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Moisture Management Properties of Bi-Layer Knitted Fabrics

DOI: 10.5604/01.3001.0014.6086

Abstract

For investigation of the moisture management properties of bi-layer knitted fabrics, a special knitting structure made of the same or different combinations of yarns of cotton, polypropylene, Microdenier polyester and polyester staple fibre on the face and reverse sides fibre was studied. Moisture management properties, which determine the warm-cool feeling, of the fabrics produced were determined and statistical analysis made. The results indicated that the Microdenier polyester (inner) – Microdenier polyester (outer) fabric had a better moisture management property, providing high levels of comfort, and is recommended for summer, active and sportswear. The results were discussed together with one-way ANOVA test results at a 0.05 significance level. The results indicate that the Microdenier polyester yarn inner and outer layer of bi-layer knitted fabric shows a better moisture management property due to its appreciable wetting radius, as well its good absorption rate, wetting time and spreading speed of sweat, thus exhibiting a very higher level of the comfort property.

Key words: moisture management, microdenier polyester, comfort.

Introduction

The human body tries to maintain a balanced temperature around 37 °C, and it is in constant interaction with its surroundings. One of the most important mechanisms for the thermal regulation system is the sweating process, and yet it is also a major cause of discomfort. Particularly, only very little microclimate areas are allowed by textile garments on skin, which prevents quick dispersion to the atmosphere [1, 2].

In fabric meant for apparel, the comfort level of that fabric is decided by the moisture management property [3]. The moisture management properties of a fabric are very critical to the comfort of the wearer, mainly for sports garments and protective wear, in which an intensive level of active physical activities occurs [4-5]. Conventional textile products do not fulfill these complex functions. For example, even during the quick spread of moisture by hydrophobic fibre, which leads to quicker drying, a wet feeling cannot be prevented. However, fibres that are highly hygroscopic have good moisture absorbency, but weak drying efficiency. Thus, bi-layer fabric structures formed by combining different layers with different properties have a better thermoregulation effect than those formed from a single layer structure.

This study aims to reveal the effects of the combination of different yarn types on the moisture management characteristics of bi-layer knitted fabrics. Geraldies et al. [6] produced a functional knitted fabric using polypropylene and cotton yarns containing suction channels.

Zhu *et al.* [7] found that bilayer fabrics (knitted/woven) can be used as moisture-management fabrics without any additional treatments. Mbise *et al.* [8] found that the hydrostatic pressure difference between the two layers of spacer fabric is one of the factors affecting moisture transfer. However, the temperature, which influences hydrostatic pressure, is not constant among the body regions. Vidya & Prakash stated that Polyester yarns treated with Plasma show better moisture management properties when compared to those of other untreated fabrics. Plasma treatment results in better moisture management characteristics of the fabric [17]. In conclusion, to improve clothing comfort in apparel design, regional temperature and fit should also be considered. The aim of this study was to achieve a greater level of comfort in clothing by developing a bi-layer knitted fabric.

Materials and methods

In order to study the effect of the type of yarn on the moisture management properties of bi-layer knitted fabrics, four different yarns: polyester staple filament (PSF), polypropylene (PP), cotton (C) and microdenier polyester (MDP) were selected. Polyester is ideal for wicking perspiration away from the skin, cotton shows a good absorption property, while polypropylene shows good thermal and moisture transfer properties. The yarns selected were knitted with a loop length of 0.30 cm using a 2016 model Mayer and Cie bi layer 28[”] circular knitting machine with a 29 gauge and speed of 20 r/min to produce six different double-face fab-

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Polyester staple filament (Inner layer)	Polyester staple filament (Inner layer)
Polyester staple filament (Outer layer)	Cotton (Outer layer)
Sample 1 (PSF/PSF)	Sample 2 (PSF/C)
Cotton (Inner layer)	Polypropylene (Inner layer)
Cotton (Outer layer)	Cotton (Outer layer)
Sample 3 (C/C)	Sample 4 (PP/C)
Microdenier polyester (Inner layer)	Microdenier polyester Inner layer)
Cotton (Outer layer)	Microdenier polyester (Outer layer)
Sample 5 (MDP/C)	Sample 6 (MDP/MDP)

Figure 1. Bi-layer knitted fabric samples.

