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Thermo-regulative finish on polyester blend knitted fabric

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The study is focused on the thermal comfort properties of single jersey materials. Three types of fabric blends, viz. polyester/modal, polyester/cotton and polyester/viscose, are selected. The selected fabrics are initially pretreated (scoured) to remove the impurities and then padded with a thermo-regulating finish (HeiQ Adaptive AC-06) at 2%, 4% and 6% concentrations. The coated materials are then characterized for geometrical properties and functional characteristics. The polyester/modal fabric coated with 6% finish concentration exhibits excellent thermal conductivity, thermal resistance, and thermal absorptivity characteristics.

Keywords: Cotton blends, Modal blends, Polyester blends, Single jersey, Thermal comfort, Thermo-regulating finish, Viscose blends

1 Introduction

Comfort is among the most crucial components of clothing. In terms of casual wear, the thermal comfort quality of materials is an essential feature for buyers. Thermal comfort is described as a feeling of contentment with one's surroundings' thermal conditions[1-3]. Fabric structure, density, moisture, composition, characteristics of fibres, kind of weave, surface treatment, finish and compressibility, air permeability, and external temperature are all factors that affect the comfort conditions of a clothed body[4-6]. The human body is thought to have a complex thermodynamic mechanism that balances energy generation and dissipation to keep thermodynamic balance with the environment.

Based on ambient environmental circumstances and individual physical exercise, energy is continuously generated by metabolic functions and must be constantly dispersed into the surroundings via dry heat loss or latent heat loss[7]. Clothing maintains the temperature balance between the human body and the environment. It functions as a medium for moisture vapor, heat, and liquid moisture transfer[8,9]. The capability of a fabric to maintain this balance is referred to as thermo–physiological comfort. The acceptance of textiles is mostly determined by factors of thermos-physiological comfort[10].

Fabric is intended to maintain the individual body's micro-environment stable and pleasant in a variety of weather conditions[11]. Poor thermal or moisture transport qualities of fabrics have been proven to reduce overall comfort and even pose a health risk due to germs development in heavy sweat[12,13]. Pac *et al*.[14] investigated the effects of fibre morphology, yarn, and structure on transient thermal characteristics and found a relationship between such behaviors and warm-cold touch. As compared to fabrics from Kaba cotton, fabrics created from Pima cotton absorbed more energy and felt cooler due to their lower roughness and hairiness. However, as the cloth stitch length was extended, the cotton variety seemed to have less impact on the warm-cool feeling. Ozdil *et al.*[15] analyzed the performance of yarn characteristics on various thermal comfort qualities of rib-knitted materials, finding that as yarn twist and yarn count increased, thermal resistance decreased and water vapor permeability increased.

Oglakcioglu *et al.*[16] investigated the thermal characteristics of individual cotton and angora rabbit fibre blended textiles, finding that as the angora rabbit fibre ratio increased, the thermal resistance increased while heat transfer, thermal absorptivity and relative water vapor permeability decreased. The impact of fibre fineness on fabric heat resistance was discussed by Ramakrishnan *et al.*[17]. They claimed that micro denier fibre has low heat conductivity and high thermal resistance. Heat resistance is increased by increasing the

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quantity of air trapped in the fabric, and fabric thickness[18]. Bedek *et al.*[19] evaluated the association between thermal comfort and textile qualities, finding that the fibre variety influences the features of fabrics associated with comfort, moisture resorption, and knitted structural characteristics. The thermal resistance qualities of interlock knitted fabrics were determined by Afzal *et al.*[20]. They discovered that the fibre type had a statistically significant effect on the interlock knitted textiles' thermal resistance. Fabric construction characteristics have been shown to have a direct influence on the permeability of interlock knitted materials.

There are several studies that are focused on the impact of fibre, yarn, and fabric constructional variables on the comfort qualities of various knitted constructions. However, the thermal comfort qualities of single jersey structures treated with thermo-regulative finishes on polyester-containing blends of a 50/50 ratio have received little attention. In the light of this, the present investigations study the impact of fabric qualities and thermo-regulative finishes on the thermal comfort properties of polyester/modal, polyester/cotton and polyester/viscose blended fabrics.

