Moisture transport in knitted fabrics

Transport wilgoci w dzianinach

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Abstrakt

Dzianiny często stosowane są w odzieży noszonej bezpośrednio przy skórze. Dlatego oczekuje się, że będą one charakteryzowały się bardzo dobrymi właściwościami wpływającymi na komfort fizjologiczny użytkowania odzieży, zwłaszcza zdolnością odprowadzania potu. W ramach pracy przeprowadzono badania 5 wariantów dzianin w zakresie zdolności do transportu potu w postaci pary oraz płynu. Badania wykonano za pomocą przyrządów Permetest i Moisture Management Tester M290. Stwierdzono, że wszystkie dzianiny charakteryzowały się bardzo dobrą przepuszczalnością pary wodnej. Transport płynnej wilgoci w dzianinach był zróżnicowany w zależności od składu surowcowego dzianin. Najlepszą zdolnością transportu płynnej wilgoci odznaczała się dzianina wykonana z mieszanki: bawełna 54%/ poliester 46%.

Abstract

Knitted fabrics are often used in clothing worn next to the skin. Therefore, they are expected to be characterized by excellent properties affecting the physiological comfort of clothing usage, especially the ability to wick away sweat. As part of the work, tests were carried out on 5 variants of knitted fabrics in terms of the ability to transport sweat in the form of vapor and liquid. The tests were performed using Permetest and Moisture Management Tester M290. It was found that all knitted fabrics were characterized by very good water-vapor permeability. The transport of liquid moisture in knitted fabrics varied depending on the raw material composition of the knitted fabrics. The best ability to transport liquid moisture was found in a knitted fabric made of a 54% cotton/46% polyester blend.

Słowa kluczowe: dzianiny, odzież, komfort, pot, pomiar, przepuszczalność pary wodnej, transport płynu

Keywords: knitted fabrics clothing, comfort, sweat, measurement, water-vapor permeability, liquid transport

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1. Introduction

Knitted fabrics, especially from natural fibres, are often used in underwear and clothing worn next to skin. For this reason, they are expected to be characterized by excellent properties affecting the physiological comfort of using the clothing. Physiological comfort is one of the four basic types of clothing comfort. In addition to physiological comfort, there are: psychological, sensory and fitting comfort [1, 2]. Physiological comfort, also known as thermo-physiological comfort, is defined as the state of satisfaction with the thermal conditions of the environment [3]. The basis of physiological comfort is thermal comfort. The crucial properties of textile materials related to the thermo-physiological comfort of clothing usage are the following [4]:

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

Thermal resistance of textile materials determines their thermal insulation. It influences an ability of clothing to protect the human being against cold or overheating. The thermal resistance of textile materials can be measured using the sweating guarded hotplate test called “skin model”, Permetest, Alambeta, Thermo Labo II. Two first instruments: the “skin model” and the Alambeta are the most popular all over the world [2, 5 - 7].

Water-vapor resistance (water-vapor permeability) of fabrics is usually measured be means of the “skin model” and the Permetest. In practice the Permetest is a portable “skin model” [2, 8, 9]. To assess an ability of the textile materials to transport the liquid moisture the wetting and wicking are usually determined [10]. Last decade the new instrument – the Moisture Management Tester was developed by the SDL Atlas. It makes possible to assess in a complex way an ability of textile materials to transport the liquid moisture. The instrument measures the dynamic liquid transport properties of textiles in three aspects [11-14]:

- moisture absorbing time for inner and outer surfaces of the fabric,
- one-way transport of liquid moisture from the inner surface to outer surface of fabric,
- speed of liquid moisture spreading on the inner and outer surfaces of fabric.

