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The Influence of Double Layer Knit Fabric Structures on Air and Water Vapor Permeability

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ABSTRACT

The double layer fabrics are produced in circular knitting machine. The face and back surfaces of the fabrics are connected by a) Loop and b) Tuck. The developed fabrics are taken to measure the water vapor permeability and air permeability properties. The test results were discussed statistically with single factor ANOVA. The results in the analysis of variance were based on conclusions from Tukey's Least Significant Difference test. They showed that the differences among the double layer structures were highly significant in the WVP and air permeability properties of the knit fabrics. The stitch densities in the fabric were found to influence more on the permeability property of the fabrics.

Keywords: Knitting, Double Layer, Air permeability, Water vapor permeability

1. Introduction

The human body produces moisture in the form of perspiration, it should be removed from the surface of skin to the fabric of the next-to-skin clothing. The fabrics should allow moisture in the form of sensible and insensible perspiration to be transmitted from the body to the atmosphere in order to cool the body. After the body has stopped sweating, the textile fabric should release the vapor held in the atmosphere in order to reduce the humidity on the surface of the skin. Considerable research work has been carried out to improve the transport characteristics of fabric through various approaches. Air and water vapor transport properties are mainly related to heat and moisture transfer characteristics of textile material[(1)]. The water vapor permeability of a fabric plays an important role in determining the clothing performance and maintaining human body comfort. The water vapor permeability indicates the quantity of water vapor that has been moved through a unit area of the fabric in a certain point in time as a result of the pressure gradient between the two sides of the sample[(4)]. Brojeswari Das et al.,[(2)] pointed out the water vapor can pass through the textile layers by the various mechanisms: such as a) diffusion of the water vapor through the layers. b) absorption, transmission and desorption of the water vapor by the fibers. c) adsorption and migration of the water vapor along the fiber surface. and d) transmission of water vapor by forced convection.

The measurement of water vapor permeability is a slow and somewhat delicate operation. The different methods used for determining the water vapor permeability of textile assemblies[3] the evaporative dish method or control dish method (BS 7209), the upright cup method or Gore cup method (ASTM E 96-66), the inverted cup method, the desiccant inverted cup method (ASTM F 2298), the dynamic moisture permeable cell (ASTM F 2298), and the sweating guarded hot plate method, knowing as the skin model (ISO 11092). The authors [6] studied the water vapor permeability of the various cotton knitted fabric in evaporative dish method based on the British Standard, BS 7209. The WVP is largely affected by the air spaces surrounding the fibers in both yarns and fabrics. These air spaces offer resistance to the flow of moisture through the textile structures. In comparison of the bio-physical properties of knitted fabrics, double-layered cotton/cotton knitted fabric and polyester/polyester knitted fabric were made by the author and their team[4] and concluded that the high values of water vapor permeability for cotton/cotton knitted fabrics.

C Prahsarn[5] et al studied the effect of fabric thickness, density, porosity and fiber-cross section on moisture vapor transport properties of the fabric. The various polyester fabrics differing in construction, yarn type, and fiber feature are taken for the research work. Concluded with the fabric construction has a dominating influence on moisture vapor transport behavior especially in low density open textile structure. Fiber cross sectional shape and moisture absorbing properties are not play a significant role. The fabric thickness serves as an important factor since it determines the distance through

The tuck connected fabrics are produced with face as polyester and back as cotton. Table-2 shows the knitting machine detail.

which the moisture vapor and heat pass in traversing from one side of the fabric to the other surface of the fabric.

There are many factors influences the air permeability through textile structure such as Fiber – Orientation, morphological structure, volume of fiber fraction. Yarn – twist, linear density, type of material, yarn flattening, yarn structure. Fabric – Surface Porosity, fabric thickness, specific energy of the fabric, loop length, tightness factor, type of structure, types of stitch.[8&10,11] The barrier ability of the plain double-layered cotton/polyester knitted fabric to the air is based on surface porosity, fabric thickness & type of stitch[4]. The air permeability of the fabrics made from natural yarns is higher than textured polyamide, highest than elastane knitted socks. There is no correlation between water vapor permeability and the air permeability of the double-layered knitted fabrics[13]. The structure of the fabric is important factor that influence the permeability properties of the textile fabrics.