2 Materials and Methods

2.1 Materials

Three types of fabrics, viz polyester/modal, polyester/cotton, and polyester/viscose single jersey knit (50/50 blend ratio), of the same diameter were used (Table 1). NaOH, Na_2CO_3, and soap solutions were used as scouring agents to remove added impurities. The selected fabric samples were finished with HeiQ Adaptive AC-06 (a thermos-regulating finish) to impart thermal comfort properties.

2.2 Methods

2.2.1 Fabric Relaxation

Before testing, the samples were maintained for 24 h at RH 65±2% and temperature 27±2°C. Care is also taken to ensure that K_c/K_w is maintained at around 1.5.

2.2.2 Sample Preparation

Initially, the specimens were scoured to eliminate dirt and grease from the manufacturing process before being tested. As part of scouring the fabric, 40 cm × 40 cm size samples were treated with 3% NaOH, 3% Na_2CO_3, and 2% soap solution at 40°C for 30 min in a hot bath. After the treatment, fabric samples were washed and dried[21].

2.2.3 Thermo-regulating Finish

HeiQ Adaptive AC-06 can be added directly to the textile finishing bath during padding or exhaust operation. Fabric samples of 40cm × 40cm were scoured. HeiQ adaptive AC-06 was applied at different add-on levels (2%, 4% and 6%) on fabric weight with distilled water of M: L ratio 1:10. The scoured fabrics were saturated in the mixture for some time. Then the samples were padded, dried, and cured at 110 – 120°C.

2.2.4 Determination of Fabric GSM

Each of the specimens (10cm × 10cm) was weighed by measuring balance and the mass per unit area was estimated as the average of the five specimens. GSM of a fabric sample was measured as per ASTM D 3776.

2.2.5 Measurement of Porosity

It was the difference between total fabric volumes to total fibre volume in the sample. Porosity was determined using the below equation[22]:

$$\varepsilon = 1 - \frac{\pi d^2 lcw}{2t} \qquad \text{... (1)}$$

where Ɛ is the fabric porosity; *l*, the inner section loop length (cm); *d*, the diameter of yarn (cm); *t*, the specimen thickness (cm); *c*, the courses/cm; and *w*, the wales/cm.

2.2.6 Determination of Loop Length

The stitch density was utilized to measure loop length. The diameter of yarn was estimated using the below-mentioned equation[23]:

$$d = 2\sqrt{\frac{4T}{\pi \rho^s}} \qquad \text{... (2)}$$

where *d* is the yarn diameter (cm); *T*, the yarn linear density (tex); and *ρ*, the density of fibre (g/cm³).

Below are the formulae used for the measurement of loop length:

$$\mathrm{L} = \frac{2}{C} + \frac{1}{W} + 5.94d \qquad \text{... (3)}$$

Table 1 — Physical characteristics of fabrics

Fabric	Courses per cm	Wales per cm	Loop shape factor (R)	Stitch density loop/cm²	loop length mm	Yarn diameter µm	Tightness factor (K)	GSM	Porosity, %
Polyester/modal	20	21	1.0	420	2.6	180	17.7	160	94.3
Polyester/cotton	17	16	1.1	272	2.6	170	18.0	165	91.8
Polyester/ viscose	16	17	1.0	272	3.0	180	14.2	125	90.4

where L is the length of loop (cm); c, the courses/cm; w, the wales/cm; and d, the yarn diameter (cm).

2.2.7 Measurement of Cover Factor

It is described as the ratio of the area covered by one loop's yarn to the area filled by that loop. The cover factor was determined using the below mentioned formula[24]:

$$\text{Cover factor} = \sqrt{\text{Tex}/l\text{L}} \quad \text{... (4)}$$

where Tex is the yarn count; and L, the loop length (cm).

2.2.8 Thermal Tester

The Alambeta apparatus was used to evaluate the thermal properties of samples. The observations are performed five times on different portions of the materials at random, and the mean values and standard variations are computed (ASTM C518).

2.2.8.1 Thermal Conductivity (λ)

It is a material attribute that reflects a material's capacity to conduct heat. Thermal conductivity diminishes as the structure becomes more open. Thermal conductivity (λ) is measured as per the following formulae:

$$\lambda \text{ (W/Mk)} = Qh / A\Delta Tt \quad \text{… (5)}$$

where Q is the quantity of conducted heat (J); A, the area of specimen (m^2); t, the time of conductivitys (s); ΔT, the drop of temperature (°C); and h, the thickness of material (mm).

