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Evaluation of Regenerated Bamboo, Polyester and Cotton Knitted Fabrics for Summer Clothing

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Abstract
Apparel products worn next to the skin used as summer clothing should satisfy good thermal and moisture management properties. In this paper, fabrics which are produced from three different types of fibres – regenerated bamboo, polyester, cotton and blends of these fibres, were compared with each other in terms of mechanical, thermal comfort and moisture management properties to explain the influence of the fibre type. Moreover the Analytic Hierarchy Process (AHP) was adopted to allow to make a selection among these fabrics of the best option to be used in summer wear. It was found that fibre type had a significant effect on the properties measured. Fabrics made with polyester fibre showed the required performance in terms of mechanical and moisture management properties, whereas regarding the thermal comfort properties, all fibre types had some special distinguishing performances. AHP assessment results revealed that 100% cotton fabrics should be preferred for use in summer clothing with regard to mechanical and thermos-physiological comfort related properties.

Key words: *mechanical properties, thermal, comfort, AHP, bamboo, polyester, cotton, summer clothing.*

Introduction

When compared to the weaving process, the simpler production and lower cost of knitting technology offer advantages to garment manufacturers. Besides there has been a growing demand from consumers for comfortable casual wear products, hence knitted fabrics are commonly preferred in the production of sportswear, casual wear and underwear products as well as summer wear due to their high elasticity, freedom of movement, good handle, ease of care... etc. Comfort, related to thermal comfort and moisture management specifically, has a priority among the expectations of consumers from such products. Developments in fibre manufacturing techniques and the increasing interest in the use of novel fibres have made researchers seek out the advantages of different fibre types and their blends in terms of comfort related performances as well as physical and mechanical properties.

Cotton fibre is the most commonly used natural fibre in clothing because of its breathability, soft touch, absorbency, and durability. Polyester and polyester/cotton blends also have common use in the manufacturing of products with improved comfort properties. As one of the new generation cellulose based fibre types, regenerated bamboo fibre has many outstanding properties, especially in terms of comfort. Bamboo is a renewable and biodegradable fibre with less impact on the environmental issues when compared to other petroleum derived synthetic fibres. The easy and fast growing of bamboo plants and their cultivation without requiring chemicals such as pesticides are also remarkable advantages of regenerated bamboo fibre when compared to conventional cotton [1].

There are many studies within the literature which evaluated these three fibres: cotton, polyester and regenerated bamboo, within physical, mechanical and thermophysiological aspects. With regard to physical and mechanical properties, knitted fabrics made of regenerated bamboo fibre are stated to have lower bursting strength when compared to those made of cotton fibre [2]. Moreover an increase in the bamboo content in regenerated bamboo/polyester blended fabrics results in a decrease in the bursting strength of knitted fabrics [3, 4]. On the other hand, it was found that the lowest weight loss values are obtained in bamboo/cotton knitted fabrics at the end of the abrasion test when compared to viscose/cotton and modal/cotton knitted fabrics [5]. Studies on the thermo-physiological comfort related performances of fabrics made of regenerated bamboo fibre indicated that these fabrics have a higher thermal resistance, air permeability, water vapour transfer rate and transfer wicking ability when compared to fabrics made of cotton fibre [6]. In contrast, regenerated bamboo fibre exhibits lower a vertical wicking ability and drying rate when compared to cotton fibre [6]. When blended with cotton, an increase in the proportion of regenerated bamboo fibre was recorded to have reduced the thermal conductivity of the fabric [7, 8], whereas it increases water vapour permeability and air permeability [8, 9]. Likewise when blended with polyester, an increase in regenerated bamboo content results in an increase in water vapour permeability as well as vertical and transfer wicking ability. On the other hand, there are conflicting results about the air permeability performances of regenerated bamboo/polyester blended fabrics [4, 10], while it was stated that an increase in regenerated bamboo content decreases the thermal resistance of fabrics [9, 10]. A study about the moisture management properties of polyester/regenerated bamboo and polyester/cotton blended bi-ply knitted fabrics concluded that polyester regenerated bamboo bi-ply knitted fabrics have better air permeability, water vapour permeability and wickability than polyester/cotton bi-ply rib knitted fabrics [11].

In this study, it was attempted to compare the mechanical, thermal comfort and moisture management properties of different types of fibres and fibre blends as well as to select the most suitable fibre type for usage in summer clothing. For this aim, mechanical properties including pilling propensity, abrasion resistance and bursting strength; thermal comfort properties including air permeability, thermal resistance and thermal absorptivity, and moisture management properties including transfer wicking ability, relative water vapour permeability and drying time of single jersey knitted fabrics made with 100% regenerated bamboo, 100% cotton and 100% polyester were measured and compared with each other in order to evaluate the mechanical behaviour and thermophysiological comfort properties. In addition, 50/50% regenerated bamboo/cotton, 50/50% regenerated bamboo/polyester and 50/50% cotton/polyester single jersey fabrics were knitted and evaluated within the same respect in order to distinguish positive or negative influences of the fibre types on the above-mentioned properties. Considering the values that the different types of fabrics have in terms of the properties referred to, a method based on AHP was proposed and executed in order to find out the best alternative for the usage of the different fibres in summer clothing.

Materials

Single jersey knitted fabrics produced from three different types of fibres: regenerated bamboo, polyester, cotton and the blends of these, were used for the study. Physical and structural properties of the specimens are summarised in ***Table 1*** and ***2***. Within these tables, the average values and standard deviations are given for three samples of each fabric.

