Nida Oğlakcioğlu, Arzu Marmarali

Ege University
Department of Textile Engineering,
Izmir, Turkiye
E-mail: arzu.marmarali@ege.edu.tr

Thermal Comfort Properties of Some Knitted Structures

Abstract
In this paper, the thermal properties of cotton and polyester based single jersey of 1×1 rib and interlock structures were statistically investigated. The thermal properties of samples were measured using Alambeta and Permetest devices. The results indicate that each knitted structure tends to yield rather different thermal comfort properties. Interlock and 1×1 rib fabrics have a remarkably high thermal conductivity and thermal resistance value. On the other hand, single jersey fabrics have higher relative water vapour permeability values than 1×1 rib and interlock fabrics, and give a warmer feeling with lower thermal absorptivity values.

Key words: *knitted fabrics, thermal comfort, thermal resistance, thermal absorptivity, water vapour permeability*

Nomenclature

- *Tex* *yarn count*
- α_m *twist coefficient*
- *m* *fabric weight, g/cm²*
- *h* *fabric thickness, mm*
- *CV* *Coefficient of variation, %*
  water vapor permeability, %
- λ *thermal conductivity, W/m K*
- R_{ct} *thermal resistance, m² K/W*
- *b* *thermal bsorptivity, W s^{1/2}/ m² K*

Introduction

Over the last few years, there has been growing interest in knitted fabrics due to its simple production technique, low cost, high levels of clothing comfort and wide product range. Knitting technology meets the rapidly-changing demands of fashion and usage. Knitted fabrics not only posses stretch and provide freedom of movement, but they also have good handle and easily transmit vapour from the body. That's why knitted fabrics are commonly preferred for sportswear, casual wear and underwear.

The demands from fabrics have changed with developments in textile technology and the rise of people's living standards. Now the requirement is not only style and durability, but also clothing comfort [1]. The term comfort is defined as "the absence of displeasure or discomfort" or "a neutral state compared to the more active state of pleasure" [2]. Clothing comfort includes three main considerations: psychological, sensorial and thermo-physiological comfort. The thermo-physiological comfort, the subject of this research, entails both thermoregulation and moisture management [3]. It is known that fibre type, yarn properties, fabric structure, finishing treatments and clothing conditions are the main factors affecting thermo-physiological comfort. In this study, we investigated the effect of fabric structure on thermal properties.

Extensive research has been carried out on the thermal behaviour of textile materials. Anand [4] reported that the open construction 3D eyelet has better water vapour permeability than micromesh, pique and mock rib structures. Shoshani and Shaltiel [5] noted that thermal insulation increases with decreases in the density of fabric. Milenkovic et al. [2] proved that fabric thickness, enclosed still air and external air movement are the major factors that affect the heat transfer through fabric. Greyson [6] and Havenith [7] mentioned that heat and water vapour resistance increases with the increment of material thickness and air entrapped in the fabric. Hes et al. [8] developed a new functional knitted fabric possessing double layers by using different yarn components (like polypropylene and cotton) in order to maximize the suction and transport moisture properties. Thermal properties of 1×1, 2×2 and 3×3 rib knit fabrics were compared by Ucar and Yilmaz [9]. They noted that a decrease in rib number leads to a decrease in heat loss; the use of 1×1 rib and tight structure would provide better thermal insulation.

Experimental

Material

Single jersey, 1×1 rib and interlock structures were knitted using 100% cotton (Co) yarn (20 tex, carded, $\alpha_m = 112$) and 100% staple polyester (PES) yarn (20 tex, $\alpha_m = 91$). The knitting process of the single jersey fabrics was performed on an 18 gauge and 3¾"diameter Lonati circular knitting machine. Other samples were produced on a 28 gauge and 30" diameter Fouquet circular knitting machine. All machine settings on each machine were kept exactly the same during the knitting process.

