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Thermal Comfort Properties of a Bi-layer Knitted Fabric Structure for Football Sportswear

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ABSTRACT

The application of textile products in functional area like sportswear has been increasing in last decade. The thermal properties of knitted fabric sample made up of polyester and cotton were studied for football sportswear. Six samples were manufactured, two were plain, two rib and two are bi-layer interlock structures. Airflow and WVP (Water vapor permeability), thermal properties, and drying capacity of bi-layer knitted samples made up of polyester as the inner surface and cotton as the outer surface. The outcome indicates bi-layer samples with polyester as the inner surface and cotton as the outer surface having single(one) tuck point of replication is preferable for football wear. The thickness, structure and weight of the sample have great influence on the thermal comfort properties of bi-layer knitted fabrics. As thickness of the sample increases the thermal property, air permeability and drying ability decreases and higher absorbency. The results are discussed together with Statistical analysis system (SAS) test results at a 95% significance level.

Keywords: consumption, thermal comfort, bi-layer, sportswear, Statistical analysis system

1. Introduction

The producers of sportswear have been focusing their efforts on modifying their strategic position, productivity, added value product variety and niche positions in order to expand their markets [1].

Football players are much more aware of sportswear and demand more specific functions to be performed by it. As a result, a few fibers and fabrics are used to satisfy the needs and developments arising mainly in the areas of comfort and aesthetic acceptability [2]. Sports wears are worn next to the skin and are key to the physiological comfort of players and their attributes in this aspect are critical to their performance [3]. In traditional sportswear, players face problems like sweating and feeling hot while run. The requirements of football are sweat absorption, fast drying and cooling [4]. The comfort of sportswear can be achieved by thermo-physiological, skin sensorial, and psychological comfort. Moisture movement and the drying ability of fabrics are vital factors affecting the functional comfort of sportswear [5,6]. The capacity of layered fabric in thermo-regulation is better comparing to single layer structure [7,8,9]. For doubled layer fabric, it is recommended that the inner layer, which touches the skin, is made from synthetic fibers having good moisture transfer properties, such as polyester, acrylic and nylon. The outer layer should be made from fibers that have good moisture absorption properties such as cotton, wool, viscose or their blends [10]. Advancements in synthetic fibers have opened up huge avenues for their use in sportswear to meet specific requirements [11]. The growth in improvement and use of high-tech materials used in sportswear and outdoor leisure clothing is amazingly increased. The requirements of these products are properties of thermal insulation, blocking to liquids, stretch, thermal comfort etc. [12]. Sport tech and sports equipment that improve comfort and performance are grouped into three classes i.e. sportswear, sports good and games equipment. Synthetic fibers play a great role in current high technology sports uniform: warmth, wind resistance, moisture absorbency, and lightness; comfort and feel like natural fibers and style and variety of colors [13,14]. The objective of this study was to produce a bi-layer knitted fabric that will be comfortable for football sports. Characteristics of this structure concern the existence of two different fabric layers: the outer layer has hydrophilic properties, in which cotton yarn was used due to its high moisture absorption property; the inner part is hydrophobic fiber; polyester was selected due to its high-water transfer capillarity, lightweight and easy-care properties..

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Yarn

Two different types of yarns, cotton and polyester were used for sample preparation. The yarn linear density for cotton and polyester is 150 Decitex.

2.1.2 Fabric

The bi-layer fabrics were knitted on an interlock jacquard knitting machine (Mayer & Cie – OVJA36) machine gauge of 20, with a machine diameter of 32-inch, and number of feeders 36. Six samples were manufactured, two samples were plain single jersey structures, two samples were rib knitted structures and two samples were bi-layer knitted constructions as shown in table 1.

