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Moisture management properties of knitted fabrics with varying structures and fibre content

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Moisture Management Properties of Knitted Fabrics with Varying Structures and Fibre Content

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Abstract: Heat stress can occur in high-intensity sports due to the high amounts of metabolic heat output. The heat released through the evaporation of water serves to lower the body's internal temperature, making sweating an important physiological process. Moisture management qualities, which allow for the rapid absorption and transport of water vapour and liquid perspiration from the skin to the outer surface of garments, are crucial in multilayer sportswear, as they allow for maximum wearer comfort. In this investigation, the moisture management qualities of knitted textiles used in the layers of athletic apparel were examined. The machine determines how much liquid moves through the fabric in all directions and on both sides. When compared to other fabric structures, R1 fabric was shown to have the highest liquid moisture management capacities, suggesting that it would be an excellent choice for the inner layer of sportswear due to its ability to wick perspiration away from the skin and into the garment. In this context, "Waterproof fabric" refers to fabrics S1, S2, and S3, while "Water repellent fabric" refers to fabric T1. Although fabrics of varying fibre content (S1, S2, and S3) showed similar moisture management properties, fabrics of varying structures showed varying values for dynamic liquid transfer. This shows that the fibre content of fabrics does not change depending on the fabric's ability to regulate moisture.

INTRODUCTION

There has been a huge uptick in sports participation due to the growing popularity of both indoor and outdoor sports and recreational activities. Several factors, including more leisure time, a focus on health and wellness, an expansion of indoor and outdoor recreation opportunities, and the creation of sport-specific apparel [1,2], have contributed to these rises. Flexibility and comfort have contributed to the rise in popularity of active sports materials in recent years. Modern textile science and technology is applied in the production of sports and leisurewear to address the growing need for enhanced performance in these arenas [3]. As an application of the aerodynamics concept, modern sportswear incorporates pressure treatment to decrease drag during high-velocity activities, resist the impact force of muscle caused by running or jumping, thereby decreasing unnecessary muscle vibration, and applying pressure to specific muscles to increase blood flow [4,5]. It has become a popular tool for athletes to enhance performance in competition, reduce post-exercise trauma, reduce muscle soreness and reduce recovery time after exercise and training [6-9].

Besides the effectiveness of sports clothing, comfort performance is also an important attribute demanded by modern consumers [10,11]. Clothing requirements for various sporting activities differ, and the criteria for sportswear change with the seasons and weather. When it comes to winter sports apparel, it is essential that it provides enough thermal insulation and weather protection [12]. An upper layer that can keep water out is essential for rainy conditions. Heat stress can be reduced by wearing clothing that is low in heat insulation and high in air permeability [13].

Significant effort has been put into studying multilayer fabrics [14–16] for their potential to provide a high level of comfort. Questions like what happens to multilayer garments when you change the yarn or the knitting pattern. This is because multi-layered materials are more effective in maintaining a comfortable internal temperature [17]. Researchers found that multilayer fabrics can be used as moisture management fabric without extra treatment [17-19].

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Figure 1 shows the construction method of multilayer sportswear fabric. Adhesive bonding or sewing can be used to join the layers together.