Test methods

An Alambeta instrument was used to measure thermal conductivity, thermal resistance, sample thickness and to calculate all the statistical parameters of the measurement. Objective measurement of the warm-cool feeling of fabrics, so called thermal absorptivity [$Ws^{1/2}/m^2K$], is possible [10]. The contact pressure was 200 Pa in all cases, and the CV values of all the samples were lower than 4%. Relative water vapour permeability was measured on a Permetest instrument by a similar procedure to that given by Standard ISO 11092 [11]. The number of measurements was 5 for Alambeta and 3 for Permetest. All the measurements were done in controlled laboratory conditions.

Because of the difference in α_e values of cotton and PES yarns, fibre types were not compared in this study. The aim of this research was the comparison of the thermal properties of single jersey, 1×1 rib and interlock structures knitted using cotton and PES yarns.

SPSS 13.0 for Windows statistical software was used for evaluating the test outcomes. To determine the statistical importance of the variations, ANOVA tests were applied. To deduce whether the parameters were significant or not, p values were examined. Ergun [12] emphasised that if the p value of a parameter is greater than 0.05 ($p > 0.05$), the parameter wouldn't be important and should be ignored.

Results and discussion

Table 1 displays the thermal properties of some fabric structures knitted with cotton and polyester yarns.

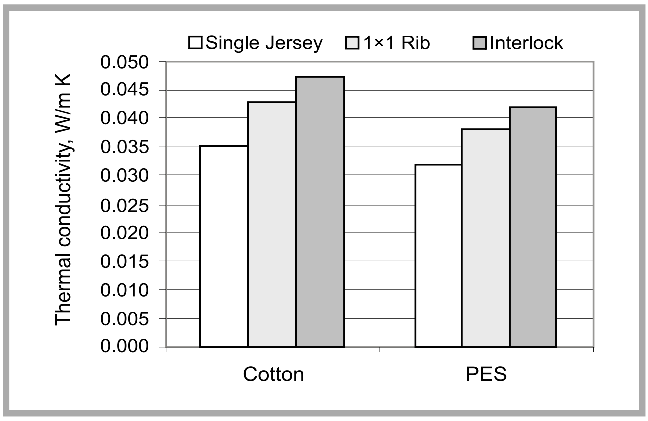
Thermal conductivity

Thermal conductivity is an intensive property of a material that indicates its ability to conduct heat.

According to Figure 1, thermal conductivity increases depending on the single jersey, 1×1 rib and interlock structures of the cotton and polyester fabric samples.

This situation can be explained by the amount of entrapped air in the fabric structure. The amount of fibre in the unit area increases and the amount of air layer decreases as the weight increases. As is known, thermal conductivity values of fibres are higher than the thermal conductivity of entrapped air [13]. So heavier fabrics that contain less still air (like interlock) have higher thermal conductivity values.

Figure1. Thermal conductivity values of single jersey, 1×1 rib and interlock fabrics.



Thermal resistance

Thermal resistance is a measure of the body's ability to prevent heat from flowing through it. Under a certain condition of climate, if the thermal resistance of clothing is small, the heat energy will gradually reduce with a sense of coolness [1].

As can be seen from the results (Figures 2 and 3), as the fabric thickness increases the thermal resistance the increases. Both the cotton and polyester fabric samples gave the lowest thermal resistance values for the single jersey structure, and the greatest values were obtained for the interlock structure (Figure 3). The differences between the values of the three structures are statistically significant ($p = 0.000$).

In fact the general expectation was to register an inverse relationship between thermal conductivity and thermal resistance, as for idealised conditions $R = h/\lambda$; where R - thermal resistance, h - thickness, λ thermal conductivity [14]. However, the test results revealed that as thermal conductivity increases thermal resistance increases as well. This contradiction might be explained by the fabric thickness. If the amount of increase in fabric thickness is more than the amount of increase in thermal conductivity ($R_{ct} = h/\lambda$), thermal resistance will also increase. And a significant increase is seen in the fabric thickness value, respectively (Figure 3). So the increment of thermal resistance values depending on single jersey, 1×1 rib and interlock structures is normal.