The air permeability of textile materials is measured using the Air Permeability Tester [15]. One of the most important properties from the point of view of physiological comfort is an ability to wick away sweat secreted by the user's body [16]. Sweat is released in the form of vapour and should be drained from the underclothing zone to the outside. However, in certain conditions: at high ambient temperature, high humidity of the surrounding air, intense physical effort or poor water-vapor permeability of clothing, some of the sweat vapor remains in the underclothing zone and condenses on the user's skin, giving unpleasant feeling of moisture and the effect of clothing sticking to the skin. Considering the above, when selecting a knitted fabric for underwear or clothing (T-shirts, blouses, dresses) worn next to the skin, one should take into account – their ability to wick away sweat both in the form of vapour and in the form of liquid [17]. Both aspects are equivalent: sweat removal in the form of vapor and sweat removal in the form of liquid. Presented work aimed to assess the selected variants of knitted fabrics in the aspect of their ability to sweat release form the underwear zone to the environment. Five variants of thin knitted fabrics for T-shirts were measured in the range of the water-vapor resistance and moisture management ability. Measurement was performed using the Permetest by Sensora (Czech Republic) and Moisture Management Tester M290 by SDL Atlas Ltd (US).

2. Material and Methods

The knitted fabrics for underwear and next-to-ski clothing have been the objects of the investigations. There were knitted fabrics made of cotton and blends of cotton with other fibres. Generally, five variants of knitted fabrics were measured. The basic properties of the fabrics being analysed are presented in Table 1.

Tab. 1. The basic properties of the investigated knitted fabrics.

Fabric variant	**Raw material**	**Stitch**	**Thickness, [mm]**	**Mass per square [meter, gr/m$^{2]}$**
V1	CO	Single jersey	0.47	161.09
V2	CO	Rib stitch	0.61	138.59
V3	54 CO/ 46 PES	Single jersey	1.27	198.44
V4	CO (TransDry)	Single jersey	0.96	149.53
V5	51modacrylic, 26 CO/19 PA/ 2 antistatic fiber/1 elastane	Single jersey	1.32	205.47

The V1 – V3 variants are used in standard T-shirts. The V1 and V2 fabrics are made of cotton, whereas the V3 variant contains a great amount (46 %) of polyester fibres. The V4 variant is made of cotton especially treated using patented technology developed by the Cotton Incorporated (US). The TransDry® technology for cotton is a high-performance moisture management application that allows fabrics to wick and spread the perspiration. In the technology the cotton yarns are specially treated to make them water repellent. The repellent yarns are blended in the knitted fabric together with the standard untreated cotton yarns, which are sweat absorbing. Such structure (Fig. 1) makes the fabrics moisture managing [18]. The V5 variant is the knitted fabric for firefighter's T-shirt. It is made of flame retardant / antistatic material. It is a certified flame retardant and antistatic thermo-active underwear from the PROTECT line [19].

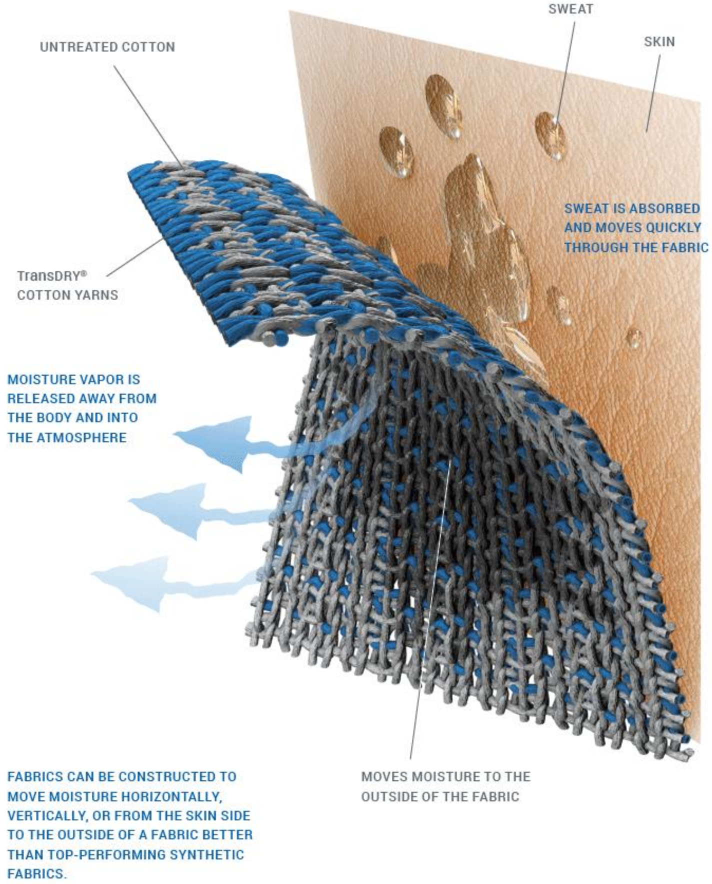

Fig. 1. T Trans Dry® technology;
https://www.cottonworks.com/en/topics/fabric-technology/performance-technologies/transdry-technology/

The knitted fabrics were measured in the range of comfort-related properties using the Permetest (Fig. 2) and Moisture Management Tester M290 (Fig. 3).