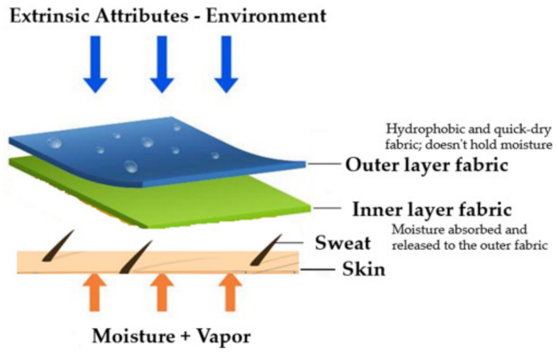


FIGURE 1. The construction method of multilayer sportswear fabric

The average human body temperature is 37 degrees Celsius, and it strives to stay at that temperature under all circumstances. To keep itself at a comfortable temperature, the human body uses a combination of vapour perspiration, normal atmospheric conditions, and conduction, convection, and radiation [17]. Sensible perspiration and moderate to severe liquid sweating [20] are the results of strenuous physical activity and harsh climatic circumstances. To maintain a constant 37 degrees Celsius [21], heat must be dissipated from the body and released into the surrounding environment. In order for perspiration to evaporate into the air, it must first be removed from the skin. The microclimate's relative humidity (RH) rises if perspiration cannot be dissipated into the surrounding atmosphere [22]. Non-transfer of moisture has several consequences for heat transmission systems, including heat stress, damp sensation, hyperthermia, and hypothermia [22]. Moisture transfer through materials is therefore crucial to the wearer's comfort in hot and cold conditions, and at moderate and vigorous levels of exertion. Because of this, studying the fabric's ability to wick away sweat is essential for sportswear.

METHODOLOGY

There are three distinct knits here, each with its own fabric structure and blend of fibres were selected in this study. The weft-knitted fabrics are produced on a circular knitted machine using cotton yarn (30 Ne) and spandex yarn (40 Ne). The fabrics were made and grouped into two groups which are; i) a homogeneous fabric, and ii) a homogeneous fabric with the same fibre composition. Each fabric was weighed using the ASTM D3776 Standard Method to determine its mass per unit area in g/m^2. Thickness values of fabrics were calculated using ASTM D 1777 standard. Five replicates of each experiment were conducted, and the mean results are shown here. Specifications for the fabric were laid out in Table 1, and a diagram of the fabric's construction was included in Table 2.

Moisture Management Properties

To evaluate the moisture-wicking capabilities of the fabrics, a Moisture Management Tester (MMT) was utilized in accordance with the AATCC 195-2017 test standard [22,23]. The MMT (Figure 2) allowed for the quantitative assessment of liquid moisture spread in multiple directions on both sides of the fabric [20]. As moisture is conducted through the fabric, the electrical contact resistance changes in magnitude, which is dependent on the liquid components and the water content of the fabric [24].

To create a sweat-like test solution, 9 grammes of sodium chloride were dissolved in one litre of distilled water. During the experiment, 0.15 g of solution was sprinkled onto the top of each specimen by the machine [25]. The tester's top surface corresponds to the inside of the garment, while the bottom surface corresponds to the outside of the garment when worn [26]. Fabric's dynamic liquid transport qualities can be measured by the MMT using the following equations:

i. Wetting times were measured for the top surface (WTt) and bottom surface (WTb) in seconds.
ii. WTt represents the time when the top surface starts absorbing water, while WTb indicates when the bottom surface starts absorbing water.

iii. Maximum rates of moisture absorption were measured for the top (MARt) and bottom (MARb) surfaces of the fabric in percentage per second.
iv. The Maximum Wetted Ring (MWR) was determined by adding the radii of the top surface (MWRt) and the bottom surface (MWRb) measured in millimetres.
v. The spreading speeds (SSt and SSb) at which the largest wetted radius is achieved were measured in millimetres per second. Total Throughput for One-Way Transport (OWTC) was calculated by determining the accumulated moisture content differential between the fabric's face and back during the unit test period.
vi. The overall capacity of the fabric to manage moisture was expressed as the Total Capacity to Manage Moisture (OMMC).

The index measures the fabric's performance in three categories related to its ability to control the flow of liquid moisture: bottom-side moisture absorption rate, one-way liquid transport ability, and bottom-side moisture drying speed (measured in terms of maximum spreading speed).

Each fabric was subjected to MMT testing on both the front (the layer furthest from the skin) and rear (the layer closest to the skin) during the course of the study. In daily life, the fabric's face is exposed to the elements, while the reverse side is worn against the skin. If the pace of physical activity and perspiration is high, it is crucial that liquid sweat and vapour be transported from the skin to the outer surface of the clothing. The test subject is put on the upper surface facing the upper sensors, which simulate the skin-contacting interior of a garment, while the lower surface facing the lower sensors simulates the exterior of the garment, which is exposed to environmental influences.