2.2.8.2 Thermal Resistance (R)

The process is similar to the one described above, except the testing head is kept dry at a temperature of $t_H = t^o + 10^oC$ (practically 32-35°C) for at least 5 min. In this situation, the measurement period is incredibly short, taking less than one minute for one sample. It is measured as per the following equation:

$$R \text{ (m}^2\text{K/W)} = h / \lambda \quad \text{… (6)}$$

where R is the thermal resistance of the fabric; h, the thickness of material (mm); and λ, the thermal conductivity.

2.2.8.3 Thermal Absorptivity

It is a parameter, specifically warm absorptivity that is offered to indicate the warm-cool feeling of substances. Warm absorptivity is a variable that displays the dimensions of the heat flow that passes between the infinite warmth limit and temperature of the skin and the approaching fabric.

3 Results and Discussion

3.1 Thermal Conductivity

The thermal properties of control and coated fabrics are listed in Table 2. It is found that the thermal conductivity is higher for polyester/ modal material, polyester/cotton, followed by polyester/viscose at the control stage (Fig. 1). Generally, the moisture regain property is better for modal followed by viscose and cotton. Modal fibre exhibits excellent thermal conductivity, whereas viscose has poor conductivity, the cotton material has 0.026 W/mK and polyester has 0.14W/mK of thermal conductivity. Therefore, the basic fibre composition of polyester/modal fabric offers more excellent thermal conductivity than other considered materials. In addition, the stitch density is quite higher for polyester/ modal fabric compared to others; the more stitch density leads to a higher number of fibres across the cross-section. Therefore, the quantity of entrapped air is less. Hence, the polyester/ modal fabric shows

Table 2 — Effect of thermo-regulative finish concentration on thermal comfort characteristics

Fabric	Finish concentration %	Thermal conductivity W/mK		Thermal absorptivity w.s/m^{2}K		Thermal resistance mK/wm^2		Thickness, mm	
		Value	% Shift	Value	% Shift	Value	% Shift	Value	%Shift
Polyester/modal	Nil	43.70	-	149.27	-	12.00	-	0.538	-
	2	43.73	-0.1	153.77	-3.0	12.60	-5.0	0.552	-2.6
	4	43.93	-0.5	155.60	-4.2	12.67	-5.6	0.553	-2.8
	6	45.20	-3.4	157.70	-5.6	12.71	-5.9	0.558	-3.7
Polyester/cotton	Nil	42.43	-	122.17	-	16.17	-	0.711	-
	2	42.83	-0.9	135.47	-10.9	16.63	-2.8	0.713	-0.3
	4	42.73	-0.7	135.73	-11.1	16.93	-4.7	0.718	-1.0
	6	44.57	-5.0	147.00	-20.3	17.00	-5.1	0.719	-1.1
Polyester/ viscose	Nil	34.67	-	125.30	-	15.40	-	-0.526	-
	2	36.30	-4.7	127.83	-2.0	17.47	-13.4	0.530	-0.8
	4	36.47	-5.2	127.77	-2.0	18.67	-21.2	0.540	-2.7
	6	36.23	-4.5	133.40	-6.5	18.50	-20.1	0.554	-5.3

higher thermal conductivity. The conductivity values are greater for fibres over entrapped air.

Further, a higher amount of moisture in modal fibre increases the thermal conductivity due to heat transfer by conduction; this increases with time. It is also found that thermal conductivity values are much better for treated fabric than untreated; the values increase with an increase in the concentration of finish. All fabrics treated with a 6% thermo-regulative finish exhibit excellent thermal comfort properties due to the specialized nonionic hydro-functional polymer that is triggered once the human body temperature crosses 37^{o}C and deactivated once the body cools down. When body heat rises, it offers the lengthy, active cooling impact of vaporization, which provides an immediate cool feeling through melting activity. The test results are similar to the findings of Oğlakcioğlu and Marmarali[25].

