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A Study of the Thermal Properties of Textured Knitted Fabrics

Abstract
The smooth and compact shape of filament yarns differentiate them from natural fibres, and this regular characteristic of synthetic fibres affects the handle and thermo-physiological properties of the fabrics. The properties of filament yarns are improved by the texturing process, which provides crimp, bulkiness and entangled effects. In this study, the thermo-physiological properties of interlock knitted fabrics produced with air-jet textured, false-twist textured and non-textured filament PES yarns have been compared by using the Alambeta instrument. In addition, the cover factor and air permeability of the fabrics were determined, and the surface characteristics were compared by using scanning electron microscope.

Key words: *knitted fabric, thermo-physiological comfort, air-jet textured, false-twist textured.*

Introduction

The heat and fluid transmitting properties of textiles, which are fundamental factors that affect clothing comfort, are affected by the mechanical characteristics of the fabrics as well as the fibre properties. The mechanical properties can be classified in terms of the yarn's physical properties and fabric structures.

As natural resources decrease, synthetic yarns are becoming more popular as a result of the increase in the global demand for textile products. Since synthetic yarns do not have the appearance and handling characteristics of natural fibres, certain processes have to be applied to synthetic yarns in order to combine the superior properties of synthetics, such as high strength, uniformity and stretch, with the features that are unique to natural fibres [1]. Texturing is one of the processes that give a crimped and bulky structure, a natural appearance, touch, warmth, softness, stretch, high elastic extensibility and bulkiness [1]. The textured yarns are essentially evaluated with regard to the elastic extensibility, grade of crimp and bulkiness. The grade of crimp is expressed by the ratio of the difference of a rectified and original yarn length in the crimped form to the rectified length of the textured yarn sample, which is usually given as a percentage [2]. The high specific bulkiness of the textured yarns is caused by curling the elementary filaments and the considerably increased air spacing between particular filaments.

The basic purpose of texturing filament yarn is to create a bulky structure, which is desirable because the voids in the structure cause the material to have good insulation properties and change the density of the material. A disorganised or less organised yarn surface gives dispersed light reflections, which in turn give a desirable matte appearance. The sponge-like structure is felt to be softer than the lean twisted 'flat' yarn, and the crimped or coiled filament structure gives a lower effective modulus of elasticity to the structure when compared to that of a flat yarn [3]. There are a number of approaches to texturing yarn. The methods currently employed by the industry include air-jet, steam-jet and false-twist texturing.

Air-jet texturing is a well-established filament yarn processing technology that has been around for more than half a century [4]. In contrast to other technologies, the air-jet texturing method can be applied to all filament yarns. All the foregoing methods of texturing require the yarns to be thermoplastic so that they can be heat-set. The air jet precludes the use of non-thermoplastic yarns such as rayon. Furthermore, it is a useful means of producing a yarn structure close to that associated with staple yarns. This is an important concession to the tastes of the end consumer [3]. In the air-jet texturing method, the yarn is textured by overfeeding into a high-pressure jet of air, to create a looped and more natural yarn appearance. The bulkiness level is controlled by input speed and jet-take out speed. Texturing the continuous polyester filaments by means of air flow ensures the production of a wide range of yarn counts (50 to 60,000 dtex), which cannot be obtained with other texturing procedures. One of the main advantages of the process, namely the ability to produce an infinite variety of blended-fibre yarns, has by no means been fully exploited [5]. A diagram of a continuous filament yarn being air-jet textured is presented in Figure 1.

False-twist texturing is used in thermoplastic filaments. In false-twist texturing, the yarns are twisted, heated, cooled in the twisted state, and then untwisted [7]. During the process, a thermoplastic yarn is first highly twisted, next heated to alleviate the stress resulting from twisting to set the twist in the molecular structure of the filaments, and then cooled in a twisted form. After being cooled, the yarn is untwisted by the twist head to obtain a high-bulk product. The production of textured filament yarns by false-twist texturing is an important commercial method, due to its higher texturing speeds and convenience [1].