Table 1. *Physical and structural properties of the fabric samples.*

Sample code	Fibre type	Yarn count, tex	Mass per unit area, g/m²	Thickness, mm
BA	100% bamboo	17.06±0.55	113.1±0.03	0.50±0.02
CO	100% cotton	14.99±0.27	105.4±1.74	0.56±0.01
PET	100% polyester	18.77±0.53	125.1±0.28	0.52±0.02
BA/PET	50/50% bamboo/polyester	17.64±1.01	123.1±0.21	0.51±0.01
BA/CO	50/50% bamboo/cotton	15.09±0.80	105.6±0.83	0.53±0.02
CO/PET	50/50% cotton/polyester	16.96±0.19	123.4±1.20	0.55±0.01

Table 2. *Physical and structural properties of the fabric samples.*

Sample code	Loop Length-*l* cm	Courses per cm	Wales per cm	Loop density, loops/cm²	Tightness factor – K, tex$^{1/2}$/*l*
BA	0.26±0,0006	18±0,58	17±0,58	306±9,24	15.9±0,03
CO	0.26±0,0017	18±0,58	16±0,58	288±1,73	14.9±0,08
PET	0.25±0,0006	20±1,00	13±1,00	260±15,7	17.3±0,03
BA/PET	0.25±0,0025	20±0,58	15±0,00	300±8,08	16.84±0,14
BA/CO	0.26±0,0020	18±1,15	16±0,58	288±22,72	14.9±0,10
CO/PET	0.27±0,0025	18±0,00	15±0,29	270±4,62	15.3±0,12

Method

The yarn count, the number of courses and wales per cm, loop length, mass per unit area and thickness of the fabric samples were measured according to the relevant standards [12-16]. The loop density and tightness factor of the fabric samples were calculated from ***Equations (1)*** and ***(2)***, respectively.

$$Loop\ density = \frac{courses}{cm}\ x\ \frac{wales}{cm} \quad (1)$$

$$Tightness\ factor\ (K) = \frac{\sqrt{tex}}{l} \quad (2)$$

where *l* is the loop length in cm.

The pilling propensity, abrasion resistance and bursting strength of the samples were determined to evaluate mechanical performances of the knitted fabrics. The pilling propensity of the fabric samples were evaluated using an ICI pilling tester (James H. Heal, UK) in accordance with BS EN ISO 12945-1 [17]. Pilling tests were conducted for four samples of each fabric. Ratings for the samples were determined by comparing standard photographs. A "5" rating indicates that there is no visible change on the surface of the fabric, while a "1" rating indicates intensive pilling on the whole surface of the fabric. Abrasion resistance tests were performed on three samples for each fabric using a Martindale abrasion tester (James H. Heal, UK) in accordance with BS EN ISO 12947-2 and 12947-3 [18, 19]. To measure the abrasion resistance of the fabrics, the weight losses (%) of the samples were calculated at the end of 5000 cycles. A bursting strength tester (Cometech, Taiwan) applying a hydraulic method based on ASTM D 3786 [20] was used to determine the bursting strength of the fabric samples. Three measurements were conducted for each fabric.

Transfer wicking measurements of the fabric samples were conducted based on the method developed by Zhuang et al [21]. For each fabric sample, two circular test specimens with a diameter of 74.5 mm were prepared, one of which was soaked completely in distilled water, then the excess water was removed with a paper towel, and both wet and dry specimens were placed between two dishes. Liquid transfer was continuously allowed for a certain period of time, then the amount was measured by weighing the dry fabric layer at 5, 10, 15, 20, 25 and 30 minutes. To measure the drying behaviour of the fabrics, the method of Coplan [22] and Fourt et al. [23] was followed. Fabric specimens of 4x4 cm dimensions were soaked in distilled water for 30 minutes. Then the specimens were removed from the water, suspended vertically for 15 seconds, and afterwards laid on a dry paper towel for 2 minutes on each side. The samples were weighed at half-hour intervals as drying progressed. When the measurement value was 105% of the dry conditioned weight, the test was ended and the drying time recorded. The air permeability of the samples was measured using Prowhite test apparatus – 2015 (Turkey) according to ISO 9237: 1995 [24] by applying a 100 Pa constant air pressure to each sample attached to a 20 cm² circular holder. The thermal resistance and relative water vapour permeability of the fabric samples were measured on a Permetest instrument (Czech Republic) [25]. An Alambeta instrument (Czech Republic) was used to measure the thermal absorptivity of the samples [26]. The average values of three tests were obtained for each fabric sample.

Correlation analysis and one-way ANOVA tests were applied using IBM SPSS Version 21 (USA) in order to analyse the experimental results statistically.

