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Functional properties of bamboo/polyester blended knitted apparel fabrics

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The functional properties of bamboo/polyester blended knitted fabrics, intended to be used for summer clothing, have been studied. It is observed that with increasing bamboo content the yarn hairiness and unevenness increase and the tenacity decreases. It is also found that the increase in bamboo content in the blend increases the ultra-violet protection factor, water vapour permeability and wickability. On the other hand, with the increase in bamboo content in the fabric there is a decrease in bursting strength, air permeability and thermal resistance. The fabrics loose their anti-bacterial property when bamboo is gradually replaced by polyester. The findings of the study suggest that polyester/bamboo blends must contain more than 80% bamboo fibres in order to retain sufficient anti-bacterial property of bamboo fibres in the fabrics.

Keywords: Anti-bacterial activity, Bamboo, Knitted fabrics, Transverse wicking, UV protection

1 Introduction

The demands from fabrics have changed with the developments in technology and the rising living standards. Now the requirement is not only style and durability, but also clothing comfort which includes psychological, sensorial and thermo-physiological comfort. It is evident that fibre type, yarn properties, fabric structure, finishing treatments and clothing conditions are the main factors affecting clothing comfort. Over last few years, there has been growing interest in knitted fabrics due to their simple production technique, low cost, high levels of clothing comfort and wide product range. Knitted fabrics not only posses stretch and provide freedom of movement, but they also have good handle and ability to transmit vapour from the body. Therefore, knitted fabrics are commonly preferred for sportswear, casual wear and all types of intimate apparel like underwear, bath-suits, tight t-shirts and socks.

Bamboo fibre is a regenerated cellulosic fibre produced from bamboo. The type of bamboo used for apparel is Moso bamboo (***Phyllostachys pubescens***)[1]. Starchy pulp is produced from bamboo stems and leaves through a process of alkaline hydrolysis and multi-phase bleaching. Further chemical processes produce bamboo fibre. They have got numerous unique properties like inherent anti-bacterial property (a unique anti-bacteria and bacteriostasis bio-agent named "Bamboo Kun" is combined with bamboo cellulose molecules tightly and remains all along during the process of being produced into bamboo fibre), good level of ultra violet protection (UPF), and anti-static property. Bamboo fibre fabrics are characterized by their good hygroscopicity, excellent permeability, soft feel and easy dyeing[2-4]. Also, bamboo cultivation does not require fertilizers, pesticides and chemical herbicides. They are regarded as a renewable and biodegradable fibre because of their remarkable attributes. It's cultivation requires very little water and it is naturally regenerative. Bamboo is one of the fastest growing plants. It has lesser impact on environmental issues as compared with conventional cotton and other petroleum derived synthetic fibres. Cultivation of conventional cotton involves large quantities of water and pesticides. So, bamboo fibre can be considered as a potential substitute to conventional synthetic fibres and cotton fibres. Bamboo fibres are 100% bio-degradable. In spite of all these, bamboo fibres have got certain negative attributes, like spinners find it difficult to spin 100% bamboo yarns as they produce fly in roving and drawing. Also due to the technology involved in the production of bamboo fibres it is around 2.5 times costlier than cotton. In order to avail the positive attributes of the fibre and to achieve economy we have tried blending bamboo with polyester. The secondary reason for selecting this blend lies in the fact that bamboo fibre has got low tensile strength which decreases further, when it is wet[5].

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Hence, in this research work, yarns and fabrics made of different blends of polyester and bamboo have been studied and analysed. Keeping in view the demand for knitted garment these days, knitted fabrics have been produced and studied.

2 Materials and Methods

For the study, bamboo fibres have been imported from "Shanghai Tenbro Bamboo Textiles Co. Ltd", Shanghai, China and polyester fibres from Reliance Industries Ltd, Patalganga, India. Seven plain-knitted (single-jersey) fabrics of 15.75 wales/cm (40 wales/inch) and 17.3 courses/cm (44 courses/inch) were prepared using ring-spun blended yarns of 70/30, 60/40, 50/50, 40/60, 30/70, 20/80 and 10/90 polyester/bamboo. Polyester and bamboo fibres of 38 mm and 1.4 denier were used to prepare the yarns of the above blends. Yarns of 197 dtex (30s Ne) (nominal count) were prepared by conventional ring spinning method in G5/1 ringframe at a spindle speed of 14000 rpm and a twist factor of 3.4. 100% polyester and 100% bamboo yarns were also prepared for comparison purpose. Sample fabrics were then knitted from the above yarns on a 22 gauge Monarch-Vanguard supreme circular knitting machine with 24inch diameter and 72 feeders. The fabrics were then bleached with 2 g/L caustic soda, 9ml/L hydroperoxide (35%), and 3 g/L Tinoclarite CSW refining agent at 98°C for 50 min. They were then dyed in a single bath[6] using Dianix Dark blue SE-3RT (Disperse) and Procion Blue HE-RD (Reactive) dyes at 120°C and neutral ***p***H. Half of each dyed samples were given 35 wash cycles of home laundering (AATCC 135-2000).