Fig. 2. The Permetest by Sensora (Czech Republic).

The Permetest is a fast response measuring instrument for the non-destructive determination of thermal resistance, water-vapor resistance and relative water-vapor permeability of textile materials [2, 8, 9]. The instrument provides all kinds of measurements very similar to the ISO Standard 11092 [20], and the results are evaluated by the identical procedure as required in the ISO 11092. In the presented work the Permetest was applied to measure the water-vapor resistance R_{et} and relative water-vapor permeability P of the knitted fabrics being analysed. During the measurement of water-vapour resistance the measuring plate of the device is wetted by the distilled water containing 0,1 % of pure non-aggressive liquid soap. The measuring head is maintained at the same temperature than the ambient temperature. Relative water-vapor permeability P determined by the Permetest is not a standardized indicator, however, it is a very practical tool for evaluating textiles from the point of view of their ability to provide physiological comfort. The value of the parameter is in the range from 0 to 100%. The value of relative water-vapor permeability P = 100% means total water-vapor permeability. The lower the value of the P index is, the lower the water vapor permeability, and thus the worse the physiological comfort of using a given product. For each fabric variant 3 repetitions of measurement were performed and next an arithmetic mean from 3 individual results was calculated as a final result. The Moisture Management Tester (MMT) is an instrument designed to measure the dynamic liquid transport properties of textiles in three aspects [11-14, 21, 22]:

- absorption of liquid moisture of inner and outer surfaces of the fabric,
- one-way transport of liquid moisture from the inner surface to outer surface of fabric,
- spreading the liquid moisture on the inner and outer surfaces of fabric.

Fig. 3. The Moisture Management Tester M290 by SDL ATLAS (US).

The device provides the values of the following parameters:

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

The device is controlled by PC and the MMT290 SOFTWARE. Measurement is done for samples cut into 80 mm x 80 mm squares. For each fabric 5 repetitions of measurement are performed according to the ACCT standard [21] and instrument manual [22].

3. Results and Discussion

Results of measurements using the Permetest are presented in Table 2.

Tab. 2. The results from the Permetest.

Fabric variant	**Ret, [m^{2}Pa/W]**		**P, [%]**	
	average	**SD**	**average**	**SD**
V1	2.90	0.10	66.20	1.00
V2	3.70	0.17	60.70	1.13
V3	3.83	0.12	60.07	0.93
V4	3.60	0.36	61.43	2.15
V5	3.43	0.15	71.57	0.55

SD – standard deviation

On the basis of the results from the Permetest it was stated that knitted fabrics being the objects of the investigation differ between each other in the range of their ability to transfer the water-vapor. The water vapor resistance R_{et} of the investigated fabrics is in the range from 2.90 to 3.83 m^{2}Pa/W. The highest water-vapor resistance (R_{et} = 3.83 m^{2}Pa/w) was stated for the V3 knitted fabric, whereas the lowest (R_{et} =2.90 m^{2}Pa/W) – for the V1 fabric variant. The values od the water-vapor resistance of the V2 and V4 variants are slightly lower than that for the V3 variant (Fig. 4).