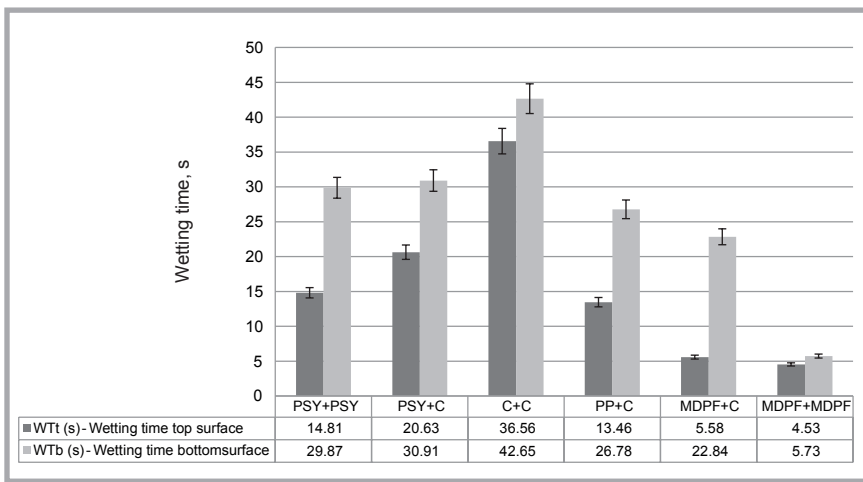


Figure 2. Wetting time of bi-layer knitted fabrics.

rics. The yarn combinations used to knit the bi-layer fabric were polyester staple filament – polyester staple yarn (PSF/PSF), polyester staple yarn-cotton (PSF/C), cotton-cotton (C/C), polypropylene-cotton (PP/C), microdenier polyester-cotton (MDP/C), and microdenier polyester-microdenier polyester (MDP/MDP) for the face and reverse sides, respectively. The face and reverse side of the double-face fabric were named ‘the top surface’ (outer) and ‘the bottom surface’ (inner), respectively. The bottom surface of the fabric was designed to touch the human skin. Geometrical properties of the samples are given in **Table 1**. After knitting, the bi-layer fabric samples were

subjected to relaxation as per the relaxation procedure. Standard atmospheric conditions of 65% RH and 27±2 °C were maintained to carry out testing of the double-face knitted fabrics. MMT (SDL Atlas) was used to test the moisture management properties according to AATCC TM 195 [9].

Dimensional properties

The loop length, thickness and areal density of the bi-layer knitted fabrics were measured. The standard ASTM D 3887 was used to evaluate wales (WPI) and courses per unit length (CPI). CPI is the course per inch, denoting the number of

courses in one inch length of the fabric. A course is a horizontal row of loops in knitted fabric. WPI is the wales per inch, denoting the number of wales in one inch of the width of a fabric. Wales is a vertical row of loops in knitted fabric.

Fabric thickness measurement was carried out using a Shirley thickness gauge according to ASTM D1777-96. The ASTM D3776 standard with an electronic balance was used to determine the areal density. The mass per unit area is the mass of knitted fabric i.e. the GSM (gram per square metre) of the fabric expressed as the areal density. Areal density is the general term for GSM. The areal density varies according to the area of the fabric; here it was calculated for a fabric size of 1 m × 1 m .