The aim of this study is to investigate the influence of knitting structure produced by loop and tuck on the water vapor permeability and air permeability of double layered weft knitted fabrics. The test results were discussed statistically with ANOVA single factor data analysis. The significant results in analysis of variance concluded with Tukey's least significant test.

2. Materials and Methods

2.1 Fabric development

The double layer fabrics are produced in knitting by the following principles, the face and back surfaces connected by a) Loop and b) by tuck[12]. The table 1 shows material specifications used for this study. Figure-1 structure shows a double jersey interlock structure, the loop connected fabrics are constructed with cotton thread in face & back and polyester thread connects these two surfaces (inner).

In Structures (L1, L2 & L3), the alternate cylinder and dial needles produces knit stitches separately, forms the face and back of the fabric using cotton. The polyester yarn is stitched/connected the two surface of the fabric by alternate knit stitches in structure L1. The structure L2, knit loops in dial & a tuck stitches in cylinder so the stitch density in back of the fabric is higher than face of the fabric. But in structure L3 the polyester yarn connects the two surfaces with only tuck stitches in both cylinder & dial needles.

In Structures (T1, T2 & T3), the cotton yarn produces back surface of the fabric and polyester produces skin touching surface of the fabric. All dial needles in the machine produces knit stitches in three structures. But the cylinder needles stitched the knit and tuck stitches. The tuck stitches used in the cylinder needles are increased from the structure T1, T2 & T3.

Table 1. Double layered fabrics

Sample Code	Yarn Combinations
L1	40^s Ne Cotton/80D Polyester/40^s Ne Cotton
L2	40^s Ne Cotton/80D Polyester/40^s Ne Cotton
L3	40^s Ne Cotton/80D Polyester/40^s Ne Cotton
T1	80D Polyester/40^s Ne Cotton
T2	80D Polyester/40^s Ne Cotton
T3	80D Polyester/40^s Ne Cotton

Table 2. Knitting Machine detail

Machine Details	Interlock Knitting for L1, L2 & L3	Interlock Knitting for T1,T2 & T3
No. of Needles	576 x 2	1872 x 2
Total feeders	72	36
M/c Gauge	18	20
M/c Speed (rpm)	20	15

