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Effect of yarn properties on thermal comfort of knitted fabrics

Nilgün Özdil *, Arzu Marmaralı, Serap Dönmez Kretzschmar

Ege University, Department of Textile Engineering, 35100 Bornova, İzmir, Turkey

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Abstract

In this research, thermal properties of 1 × 1 rib fabrics knitted by using various yarns of different properties were investigated with all details. The mentioned yarn properties were yarn count, yarn twist and combing process. The thermal resistance, thermal absorptivity, thermal conductivity, water vapour permeability of samples were measured with the aid of Alambeta and Permetest devices respectively. The results of the tests were evaluated statistically and the importance levels of the relationship between the measured parameters were determined. It is observed that yarn properties like yarn count, yarn twist and combing process of cotton have affected different thermal comfort properties of 1 × 1 rib knitted fabrics. While the yarn twist and yarn count increase thermal resistance values decrease and water vapour permeability values increase. The combing process has the same effect on the thermal properties.

Keywords: 1 × 1 rib fabrics; Yarn count; Yarn twist; Combing process; Fabric comfort; Thermal resistance; Thermal absorptivity; Thermal conductivity; Water vapour permeability

1. Introduction

Comfort, which is defined as a pleasant state of psychological and physical harmony between a human being and environment, became the most important feature along with the development of textile technology [1]. It is expected from a garment to help to protect thermal balance of the body, and to maintain the body temperature and humidity. Garments work as a tampon to conserve body temperature of a human being in different atmospheric conditions. The fabric itself, the air it encloses and the still air on its surface act as insulators preventing heat transfer by conduction and radiation. Since the volume of air enclosed is much higher than the volume of the fibers, the insulation is dependent more on the thickness of the material than on the fiber type. So the main function of the garments is to constitute a regulation system for keeping body temperature at the mean value even if outer atmospheric conditions and physical activities change. Clothing comfort is closely related to thermal comfort [2–4].

During heavy activities the body produces lots of heat energy and the body temperature increases. To reduce the high temperature, the body perspires a lot in liquid and vapour form. While this perspiration is transmitted to atmosphere, the body temperature reduces and then the body feels cool. So the garments should allow the perspiration to pass through, otherwise it will result in discomfort [5]. Therefore thermal properties and water vapour permeability of the fabrics are very important for body comfort.

Another parameter showing the comfort is warm–cool feeling. When the human touches a garment that has a different temperature than the skin, heat exchange occurs between the hand and the fabric, and the warm–cool feeling is the first sensation. Which feeling is better depends on the customer; for hot summer garments a cooler feeling is demanded, whereas in winter warmer feeling is preferred.

The effect of different materials and fabric constructions on the thermal properties of knitted and woven fabrics was investigated by various researchers [6–13]. Shoshani and Shaltiel [6] noted that the thermal insulation increases while the density of fabric decreases. Pac et al. [14] investigated the influence of fiber morphology, yarn and fabric structures on transient thermal properties and friction behaviour. In order to mea-

* Corresponding author.
E-mail address: nilgun.ozdil@ege.edu.tr (N. Özdil).

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Nomenclature

b	thermal absorptivity	$\mathrm{W\,s^{1/2}\,m^{-2}\,K^{-1}}$
CV	coefficient of variation	%
h	fabric thickness	mm
K	tightness factor	
ℓ	loop length	cm
m	fabric weight	$\mathrm{g\,cm^{-2}}$
Ne	yarn count	
P	porosity	%
Rct	thermal resistance	$\mathrm{m^2\,K\,W^{-1}}$
T	temperature	K
WVP	water vapour permeability	%
X	dependent variables	
Y	independent variables	

Greek symbols

αe	twist coefficient	
λ	thermal conductivity	$\mathrm{W\,m^{-1}\,K^{-1}}$
ρ	fiber density	$\mathrm{g\,cm^{-3}}$

sure warm–cool feeling, they used an apparatus based on a hot guarded plate. They found that, the contact interfacial area between skin and fabric is small for rough fabrics and more air is entrapped on a hairier fabric surface so these fabrics give warmer feeling. They also stated that structural roughness and warm–cool feelings of the fabrics change according to fiber type, yarn and fabric structure.