Thermal properties are among the most important features of textiles. Most of the studies carried out have been devoted to measuring static thermal properties such as thermal conductivity, thermal resistance, and thermal diffusion. Kawabata & Yoneda pointed out the importance of the so-called 'warm-cool feeling' [8]. This property tells us whether a user feels 'warm' or 'cool' upon the first brief contact of the fabric with the human skin. Hes introduced the term of 'thermal absorption' as a measure of the 'warm-cool feeling' of textiles [9].

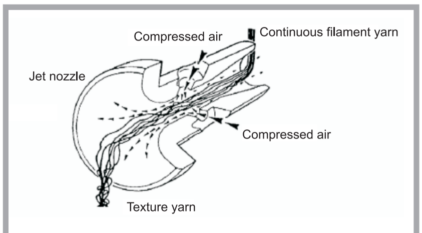

***Figure 1.** Diagram of a continuous filament yarn being air-jet textured [6].*

Thermal absorption can be expressed as follows [8]:

$$b = \sqrt{\lambda \rho c}\ ,\ Ws^{1/2}m^{-2}K^{-1} \qquad (1)$$

where λ – the thermal conductivity, ρ – the fabric's density, and c – the specific heat of the fabric. The heat flow passing between the textile samples and the measuring head during thermal contact is measured by a special thin sensor, whose thermal inertia is similar to that of human skin. The thermal contact sensation is strongly affected by the fabric's structure and composition.

The thermal resistance, thermal conductivity and thermal absorptivity of the textured fabrics have been measured by means of the computer-controlled Alambeta device, which enables rapid measurement of both the steady-state and transient-state thermal properties of any plain compressible non-metallic materials such as textile fabrics, plastic or rubber foils, paper products, liquids, pastes and fine powders [10, 11]. The instrument directly measures the classical stationary thermal properties of fabrics such as the stationary heat flow density, thermal resistance and the fabric's thickness. The rest of the thermal parameters, such as thermal conductivity, thermal absorption and thermal diffusion are calculated on the basis of the measured properties using algorithms appropriate for the unstratified materials [12].

***Table 1.** Yarn properties.*

Sample no	Linear density, dtex	Texturing method
A1	190/36	Air-jet textured
A2	190/72	
A3	190/144	
Ft1	167/36	False-twist textured
Ft2	167/72	
F1	167/36	Non-textured
F2	167/72	
F3	167/144	

***Table2.** Air permeability results.*

Sample no	Air permeability, $lm^{-2}s^{-1}$	
	Average ($\overline{X}$)	Standard deviation (S)
A1	3816	120.9
A2	3884	98.4
A3	3754	80.6
Ft1	2420	40.0
Ft2	1878	98.1
F1	4308	135.5
F2	4596	135.0
F3	5068	110.9

The whole measurement procedure includes the measurement of thermal conductivity (λ), thermal resistance (R), peak heat flow density (q_{max}), sample thickness (h), thermal absorptivity (b).

In this article, the effect of yarn bulkiness obtained via the texturing process on the thermal properties of the fabrics has been investigated. Additionally, the cover factor variation and the air permeability features of the textured fabrics were compared with the non-textured fabrics. The surface characteristics of the fabrics were examined with photos taken from a scanning electron microscope.

Experimental

In this study, the effects of the texturing process on fabric properties were investigated. For this purpose, interlock knitted fabrics produced with air-jet textured, false-twist textured and non-textured polyester filament yarns were used. The supplier of the yarns was Korteks A.Ş (Turkey). The properties of the samples are presented in Table 1. The thermal properties of the fabrics were measured by the Alambeta instrument according to standard ISO EN 31092. The measurements were repeated 5 times on randomly chosen parts of the fabrics, and average values and standard deviations were calculated. The air permeability of the samples was measured according to standard ISO 9237 with a Textest FX-3300 air permeability tester. The air permeability measurements of the fabrics were carried out 10 times, and the average and standard deviation of the test values were calculated. The cover factors of the samples were calculated by using image analysis technique with the Lucia programme. In order to observe the effect of the texturising process on the surface characteristics of the fabrics, SEM photos were taken using a Vega, Tescan Scanning electron microscope at a magnification of 80×.