Code	Cam and needle
S1, S2	

X	X
X	X

Code	Cam and needle
S3, S4	

	F1	F2	F3	F4	F5	F6	F7	F8
DN1	X	O	X	O	X	O	X	O
DN2	X	O	X	O	X	O	X	O
CN1	O	X	O	X	O	X	O	X
CN2	O	X	O	X	O	X	O	X

Code	Cam and needle
S5, S6	

	F1	F2	F3	F4	F5	F6	F7	F8	… F36
DN1	X	-	X	-	X	-	X	-	-
DN2	X	-	X	-	X	-	X	-	-
CN1	-	X	-	X	-	X	-	X	X
CN2	-	X	-	X	-	X	-	X	X
CN3	O	X	-	X	-	X	-	X	X

Dial needles: Two tracks
DN1-Dial needles Track 1; Dial needles Track 2
Cylindrical needles: Three tracts
CN1- Cylindrical needles Track 1; CN2- Cylindrical needles Track 2;
CN3- Cylindrical needles Track 3
F1, F2, ………F36= Number of feeders: X-Knit stitch; O- Tuck stitch; --miss stitch

Figure 1. Cam setting and needle order of samples

Table 1. Sample code details

Sample Code	Details
S1	100% cotton – Single Jersey Fabric
S2	100% polyester – Single Jersey Fabric
S3	50%cotton and 50%polyester – Rib Fabric
S4	50%cotton and 50%polyester – Bi-layer (one tuck point)
S5	50%cotton and 50%polyester – Bi-layer (Five tuck point)
S6	50%cotton and 50%polyester – Bi-layer (Seven tuck point)

The yarn used for the inner surface is fed in the dial needle and the outer surface in the cylinder needle. The cam setting and needle order is shown in Figure 1. Due to heat generation around the back, under arm, and waist line, sweat is accumulated in sportswear, which is uncomfortable for players and disturbing their performance. Sweat generated should be evaporated to the atmosphere to keep the fabric dry. This can be performed by a bi-layer structure fabric in which the inner surface is made up of hydrophobic yarn and the outer surface of hydrophilic yarn.

2.2. Methods

2.2.1 Property Tests

Course and wale density were evaluated as per the ASTEM D3887 Standard [15]. Fabric thickness was evaluated as per ASTEM D1777[16] and Fabric weight per unit area was according to ASTM D3776 [17]. The tightness factor of the samples was calculated by the formula below.

The air permeability of sample was measured using KES–F8 AP1, with the Air Permeability Tester following the BS 5636 1990 standard [18]. Thermal conductivity was measured using Lee’s disk instrument as per to Standard ASTM D7340 [19]. Water vapor permeability test is conducted using the evaporative dish method based on BS 7209:1990 [20].

3. Result and Discussion

3.1. Fabric Structural Partners

As it is shown in table 2 below, the areal density of all six samples varies according to the fabric structure

Table 2. Sample structural parameters

Sample Code	Stitch density	Areal density(gm^2)	Loop length(mm)	Thickness (T) (mm)
S1	2130	110	2.6	0.59
S2	1850	89	3.2	0.57
S3	1840	121	3.0	1.1
S4	2110	128	2.85	0.70
S5	2324	150	2.93	0.98
S6	2252	130	2.9	0.81

Table 3. Thermal properties of samples

Code	Coefficient of thermal conductivity ($Wm^{-1}k^{-1}$)	WVP ($gm^{-2}.day^{-1}$)	Air permeability ($cm^3s^{-1}cm^{-2}$)		Moisture absorbency (%)	Drying behavior, (Minutes)
			Dry	Wet		
S1	0.023	1218	320	250	55.2	13.9
S2	0.022	1380	260	235	51.4	12.1
S3	0.018	1322	300	220	72.3	11.8
S4	0.051	2300	850	650	79.6	10.6
S5	0.039	1545	264	225	92.4	8.9
S6	0.024	1855	330	260	82.1	11.3