The effect of the some yarn parameters on the thermal properties of knitted fabrics has not been researched systematically yet. Thus, in this study, we searched the effect of yarn count, twist coefficient and combing process on the thermal properties of 1×1 rib fabrics.

2. Materials and methods

2.1. Preparation of samples

1×1 rib structure was knitted using (a) 100% combed cotton yarns in three different yarn counts (*Ne* 20, *Ne* 30 and *Ne* 40) and with the same twist coefficient ($\alpha e = 3.7$), (b) 100% cotton *Ne* 30/1 yarns which have different twist coefficient values ($\alpha e = 3.5$, 3.69 and 4.13), (c) *Ne* 20/1 100% cotton carded and combed yarns which have the same twist coefficient ($\alpha e = 3.8$). Knitting process was performed on a 28 gauges and 30″ diameter Fouquet circular knitting machine. Samples were produced in three different tightness values in order to obtain tight, medium and loose fabrics. But the tight sample could not be knitted with *Ne* 40/1 yarn.

2.2. Test methods

Alambeta instrument was used to measure thermal conductivity, thermal resistance and thermal absorptivity values [15]. Relative water vapour permeability was measured on Permetest instrument by similar procedure as given by the ISO 11092 [16]. All the measurements were done under the standard atmospheric conditions.

Alambeta measures thermal conductivity, thermal resistance, $q_{\max}$, sample thickness and calculates all the statistical parameters of the measurement. The objective measurement of warm–cool feeling of fabrics, so-called thermal absorptivity is possible. Permetest instrument determines the relative water vapour permeability which is defined as the ratio of the heat loss measured with sample and without sample. The number of measurements is five for Alambeta and 3 for Permetest. All the measurements were done in controlled laboratory conditions and the contact pressure was 200 Pa in all cases. The CV values of all samples are lower than 3%.

Evaluation of the test results was made using SPSS 10.0 for Windows statistical software. To determine the statistical importance of the variations, ANOVA and correlation tests were applied. To deduce whether the parameters were significant or not, p values were examined. Ergun [17] emphasized that if p value of a parameter is greater than 0.05 ($p > 0.05$), the parameter will not be important and should be ignored. Porosity values were calculated using the equation given below.

$$P = (1 - m/\rho \cdot h)100 \tag{1}$$

where $P =$ porosity, $m =$ fabric weight ($\mathrm{g\,cm^{-2}}$), $\rho =$ fiber density ($\mathrm{g\,cm^{-3}}$) and $h =$ fabric thickness (cm) [18].

3. Results and discussion

Test results showing the effects of the yarn count on the thermal properties of the knitted fabrics are given in Table 1. Table 2 displays the thermal properties of 1×1 rib fabrics knitted with the yarns having different twist coefficients. Test results related with the effect of combing process on the thermal properties of 1×1 rib fabrics are seen in Table 3.

3.1. Results for different yarn counts

According to statistical evaluation, the differences between the thermal resistances of the fabrics knitted with *Ne* 20/1–*Ne* 40/1 and *Ne* 30/1–*Ne* 40/1 yarns were significant. So thermal resistance values of these fabrics were compared and it was found that as the yarn gets finer the thermal resistance and thermal conductivity decrease. In fact the general expectation was to register an inverse relationship between thermal resistance and thermal conductivity ($Rct = h/\lambda$; Rct: thermal resistance, h: thickness, λ: thermal conductivity). However, the test results revealed that as the thermal resistance decreases the thermal conductivity decreases as well. This contradiction might be explained by the fabric thickness. When finer yarn is used in fabric, yarn diameter and therefore fabric thickness decreases. If the amount of decrease in thickness is more than the amount of decrease in thermal conductivity, thermal resistance

Table 1
Thermal comfort properties of the 1 × 1 rib fabrics for different yarn counts