Results and discussion

Air permeability

The average and standard deviation of air permeability measurements of the air-jet, false-twist textured and non-textured knitted polyester fabrics are given in Table 2 and Figure 2.

Non-textured fabrics show the highest air permeability results. Air-jet textured fabrics have lower air permeability compared to non-textured filaments. However, fabrics with filaments textured by the false-twist method have the lowest air permeability results, although the filament linear densities are lower than those of air-textured fabrics. It is obvious that the texturing effect of the false-twist method is more effective and ensures a highly bulky structure. The inter-fibre pore dimensions of the textured filaments are higher due to the crimp of the filaments, which for knitted fabrics however are too loose; the air flow predominantly passes through the inter-fibre pores. Thus, increasing the inter-yarn pore dimensions has no direct effect on air permeability. However, increasing the inter-fibre pore dimensions causes the thickness of the yarns to increase also, and during air flow, the air is subjected to a higher resistance in fabrics with textured yarns due to the smaller inter-yarn pores. On the other hand, the non-textured filaments have a very smooth and linear surface, which forms a more open structure when compared to the textured ones.

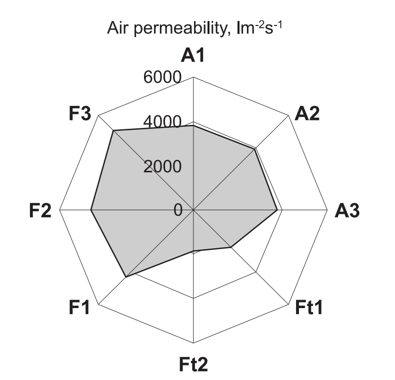

***Figure 2.** Air permeability data of the textured and non-textured fabrics ($lm^{-2}s^{-1}$).*

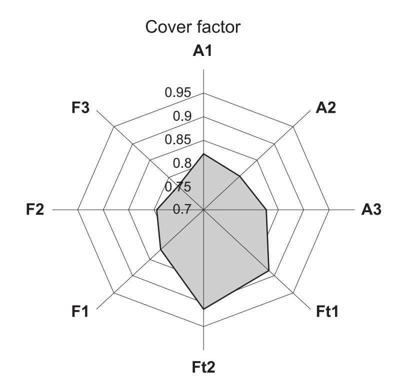

***Figure 3.** Cover factors of the textured and non-textured fabrics as calculated by the Lucia program.*

Table 3. Results of the thermal insulation properties of woven fabrics and thermal insulation material.

Parameter	A1	A2	A3	Ft1	Ft2	F1	F2	F3
Thermal conductivity - λ (x 10 $^{-3}$), $Wm^{-1} K^{-1}$	49.6 (1.289)	48.1 (1.394)	46.8 (0.936)	48.3 (0.772)	49.4 (0.543)	49.1 (1.227)	49.6 (0.644)	49.3 (0.936)
Thermal diffusion - a (x 10^{-6}), $m^2 s^{-1}$	0.171 (0.0126)	0.173 (0.0129)	0.179 (0.0075)	0.194 (0.0139)	0.17 (0.0059)	0.159 (0.0103)	0.165 (0.0084)	0.142 (0.0041)
Thermal absorption - b, $Wm^{-2} s^{1/2} K^{-1}$	120 (6.60)	116 (2.20)	111 (3.10)	110 (5.28)	120 (1.08)	123 (5.41)	122 (1.83)	131 (1.44)
Thermal resistance - R (x 10^{-3}), $W^{-1} K\ m^2$	17.4 (5.610)	18.2 (0.364)	17.9 (0.125)	19.9 (0.577)	18.6 (0.372)	16 (0.800)	15.4 (0.446)	14.2 (0.227)
Thickness – h, mm	0.86 (0.063)	0.87 (0.034)	0.84 (0.0176)	0.96 (0.0201)	0.92 (0.0257)	0.78 (0.0202)	0.77 (0.0308)	0.7 (0.0133)
Stationary heat flow density - q_s, KWm^2	0.406 (0.026)	0.397 (0.006)	0.382 (0.008)	0.364 (0.012)	0.39 (0.007)	0.43 (0.0210)	0.424 (0.0254)	0.45 (0.0162)