A multi-criteria decision making approach was used in order to rank the fabrics in terms of comfort related quality and select the appropriate fibre type or blend for use in summer clothing. For this aim, AHP was applied to determine the relative importance of the following three criteria: mechanical properties, thermal comfort properties and moisture management properties, of the fabrics, which were placed at the 1st level of the hierarchy. The sub-criteria, which are the bursting strength, pilling propensity and weight loss of the fabrics during abrasion, as well as their air permeability, thermal resistance, thermal absorptivity, drying time, relative water vapour permeability and transfer wicking properties, were placed at the 2nd level of the hierarchy. At the 3rd level of the hierarchy, 6 different fabrics ranked with respect to the objective of investigation, which is the comfort related quality of the fabrics for use in summer

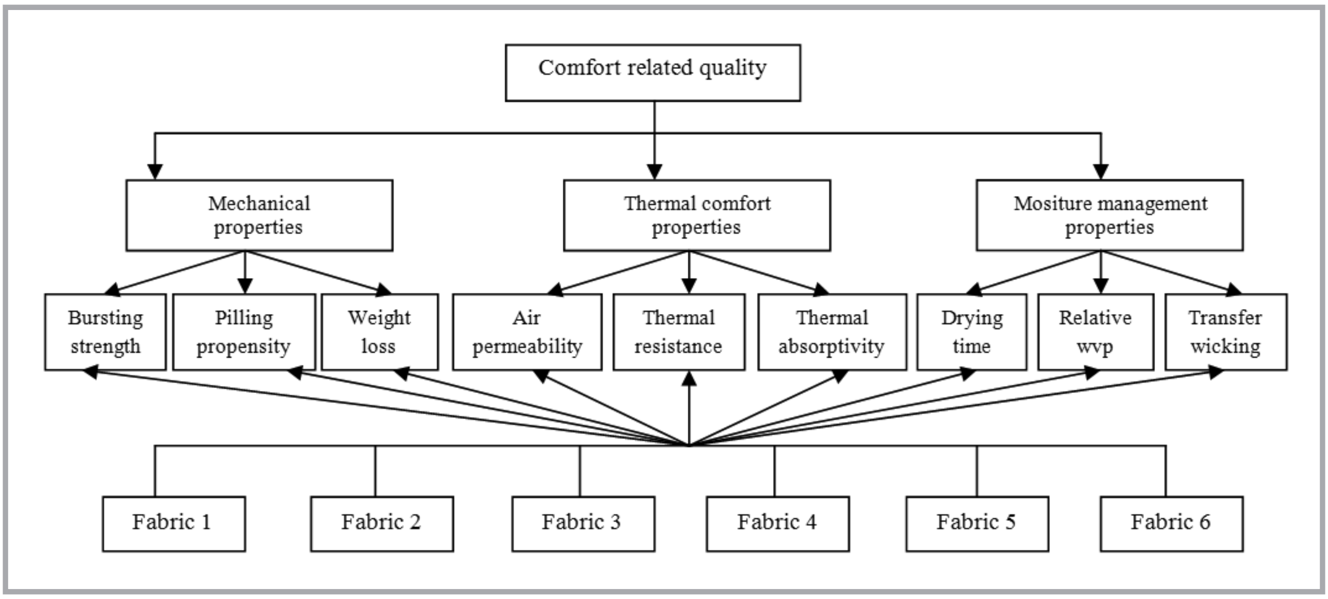

Figure 1. *Hierarchical structure.*

clothing, were placed. A diagram of the hierarchical structure is shown in ***Figure 1***.

In the next step, pairwise comparison judgment matrices were constructed using the nine-point scale of relative importance given in ***Table 3*** by comparing two criteria or sub-criteria with respect to the property in a higher level.

Entry c_{ij} denotes the relative importance of criterion i with respect to criterion j. In matrix C_1 below, $c_{ij} = 1$ when i = j and $c_{ji} = 1/c_{ij}$ and N is the number of sub-criteria [27, 28].

$$C_1 = \begin{bmatrix} 1 & c_{12} & ... & c_{1N} \\ c_{21} & 1 & ... & c_{2N} \\ ... & ... & 1 & ... \\ c_{N1} & c_{N2} & ... & 1 \end{bmatrix}$$

The relative importance of the i^th^ criterion (W_i) was determined by calculating the geometric mean (GM) of the i^th^ row and then normalising the geometric means of rows of the pairwise comparison judgment matrix. These calculations were done according to the ***Equations (3)*** and ***(4)*** [27, 28].

$$GM_i = \left\{ \prod_{j=1}^{N} cij \right\}^{\frac{1}{N}} \qquad (3)$$

$$W_i = \frac{GM_i}{\sum_{i=1}^{N} GM_i} \qquad (4)$$

The consistency was measured by calculating and comparing the Consistency Ratio (CR) with the threshold value < 0.1 [29]. The consistency ratio was calculated using ***Equation (5)***:

$$CR = CI/RCI \qquad (5)$$

where CI is the consistency index, which was calculated according to ***Equation (6)***, and RCI is the random consistency index, whose value, which differs according to the number of sub-criteria (N), can be obtained from ***Table 4*** [29].

$$CI = (\lambda \max - n)/(n-1) \qquad (6)$$

In ***Equation (6)***, n is the number of criteria evaluated in the pairwise comparison matrix, and λ_{max} is the largest eigen value.

In order to evaluate the fabrics as alternatives for summer clothing, the revised AHP method, which was proposed by Belton and Gear [30], was used. According to this method, all the performance scores of alternatives in the corresponding criterion were listed to form a decision matrix. In order to obtain the final decision matrix, the experimental results were normalised within the range from 0 to 1 [31].

Table 3. *Nine-point scale of relative importance [27].*

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favour one activity over another
5	Essential or strong importance	Experience and judgment strongly favour one activity over another.
7	Very strong importance	An activity is very strongly favored and its dominance is demonstrated.
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation.
Reciprocals	If activity p has one of the above numbers assigned to it when compared with activity q, then q has the reciprocal value when compared with p.	