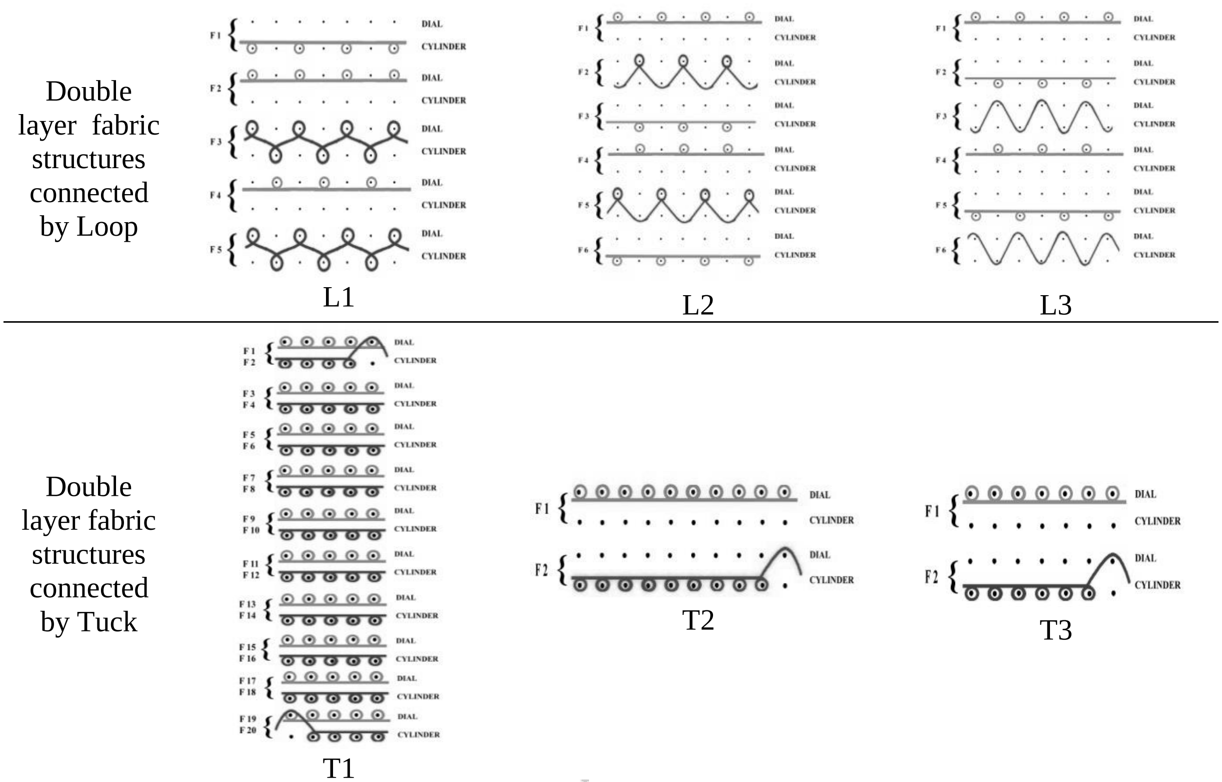

Figure 1. Needle representation for the double layered knit fabrics

2.3 Testing

The permeability characters, namely air and moisture vapor permeability tests were conducted in this study. The produced double layer knit fabrics was given relaxation process and carried out the following test. The knitted fabric parameters are given in table 3.

The courses and wale density of the samples in face and back were calculated individually in the direction of the length and width of the knit fabric. The average density per square centimeter was taken for the discussion.

The 20 loops in a course were unraveled and measured the length of yarn in cm (L_T) both face and back of the fabric. From the L_T value the stitch length/loop length was measured by using the following formula, the average loop length (cm) was taken and reported in table 3.

Stitch length/loop length in cm = $(L_T)/20$

The tightness of knits was characterized by the tightness factor. It is known that, is a ratio of the area covered by the yarns in one loop to the area occupied by the loop. It is also an indication of the relative looseness or tightness of the knitted structure. For determination of TF the following formula was used

Tightness Factor = $\sqrt{T}/l$

Where T= Yarn linear density in Tex, l = loop length of fabric in cm. The tightness factor of double layers (face & back) was calculated separately given in table 3.

2.3.1 Water Vapor Permeability (WVP)

Seshadri S. Ramkumar et al.[(6)] elected the method to analysis the Moisture Vapour permeability in their study. The evaporative dish method based on the British Standard, BS 7209 was used to determine the water vapor permeability (MVTR) of layered knit fabrics. The MVTR in g/m^2/day is calculated as per equation given below.

MVTR= 24 M/At

where,

M - Loss in mass of the assembly over the time period t in grams

t - Time between successive weighing of the assembly in hours and

A - Area of the exposed test fabric (0.0054 m^2)

2.3.2 Air Permeability (AP)

The measurement of the air permeability is the rate of air flow passing perpendicularly through a known area under a prescribed air pressure differential between the two surfaces of a material of textile fabrics.[9] The air resistance values of the multi-layer knitted fabrics were measured individually by using Kawabata evaluation system (KES-FB-AP1 Katotech co, Ltd.,) under automatic air permeability tester. The air resistance value of KES is converted into Air permeability (Cm^3.Cm^2.S) = 124.55/(R*1000*10^{-2})