The yarns were tested for strength and elongation (ASTM D2256-95a)[7], hairiness (UT-3) and unevenness (Zweigle hairiness tester - Model G565). The fabrics were tested for bursting strength (IS 1966:1975), abrasion resistance (BS EN ISO 12947-2 and 3), pilling (BS5811-1986 - ICI Pilling Tester)[8], ultra- violet protection factor (AATCC 183 – 2000), anti-bacterial property (AATCC 100-1999 and 147-1998)[9], whiteness index (AATCC-110-1995), thermal insulation (Alambeta), vertical (TAPCC) and transverse wicking, water vapour permeability (ISO 11092- Permetest) and air permeability (IS 11056 – 1984). Transverse wicking (in-plane wicking) is the transmission of a liquid through the thickness of the fabric. An instrument developed by IIT-Delhi has been used to measure in-plane wicking of fabrics. A fabric sample (160 mm×160 mm) was placed on a horizontal base plate which was connected to a liquid reservoir by means of a siphon tube. The fabric sample was covered by a cover plate so as to ensure intimate contact between the base plate and the fabric. The spatial relationship between the bottom surface of the test specimen in contact with the liquid in the siphon tube and the liquid level in the reservoir is adjustable. Water level in the reservoir and fabric level was kept the same. The liquid reservoir was placed on an electronic balance interfaced with a PC. The balance indicates the weight of water that left the reservoir and the difference between the two consecutive readings shows the weight of water taken by the fabric with time. Five observations were taken after 30s and 90s for each sample.

Results are compared between the blends and also within the blends of washed and unwashed fabrics. Before testing, all the fabric samples were pre-conditioned in standard atmosphere for 8 h according to ASTM D 1776 – 98 standards.

3 Results and Discussion

3.1 Fibre and Yarn Test Results

The fibres used in this study have the specifications as shown in Table 1. The yarns are tested for strength, elongation-at-break, hairiness and U%. The results are shown in Table 2.

Table 2 shows that the yarn strength and elongation-at-break reduce with the increase in bamboo content in the blend. This may be attributed to the low tenacity (Table 1) and weak cohesion of the bamboo fibres. Also there exists a large difference in the tensile properties of 100% polyester and 100% bamboo yarn.

Table 3 shows that, in general, there is an increase in U% which may be due to the increase in bamboo content. As mentioned in the literature[2], the yarn irregularity increases with increasing movement of floating fibres in drafting zone and the bamboo fibres are difficult to get integrated in the drafting strand

Table 1—Fibre specifications

Fibre	Dry tensile strength cN/dtex	Dry tensile strength CV%	Wet tensile strength cN/dtex	Linear density denier	Denier CV%	Fibre length, mm
Bamboo	2.11	10.74	1.18	1.4	0.7	38
Polyester	3.96	7.23	3.90	1.4	0.4	38

Table 2—Yarn strength and elongation

Blend (P/B)	Strain-at-break %		Tenacity-at-break cN/dtex		Modulus cN/dtex	
	Mean	CV%	Mean	CV%	Mean	CV%
100/0	12.26	4.22	3.49	6.21	62.43	5.55
70/30	10.95	8.63	2.62	7.42	55.89	12.62
60/40	10.72	4.56	2.38	7.81	51.51	8.89
50/50	10.58	5.42	2.12	6.96	49.20	8.71
40/60	10.53	6.53	1.99	7.37	48.17	7.95
30/70	10.56	6.70	1.83	6.75	46.59	6.11
20/80	10.12	7.31	1.78	4.87	45.96	7.87
10/90	10.18	6.34	1.65	5.56	45.20	5.98
0/100	8.76	6.42	1.39	6.54	41.32	6.47