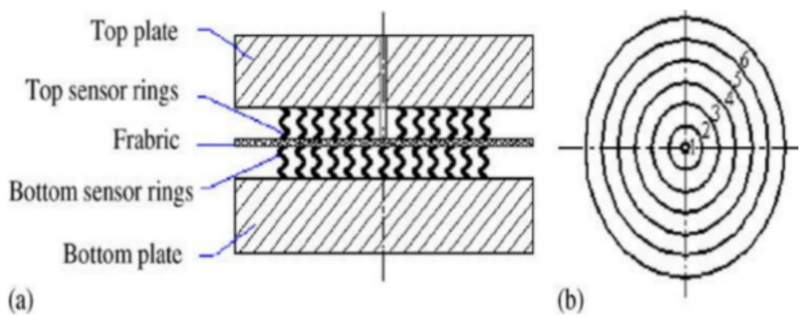
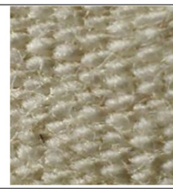


FIGURE 2. Fabrics' ability to wick away moisture, as measured by the Moisture Management Tester (MMT).

TABLE 1. Constructions and compositions of fabric samples

Fabric code	Fabric Constructions	Fibre Compositions (%)	Fabric Weight (g/m^2)	Fabric Thickness (mm)
S1	Single Jersey	95% Cotton, 5% Elastane	265.20 ± 0.07	0.88 ± 0.01
S2	Single Jersey	92% Cotton, 8% Elastane	309.99 ± 0.15	0.84 ± 0.01
S3	Single Jersey	90% Cotton, 10% Elastane	280.70 ± 0.20	0.84 ± 0.01
R1	1x1 Rib	95% Cotton, 5% Elastane	247.46 ± 0.11	0.94 ± 0.01
T1	Terry	95% Cotton, 5% Elastane	348.01 ± 0.25	1.23 ± 0.01

TABLE 2. Microscopic images of experimental fabric in relaxed state.

				
S1	S2	S3	R1	T1
Technical front				
				
S1	S2	S3	R1	T1
Technical back				

The fabrics that underwent testing were categorized into seven distinct groups, namely type 1 through type 7. The classification was based on the grades and indices values, which enabled a comprehensive and direct assessment of the liquid moisture management properties. Figure 3 presents the criteria and techniques used to carry out the classification process.

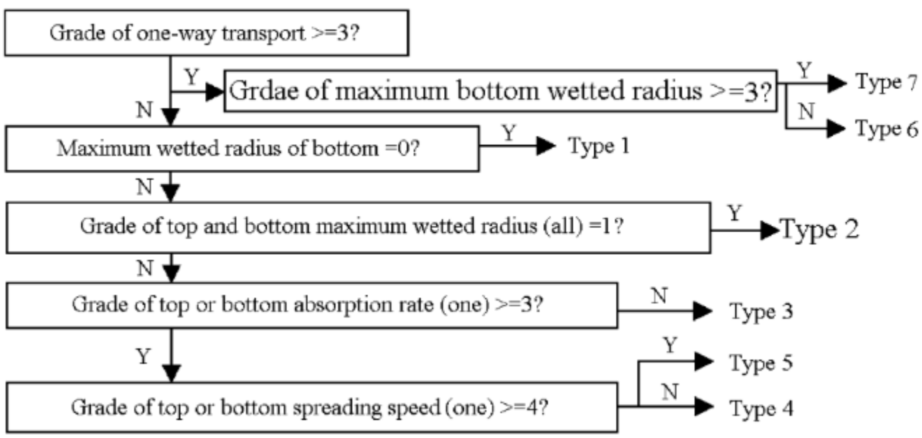


FIGURE 3. The flow chart of the criteria and the procedure for classification method.