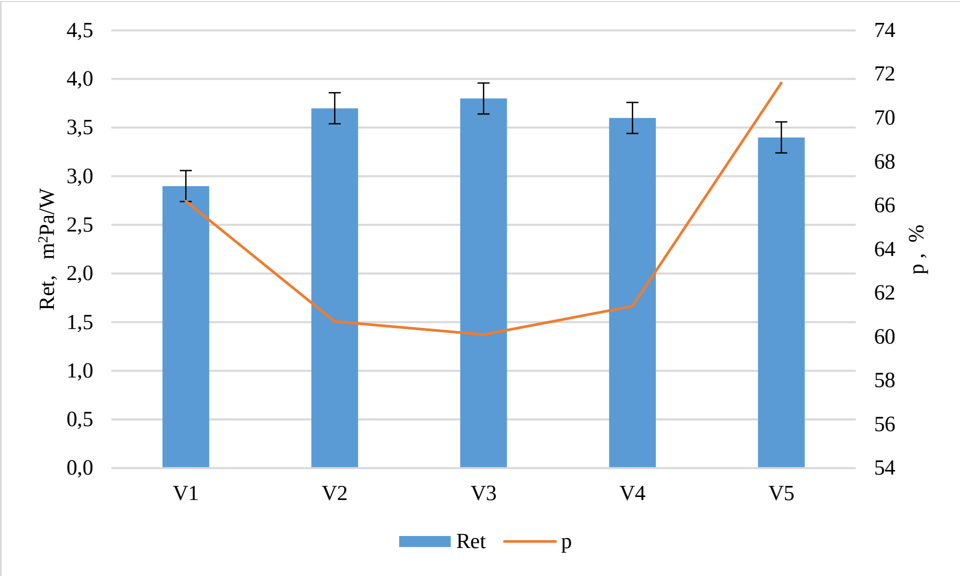

Fig. 4. Water-vapor resistance and relative water-vapor permeability of the investigated knitted fabrics.

In the aspect of the relative water-vapor permeability the highest values were stated for the V5, and next the V1 fabric variants, appropriately: 71.57 and 66.20 %. The lowest relative water-vapor permeability occurred for the V3 fabric variant. It is 60.07 %. Generally, it should be stated that the relative water-vapor permeability of all investigated variants of knitted fabrics is high, greater than 60 %. It means that all investigated fabrics transport the water-vapor well. It results from the structure of the knitted fabrics, especially their porosity. The number and size of pores between the yarns and fibres in the fabric is a crucial factor influencing bot air permeability and water-vapor permeability.

The results of liquid moisture transport measurement are presented in tables 4 and 5. The MMT provides the values of 10 parameters characterising the liquid moisture transport in the fabrics. Eight of them (WTT, WTB, TAR, BAR MWRT MWRB, SST, SSB) are connected with the sides – top (inner) and bottom (outer) of the investigated fabrics. They characterize the top and bottom surfaces. Two last parameters: R and OMMC characterize the whole fabric. They are calculated from other parameters provided by the MMT. The R index characterizes the liquid transport from the inner to outer side of the fabric. A fabric with good accumulative one-way transport from the 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 the 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.

The OMMC is calculated on the basis of absorption rate for bottom surface - BAR, spreading speed for bottom surface – BSS and accumulative one-way transport index – R. The manual of the MMT [22] suggests a classification for moisture management capability according to the OMMC value, as follows:

0 a 0.2 – very poor,

0.2 a 0.4 – poor,

0.4 a 0.6 – good,

0.6 a 0.8 – very good,

0.8 a 1.0 – excellent.

Tab. 3. The results from the Moisture Management Tester.

Fabric variant	Wetting Time, [s]		Absorption Rate, [%/s]		Max Wetted Radius, [mm]	
	Top	Bottom	Top	Bottom	Top	Bottom
V1	55.5	6.5	245.49	50.85	3	5
V2	53.7	74.5	228.55	29.65	3	2
V3	90.7	8.8	22.68	73.88	2	10
V4	5.0	5.1	36.33	50.03	26	25
V5	33.6	97.2	393.73	10.85	4	1

Tab. 4. The results from the Moisture Management Tester; continuation.

Fabric variant	Spreading Speed		R, [%]	OMMC
	average	SD		
V1	0.24	0.80	424.31	0.410
V2	0.32	0.32	-59.64	0.271
V3	0.08	2.06	1021.32	0.762
V4	3.02	3.06	-12.62	0.329
V5	0.33	0.17	-551.04	0.125

Based on the presented results it is seen that the investigated knitted fabrics differ between each other in the range of their ability to transfer the liquid moisture. Thera are also significant differences between the left (inner, top) and right (outer, bottom) sides of the fabrics.

