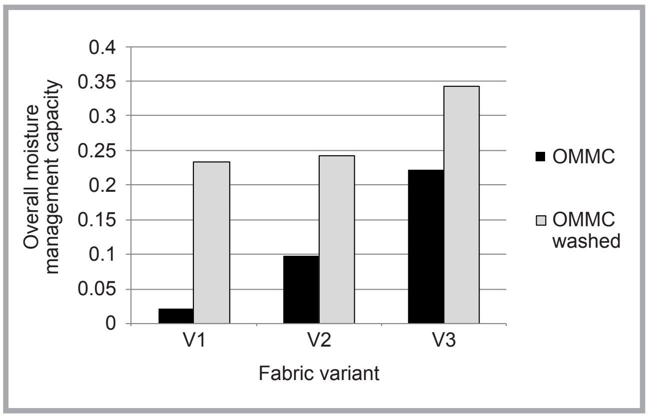

Figure 11. *Overall moisture management capacity of seersucker woven fabrics before and after washing.*

Conclusions

Cotton seersucker woven fabrics of different structure were the object of the investigations. The fabrics were measured in the range of their moisture management properties. Measurement was performed by means of a Moisture Management Tester model M290, made by SDL Atlas according to AATCC Test Method 195-2011 and the procedure described in the MMT manual.

On the basis of the results obtained, it was stated that the seersucker woven fabrics investigated are not very satisfactory from the point of view of their liquid moisture management capability. The results are rather surprising. Till now, cotton fabrics have very often been considered as satisfactory from the point of view of the physiological comfort due to the excellent natural hygienic properties of cotton. The structure of seersucker woven fabrics, characterised by the presence of puckered and flat strips, was also assessed, showing that they ensure high physiological comfort due to good human body ventilation.

The investigations performed also showed that the repeat of the seersucker effect influences the moisture management properties of seersucker woven fabrics. The best results from the point of view of the moisture transport capability were obtained for the V3 fabric variant, which is probably due to the bigger distance between puckered strips in the V3 fabric. Observations of the shape of wet spots on the fabric sample after the MMT test suggest that the puckered strips impede the spreading of liquid water on the fabric surface. The washing process improved the moisture transport performance of the seersucker woven fabrics investigated.

Acknowledgements

This work is financed by the National Science Centre, Poland, within the framework of the project entitled 'Geometrical, mechanical and biophysical parameterisation of three-dimensional woven structures", project No. 2016/23/B/ST8/02041.

References

1. Nemcokova R, Glombikova V, Komarkova P. Study on Liquid Moisture Transport of Knitted Fabrics by Means of Mmt, Thermography and Microtomography Systems. *Autex Research Journal* 2015; 15, 4: 233-242.
2. Rossi R. *Interactions between protection and thermal comfort, chapter in textiles for protection*, edited by Scott A, Woodhead Publishing Ltd, Cambridge England, 2005, ISBN-13: 978-1-85573-921-5, p. 233-260
3. ISO 7730 1984 Moderate thermal environments – Determination of the PMV and PPD indices and specification of the conditions for thermal comfort.
4. Hes L. Alternative Methods of Determination of Water Vapour Resistance of Fabrics by Means of a Skin Model, *3rd European Conference on Protective Clothing and NOKOBETEF* 8, Gdynia, 2006.
5. Matusiak M. Thermal Insulation of Woven Fabrics for Clothing. *Monograph, Works of Textile Research Institute, Special edition*, Ed. Textile Research Institute, Lodz, Poland, 2011.
6. Jianhua H, Xiaoming Q. Comparison of Test Methods for Measuring Water Vapor Permeability of Fabrics. *Textile*