3. Thermal Conductivity

It is related to the sample thickness, material type, and structure. From table 3. It was observed that the value of thermal conductivity for S4 is higher whereas the lowest was for S6. Because S4 had lower thickness and higher volume of air with in it. It is significant to note that the higher number of tuck points increase in thickness shows a comparatively lower thickness than for one tuck point bi-layer fabrics. As it is seen from the figure 2, sample T4 has lower thickness value (0.70mm) and higher thermal conductivity (0.051 $Wm^{-1}k^{-1}$) related to other bi-layer knitted fabrics. T5 and T6 have higher thickness of 0.98 and 0.81mm respectively with lower thermal conductivity of 0.039 and 0.024$Wm^{-1}k^{-1}$) respectively. This is because of the thermal conductivity of bi-layer knitted fabrics is highly dependent on the weight and thickness of the sample. As it is seen from the figure 2, sample T4 has lower thickness value (0.70mm) and higher thermal conductivity (0.051 $Wm^{-1}k^{-1}$) related to other bi-layer knitted fabrics. T5 and T6 have higher thickness of 0.98 and 0.81mm respectively with lower thermal conductivity of 0.039 and 0.024$Wm^{-1}k^{-1}$) respectively. This is because of the thermal conductivity of bi-layer knitted fabrics is highly dependent on the weight and thickness of the sample.

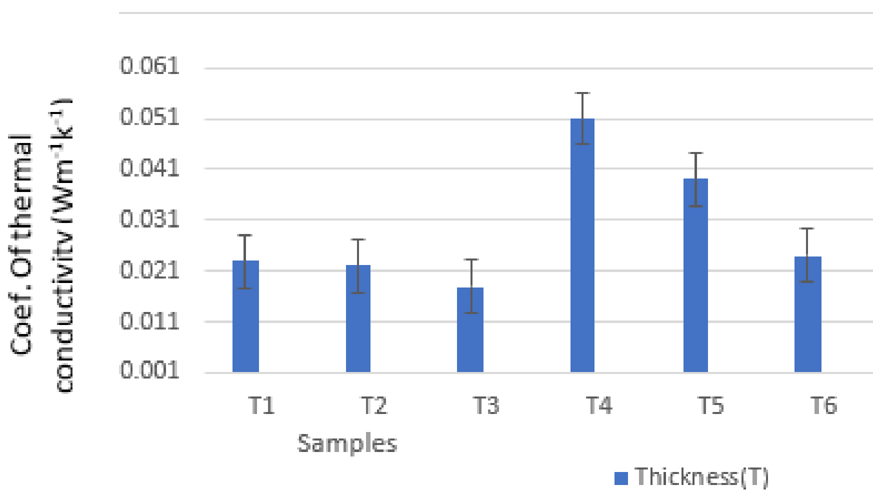

Figure 2. Effect of thickness on thermal conductivity

3.3 Air Permeability

This property is affected by the pores & thickness of the samples. Air permeability value of one tuck point in S4 was higher due to decrease in stitch density, as indicated in table 2 and 3. Lower of air permeability was mentioned in plain/single jersey, because loops are closely filled than bi-layer Knitted samples. Air permeability was lower for S5 and S6 because of more tuck points and higher thickness. The movement of air will be less in thicker samples and vice versa. Generally, air permeability of bi-layer samples decrease with the increase in thickness and stitch density. During sport activity sweat is formed and the fabric is wet, so the fabric should have enough air permeability results in higher vapor transfer. From figure 3, sample S4 has higher drying and wet ability 850 cc/sec/cm^2 and 650 cc/sec/cm^2 respectively. Sample S5 has lower drying and wet ability 264 and 225 cc/sec/cm^2 respectively. This is because of the thickness, weight and structural variations. The air permeability value was lower for S5and S6 due to the presence of more tuck points, higher thickness and increased number of loops present per area. The movement of air will be less in thicker samples. Bi-layer fabric on S5 has thicker value so, it takes many times to dry and wet. The air flow theory states that the movement of air will be less in thicker fabric and more in thinner fabric. Even though the thickness is less for plain structure S1, and S2 the presence of more tuck stitches in S5 and S6 increases the flow of air from one-layer surface to the other. Finally, the air permeability of bi-layer sample fabrics can decrease with increased stitch density and thickness of the samples.