The wetting time means the time when the surface of the measured sample start wetting after starting the test [22]. The shorter wetting time is the better ability of fabric to manage the liquid moisture. The shortest wetting time was observed for the V4 variant. It is the knitted fabric made of TransDry® technology. Both sides of the fabric wet very quickly (Fig. 5). Very short wetting time for the bottom surface was observed for the V1 and V3 fabrics. It means that the outer side of the fabrics wets fast. In is positive from the point of view of the physiological comfort. The transport of liquid to the outer (bottom) surface causes that the liquid can be quickly and ease evaporated.

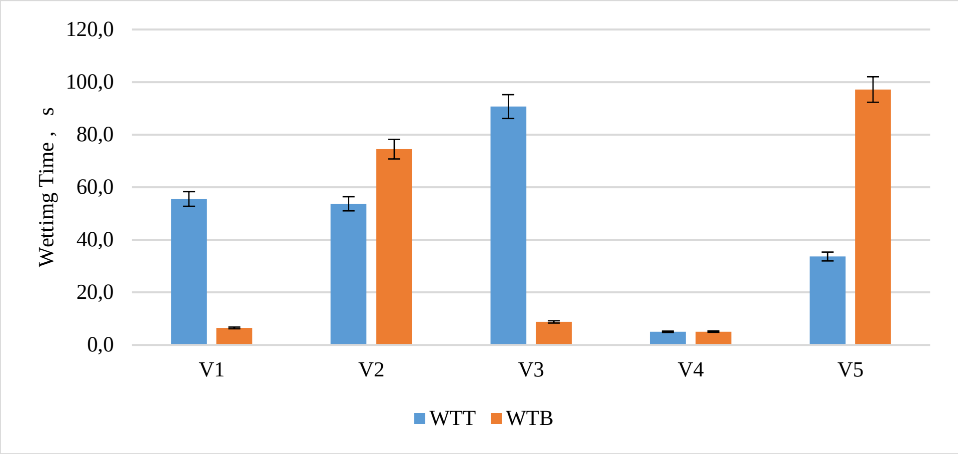

Fig. 5. Wetting time of top and bottom surfaces of the investigated knitted fabrics.

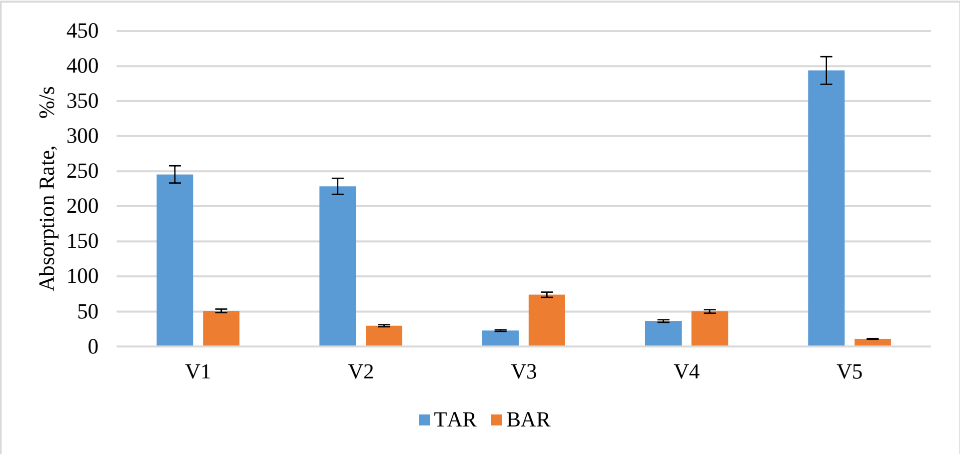

Fig. 6. Absorption Rate of top and bottom surfaces of the investigated knitted fabrics.