Yarn count	Tightness factor (K)	Loop length (cm)	Porosity (%)	Fabric thickness (mm)	Water vapour permeability (%)	Thermal conductivity ($W\,m^{-1}\,K^{-1}$)	Thermal resistance ($m^2\,K\,W^{-1}$)	Thermal absorptivity ($W\,s^{1/2}\,m^{-2}\,K^{-1}$)
Ne 20/1	15.5	0.35	86.28	1.16	33.68	0.054	0.022	134
	14	0.39	86.84	1.12	33.87	0.054	0.021	138
	12.5	0.43	88.41	1.25	35.23	0.054	0.023	121
Ne 30/1	15.5	0.29	89.14	1.05	36.77	0.048	0.022	126
	14	0.32	89.60	1.01	37.07	0.047	0.022	122
	12.5	0.36	90.49	1.05	37.07	0.045	0.024	110
Ne 40/1	15.5	–	–	–	–	–	–	–
	14	0.27	90.42	0.81	37.36	0.044	0.018	107
	12.5	0.31	91.35	0.82	37.10	0.042	0.019	106

Table 2
Thermal comfort properties of the 1 × 1 rib fabrics for different twist coefficient levels

Twist coefficient (αe)	Tightness factor (K)	Loop length (cm)	Porosity (%)	Fabric thickness (mm)	Water vapour permeability (%)	Thermal conductivity ($W\,m^{-1}\,K^{-1}$)	Thermal resistance ($m^2\,K\,W^{-1}$)	Thermal absorptivity ($W\,s^{1/2}\,m^{-2}\,K^{-1}$)
3.50	15.5	0.29	88.76	1.01	36.88	0.048	0.021	118
	14	0.32	88.59	0.92	37.94	0.046	0.020	119
	12.5	0.36	89.36	0.89	38.80	0.045	0.020	117
3.69	15.5	0.29	89.14	1.05	36.77	0.048	0.022	126
	14	0.32	89.60	1.01	37.07	0.047	0.022	122
	12.5	0.36	90.49	1.05	37.07	0.045	0.024	110
4.13	15.5	0.29	87.63	0.85	39.86	0.046	0.018	127
	14	0.32	88.32	0.90	39.72	0.047	0.019	119
	12.5	0.36	89.32	0.92	39.74	0.046	0.020	123

Table 3
Thermal comfort properties of the 1 × 1 rib fabrics for *Ne* 20/1 carded and combed yarns

Yarn count	Tightness factor (K)	Loop length (cm)	Porosity (%)	Fabric thickness (mm)	Water vapour permeability (%)	Thermal conductivity ($W\,m^{-1}\,K^{-1}$)	Thermal resistance ($m^2\,K\,W^{-1}$)	Thermal absorptivity ($W\,s^{1/2}\,m^{-2}\,K^{-1}$)
Carded	15.5	0.35	86.84	1.14	25.54	0.051	0.023	140
	14	0.39	89.45	1.37	25.71	0.051	0.027	120
	12.5	0.43	89.77	1.31	26.88	0.051	0.026	119
Combed	15.5	0.35	86.63	1.14	26.26	0.052	0.022	151
	14	0.39	86.81	1.18	27.53	0.052	0.023	143
	12.5	0.43	87.83	1.17	27.69	0.053	0.022	135

also decreases. As a result of statistical evaluation, fabric tightness does not have an important effect on thermal resistance and thermal conductivity.

Thermal absorptivity values of the fabrics produced by using *Ne* 20/1 and *Ne* 30/1 yarns were different from each other significantly. As it can be seen in Fig. 1, thermal absorptivity value decreases while the yarn is getting finer. Fabrics knitted with finer yarns on the same machine give slacker constructions and these fabrics give a warmer feeling at first contact as mentioned by Pac and his colleagues [14]. Fabric tightness does not have an important effect on thermal absorptivity of the fabric knitted with *Ne* 40/1 yarn.