3.2 Thermal Resistance

Figure 2 shows that thermal resistance is high for polyester/ viscose fabric and polyester/cotton, followed by polyester/ modal for treated and untreated fabrics. The polyester/viscose fabric shows a smaller number of fibres, reduces the fabric weight, and improves the quantity of air layer in the structure; the presence of air layer results in thermal resistance. The increase in the thermo-regulative finish was also found to increase thermal resistance generally. Thermal conductivity is inversely proportional to thermal resistance, but the study shows the increase in thermal conductivity, and also increases thermal resistance. This might be due to fabric thickness; the thermal resistance will increase if the quantity of rising in the material thickness is higher than the quantity of rising in thermal conductivity. A similar trend is also reported by Atalie *et al.*[26].

3.3 Thermal Absorptivity

Thermal absorptivity is used to evaluate the absorbency of heat by fabrics at a specific wavelength. It is a surface attribute used for the cool–warm feeling of the property. The textile materials

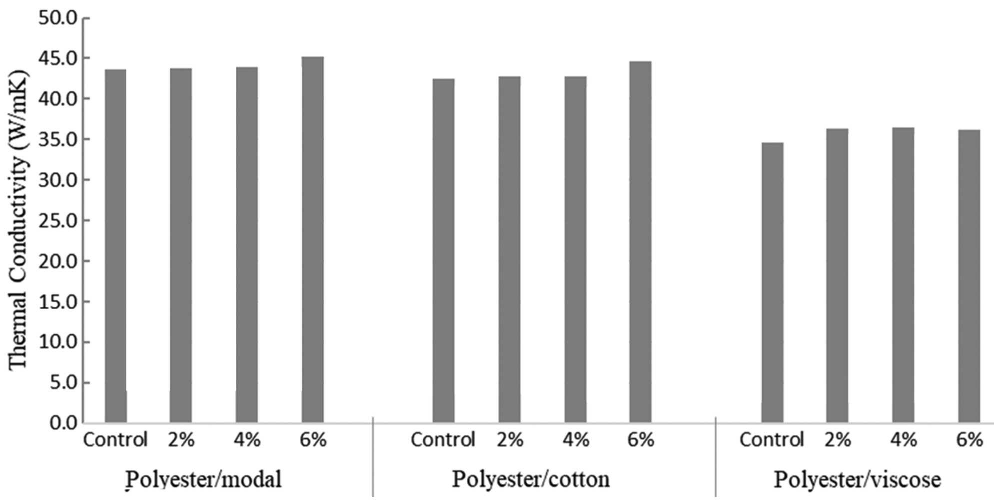

Fig. 1 — Thermo-regulative finish on thermal conductivity of fabrics

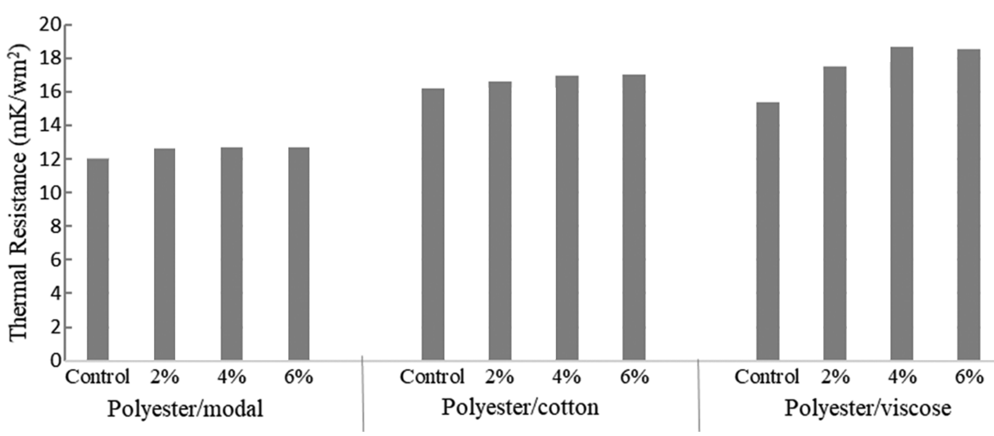

Fig. 2 — Thermo-regulative finish on thermal resistance of fabrics

with low thermal absorption make us feel 'warm.' Like thermal conductivity, polyester/ modal fabric offers thigh thermal absorption followed by other fabrics before and after treatment (Fig 3). The increase in concentration increases thermal absorption, and the higher absorption rates are observed at 6% finish concentration. Polyester/modal fabric contains lower loop length and yarn diameter, resulting in reduced entrapped and increased specific surface area available for skin to contact air than other fabrics, giving a cool feeling. Thermal absorption values range from 20 w.s/m^{2}K w to 900 w.s/m^{2}K; the higher value indicates a cool sensation on touching the specimen over a short time. The thermal absorptivity of the fabric increases with increase in fabric thickness. The results are statistically significant (p-value-0.00000263) at a 95 % confidence level (Table 3).