Where R is the air resistance value measures in KES- FB-AP1 tester in Kpa.S/m

Table 3. Layered Fabric Characteristics

Sample Code	Wale density (W/Cm)		course density (C/Cm)		Loop Length (Cm)		Stitch Density (Stitches/ Sq.Cm)		Tightness Factor (Tex$^{1/2}$.cm^{-1})		Areal Density (gsm)	Thickness (mm)
	Face	Back	Face	Back	Face	Back	Face	Back	Face	Back		
L1	13.8	14	12	16	0.53	0.43	163	218	7.25	8.9	168	0.955
L2	12.2	12.8	22	22	0.45	0.45	268	282	8.62	8.6	248	1.29
L3	11.8	11.8	12	12	0.48	0.49	146	144	7.94	7.9	242	1.34
T1	11.181	11.024	15.67	15.748	0.313	0.313	175.2	173.6	12.304	9.565	119	0.39
T2	11.102	10.945	15.91	15.748	0.315	0.315	176.6	172.4	12.19	9.452	122	0.41
T3	11.339	10.945	15.75	15.748	0.316	0.316	178.6	172.4	12.151	9.428	126	0.44

3. Results and Discussion

3.1 Water Vapor Permeability

The water vapor permeability of double layered knit fabrics is influenced by the kind of raw material and its properties [13]. The water vapor permeability of the double layered knit fabrics is shown in table-4 & figure-2. The fabric produced by the loop connection shows higher WVP compared to tuck connected double layer fabrics.

The graph shows the higher WVP values in L2 followed by L1 and L3. The stitch density fabric influences more on WVP property of the fabric. The larger hole size or less stitch density on the back side and smaller holes or high stitch density on the face side also create a less resistant for entering of water vapor molecules, which increases the water vapor permeability.

When increases in stitch density in the fabric there is more resistance per unit area so, the permeability property of the fabric decreased. Anova shows significant difference in the water vapor permeability of the double layer fabrics produced by loop connection for various structures. [F (2, 12) > *F critical*] in table 5. The water transport capacity of the fabric is significant in various biomimetics of plant knit structures, and the effects of yarn types and the interaction between the structure and yarn types were also highly significant [15].

Table 4. Air & Water vapor permeability of Layered knit Fabric

Air permeability ($cm^3.Cm^2.S$)

	L1	L2	L3	T1	T2	T3
Average	232.4933	132.8533	97.86901	415.1667	415.1667	415.1667
Variance	459.6356	51.07063	61.29149	3.59E-27	3.59E-27	3.59E-27

Water Vapor Permeability ($g/m^2/day$)

	L1	L2	L3	T1	T2	T3
Average	2102.37	2181.185	1613.778	634.7937	667.6825	706.5397
Variance	3.676269	12.78464	2.908093	0.685311	13.02091	7.538423

The Tukey's least significant test also confirmed that there are significant differences between the WVP of double layer knit structures L1 & L2, L2 & L3 and L1 & L3. The table value for $q_{(3,12)}$ is 3.773 and the mean difference between the above paired samples are 78.8, 567.4 & 488.6. The mean values are greater than table value; this shows the significant differences at 5% level.

The water vapor permeability depends on the structure of the fabric[13]. The WVP property of the double layer fabrics T1,T2 &T3 are shown in table 4 & figure 2. There is a linear trend observed in the double layer fabric produced by tuck connection from T1, T2 & T3. Increases the tuck stitches in the fabric there is a raises in WVP of the fabric. The anova analysis also shows significant differences at 0.05 alpha level, F (2, 12)=910.7059 > *F critical*=3.885294. The lease significant test at $q_{(3,12)}$ is 3.773< paired mean differences (L1&L2, L2&L3 and L1& L3 such as 32.9, 38.9 & 71.7). This analysis also confirmed that there is a significant difference between the water vapor permeability property and knit structures.