RESULT AND DISCUSSION

Here, we present the fabric as a single layer, based on our experimental results. Liquid moisture transmission in clothing significantly influences the notion of moisture comfort sensations [22]. The dynamic liquid transfer values of textiles can be calculated with the use of the moisture management tester (MMT) apparatus. The ability of knits to wick away moisture is tabulated in Table 3. Then, the grades are calculated (Table 4). The scale of evaluations runs from 1 (very poor) to 5 (very good) [27,28].

Tables 3 and 4 show the wetting times (WT) for the top and bottom surfaces of the tested cloth, respectively, after the test has been conducted. The wetting time of fabrics S1, S2, and S3 was medium on their upper surfaces and maximal (no wetting) on their lower surfaces. This means that liquid moisture that drops onto the top surface (the side of the fabric that is in contact with the skin) does not penetrate through to the bottom surface (the side of the fabric that is in contact with the outer layer). Wetting time on T1's upper surface is rated as medium, while wetting time on T1's lower surface is classified as slow. This means that there is a gradual exchange of liquid moisture between the upper and lower surfaces.

However, fabrics R1 showed the longest wetting time (no wetting) on the top surface and the shortest wetting time (slow wetting) on the bottom. The liquid moisture permeates the fabric nearly instantly upon landing on the top surface (next -to-skin side) and slowly migrates to the bottom surface (next-to-skin side) [24]. It's clear from this that the top of the fabric absorbs water more slowly than the bottom [29].

Second, the rate at which a fabric absorbs moisture, expressed as a percentage per second, is known as its absorption rate (AR) [30]. Table 4 displays the relative absorbency of all fabrics' top and bottom surfaces. Table 4 shows that, with the exception of R1, the top surfaces of S1, S2, S3, and T1 have a relatively high absorption rate. S1, S2, S3, and T1 have moderate absorption rates for the bottom surface, whereas R1 has a medium to fast absorption rate. This indicates that relative to the other fabrics, R1 is superior in its ability to move perspiration from the skin side of the cloth to the outside side. The top surface loses less moisture to the air than the bottom surface because it is further away from the source of the moisture [31]. To rephrase, a garment made from R1 will keep its wearer drier and more at ease. The user may experience pain from the other fabrics (S1, S2, S3, and T1) since they make the skin feel moist.

How far a liquid can travel across a cloth is measured by its maximum wetted radius [29]. Fabrics with a larger maximum wetted radius dry faster after being exposed to water. Table 3 reveals that whereas fabrics S1, S2, S3, and T1 all have a maximum wetted radius of 5 mm, R1's is 0. S1, S2, and S3 all have a wetted bottom radius of 0 mm, while R1 and T1 are 33.33 and 1.67 mm, respectively. In grading terms, all of the fabrics are non-wetting grade 1. This demonstrates that the moisture is contained and does not seep through to the underside. Since the bottom absorption rate is greater than the top absorption rate and the bottom wetting time is greater than the top wetting time, it follows that water is moved from the upper to the lower surface [32].

The term "spreading speed" is used to describe how quickly a liquid wicks through a fabric. The spreading speed of both the top and bottom surfaces of all the textiles is extremely low. This indicates that the rate at which moisture spreads from the point where skin touches the fabric to the maximum wetted radius is quite low. This means these materials have the unique property of drying very slowly.

The ability of a cloth to transfer moisture from one conductive surface to another is measured by the cumulative one-way transport index. With the exception of R1, all of the textiles have very low values for the accumulative one-way transport index in the table. The cumulative one-way travel index for R1 was very high. That's because the relative humidity on either side of the fabric R1 is very different. Signified that the bottom surface had a higher moisture content than the top surface [18].

Comparing the OMMC of different textiles, we find that R1 fabric has the highest liquid moisture management capacity (OMMC), suggesting that it effectively wicks away perspiration and keeps skin dry. Other fabrics, on the other hand, aren't very good at keeping moisture at bay.