Filament polyester of 150 microdenier with 108 filaments, polypropylene of 150 microdenier of 108 multi-filaments, cotton of 36 count, and spun polyester of 2/76 double yarn with a cut staple length of 38 mm and 0.8 denier (microfibre) were used for the manufacturing of bi-layer knitted fabric. **Figure 1** shows the yarn combinations used to knit the bi-layer fabrics: polyester staple filament – polyester staple yarn (PSF/PSF), polyester staple yarn-cotton (PSF/C), cotton-cotton (C/C), polypropylene-cotton (PP/C), micro-denier polyester-cotton (MDP/C), and microdenier polyester- microdenier polyester (MDP/MDP) for the face and reverse sides of the fabrics, respectively.

Statistical analysis

For evaluating the test outcomes, SPSS 13.0 for Windows statistical software was used. One way ANOVA tests were applied to determine the statistical importance of the variations and p values were examined to deduce whether the parameters were significant or not. The variables are considered as significant if the p value is less than 0.05 [10].

Results and discussion

Geometrical properties of the fabrics were studied, and the average value of 10 tests conducted for each sample was taken. From **Table 1**, it is observed that if the yarn type is changed, it has an impact on the geometrical characteristics of the fabrics related to the course per centimetre and Wales per centimetre. A change in the type of yarn results in a change in the areal density.

Table 1. Geometrical properties of bi-layer fabrics.

S.No.	Yarn combination	Loop length, mm	Thickness, mm	Areal density, GSM	CPI	WPI
1	PSF+PSF	3.0	0.752	159.00	55	38
2	PSF+C		0.762	160.24	57	37
3	C+C		0.790	162.36	58	37
4	PP+C		0.674	158.66	58	36
5	MDP+C		0.646	155.91	57	36
6	MDP+MDP		0.562	148.92	56	35

Wetting time

Top and bottom wetting times

The start of the wetting of the upper and lower surfaces of the fabric after the initiation of the test is the wetting time. Wetting time values of the bi-layer knitted fabrics are given in **Figure 2**. Both at the top and bottom surfaces of the cotton-cotton bi-layer knitted fabric, the highest wetting time values were seen. This means the sweat solution absorbed more slowly than for the other fabrics. The top and bottom surfaces of MDP (inner) – MDP (outer) fabrics have the lowest wetting time values. Due to the hydrophobic property of the micro denier polyester (MDP), water molecules were not absorbed. The test liquid was transferred through the fabric because of the capillary forces in the MDP (inner) – MDP (outer) fabrics, after the test liquid was given to the surface. In the MDP/MDP fabric, because of its hydrophobic character, only a comparatively small amount of moisture was absorbed by the synthetic fibres, in which capillarity was responsible for the liquid moisture transport. Cotton fibre, as a natural fibre, has hydrophilic properties, meaning its surface has bonding sites for water molecules. Thus, water tends to be retained in the hydrophilic fibres, which have poor moisture transportation and release. Due to the longer top and bottom wetting time taken by C-C, there is a poor liquid transfer to the bottom surface of the fabric. The higher thickness and mass per unit area are the reasons for changes in the yarn type in the layer [11].

The shorter wetting time on the top and bottom surfaces are facilitated by the lower thickness of MDP-MDP bi-layer knitted fabric, making it more suitable for sportswear.

Absorption rates

The average moisture absorption ability of the specimen in the pump time (20 sec) is the absorption rates on the top and bottom surfaces (%/sec). Compared to the top surfaces of the fabric, the bottom surfaces have lower absorption rates. Most of the liquid moisture being distributed on the fabric's top surface is implied in this [12].

The absorption rates of fabrics used in the research are shown in **Figure 3**. For all the bi-layer knitted fabrics, the top absorption rate is greater than that of the bottom. In MDP bi-layer knitted fabric the highest top absorption rate was