Research Journal; Apr 2008; 78, 4: 342-352.
7. Skenderi Z, Salopek Čubrić I, Srdjak M. Water Vapour Resistance of Knitted Fabrics under Different Environmental Conditions. *FIBRES & TEXTILES in Eastern Europe* 2009; 17, 2(73): 72-75.
8. Chinta SK, Gujar PD. Significance of Moisture Management in Textiles. *International Journal of Innovative Research in Science, Engineering and Technology* 2013; 2, 6: 2104-2114.
9. Zhong W. *Surface tension, wetting and wicking, chapter in: chapter in textiles for protection*, edited by Scott A., Woodhead Publishing Ltd, Cambridge England, 2005, ISBN-13: 978-1-85573-921-5, 136-155.
10. Mayur B, Mrinal C, Saptarshi M, Adivarekar R. Moisture Management Properties of Textiles and Its Evaluation. *Current Trends in Fashion Technology & Textile Engineering* 2018; 3(3): 555611.
11. Patnaik A, Rengasamy RS, Kothari VK, Ghosh A. Wetting and Wicking in Fibrous Materials. *Textile Progress* 2006, 38, 1: 1-105.
12. Harnett PR, Mehta PN, Survey and Comparison of Laboratory Test Methods for Measuring Wicking. *Textile Research Journal* 1984; 54, 7: 471-478.
13. Kissa E. Wetting and wicking. *Textile Research Journal* 1996, 66: 660-668.
14. Hes L, Dolezal I. A New Computer-Controlled Skin Model for Fast Determination of Water Vapour and Thermal Resistance of Fabrics. *7th Asian Textile Conference*, New Delhi, 2003.
15. International Standard ISO 11902:1993. Textiles – Determination of physiological properties – Measurement of thermal and water-vapour resistance under steady-state conditions (sweating guarded-hotplate test).
16. AATCC Test Method 197, Vertical Wicking of Textiles.
17. SDL Atlas MMT M 290 manual.
18. Özdil N, Gamze Süpüren G, Özçelik G, Průchová J. A Study on The Moisture Transport Properties of the Cotton Knitted Fabrics in Single Jersey Structure. *Tekstil Ve Konfeksiyon* 2009; 3: 218- 223.
19. Öner E, Atasağun HG, Okur A, Beden AR, Durur G. Evaluation of moisture management properties on knitted fabrics. *Journal of The Textile Institute* 2013; 104: 7, 699-707.
20. Sai Sangurai G, Radhalakshmi YC, Subramaniam V. Effect of polyester cross-section on moisture management properties of knitted fabrics. *International Journal of Scientific & Engineering Research* 2014; 5, 3, 69: 69-74
21. Mangat MM, Hussain T, BajzikV. Impact of Different Weft Materials and Washing Treatments on Moisture Management Characteristics of Denim. *Journal of Engineered Fibers and Fabrics* 2012; 7, 1: 38-49.
22. Çeven EK, Günaydin GK. Investigation of Moisture Management and Air Permeability Properties of Fabrics with Linen and Linen-Polyester Blend Yarns. *FIBRES & TEXTILES in Eastern Europe* 2018; 26, 4(130): 39-47. DOI: 10.5604/01.3001.0012.1311.
23. Chen X, Taylor LW, Tsai LJ. An Overview on Fabrication of Three-Dimensional Woven Textile Preforms for Composites. *Textile Research Journal* 2011; 81, 9: 932-944.
24. Soden JA, Hill J. Conventional Weaving of Shaped Preforms for Engineering Composites. *Composites Part A* 1998, 29A: 757-762.
25. Bilisik AK. Multiaxial Three-dimensional (3-D) Circular Woven Fabric. Patent No. USP 129 122, 2000.
26. Unal PG. *3D Woven Fabrics, chapter in: Woven Fabrics* edited by Han-Yong Jeon, InTech, Rijeka, Croatia, 2012, 91-120, ISBN 978-953-51-0607-4.
27. Matusiak M, Wilk E. Investigation of Mechanical and Utility Properties of Two-Layer Cotton Woven Fabrics. *Autex Research Journal* 2018, 18, 2: 192-202.
28. Gandhi K. *Woven Textiles Principles, Technologies and Applications*. 1st ed., Woodhead Publishing, ISSN 2042-0803, New Delhi, 2012
29. Szosland J. *Woven structures* (in Polish), Polish Academy of Science, Lodz, 2007.
30. Matusiak M, Sikorski K, Wilk E. *Innovative woven fabrics for therapeutic clothing, chapter in: Innovations in Textile Materials & Protective Clothing*, edited by Bartkowiak G, Frydrych I, Pawłowa M, Warsaw, 2012, 89-106.
31. Ghahraman FG, Tavanai H, Hosseini SA. A qualitative assessment of seersucker effect through spectral density and angular power spectrum function algorithms. *The Journal of The Textile Institute* 2010; 101 (3): 276-281.
32. Matusiak M, Frączczak Ł. Investigation of 3D Woven Fabric Topography Using Laser-Scanning. *FIBRES & TEXTILES in Eastern Europe* 2018; 26, 1(127): 81-88.
33. Matusiak M, Frączczak Ł. Influence of Kind of Weft Yarn on Properties of the Seersucker Woven Fabrics. *AUTEX Research Journal* 2016; 16, 4: 214-221, ISSN: 2300-0929.
34. Ashraf W, Nawab Y, Maqsood M, et al. Development of Seersucker Knitted Fabric for Better Comfort Properties and Aesthetic Appearance. *Fibers and Polymers* 2015,16, 3: 699-701.
35. Matusiak M, Fracczak Ł. Comfort-related properties of seersucker fabrics in dry and wet state. *International Journal of Clothing Science and Technology* 2017, 29 3: 366-379.
36. Kyame GJ, Lofton JT. Cool and Carefree Cotton Seersucker, Available from: https://naldc.nal.usda.gov/download/IND43895201/PDF.
37. Maqsood M, Nawab Y, Javaid MU, Shaker K, Umair M. Development of seersucker fabrics using single warp beam and modelling of their stretch-recovery behaviour. *The Journal of The Textile Institute* 2014; 1154-1160.
38. Ashraf W, Nawab Y, Maqsood M, et al. Development of Seersucker Knitted Fabric for Better Comfort Properties and Aesthetic Appearance. *Fibers and Polymers* 2015,16,3: 699-701.
39. Willard D. *The Fabric Selector*, 1st ed., 2011, Search Press Ltd, 42-78.
40. AASTCC Test Method 195-2011. Liquid Moisture Management Properties of Textile Fabrics.

Received 06.09.2018 Reviewed 31.10.2018