Thermal absorptivity

Thermal absorptivity is the objective measurement of the warm-cool feeling of fabrics [10]. A warm-cool feeling is the first sensation. When a human touches a garment that has a different temperature than the skin, heat exchange occurs between the hand and the fabric. If the thermal absorptivity of clothing is high, it gives a cooler feeling at first contact [15].

In both cotton and polyester fabrics, the interlock fabrics with the highest thermal absorptivity values, gave the coolest feeling at the beginning of skin contact (Figure 4). This situation is explained by the construction of the fabric surface. The surface area between the fabric and skin is bigger for smooth fabric surfaces and these structures cause a cooler feeling, as mentioned by Pac and his colleagues [15]. The analysis of variance showed that the differences between the thermal absorptivity values are significant ($p=0.000$).

Relative water vapour permeability

Water vapour permeability is the ability to transmit vapour from the body. If the moisture resistance is too high to transmit heat, by the transport of mass and at the same time the thermal resistance of the textile layers considered by us is high, the stored heat in the body cannot be dissipated and causes an uncomfortable sensation [1].

It can be seen from Figure 5 that relative water vapour permeability values of both cotton and polyester fabric samples increase depending on the interlock, 1×1 rib and single jersey fabrics. The analysis of variance indicates that the effect of the knitted structure on relative water vapour permeability is statistically significant. The existence of this difference is most probably a consequence of the thinner structure of single jersey fabrics. Because the transportation of water vapour through a thin fabric will be easier.

Because of the different structural properties of the fabric samples chosen, the results are valid only for these particular conditions. The reader should be cautioned that these comparisons are only to give a general opinion.

Conclusions

In this paper the thermal properties of cotton and polyester based knitted fabrics with single jersey, 1×1 rib and interlock

Table 1. Thermal properties of basic knitted structures.

Material	Fabric Structure	Thickness, mm	Weight in unit area, g/m²	Relative Water Vapor Permeability, %	Thermal conductivity, W/m K	Thermal resistance, m² K/W	Thermal absorptivity, W s^1/2/ m² K
100% Cotton (Carded)	Single Jersey	0,84	102	45,05	0,035	0,024	87
	1x1 rib	1,14	169	40,51	0,043	0,027	102
	Interlock	1,40	225	38,75	0,047	0,030	114
100% PES (Staple Fiber)	Single Jersey	0,83	114	45,37	0,032	0,026	69
	1x1 rib	1,09	147	44,79	0,038	0,029	92
	Interlock	1,37	205	40,51	0,042	0,033	98

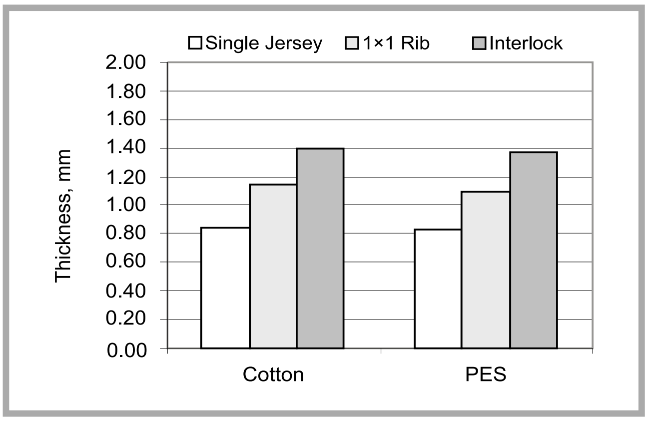


Figure 2. Thickness of single jersey, 1×1 rib and interlock fabrics.