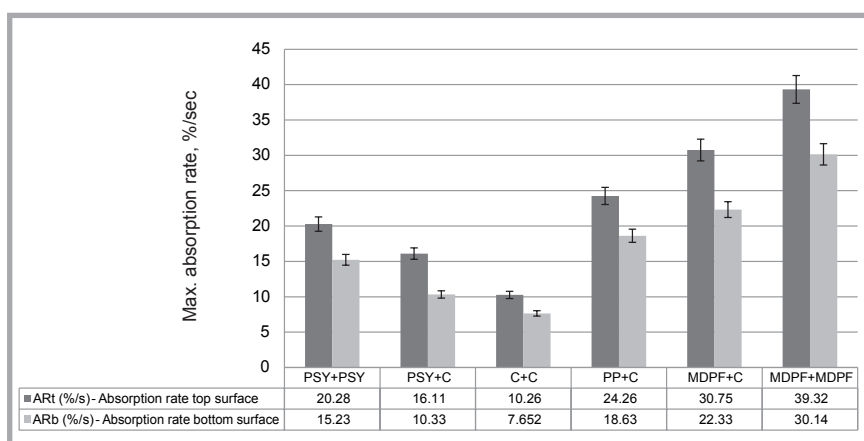


Figure 3. Wetting time of absorption rate of bi-layer knitted fabrics.

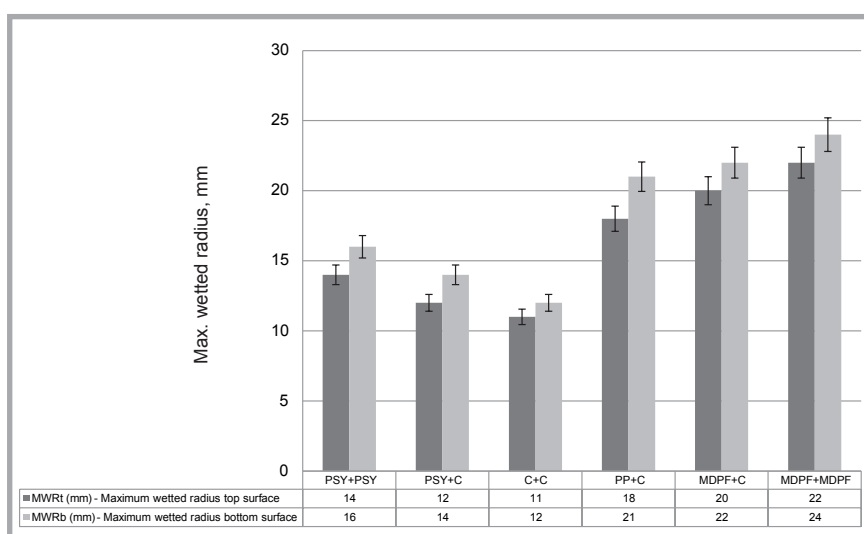


Figure 4. Maximum wetted radius of bi-layer knitted fabrics.

seen. Compared with the other bi-layer fabrics, the highest absorption rate was seen on MDP/MDP knitted fabric. This quickly acts as a capillary channel for the transportation of moisture to the bottom surface, due to the lower thickness value of MDP/MDP fabric. The thickness and mass per unit area are higher, which means a lower bottom absorption rate in MDP/MDP fabrics than for the other bi-layer knitted fabrics. In MDP/MDP fabrics sweat is transmitted quickly by the microdenier polyester yarn on the top surface, which is in contact with the skin, and transmitted to the bottom surface by means of diffusion, where it is exposed to the outer environment. The thickness is high, which means a lower bottom absorption rate for cotton-cotton bi-layer knitted fabric than for the others. The transfer of water from the top to bottom surface takes more time, thereby resulting in reducing the bottom absorption rate because of the greater thickness.

The accumulation of moisture in the microclimate results in dis-comfort to the wearer when the sweat transmission to the outer layer of the fabric does not happen quickly. Sweat was collected on the skin surface, which affects the performance of the wearer if a very little amount of sweat is transferred to the outer surface of the bi-layer knitted fabric. It can be concluded that microfibre polyester yarn transmits sweat at a faster rate on the top surface of the bi-layer knitted fabrics through the diffusion process, where it is in contact with the skin, transmitted to the bottom surface, and exposed to the outer environment [12-14].