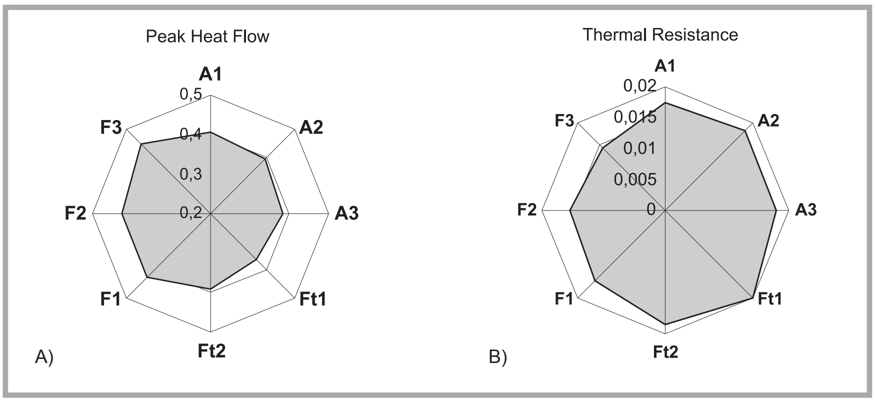

Figure 4. A) - peak heat flow (Wm^{-2}) and B) - thermal resistance ($K \cdot m^2 W^{-1}$) of textured and non-textured fabrics.

Cover factor

The cover factor of the fabrics determines the ratio between the projected geometrical area of the yarns and the total area of the fabric. A higher cover factor indicates a more compact and closer structure. Knitted fabrics produced with false-twist textured yarns show the highest cover factor, due to the increased bulkiness of the yarns as shown in Figure 3. Air-jet textured yarns also have higher cover factors compared to non-textured filaments, although the increase in cover factor in fabrics produced with air-jet textured yarns is lower than that of false-twist textured yarns.

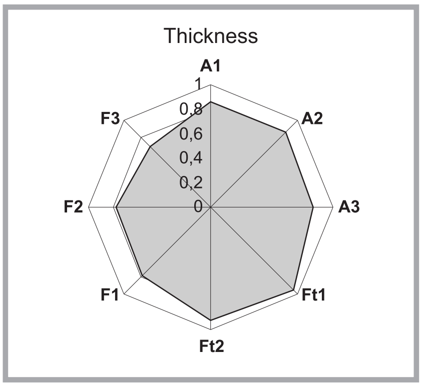

Figure 5. Thickness (mm) of the textured and non-textured fabrics.

Thermal properties and warm-cool feeling

The thermal-related properties measured by the Alambeta instrument are given in Table 3. The values of the standard deviation of the results are given in brackets.

The thermal resistance and peak heat flow of the knitted polyester filament fabrics is relatively low, as shown in Figure 4, whereas in case of using textured filaments, the thermal resistance of the fabrics increases. The texturing effect results in the increase in thickness and inter-fibre pore dimensions, where more air, which has lower thermal conductivity, can be retained, as shown in Figure 5. Thus the thermal resistance of the fabrics produced with textured yarns increases, and consequently the peak heat flow decreases. The thermal resistance of fabrics knitted with false-twist textured yarns is higher than in those fabrics knitted with air-jet textured filaments, and so a higher rate of heat is conducted in air-jet textured fabrics compared with false-twist textured fabrics.