Table 5 provides a summary of the MMT measurement grades. Waterproof fabric (S1, S2, and S3) has very low absorption rates, spreads slowly, does not allow for unidirectional transport, and prevents water from penetrating the material. We call T1 a "Water Repellent Fabric" for a reason. This fabric does not absorb liquids, does not spread, and has poor travel in one direction without the use of external forces. These characteristics are not very comfortable, especially when worn adjacent to the skin during strenuous physical activity. These features, however, make for a great outer layer and protection from weather like rain and wind when participating in outdoor sports like skiing, cycling, and mountaineering [33]. Fabric R1 is a "Moisture management fabric," to round things off. This fabric has medium to rapid wetting and absorption, good to exceptional one-way transport, a large spread area at the bottom surface, and fast spreading at the bottom surface. As an inner layer for athletic wear, fabric R1 has promising qualities. This is because these characteristics can improve comfort during exercise by reducing skin moisture and increasing sweat evaporation. Different fabric structures (S1, R1, and T1) were found to have varying effects on moisture management. Despite this, the moisture-managing properties of fabrics of different fibre contents (S1, S2, and S3) are equivalent. The moisture-wicking qualities of a fabric depend on its structure, but are unaffected by the fabric's fibre content.

TABLE 3. MMT result of fabric in value

Fabric		Wetting Time Top (WTt)(sec)	Wetting Time Bottom (WTb)(sec)	Top Absorption Rate (ARt)(%/sec)	Bottom Absorption Rate (Arb)(%/sec)	Top Max Wetted Radius (MWRt)(mm)	Bottom Max Wetted Radius (MWRb)(mm)	Top Spreading Speed (SSt)(mm/sec)	Bottom Spreading Speed (SSb)(mm/sec)	Accumulative one-way transport index (AOTI) (%)	OMMC
S1	Mean	16.006	120.000	156.9361	0.000	5.000	0.000	0.309	0.000	-850.042	0.000
	SD	1.124	0.000	48.0486	0.000	0.000	0.000	0.022	0.000	48.996	0.000
S2	Mean	17.317	120.000	269.7715	0.000	5.000	0.000	0.287	0.000	-891.225	0.000
	SD	1.404	0.000	34.2402	0.000	0.000	0.000	0.023	0.000	69.751	0.000
S3	Mean	15.818	120.000	152.9798	0.000	5.000	0.000	0.316	0.000	-834.980	0.000
	SD	1.900	0.000	48.2503	0.000	0.000	0.000	0.039	0.000	17.127	0.000
R1	Mean	120.000	42.777	0.000	53.735	0.000	3.333	0.000	0.799	909.459	0.554
	SD	0.000	66.883	0.000	52.889	0.000	2.887	0.000	0.734	653.951	0.268
T1	Mean	16.598	88.549	381.638	3.994	5.000	1.667	0.302	0.064	-999.132	0.002
	SD	2.391	54.475	41.3906	6.917	0.000	2.887	0.041	0.111	269.319	0.003

TABLE 4. MMT result of fabric by grading

Fabric	Wetting Time Top (WTt) (sec)	Wetting Time Bottom (WTb)(sec)	Top Absorption Rate (ARt) (%/sec)	Bottom Absorption Rate (Arb) (%/sec)	Top Max Wetted Radius (MRt) (mm)	Bottom Max Wetted Radius (MWRb) (mm)	Top Spreading Speed (SSt) (mm/sec)	Bottom Spreading Speed (SSb) (mm/sec)	Accumulative one-way transport index (AOTI) (%)	OMMC
S1	3	1	5	1	1	1	1	1	1	1
S2	3	1	5	1	1	1	1	1	1	1
S3	3	1	5	1	1	1	1	1	1	1
R1	1	2	1	4	1	1	1	1	5	3
T1	3	2	5	1	1	1	1	1	1	1