Maximum wetted radius

From **Figure 4**, the highest maximum top wetted radius values can be seen for MDP (inner) – MDP (outer) fabric. Indeed, by capillary forces the test liquid can be easily transferred through the surface of MDP fibres.

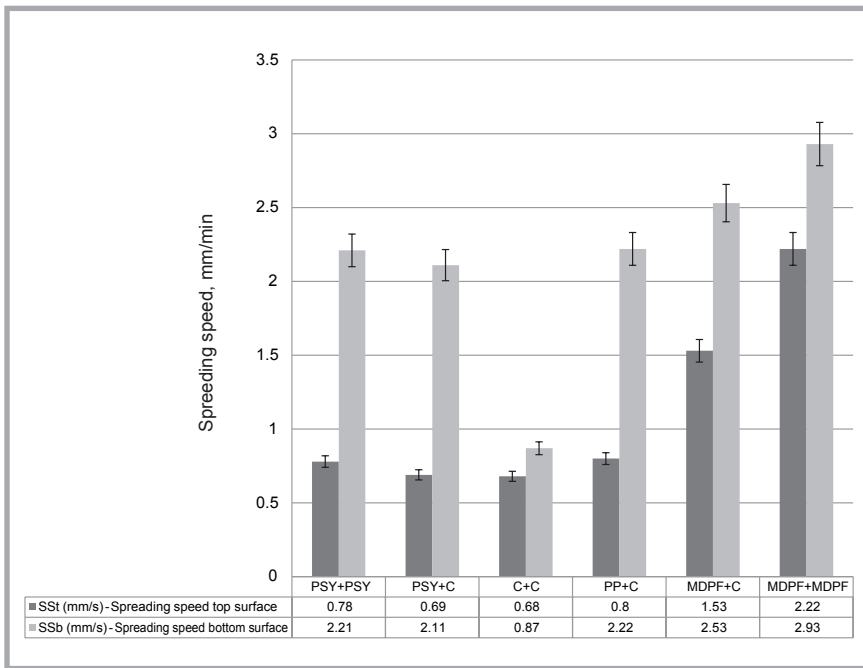


Figure 5. Spreading speed of bi-layer knitted fabrics.

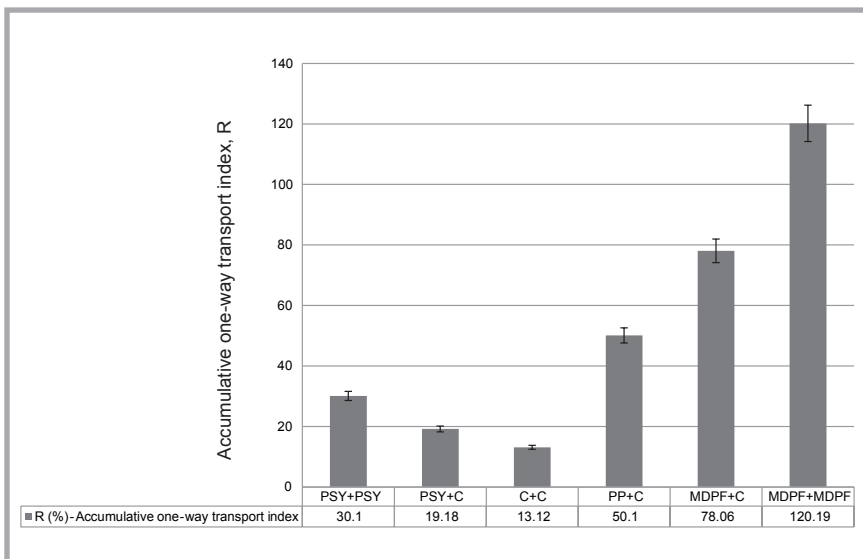


Figure 6. Accumulative one way transport index of bi-layer knitted fabrics.

Table 2. One-way ANOVA for the wetting time of the top surface of the Bi-layer fabric.