Table 5. **ANOVA single factor data analysis**

L1,L2&L3 - Water Vapor Permeability of the layered knit fabric (WVP)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Fabrics	944809.4	2	472404.7	73169.20113	3.04E-25	3.885294
Within Fabric	77.47599	12	6.456333			

T1,T2&T3 - Water Vapor Permeability of the layer knit fabric (WVP)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Fabrics	12898.42	2	6449.208	910.7059	7.86E-14	3.885294
Within Fabric	84.97858	12	7.081549			

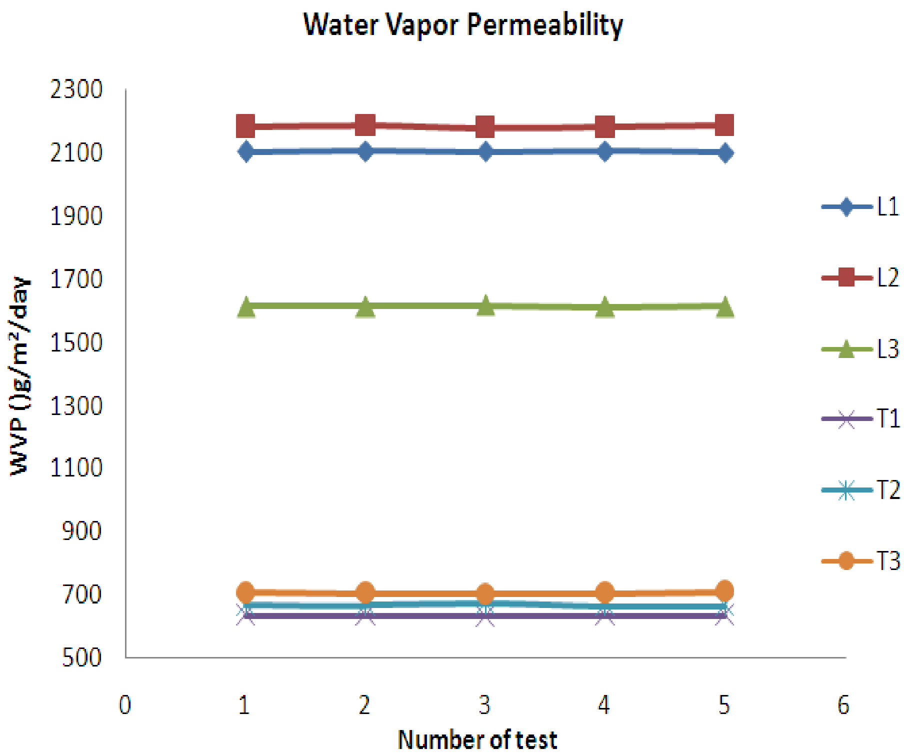

Figure 2. Water vapor permeability of double layer knit fabrics

3.2 Air permeability

The air permeability of the double layer knit structures is shown in table 4 & figure 3. The yarn diameter, knitting structure, stitch density and yarn linear density are the important factors affecting the pore size of knitted fabrics. The air permeability of double layered knitted fabrics with the same pattern depends on the loop length. But, if the pattern is different the loop length cannot be as the common rate[(13)]. The air permeability value of the sample is higher from L1 followed by L2 and L3. From the fabric parameter the thickness decreases, the air permeability rises. And also it is observed that the stitch density of the face fabric is lower as compared with back fabric. The linear trend was observed in air permeability value, higher the difference between the stitch density of face and back of fabric.

The fabric pore characteristics and distribution in a fabric determine the air permeability of the fabric[(13)]. The analysis of variance (ANOVA) confirmed that there is a significant difference in the test results obtained from double layered knit fabrics connected by loop. The table 6 shows the F-value is greater than the F-critical value (255.9078>3.354131). In order to confirm the significant, the Tukey's least significant test also analyzed. The difference between the air permeability results of the paired double layer knit samples L1& L2, L2& L3 and L1& L3 is greater than (99.6, 34.9 & 134.6 > $q_{(c,k)=}$3.506) table value. It shows all the three structures are highly significant in air permeability of the double layer knit fabric.