Table 4. *RCI values for different numbers of criteria [29].*

N	1	2	3	4	5	6	7	8	9
RCI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Table 5. *Final decision matrix [31].*

Fabric	Criterion									AHP score
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	
1	a_{11}	a_{12}	a_{13}	a_{14}	a_{15}	a_{16}	a_{17}	a_{18}	a_{19}	t_1
2	a_{21}	a_{22}	a_{23}	a_{24}	a_{25}	a_{26}	a_{27}	a_{28}	a_{29}	t_2
3	a_{31}	a_{32}	a_{33}	a_{34}	a_{35}	a_{36}	a_{37}	a_{38}	a_{39}	t_3
4	a_{41}	a_{42}	a_{43}	a_{44}	a_{45}	a_{46}	a_{47}	a_{48}	a_{49}	t_4
5	a_{51}	a_{52}	a_{53}	a_{54}	a_{55}	a_{56}	a_{57}	a_{58}	a_{59}	t_5
6	a_{61}	a_{62}	a_{63}	a_{64}	a_{65}	a_{66}	a_{67}	a_{68}	a_{69}	t_6

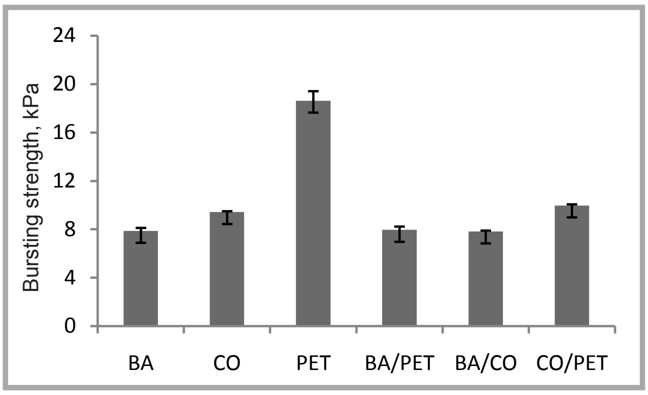

Figure 2. *Bursting strength of the fabric samples.*

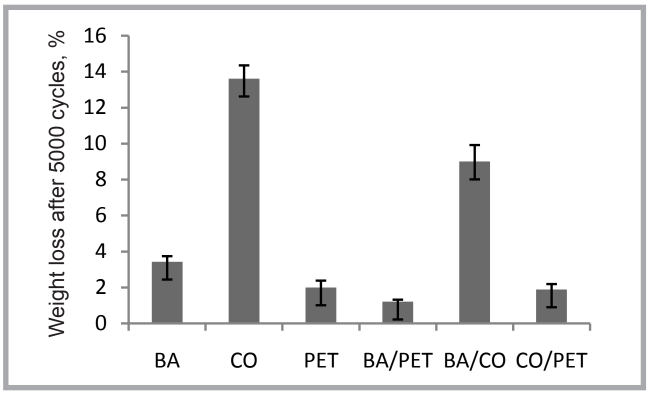

Figure 3. *Abrasion resistance of the fabric samples.*

Considering the revised AHP method, the bursting strength, pilling propensity, air permeability, thermal absorptivity, relative water vapour permeability and transfer wicking properties were determined as benefit criteria (the higher the score is, the more preferable it is), while the weight loss during abrasion, thermal resistance and drying time properties were determined as cost criteria (the lower the score is, the more preferable it is). ***Equations (7)*** and ***(8)*** were used for normalisation of both benefit and cost criteria [31].

$$Normaij = \frac{\text{aij}}{\text{Maxaij}} \quad (7)$$

for benefit criterion

$$Normaij = \frac{\text{Minaij}}{\text{aij}} \quad (8)$$

for cost criterion

The final priority values of all fabrics were determined using ***Equation 9*** [28].

$$AHP\ score = \sum_{i=1}^{N} NormaijWi \quad (9)$$

for j = 1, 2, 3, ... N

Results

Mechanical properties

Table 6 displays the pilling propensity, abrasion resistance and bursting strength properties of the fabric samples.

According to one-way ANOVA results, the influence of the different types of fibres on pilling propensity was found to be statistically significant, achieving a p value of 0.006 (F = 5.700). The fabric sample knitted from polyester fibre tends to have better pilling resistance (5) than those made from regenerated bamboo and cotton fibres, revealing a similar pilling tendency (4.5), as seen in ***Table 6***. It was also observed that the blending of cotton and regenerated bamboo fibres with polyester improved the pilling behaviour of the fabrics, resulting in lower pilling tendencies when compared to pure regenerated bamboo and pure cotton fabrics. Moreover blending cotton fibre with regenerated bamboo improved the pilling behaviour of pure cotton fabric, which may be attributed to the fact that pilling tendency decreases with an decrease in yarn hairiness [32], which is dependent mainly on the average fibre length and variation there in. The findings revealed that fabrics made with polyester fibres have better quality in terms of pilling resistance, and including polyester fibres in the blends of regenerated bamboo and cotton fibres improves the pilling resistance of fabrics.

Bursting strength values of the fabric samples are shown in ***Figure 2***. According to the results of one-way ANOVA, the influence of fibre type on bursting strength was found to be statistically significant, achieving a p-value of 0.000 (F = 438.698). It is evident from ***Figure 2*** that 100% regenerated bamboo fabrics exhibited lower bursting strength when compared to 100% cotton and 100% polyester fabrics, respectively. This was an expected result due to the lower strength of regenerated bamboo fibre than that of cotton and polyester fibres [2, 5, 10, 33-39].