Property	Factor	Sum of square	Degrees of freedom	Mean square	F Value	p-Value	F-Critical
Top wetting time, seconds	Bi-layer fabrics	6871.587	5	1374.317	574.1555	1.7x10 ⁻⁴⁵	2.38607
	Error	129.2562	54	2.393633			
	Total	7000.843	59				

Table 3. One-way ANOVA for the wetting time of bottom surface of the Bi-layer fabric.

Property	Factor	Sum of square	Degrees of freedom	Mean square	F Value	p-Value	F-Critical
Bottom wetting time, seconds	Bi-layer fabrics	7202.928	5	1440.586	1010.906	4.98x10 ⁻⁵²	2.38607
	Error	76.95235	54	1.425044			
	Total	7279.881	59				

Referring to **Figure 4**, due to the good capillary transfer property, the wetted areas of the fabric on both sides are very high. In cotton-containing fabrics, the MWR values are lower compared with the other bi-layer knitted fabrics. Some of the test liquid spreads slowly due to the fibrous nature of cotton fabrics, and penetrates into the fibre structure, which results in lower moisture spreading along the fabric because of the hydrophilic character of cotton fibres. In order to avoid a cool feeling, a structure that possesses a good capillary effect can be useful to take the moisture away from the surface of the skin, as can be derived from this study. The top surface of the fabric is designed as the inner surface, which will be touching human skin on the test equipment. Therefore, for this type of bi-layer knitted structure, a lower top MWR means a lower wet touch and chill feeling, and greater skin comfort. MDP/MDP bi-layer knitted fabrics with lower thickness showed a better MWR. All the other bi-layer fabrics were observed to possess a lower bottom MWR when compared to that of MDP/MDP fabric. The main reason for the decline in performance of the other bilayer fabrics is because of the higher thickness compared to MDP/MDP knitted fabrics. It can be inferred that sweat transmission is quick from the inner layer (next to skin), leading to the minimum absorption of liquid in the fabric outer layer [15-16].

Spreading speed

Figure 5 shows the highest spreading speed for MDP-MDP bi-layer knitted fabrics. Less air is entrapped within the fabric because of the lower mass per unit area and thickness of MDP-MDP bi-layer knitted fabric. A higher bottom spreading speed is there in the MDP-MDP bi-layer knitted fabric. One of the most dominant physiological parameters for sportswear comfort is a reduced drying time. From **Figure 4**, because of the lower MWR of the cotton layer, SS values of the sides with cotton are lower. As a result of the high MWR of the MDP surface, SS values of the MPD layer are very high. These results can be explained with the following situations: in polypropylene (inner) – cotton (outer) fabrics, the polypropylene fibres transfer water to the cotton side by capillary forces and the cotton fibres absorb the water transferred; therefore, the increase in the SS value caused by the wetted area on the cotton side is higher. The test liquid is absorbed by the fibres due to the high hydrophilic charac-

teristic of cotton fibres on both sides of the fabric. MWR is found to be lower for the cotton (inner) – cotton (outer) fabric.

OWTC and overall moisture management capacity

By changing the yarn combination, different moisture transport properties can be achieved and the sweat generated out can be easily transferred while keeping a dry feeling, developed by the bi-layer knitted structure. **Figures 6** and **7** show the values of OWTC and OMMC of the bi-layer knitted fabrics. MDP/MDP bi-layer knitted fabric was classified as being of very good grade (OMMC: 0.6-0.8) in OMMC. The fabric next to skin becomes dry due to the higher absorption rate on the top surface as well as to the higher MWR and spreading speed on the bottom surface. MDP/MDP followed by MDP/C and PP/C possessed good moisture management capacity. The moisture management properties of bi-layer knitted fabrics are mainly constituted by the geometrical properties, such as the mass per unit area porosity and thickness of the fabric.