The absorption rate is the average speed of liquid absorption for given surface of fabric during the initial change of water content while testing [21]. The absorption of liquid by fibrous material limits the movement of liquid caused by the capillary forces. Due to this fact, the greater absorption rate is the more limited the liquid spreading on fabric surface. Additionally it should be mentioned, that great absorption rate of top surface causes that the liquid is trapped inside the fibres of the top surface. In the same time it is not effectively transferred to the outer surface and next, to the environment. This is negative feature from the point of view of the physiological comfort. The highest absorption rate for the top surface occurred for the V5 variant next for the V1 and V2 variants (Fig. 6). It means that the mentioned variants are not good from the point of view of liquid sweat transport from the human skin to the outer surface of clothing, and next to the environment. The lowest absorption rate was stated for the V3 and V4 variants. The V3 variant is the cotton/polyester fabric. Polyester fibres are hydrophobic. They do not absorb water. The 46 % share of polyester in the V3 fabric structure is a reason of low absorption rate of the fabric. Similarly, the V4 variant contains a big amount of hydrophobic fibers (Fig. 1). There are cotton fibers specially treated using the patented technology. It casus the observed results. The maximum wetted radius expresses the maximum radius of the sensor on which the liquid has been detected. The greatest maximum wetted radius is, the better spreading the liquid on the surface, and in the same time the better condition for liquid evaporation. It concerns mostly the bottom surface of the fabric which is far from the human skin.

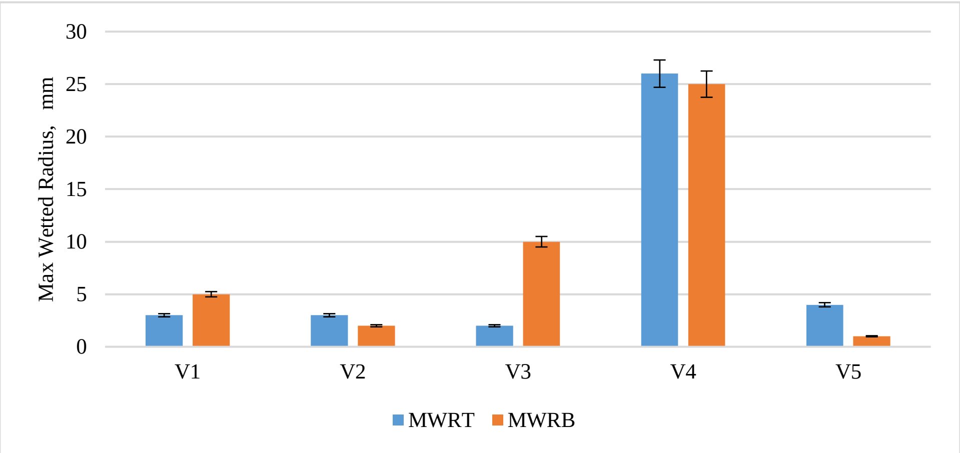

Fig. 7. Maximum wetted radius of top and bottom surfaces of the investigated knitted fabrics

In the case of the investigated knitted fabrics the greatest maximum wetted radius occurred for the V4 fabric – made in TransDry® technology (Fig. 7). Big area of liquid on the outer surface of fabric ensures quick evaporation of liquid sweat. However, the great maximum wetted radius of the top surface is not favourable for the physiological comfort. The top (inner) surface of the fabric adheres to the user's skin. Big wet area on the inner clothing surface causes unpleasant feeling of clothing user, and additionally the liquid on the inner surface is not evaporated effectively. It remains in the underclothing zone. More favourable situation is observed in the case of the V3 variant. The maximum radius on the bottom surface is greater than that on the top surface. It causes that the sweat is not retained on the inner surface but is transferred to the outer surface of clothing and next evaporated.

Results of spreading speed (Fig. 8) are in agreement with previous results. The greatest spreading speed was stated for the V4 and next V3 fabric variants. The lowest spreading speed occurred for the V2 and V5 variants. Favourable situation occurred for the V3 and V1 variants because in both cases the spreading speed for the outer surface is significantly greater than that for the inner surface.