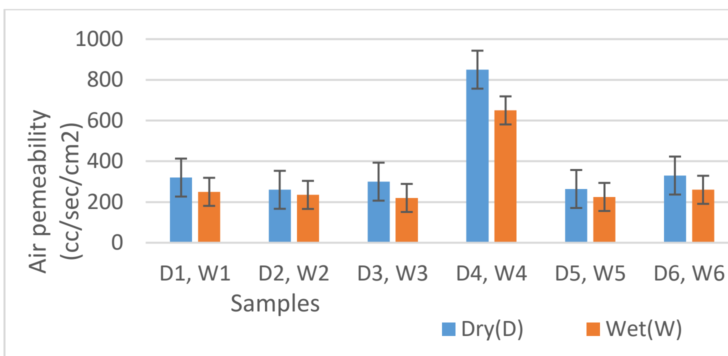

Figure 3. Effect of fabric thickness on air permeability

3.4 Water Vapor Permeability

Figure 4, indicates that Sample with lower thickness shows higher water vapor permeability. So, sample T4 and T6 had higher water vapor values of 2300 and 1855gm^{-2}.day^{-1} respectively because their thickness values (0.7mm and 0.81mm respectively) were lower than T5. As shown in table 4, sample S4 and S6 had higher water vapor values because their weight and thickness value were lower than S5. WVP of a sample is influenced by thickness, porosity and structure. S5 had lower air permeability because it had more thickness value. Sample with low moisture value can deposit sweat in the fabric, which is uncomfortable. Fiber related factors, such as the cross-sectional shape and moisture absorbing properties, do not play a significant role

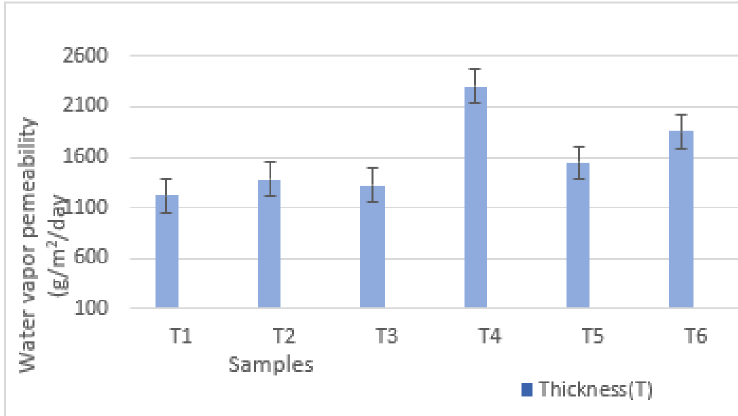

Figure 4. Effect of thickness on water vapor permeability

3.5 Absorbency

As shown in table 3, bi-layer fabrics have greater value of water absorbency as related to other. S5 and S6 had higher absorbency of 92.4% and 82.1% respectively. Because as stitch density increase the moisture stored in the cloth increases. Bi-layer fabric with one tuck point (S4) had lower absorbency (79.6%) than bi-layer with five and seven tuck points (S5 and S6) fabrics because its thickness and weight were lower and vice versa.

3.6 Dry Behavior

The fabrics should have a quick drying capacity for the regulation of body heat. S5 has higher rate of drying. The drying capacity of a sample is dependable on thickness and weight. The sample with lower thickness value has the ability to transfer perspiration from inner surface to outer then easily dried. It is clearly seen on figure 5, that as the thickness of bi-layer fabrics increases, moisture absorbency also increases with the decrease drying behavior/ability. So, sample S4 and S5 has small thickness and easily drying ability (10.6 and 8.9minutes). The drying ability of bi-layer and rib fabrics was greatly influenced by the thickness and weight of the fabrics, as a result of which there was lower thickness and the presence of a layer structure which has the ability to transfer perspiration from the inner layer (Polyester) of the fabric to the outer layer (cotton), which it easily gets evaporated and dried.