ANOVA testing was conducted to analyse the statistical importance of the bi-layer knitted fabrics with respect to moisture management properties. ANOVA was carried out using the SAS System (version 8 for Windows) to evaluate any changes in the moisture management properties of the various bi-layer knitted fabrics. The variables are considered as significant if the probability (p) value is less than 0.05.

The results of one-way ANOVA are given in **Table 2** to **11** for the moisture management properties of the bi-layer knitted fabrics.

In **Tables 2** to **12**, it is shown that the p-value for moisture management properties of the bi-layer knitted fabrics is < 0.05. This clearly indicates that there is a significant difference in the moisture management properties of the bi-layer knitted fabrics at a 95% confidence level. Thus, it can be concluded that the various yarns selected for the bi-layer fabrics affect the wetting time of the top surface, that of the bottom surface the, absorption rate of the top surface, that of the bottom surface, the spreading area of the top surface, that of the bottom surface, the spreading speed of the top surface, that of the bottom surface, the accumulative one way transport index, and overall moisture management capability of the fabrics.

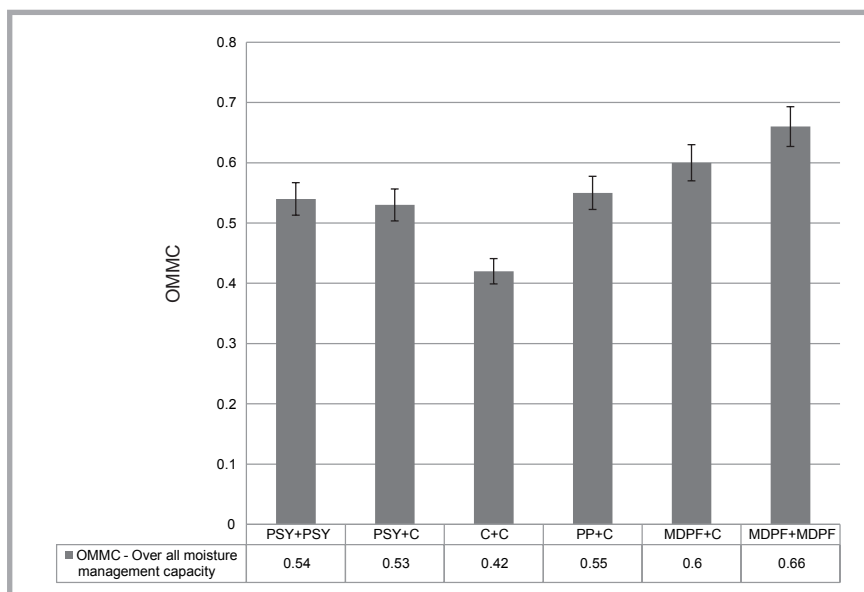


Figure 7. Overall moisture management capacity of bi-layer knitted fabrics.

Table 4. One-way ANOVA for the absorption rate of the top surface of the Bi-layer fabric.

Property	Factor	Sum of square	Degrees of freedom	Mean square	F Value	p-Value	F-Critical
Top absorption rate, %	Bi-layer fabrics	5188.382	5	1037.676	551.6016	4.92x10 ⁻⁴⁵	2.38607
	Error	101.5851	54	1.881206			
	Total	5289.967	59				

Table 5. One-way ANOVA for the absorption rate of the bottom surface of the Bi-layer fabric.

Property	Factor	Sum of square	Degrees of freedom	Mean square	F Value	p-Value	F-Critical
Bottom absorption rate, %	Bi-layer fabrics	3523.698	5	704.7397	729.5199	2.96x10 ⁻⁴⁸	2.38607
	Error	52.16574	54	0.966032			
	Total	3575.864	59				

Table 6. One-way ANOVA on the maximum wetted radius of the top surface of the Bi-layer fabric.