As the yarn count increases the relative water vapour permeability value also increases significantly for tight and medium fabrics. Because of this, the fabrics produced from finer yarns have a more porous structure as can be seen in Table 1. With the increasing of porosity, the water vapour permeability also

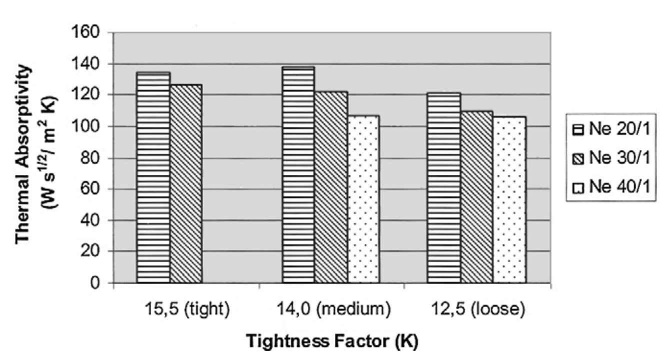

Fig. 1. Thermal absorptivity of the fabrics knitted with different yarn counts.

increases as mentioned in previous papers [15]. Because of the same reason, water vapour permeability value is higher for the slacker fabrics.

3.2. Results for different twist coefficient values

Statistical evaluation showed that the variation in thermal resistance between $\alpha e = 3.50$ and $\alpha e = 4.13$, $\alpha e = 3.69$ and $\alpha e = 4.13$ was significant. According to the results, an increase in yarn twist coefficient causes a decrease in thermal resistance. Because as the twist coefficient increases, yarn becomes finer, so fabric thickness decreases. An inconsiderable increase was found in the thermal resistance as the fabrics get slacker for $\alpha e = 3.69$ and $\alpha e = 4.13$. This situation can be explained by more air in loose structure which prevents the transmission of heat.

Statistical evaluations showed that the effect of twist coefficient on thermal conductivity is insignificant. When the effect of fabric tightness was examined, for $\alpha e = 4.13$ an insignificant effect was observed whereas the effect was significant for other twist coefficients. The looser fabrics have more static air, so, as the fabric tightness decreases thermal conductivity of fabrics considerably decreases.

Differences in thermal absorptivity values between $\alpha e = 3.50$ and $\alpha e = 3.69$ are not significant. For the other twist groups, thermal absorptivity values increase together with the twist coefficient values. This situation is explained by the less hairiness of the yarns that have higher twist coefficient values. Decrease in hairiness increases the surface area between the fabric and skin; this causes cooler feeling as mentioned by Pac and his colleagues [14]. It has been seen that fabric tightness has no effect on the thermal absorptivity for $\alpha e = 3.50$, but for the other twist coefficients thermal absorptivity values decreased and these samples gave warmer feeling as the tightness decreased.

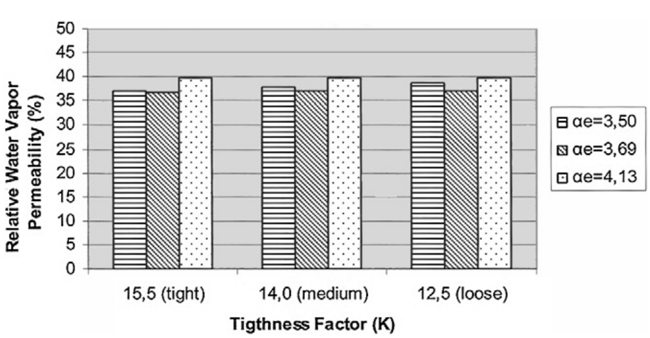

Fig. 2. Relative water vapour permeability of the fabrics knitted with the yarns which have different twist values.

Test results show that, variation in the water permeability, is not significant between $\alpha e = 3.50$ and $\alpha e = 3.69$, and significant for other twist values. As it can be seen from Fig. 2, as the yarn twist coefficient increases water vapour permeability increases also as mentioned in previous paper [14]. Because of this, the fabrics produced from yarns with high twist level have a less hairy surface and more porous structure. It is also found that the effect of tightness on the water vapour permeability is not significant for the fabrics knitted with the yarns which have chosen twist factors.