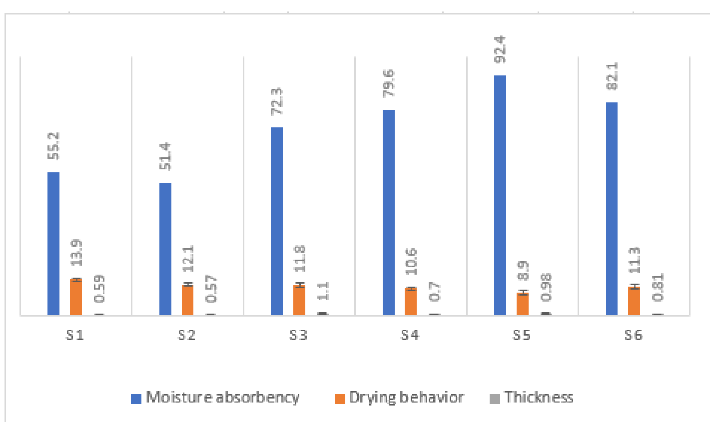

Figure 5. The relationship between thickness, moisture absorbency and drying behavior.

4. Statistical Analysis using SAS Software

SAS software is used to analyze the effect of thermal comfort characteristics on plain, rib and bi-layer fabrics. The value of significance for the tests is 0.05 and the DF (Degree of freedom) is 3, 18 for plain, rib and $F_{critical}$ is 2.75. DF for bi-layer sample is 4,22 and $F_{critical}$ is 2.59. The summary of SAS is shown in table 4, which investigates the significant difference between the thermal comfort properties of Plain, rib and bi-layer knitted structures. The value of Fcritical< Factual indicate that changes in the layer structures and types of fiber between Plain and rib fabrics show a significant difference with respect to thermal comfort properties.

Table 4. SAS analysis for thermal Properties of samples

Thermal Properties	B/n plain and rib fabrics				B/n bi-layer fabrics			
	Sum of square value (SS)	F_{actual}	$F_{critical}$	P_{value}	Sum of square value (SS)	F_{actual}	$F_{critical}$	P_{value}
Air permeability in dry state	19840.12	2054.31	2.75	<0.0001	851119.82	61985.99	2.59	<0.0001
Air permeability in wet state	9860.65	1200.8	2.75	<0.0001	359669.6	22698.89	2.59	<0.0001
WVP	23980	30.5	2.75	<0.0001	1589785.69	181.79	2.59	<0.0001
Thermal conductivity	0.00111	156.90	2.75	<0.0001	0.0029	182.96	2.59	<0.0001
Moisture Absorbency	2450.13	850.61	2.75	<0.0001	1131.98	829.87	2.59	<0.0001
Drying behavior	40.95	491.84	2.75	<0.0001	78.96	700.12	2.59	<0.0001

5. Conclusions

This research stresses on the thermal comfort properties of plain, rib and bi-layer knitted structures. The analysis results indicate that air permeability and thermal conductivity of bi-layer fabric with one tuck point are greatly influenced by the thickness and structure of the fabric. The WVP of the bi-layer fabric increases with a decrease in the thickness and presence of porous in the fabric. The structure also plays important role on the water permeability. During experimental work it is clearly seen that the moisture absorbency of the bi-layer knitted structure increases with an increase in the stitch density. The thickness and weight have influence on the drying ability of bi-layer fabric with one tuck point. Bi-layer fabric with one tuck point has the ability to transfers perspiration from the inner layer of the fabric to the outer layer, and it can easily evaporate and dried. The principal necessity of football sportswear is the rapid passage of perspiration away from the body and to keep the fabric dry as much as possible. This can be achieved by a bi-layer knitted fabric structure made up of polyester as the inner layer and cotton as the outer layer, recommended as sportswear for football players.

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