Property	Factor	Sum of square	Degrees of freedom	Mean square	F Value	p-Value	F-Critical
Top maximum wetted radius, mm	Bi-layer fabrics	1020.495	5	204.0989	305.9023	2.61x10 ⁻³⁸	2.38607
	Error	36.02896	54	0.667203			
	Total	1056.523	59				

Table 7. One-way ANOVA for the maximum wetted radius on the bottom surface of the Bi-layer fabric.

Property	Factor	Sum of square	Degrees of freedom	Mean square	F Value	p-Value	F-Critical
Bottom maximum wetted radius, mm	Bi-layer fabrics	1210.533	5	242.1067	549.3176	5.49x10 ⁻⁴⁵	2.38607
	Error	23.8	54	0.440741			
	Total	1234.333	59				

Table 8. One-way ANOVA for the spreading speed of the top surface of the Bi-layer fabric.

Property	Factor	Sum of square	Degrees of freedom	Mean square	F Value	p-Value	F-Critical
Top spreading speed, mm/sec	Bi-layer fabrics	25.84403	5	5.168807	144.3107	5.79x10 ⁻³⁰	2.38607
	Error	1.93413	54	0.035817			
	Total	27.77816	59				

Table 12. Summary of ANOVA statistical results for the moisture management properties of the fabric. **Note:** At a 95% confidence limit.

Factor	WTt, s	WTb, s	ARt, %/s	ARb, %/s	MWRt, mm	MWRb, mm	SSt, mm/s	SSb, mm/s	AOTI, %	OMMC
Yarn path	significant	significant	significant	significant	significant	significant	significant	significant	significant	significant

Table 9. One-way ANOVA for the spreading speed of the bottom surface of the Bi-layer fabric.

Property	Factor	Sum of square	Degrees of freedom	Mean square	F Value	p-Value	F-Critical
Bottom spreading speed, mm/sec	Bi-layer fabrics	23.29408	5	4.658816	83.8956	3.3x10 ⁻²⁴	2.38607
	Error	2.99868	54	0.055531			
	Total	26.29276	59				

Table 10. One-way ANOVA for the accumulative one-way transport index of the Bi-layer fabric.

Property	Factor	Sum of square	Degrees of freedom	Mean square	F Value	p-Value	F-Critical
AOTI	Bi-layer fabrics	84445.68	5	16889.14	13584.42	2.26x10 ⁻⁹²	2.38607
	Error	67.13669	54	1.243272			
	Total	84512.81	59				

Table 11. One-way ANOVA for the overall moisture management capability of the Bi-layer fabric.

Property	Factor	Sum of square	Degrees of freedom	Mean square	F Value	p-Value	F-Critical
OMMC	Bi-layer fabrics	0.41104	5	0.082208	14.91209	3.49x10 ⁻⁰⁹	2.38607
	Error	0.297694	54	0.005513			
	Total	0.708734	59				

Conclusions

In this study, using a moisture management tester, the moisture management properties of bi-layer knitted structures made of different yarn combinations in the inner and outer layers were studied. OMMC values are found to be very good in MDP fabric. MDP/MDP fabric has a good moisture management property, as indicated by OMMC values. The fabric thickness and mass per unit area affect the wetting time of the bi-layer knitted fabric. The thickness of the fabric greatly influences the absorption rate of the fabric. The maximum wetting radius and minimum wetting time affect the spreading area of sweat on the surface of fabric having microdenier polyester yarns as its inner layer, which is greatly influenced by the thickness of the fabric. One-way liquid transport capacity was determined by the thickness and mass per unit area of the fabric. The moisture management properties of bi-layer knitted fabrics are mainly affected by the one-way liquid transport capacity. Appreciable moisture management properties are exhibited by MDP bi-layer knitted fabrics, and it can be concluded that due to good moisture management properties, MDP/MDP bi-layer

knitted fabrics are more suitable for sporty apparel due to the fact that they quickly release perspiration from the skin and make the wearer feel dry and comfortable. On the other hand, the highest top absorption and one way transport index value are shown by MDP knitted fabric.

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Received 20.02.2020 Reviewed 12.05.2020