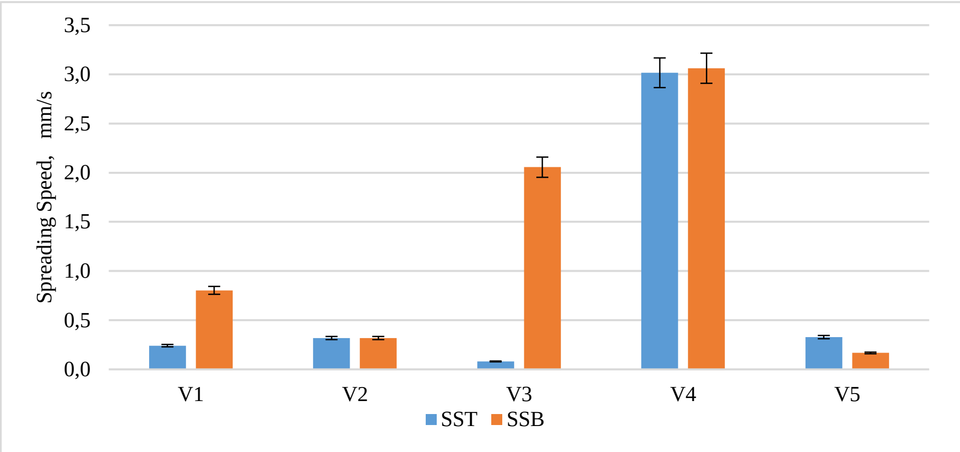

Fig. 8. Spreading Sped of top and bottom surfaces of the investigated knitted fabrics.

Based on the values of two general indicators: R and OMMC it can be stated that the best variant from the point of view of the liquid sweat transport is the knitted fabric made of cotton/polyester blend – the V3 variant. It is characterized by the highest value of the R parameter (R=1021.32%), significantly higher than the values of the R parameter for the rest of the investigated knitted fabrics (Table 3). According to the OMMC parameter the V3 variant was classified into the Grade 4 – very good (Fig. 9).

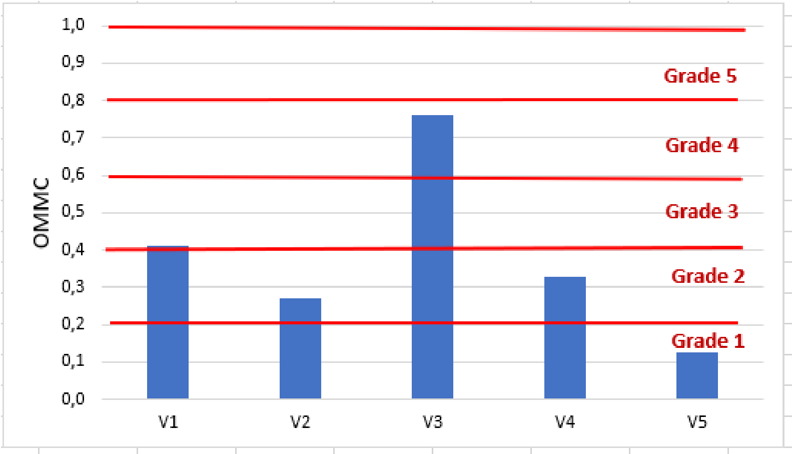

Fig. 9. Overall Moisture Management Capacity of the investigated knitted fabrics.

The lowest quality according to the OMMC value was stated for the V5 fabric variant. It is the knitted fabric for firefighter underwear. It is made of flame retardant / antistatic fibres. The share of cotton fibres is low – 26 %. Maybe it is a reason of low ability of the V5 fabric to transfer the liquid moisture.

4. Conclusions

Based on the performed investigations it was stated that the investigated knitted fabrics designed for T-shirts are characterized by very good relative water-vapor permeability – more than 60 %. It results from the structure of the fabrics, especially their porosity. The liquid moisture transport in the investigated fabrics is diversified and dependent on fibre composition of the fabrics. The best ability to transfer the liquid moisture was stated for the knitted fabric made of 54 cotton/46 polyester blend – the V3 variant. The performed investigations did not confirm the moisture management functionality of the knitted fabric made using TransDry® technology.

The fabric made of TransDry® technology was characterized by great spreading the liquid on the outer surface, what is favourable from the point of view of physiological comfort. Unfortunately, the spreading the liquid on inner surface is also great. It can cause that the fabric is wet on the inner surface adhering the user's skin. It can be a reason of unpleasant feeling causing discomfort. Additionally, the values of the wetting time and absorption rate suggest that the V4 fabric is able to ensure the liquid transport because it wets and absorb liquid moisture very fast. The results for the knitted fabric made using the Trand Dry® technology are discussable. The investigations of the Trans Dry® technology should be continued.

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