The lower fibre strength of regenerated bamboo was also observed to decrease the bursting strength of regenerated bamboo blended fabrics. This influence was more apparent within the blends of regenerated bamboo and polyester fibre, which may be attributed to the different stress–strain behaviour of regenerated bamboo fibre and polyester fibre. As the breaking elongation of regenerated bamboo fibre is much lower than that of polyester fibre [35], regenerated bamboo fibres were expected to reach the rupture point earlier during the bursting strength test of the fabric. Although 50% of the fibres are polyester, they could not contribute much to the strength of the fabric, since both fibre types did not reach the rupture point simultaneously. In fact, it was found that as the amount of regenerated bamboo fibre increases in the blends of cotton and polyester fibres, the bursting strength decreases [4]. Thus it can be stated that the fabrics made with polyester fibre are better in terms of bursting strength values, and the integration of polyester fibres into cotton fabrics gives better results in terms of strength values when compared with that of polyester fibre into regenerated bamboo fabrics.

Results regarding the weight loss of the fabric samples after 5000 abrasion cycles are illustrated in ***Figure 3***. Statistical analysis results indicated that the effect of fibre type on the weight loss values is significant at a 90% confidence interval, achieving a p-value of 0.099 (F = 2.114). It is evident from ***Figure 3*** that the high-

Table 6. *Pilling, abrasion and bursting strength properties of the fabric samples.*

Sample code	Pilling grade	Abrasion weight loss after 5000 cycles, %	Bursting strength, kPA
BA	4.5±0.00	3.4±0,30	7.87±0.23
CO	4.5±0.00	13.6±0,73	9.42±0.06
PET	5.0±0.00	2.0±0,37	18.63±0.77
BA/PET	4.8±0.29	9.0±0,10	7.95±0.26
BA/CO	4.8±0.29	1.2±0,91	7.82±0.06
CO/PET	5.0±0.00	1.9±0,29	9.97±0.08

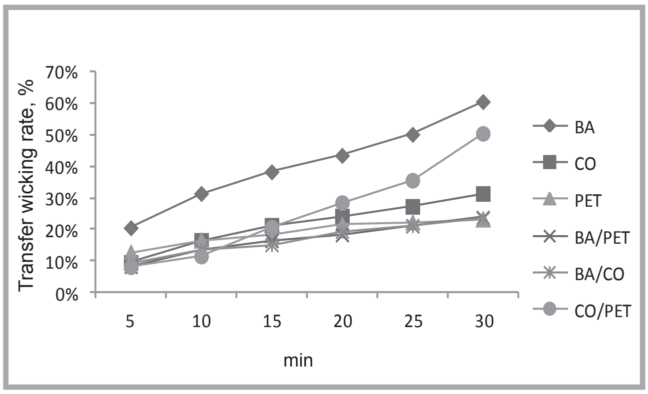

Figure 4. *Transfer wicking ratio of the fabrics against time %.*

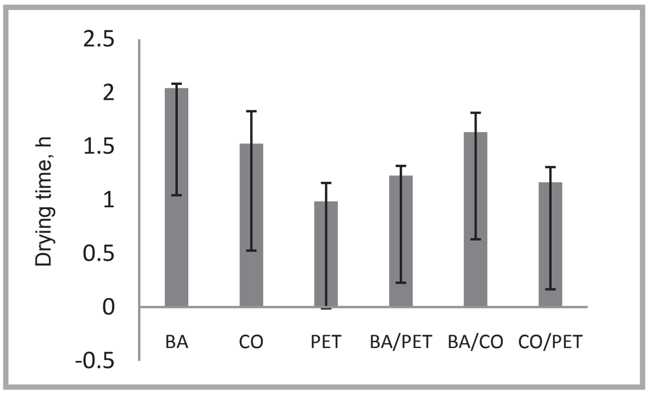

Figure 5. *Drying behaviour of the fabric samples.*

est weight loss value after 5000 abrasion cycles was observed for fabrics made of 100% cotton fibre. The results also revealed that blending regenerated bamboo fibre with polyester improved the resistance of the fabric against abrasion in comparison to the 100% regenerated bamboo fabric sample. These findings were confirmed in previous studies [3, 5, 38-40]. Moreover blending cotton with polyester also improved the abrasion resistance property of 100% cotton fabric. The weight loss of 50/50% regenerated bamboo/cotton blended fabric was found to be between the weight loss values of 100% regenerated bamboo fabric and 100% cotton fabric, i.e., it is greater than that of 100% regenerated bamboo fabric and less than that of 100% cotton fabric. Regarding these findings, it can be stated that the fabrics made with polyester and then those with regenerated bamboo have better qualities when compared with cotton fabrics, and increasing the amount of polyester and regenerated bamboo improves the abrasion resistance of the fabrics.

Thermal comfort and moisture management properties

Table 7 displays the thermal and moisture comfort properties of the fabric samples. ***Figure 4*** shows the transfer wicking ratio of the fabric samples against time in minutes. As seen in the figure, the transfer wicking ratio of the fabrics increases almost linearly with time, irrespective of the fibre type. Nonetheless the influence of fibre type on the transfer wicking rate was found to be statistically significant with a p value of 0.002 (F = 5.048). The comparative results of the study with respect to fibre type showed that 100% regenerated bamboo fabric gave the highest transfer wicking ratio, followed by 100% cotton and 100% polyester fabrics. Thus the transfer wicking values increased in correspondence to the moisture regain properties of the fibres.