3.3. Results for combing process

The test results showed that the thermal resistance values of the fabrics knitted with carded yarns are higher than the fabrics knitted with combed yarns. The reason of it is that the fabrics produced from carded yarns have more hairiness. As the yarn hairiness increase, the amount of static air that prevents the passage of heat also increases. A secondary reason is fabric thickness. Although the same yarn count is used, thickness of the fabric knitted with carded yarn is higher. It is found that the effect of fabric tightness on the thermal resistance and the thermal conductivity of the fabrics knitted with carded and combed yarns is not significant.

As it can be seen from Fig. 3, thermal conductivity values of the fabrics knitted with carded yarns are lower. This result is also related with the yarn hairiness as mentioned before.

It is observed that fabrics knitted with combed yarns displayed higher thermal absorptivity values. Because the hairiness of this yarn is less and these samples gave the coolest feeling. Decrease in fabric tightness causes decrease in thermal absorptivity of fabrics knitted with either carded or combed yarns. Thus it can be said that loose fabrics have given warm feeling.

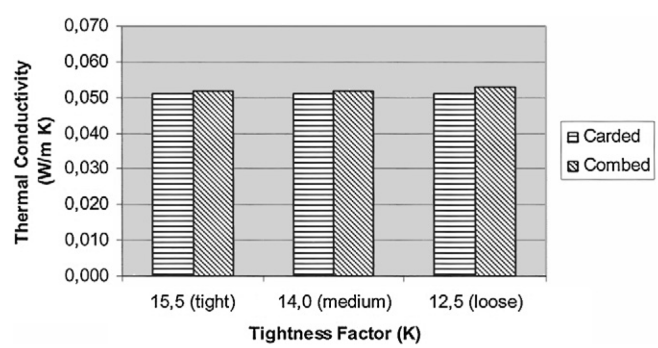

Fig. 3. Thermal conductivity of the fabrics knitted with carded and combed yarns.

Table 4
The regression equations between thermal properties and fabric parameters of the 1 × 1 rib fabrics

Thermal property	Regression equation (P: porosity h: thickness, ℓ: loop length)	Correlation coefficient (%)
Thermal resistance	$Rct = -0.0864 + 0.00105P + 0.0144h$	96.5
Thermal conductivity	$\lambda = 0.187 - 0.00171P + 0.0133h$	94.8
Thermal absorptivity	$b = 326 - 3.12Ne - 136\ell - 67.6h$	89.8
Water vapour permeability	$WVP = 39.6 + 2.10\alpha e + 7.28\ell - 12.2h$	98.0

Water vapour permeability of the fabrics knitted with combed yarns is high and statistically significant. The possible reason of this is hairiness of the carded yarns. The fabric pores are closed with hair in the fabric knitted with hairy yarn and thus water vapour permeability will be low. It is found that the effect of tightness factor on the water vapour permeability of the fabrics knitted with carded and combed yarns is statistically insignificant.

At the last step of evaluation, regression analyses were made between thermal properties and fabric parameters. Thermal properties are defined as dependent variables (Y), and yarn count, yarn twist, loop length, fabric thickness and porosity are defined as independent variables (X). We have applied a multiple linear regression analysis to the measured values and obtained the best fit equations according to best-subsets methods using MINITAB [19]. The best regression equations and correlation coefficient values for each thermal property are given in Table 4.

4. Conclusion

Because of their slacker structure, the 1×1 rib fabrics produced from finer yarns have lower thermal conductivity and higher water vapour permeability values. In addition, these fabrics have warmer feeling property together with lower thermal absorptivity values. When the yarn twist used for 1×1 rib fabrics is increased, thermal absorptivity and water vapour permeability of the fabrics also increase. Because of higher thermal absorptivity, these fabrics give cooler feeling. But thermal resistance values decrease as the twist coefficient of yarn increases. Effect of yarn twist on the fabric conductivity is insignificant. Thermal resistance values of fabrics knitted with combed cotton yarns are lower than the fabrics knitted with carded cotton yarns. Thermal conductivity, thermal absorptivity and water vapour permeability values of the fabrics knitted with combed yarns are higher. While the fabrics knitted with both carded and combed yarns are getting slacker, the thermal absorptivity values decrease and fabrics exhibit a warmer feeling.

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