Table 3 shows that the application of the thermo-regulating finish and its concentration has a p-value for thermal comfort attributes < 0.0001. This demonstrates with a 95% confidence level that the

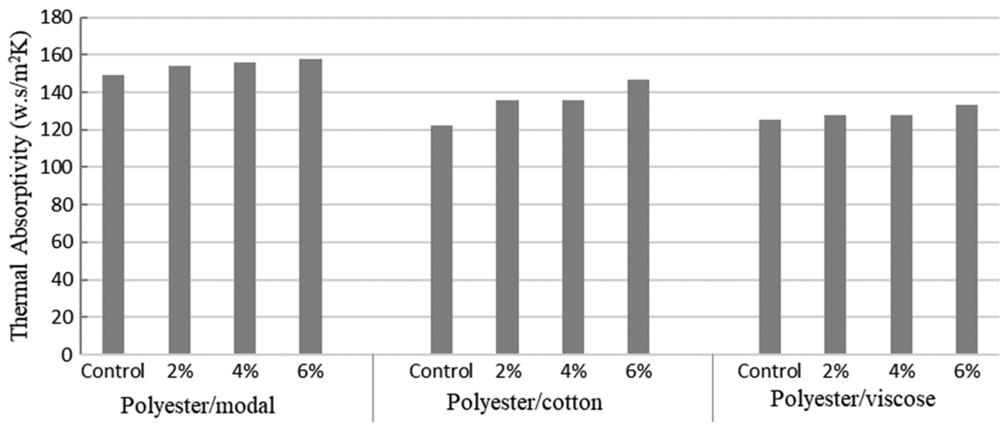

Fig. 3 — Thermo-regulative finish on thermal absorptivity of fabrics

Table 3 — ANOVA results for effect of thermo-regulative finish on thermal characteristics

Summary	Treatment	Thermal conductivity W/mK	Thermal absorptivity w.s/m^{2}K	Thermal resistance mK/wm^2	Total
			Two-Factor with Replication		
Polyester/Modal blend					
Count	4	4	4	4	16
Sum	0.12	176.56	616.34	49.98	843
Average	0.03	44.14	154.085	12.495	52.6875
Variance	0.000667	0.5098	12.8823	0.110967	3934.104
			Polyester/Cotton blend		
Count	4	4	4	4	16
Sum	0.12	172.56	540.37	66.73	779.78
Average	0.03	43.14	135.0925	16.6825	48.73625
Variance	0.000667	0.937733	103.1095	0.142492	2924.428
			Polyester/Viscose blend		
Count	4	4	4	4	16
Sum	0.12	143.67	514.3	70.04	728.13
Average	0.03	35.9175	128.575	17.51	45.50813
Variance	0.000667	0.701825	11.73643	2.2598	2628.071

Anova

Source of variation	SS	df	MS	F	*P*-value	F crit
Sample	413.7418	2	206.8709	18.75064	2.6×10^{-6}	3.2594
Columns	140691.5	3	46897.16	4250.727	6.0×10^{-6}	2.8662
Interaction	1210.388	6	201.7313	18.28479	1.3×10^{-9}	2.3637
Within	397.1785	36	11.03274	-	-	-
Total	142712.8	47	-	-	-	-

application of the thermo-regulating finish has a considerable impact on the thermal comfort characteristics of the knitted fabrics made of a polyester-containing blend.

4 Conclusion

The polyester-containing blends with a blend ratio of 50/50 have been coated with a thermo-regulating finish at different concentrations and evaluated for thermal comfort characteristics like thermal conductivity, thermal resistance, and thermal absorptivity. The polyester/modal fabrics coated with a thermo-regulating finish at 6% exhibit better thermal conductivity, thermal resistance, and thermal absorptivity values over other fabrics. The findings are studied together with the two-way ANOVA test results with a 95% level of confidence.

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