This result is in agreement with the findings of Cimilli et al [6], who showed that the transfer wicking of cotton fabrics is lower than that of bamboo fabrics. On the other hand, Yang et al [41] explains this situation in that the gaps between fibres in bamboo yarns, because of the grooves on the fibre, may produce a strong capillary effect, leading to improving absorption and desorption properties. Nonetheless the transfer wicking behaviour of the blended fabrics showed different behaviour. Whereas the cotton/polyester blend showed higher transfer wicking, the blends of bamboo with both cotton and polyester showed lower values. This can be explained by the influence of fibre properties on the transfer mechanism, which was suggested by Zhuang et al. [21]. According to the authors, liquid is transferred from the wet to the dry layer after the liquid fills the fabric interstices, and the transfer of wicking continues provided that the wet layer contains enough water. Since regenerated bamboo fibre requires more water to be saturated, the fibres within the blended fabric may have interrupted the wicking of regenerated bamboo fibre with enough water to allow the water molecules to be transferred to the dry layer. Considering the findings, it can be suggested that the transfer wicking abilities of fabrics made with regenerated bamboo fibre are better than for both polyester and cotton fabrics. However, this quality can also be provided by using blends of different fibres.

In ***Figure 5***, the drying time of the fabric samples is demonstrated. It was found that the influence of the fibre type is statistically significant, achieving a p-value of 0.000 (F = 14.378). When the drying times of the fabrics were evaluated, it was realized that 100% regenerated bamboo fabric dried in 2.04 hours, which was measured as the longest drying time. It was followed by 100% cotton and 100% polyester fabrics, respectively. In accordance with these results, the 50/50% regenerated bamboo/cotton blended fabric achieved the highest drying time, which was then followed by the 50/50% regenerated bamboo/polyester and 50/50%

Table 7. *Thermal and moisture comfort properties of the fabric samples.*

Sample code	Transfer wicking ratio, %-after 30 min	Drying time, hour	Relative water vapour permeability, %	Air permeability, l/m²/s	Thermal resistance, m² K/W	Thermal absorptivity, Ws$^{1/2}$/m² K
BA	60.6±0,87	2.04±0.04	69.5±1.60	524±34.49	8.40±2.43	130.3±2.52
CO	31.4±0,77	1.53±0.30	66.9±2.20	659±27.61	13.20±1.51	110.0±7.21
PET	23.2±3,49	0.99±0.17	65.7±5.60	397±30.32	5.93±1.88	126.0±3.61
BA/PET	23.8±9,45	1.23±0.09	69.2±1.20	435±11.37	9.87±2.48	125.3±1.53
BA/CO	23.5±5,7	1.63±0.18	68.0±0.80	475±35.50	11.90±2.03	129.3±8.39
CO/PET	50.5±16,41	1.17±0.14	65.3±1.50	514±9.29	12.97±3.06	112.0±9.54

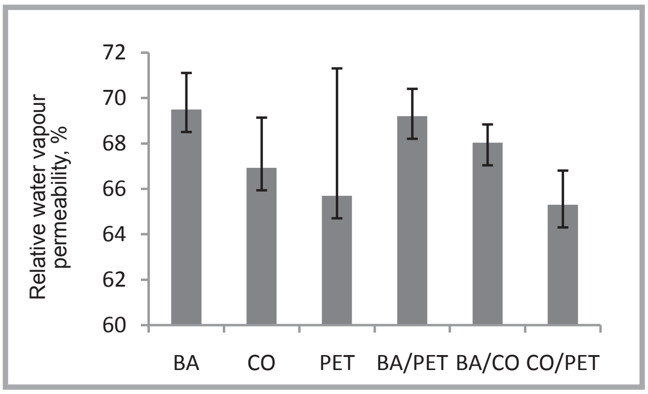

Figure 6. Relative water vapour permeability values of the fabric samples.

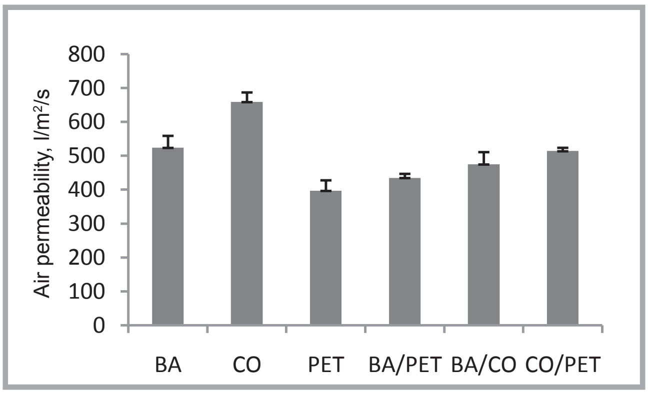

Figure 7. Air permeability values of the fabric samples.

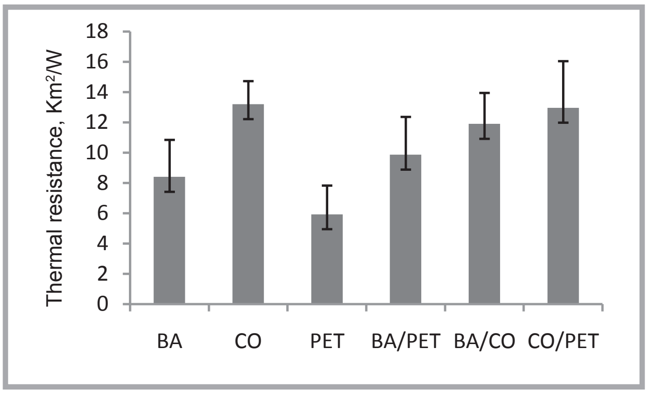

Figure 8. Thermal resistance values of the fabric samples.