TABLE 5. MMT evaluation result

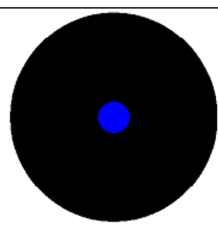
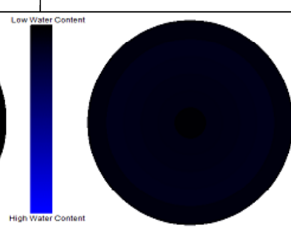
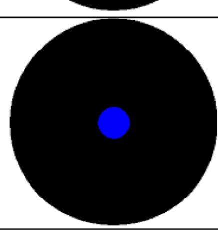
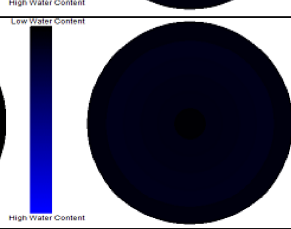
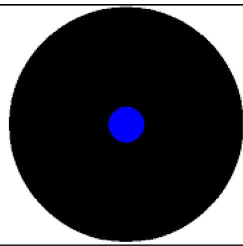
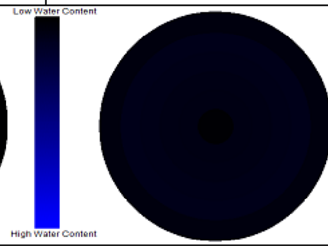
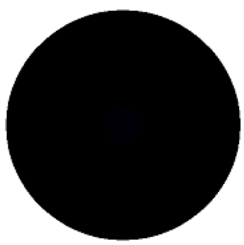
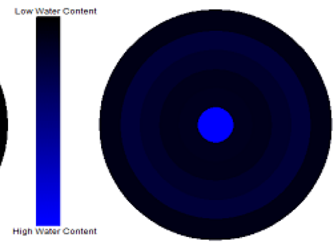
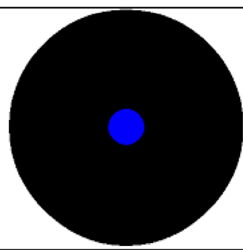
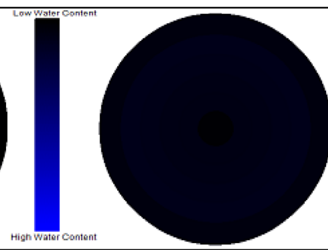
Fabric sample code	Map of water location vs time		Fabric classification and properties
	Top surface	Bottom surface	
S1			Type 1: Waterproof fabric Very slow absorption Slow spreading No one-way transport, no penetration
S2			Type 1: Waterproof fabric Very slow absorption Slow spreading No one-way transport, no penetration

TABLE 5. MMT evaluation result (Continued…)

Fabric sample code	Map of water location vs time		Fabric classification and properties
	Top surface	Bottom surface	
S3			Type 1: Waterproof fabric Very slow absorption Slow spreading No one-way transport, no penetration
R1			Type 7: Moisture management fabric Medium to fast wetting Medium to fast absorption Large spread area at bottom surface Fast spreading at bottom surface Good to excellent one-way transport
T1			Type 2: Water repellent fabric No wetting No absorption No spreading Poor one-way transport without external forces.

CONCLUSIONS

This research examined the moisture-controlling qualities of multilayer fabric used in athletic apparel with various knitting structures and fibre content were evaluated. It can be concluded that fibre content does not influence the fabric's moisture management properties compared to fabric with a different structure. Fabric R1 has the highest liquid moisture management properties compared to S1, and T1 fabrics. S1, S2 and S3 can be classified as "Waterproof fabric", and T1 fabric can be classified as "Water repellent fabric", which is suitable as an outer layer fabric as its properties provide shelter from the elements during outdoor sporting events, particularly when it's raining or windy. Lastly, the R1 classification of fabric, "Moisture management fabric," makes it an ideal choice for use as an inner layer as it offers high levels of comfort during exercise by absorbing sweat from the inner surface of clothing to the outer layer of clothing

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