The air permeability results obtained from double layered knit fabrics connected by tuck stitches shows there is no significant differences between the structures. In a combined knitted structure, the loops are arranged in two layers, both layers connected only in certain places. Therefore the amount of air in the combined knit structure is greater than in the plain plated structure[(14)]. The amount of air in the double layer is based on number of connection between the layers. The tuck stitches in a repeat increases from T1, T2 & T3 double layer knit fabrics. When tuck stitches in the fabric increases, the fabric become open and more porous at the same time the fabric become thicker[7]. So the thicker the fabric reduces the air permeability.

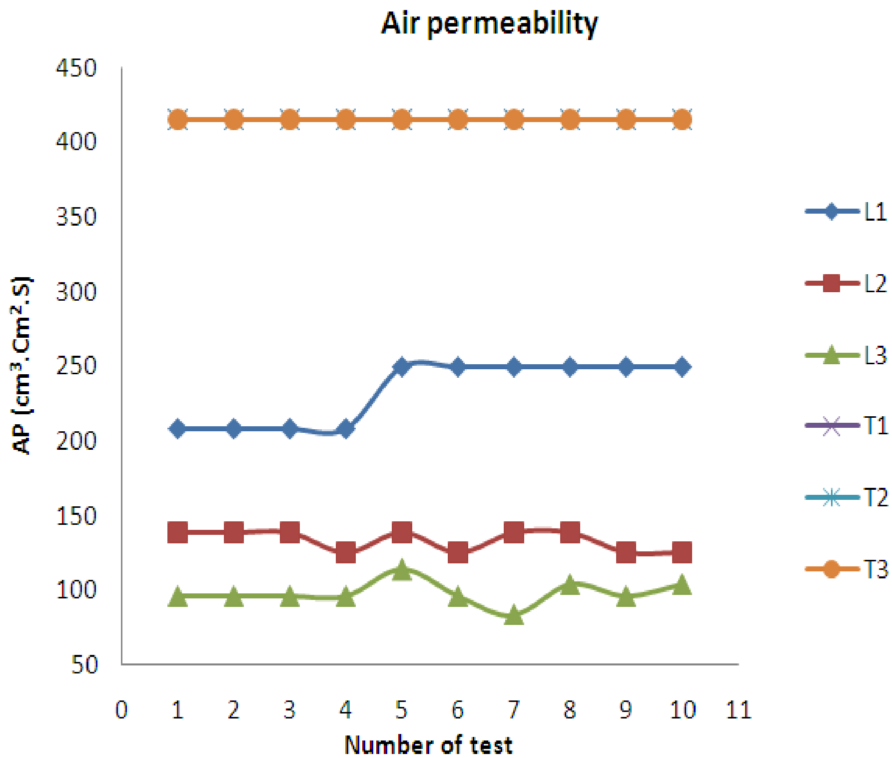

Figure-3. Air permeability property of double layer knit fabrics

Table 6 – ANOVA single factor data analysis

T1,T2&T3- Air Permeability of the layered knit fabric (AP)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Fabrics	2.91E-25	2	1.45E-25	40.5	7.45E-09	3.354131
Within Fabric	9.69E-26	27	3.59E-27			

L1,L2& L3 - Air Permeability of the layered knit fabric (AP)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Fabrics	97585.8	2	48792.9	255.9078	2.81E-18	3.354131
Within Fabric	5147.98	27	190.6659			

4. Conclusions

In this study, the double layer knit fabric was developed with the surfaces connected by tuck and loop. The water vapor and air permeability properties of the fabric are analyzed. Based on the tests conducted in this study, the between double layer structures are highly significant on the WVP and air permeability property of the fabrics. But the air permeability of the double layered knit fabrics (T1, T2 &T3) has no significant differences between the structures. The stitch density in the fabric surfaces influence more on the permeability property of the fabric. The double knit fabrics produced by the loop connection are highly beneficial to engineer the sports garment used in next to skin.

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