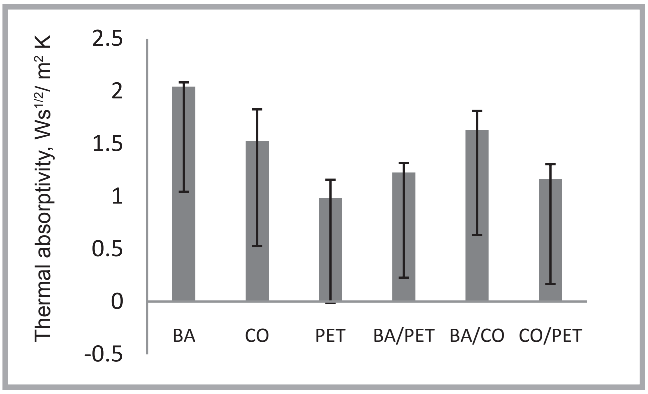

Figure 9. Thermal absorptivity values of the fabric samples.

cotton/polyester blended fabrics. Similar results were obtained for the drying time by Cimilli et al [6]. This is because the drying time is related to the amount of water held originally by the sample, which is dependent on the moisture affinity and water capacity of the fibre [23]. Regenerated bamboo fibre has the highest water holding capacity compared to cotton and polyester, and thus the drying time needed by regenerated bamboo fibre and its blends is the highest. Considering the findings, it can be indicated that the fabrics made with polyester fibre have better qualities in terms of quick drying, followed by cotton.

Relative water vapour permeability values of the fabric samples are demonstrated in ***Figure 6***. The results of one-way ANOVA revealed that the different types of fibres and blends did not have statistically significant effects on the relative water vapour permeability values of the samples at a 95% confidence interval ($p = 0.356$, $F = 1.223$). However, it can be seen from Figure 6 that the highest relative water vapour permeability value was obtained for 100% regenerated bamboo fabric, which was followed by 100% cotton and 100% polyester fabrics, respectively. Within the blended fabrics, it was observed that regenerated bamboo fibre improves the relative water vapour permeability of polyester and cotton fibre. This increase was also observed in earlier studies [3, 9]. Mahish et al. [3] explained this phenomenon in that the cross section of regenerated bamboo fibre is filled with micropockets which ease absorption and ventilation. On the other hand, Ramakrishnan et al. [9] related the result to the thickness of the fabric, adding that water vapour transmission due to diffusion was higher for regenerated bamboo fabrics as the moisture regain of regenerated bamboo fibre was higher than that of cotton. Considering the findings above, it can be stated that the usage of regenerated bamboo and bamboo blended fabrics seems to increase the permeability of water through fabric.

Air permeability values of the fabric samples are shown in ***Figure 7***. According to the one-way ANOVA results, the air permeability values of the fabric samples were found to be influenced by the fibre type ($p = 0.000$, $F = 34.523$). It was observed that 100% regenerated bamboo and 100% cotton fabrics had a higher air permeability value when compared to 100% polyester fabric, and the blends of polyester fibres showed higher air permeability values when compared to 100% polyester fabric. Despite the findings of previous studies [8, 37] that stated air permeability is independent of fibre type, the results of the present study is in agreement with the findings of Hussain et al. [4] Considering the findings, it can be stated that the fabrics made with regenerated bamboo and cotton have better air permeability values; thus this point should be kept in mind while preparing blends of fabrics.

Thermal resistance values of the fabric samples can be observed from ***Figure 8***. Thermal resistance is an indicator of a material's ability of thermal insulation, which is inversely proportional to thermal conductivity. The results of one-way ANOVA indicated that different types of fibres and blends have statistically significant effects on the thermal resistance values of the samples ($p = 0.013$, $F = 4.690$). According to ***Figure 8***, it can be stated that the 100% cotton fabric sample had the highest thermal resistance value, followed by 100% regenerated bamboo and 100% polyester fabrics, respectively. Within the assessment of

Table 8. Pairwise comparison judgment matrix of criteria for first level of hierarchy.

	Mechanical properties	Thermal comfort properties	Moisture management properties	Priority weights
Mechanical properties	1	0.143	0.200	0.072
Thermal comfort properties	7	1	3	0.649
Moisture management properties	5	0.333	1	0.279
λmax = 3.065, CI = 0.032,	CR = 0.056			

Table 9. Pairwise comparison judgment matrix of mechanical property criteria for second level of hierarchy.

	Bursting strength	Billing propensity	Weight loss	Priority weights
Bursting strength	1	0.200	3	0.014
Pilling propensity	5	1	7	0.053
Weight loss	0.333	0.143	1	0.006
λmax = 3.065, CI = 0.032, CR = 0.056	CR = 0.056			

Table 10. Pairwise comparison judgment matrix of thermal comfort property criteria for second level of hierarchy.

	Air permeability	Thermal resistance	Thermal absorptivity	Priority weights
Air permeability	1	5	7	0.474
Thermal resistance	0.200	1	3	0.122
Thermal absorptivity	0.143	0.333	1	0.053
λmax = 3.065, CI = 0.200,	CR = 0.056			

Table 11. Pairwise comparison judgment matrix of moisture management properties criteria for second level of hierarchy.