The thermal absorptivity (b) and peak heat flow (q_{max}) values depend on the thermal capacity and conductivity of the fabric and on the contact area of the skin and surface. The surface character of the fabric greatly influences this sensation. A rough fabric surface reduces the area of contact appreciably, and a smoother surface increases the area of contact and the heat flow, thereby creating a cooler feeling [13]. Thermal absorptivity data for the samples are presented in Figure 6. Samples knitted with non-textured filament yarns which have a smoother surface provide a cooler feeling. The crimps of the textured yarns decrease the surface contact area because they form a rough surface. By texturing, the thermal absorptivity values decrease (the contact feeling is warmer), due to the decreasing contact area between the textured yarns and the sensing plate of the Alambeta instrument. False-twist textured yarns have more crimp and roughness due to the more effective texturing process, which seems to yield a warmer feeling compared to air-jet textured filaments. The peak heat flow values of the fabrics with textured yarns are lower than fabrics with non-textured filaments, as expected.

Surface characteristics

The photos of the air-jet textured (A2), false-twist textured (Ft2) and non-textured fabrics (F2) are given in Figure 7.

As it can be seen from the SEM photos, textured fabrics exhibit bulkier structure and rougher surface compared to non-textured fabric. It is obvious that false-twist texturising process ensures a more efficient texturising effect than those of air-jet textured textiles.

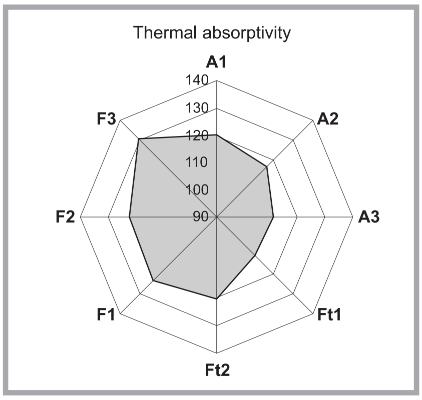

Figure 6. Thermal absorptivity ($W \cdot m^{-2} \cdot s^{1/2} \cdot K$) of textured and non-textured fabrics.

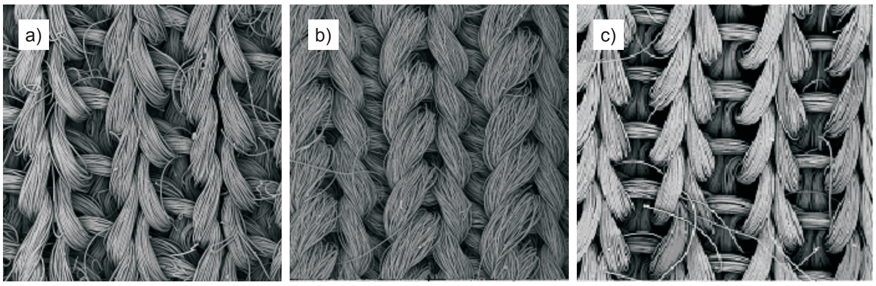

Figure 7. SEM photos of: a) air-jet textured, b) false- twist textured, and c) non-textured fabrics respectively.

Conclusion

This study reveals the comparative thermo-physiological properties of interlock knitted fabrics produced with air-jet textured, false-twist textured and non-textured filament PES yarns, compared by using the Alambeta instrument. The following conclusions can be drawn on the basis of the study:

- The thermal resistance of the textured fabrics are higer than the fabrics produced with non-textured filaments, due to the increased inter-fibre pore dimensions and the consequent thickness. By texturing, the thermal absorptivity values decrease (the contact feeling becomes warmer) due to the decreasing contact area between the textured yarns and skin.
- False-twist textured yarns have more crimp and roughness, since the more effective texturing process seems to provide a warmer feeling compared to air-jet textured filaments.
- Knitted fabrics produced with false-twist textured yarns shows the highest cover factor due to the increased bulkiness of the yarns. While the thickness of the fabric increases by texturing ,compared to non-textured samples, air permeability decreases. This decrease in air permeability is more evident in false-twist textured fabrics.

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