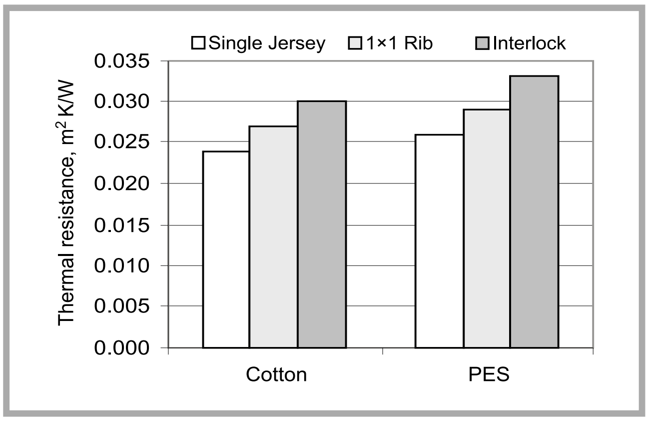


***Figure 3.** Thermal resistance values of single jersey, 1×1 rib and interlock fabrics.*

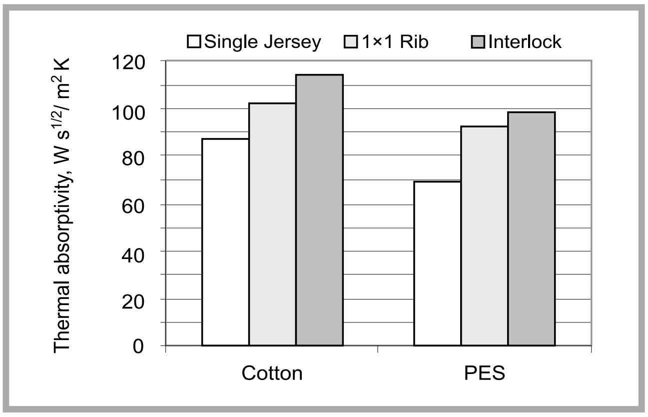


***Figure 4.** Thermal absorptivity values of single jersey, 1×1 rib and interlock fabrics.*

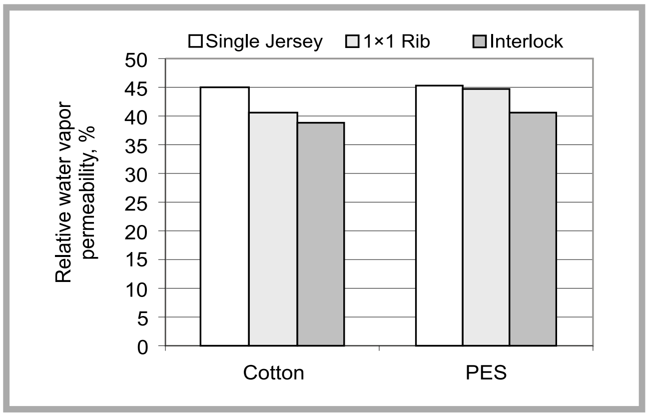


***Figure 5.** Relative water vapour permeability of single jersey, 1×1 rib and interlock fabrics.*

structures were discussed. All results indicate similar trends in both cotton and polyester groups.

Because of their structural properties, single jersey fabrics have remarkably lower thermal conductivity and thermal resistance values as well as higher relative water vapour permeability values than 1×1 rib and interlock fabrics. And they give a warmer feeling at first touch due to lower thermal absorptivity values. If we compare the double jersey fabrics, it can be seen that the interlock structures have higher thermal conductivity and less water vapour permeability values than 1×1 rib structures. This situation can be explained by the amount of fibre per unit area. While the amount of fibres increases, the amount of entrapped air decreases. Therefore thermal conductivity values will be higher for heavier and thicker fabrics, such as interlock fabrics.

It has been proven that different knitting structures have different comfort properties. Therefore, in order to achieve the ideal clothing comfort, it is necessary to consider the end use of the garment while selecting the fabrics. According to the results double jersey structures, due to their high thermal insulation values, could be preferred for winter garments in order to protect from cold. If we compare 1×1 rib and interlock fabrics, it will be better to use 1×1 rib fabrics for a warmer feeling at first contact. On the other hand, single jersey structures should be chosen for active sports or summer garments for better moisture management properties.

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