	Drying time	Relative wvp	Transfer wicking	Priority weights
Drying time	1	1	7	0.136
Relative wvp	1	1	5	0.121
Transfer wicking	0.143	0.200	1	0.022
λmax = 3.013, CI = 0.006,	CR=0.011			

blended fabrics, it was found that the high thermal resistance of cotton fibre improved that value of its blends. Comparing the fabrics that are made with bamboo and with a cotton content, Ramakrishnan et al. [9] found that fabrics produced with a higher bamboo content were found to have lower thermal resistance than cotton, which is in agreement with the findings herein. Because of the inherent lower conductivity of bamboo than that of cotton [7], Ramakrishnan et al [9] related his findings to the fabric thickness. In fact, for this study, the correlation between the thermal resistance and thickness of the fabric samples was also found to be statistically significant within a 95% confidence interval, with a correlation coefficient of 0.70 and p value of 0.001. Since summer clothing is required to have lower thermal resistance values, it can be stated that polyester fibres are much more suitable for usage in summer clothing, followed by bamboo and cotton fibres, respectively. Nonetheless it should be added that other than the fibre type, the constructional parameters of the fabrics are influential in the determination of the thermal insulation properties of fabrics.

Thermal absorptivity values of the fabric samples are demonstrated in ***Figure 9***. According to the statistical analysis, different fibre types and compositions have statistically significant effects on the thermal absorptivity values of the fabric samples, achieving a p-value of $p = 0.005$ ($F = 6.038$). 100% regenerated bamboo and 100% polyester fabrics have significantly higher thermal absorptivity values when compared to 100% cotton fabric. Besides this, the blending of both regenerated bamboo and polyester fibre with cotton increased the thermal absorptivity of the cotton fabric sample. Investigating bamboo, cotton and soybean fibres, Ozgen and Altas [42] also found that fabrics with cotton fibres have lower thermal absorptivity compared with those made of regenerated bamboo fibres. Since thermal absorptivity is defined as the objective measurement of the warm-cool feeling of fabrics [43] and an increase in thermal absorptivity means that the fabrics are cooler to touch [44], it can be stated that fabrics that are made with regenerated bamboo, followed by polyester fibre make people feel cooler when the skin comes into contact with the fabric.

Regarding the assessment of mechanical, thermal comfort and moisture management properties, it can be said that the influence of fibre type on all the properties was confirmed except relative water vapour permeability, and certain fibres have better performance for certain types of property. Therefore it is essential to use a method that evaluates all the properties for the use intended.

AHP Results

Pairwise comparison judgment matrices of criteria for the first and second level are shown in ***Tables 8-11***.

The priority weight of thermal comfort properties was found to be maximum, with a value of 0.649, whereas moisture management and mechanical properties achieved values of 0.279 and 0.072, respectively.

Table 12. Final decision matrix with comfort related quality value ranking of the fabrics.

Sample code	Bursting strength	Pilling propensity	Weight loss	Air permeability	Thermal resistance	Thermal absorptivity	Drying time	Relative wvp	Transfer wicking	AHP score	Rank
BA	0.422	0.900	0.353	0.795	0.706	1.000	0.485	1.000	1.000	0.780	4
CO	0.506	0.900	0.089	1.000	0.449	0.844	0.647	0.963	0.518	0.844	1
PET	1.000	1.000	0.605	0.602	1.000	0.967	1.000	0.945	0.383	0.787	2
BA/PET	0.427	0.950	0.134	0.660	0.601	0.962	0.805	0.996	0.393	0.732	5
BA/CO	0.420	0.950	1.000	0.721	0.498	0.992	0.607	0.979	0.388	0.726	6
CO/PET	0.535	1.000	0.640	0.780	0.457	0.859	0.846	0.940	0.833	0.782	3

At the second level of the hierarchy in ***Tables 9***, ***10*** and ***11***, pilling propensity as a mechanical property, air permeability as a thermal comfort property and drying time as a moisture management property were found to be more important than the other properties within the related criteria. Since the CR values are below the critical value (0.10), the pairwise comparison matrices were found to be consistent and acceptable.

After the determination of priorities for each sub-criteria, the final decision matrix was developed for each alternative, as shown in ***Table 12***.

From ***Table 12***, it is seen that 100% cotton fabric holds the 1st rank with respect to appropriateness for summer clothing. Pure cotton fabric is followed by 100% polyester fabric and 100% regenerated bamboo fabric, both of which have very close priority values according to the AHP assessment. Cotton and polyester can also be suggested if the blending of these fibres is considered. Regenerated bamboo fibre and its blends seem to show the lowest performance in these group of fibres as the AHP rankings of pure regenerated bamboo and bamboo blended fabrics were observed to be 4th through 6th.

Conslusions

In this paper, it was attempted to evaluate single jersey knitted fabrics made with pure cotton, pure regenerated bamboo and pure polyester and their blends with respect to suitability for use in summer clothing.

The results of statistical analysis revealed that fibre type had a significant influence on all of the properties measured except relative water vapour permeability. According to the experimental results, the fabrics made with polyester fibre showed the performance required in terms of mechanical and moisture management properties, whereas, regarding the thermal comfort properties, all fibre types had some special distinguishing performances.

According to AHP assessment, which combines all the properties measured, assigning weights in terms of their significance, it can be concluded that 100% cotton fabrics should be preferred for use in summer clothing with regard to mechanical and thermophysiological comfort related properties. Nonetheless the ranking model proposed in this study can be extended to include sensorial comfort and aesthetic properties such as handle and drape. which can lead to more comprehensive findings.

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