Table 3—Unevenness, imperfection and hairiness values of yarns

Blend P/B	U% (Mean)	Thin places (-50%) (Mean)	Thick places (+50%) (Mean)	Neps (200%) (Mean)	Hairiness (100m)			Hairiness (200m)		
					1-2 mm	2-3 mm	3mm & more	1-2 mm	2-3 mm	3mm & more
70/30	11.70	3	6	5	8003	71	1	15495	147	4
60/40	12.55	4	8	7	8377	86	2	16224	177	6
50/50	12.45	6	7	6	9000	94	3	17711	207	7
40/60	13.58	7	9	8	10673	97	5	19851	222	10
30/70	13.80	7	9	8	10730	118	5	19815	241	11
20/80	14.32	8	10	10	11634	127	6	20319	276	14
10/90	14.76	9	10	10	11956	126	6	20812	278	17

due to weak cohesion between them[2] and also may be due to high rigidity. This may be the reason for increasing yarn irregularity in the blends.

The hairiness results (Table 3) show an increasing trend with increase in the bamboo content in the blend. It has been mentioned[2] that the bamboo fibres show weak cohesion and that the bamboo fibres do not get fully integrated into yarn because of the poor twist flow. So, they have protruding hairs or wild fibres. Selvedge fibres in the strand do not get fully integrated into the yarn, as twist does not flow right up to the nip because of spinning triangle. Because of weak cohesion between the fibres the trailing portion of majority of selvedge fibres in the spinning triangle therefore remain protruded from the yarn strand and show up as hairs. The leading portion of fibres at the extreme end of selvedge may sometimes also project as hair, because of their non-integration or lesser integration into yarn strand. It has also been cited in the literature that rigidity is one of the most important properties of fibre that influences hairiness[2]. So, bamboo fibres may have higher resistance to twisting because of higher flexural and torsional rigidity, which owes to higher hairiness.

3.2 Fabric Test Results

The thickness, weight per unit area and the whiteness index of the bleached fabrics are shown in Table 4. The thickness of the fabrics increases with the increase in bamboo content which may be attributed to the higher amount of hairiness of the bamboo rich yarns (the fabric thickness measured at a low pressure of 2gf/cm^2). The whiteness index of the fabric was measured after bleaching and it is found to decrease with the increase in the blend percentage of bamboo fibre. This is due to the fact that bamboo fibre is yellower than polyester or viscose. So, as the bamboo content increases fabric yellowness increases and thus the whiteness index decreases.

3.2.1 Bursting Strength

Figure 1 shows that the bursting strength of the fabrics reduces with increasing bamboo content in the blend. Though bursting strength of a fabric is affected by many factors, here it may be accounted for the increase in bamboo content, as all other parameters of the fabric are nearly same. The elongation-at-break of the bamboo fibres is lower than that of polyester[2], which may result in decreasing elongation of yarn samples with increasing bamboo content in the blend. This could be the reason for lower bursting strength of bamboo rich fabrics. It may also be attributed to the lower strength of bamboo fibres[10]. It is also observed that the bursting strength decreases after 35 cycles of wash given to the fabric. But the extent of decrease in bursting strength is not to an objectionable extent.

3.2.2 Thermal Resistance

The thermal resistance is found to decrease (Fig. 1) as the blend percentage of bamboo is increasing. As per the results obtained from the air permeability and hairiness test, the thermal resistance should increase with increasing bamboo content. But the trend is reversed here. So, other affecting factors must be playing a role. The thermal insulation value depends upon many factors of fabric, yarn and fibre. The varying parameter used in this study is the change in blend content of bamboo. One of the reasons may be due to the nature of fibre in the blend, i.e. poor insulation property (higher heat conductivity) of bamboo fibres consisting of cellulose. Therefore the thermal resistance is decreasing with the increase in bamboo content in the various blends of fabrics. But the values of thermal insulation of fabrics with very high amount of bamboo also are still good which may be due to the fibre microstructure which is filled with lot of air pockets which can entrap large amount of air. The washed fabrics show slightly reduced thermal insulation due to reduction in porosity of the fabrics marginally due to fabric shrinkage.

Table 4—Specifications of fabrics

Fabric code	Polyester/bamboo %	Thickness mm	Whiteness index (Bleached fabrics)	Fabric weight g/m^2
PB1	70/30	0.602	61.330	135
PB2	60/40	0.603	56.307	138
PB3	50/50	0.605	51.545	140
PB4	40/60	0.614	49.302	140
PB5	30/70	0.621	48.292	142
PB6	20/80	0.630	46.917	149
PB7	10/90	0.642	44.234	148

3.2.3 Ultra Violet Protection

Form Fig. 1 it is evident that the UPF of the fabrics increases with the increase in bamboo content in the blend. Bamboo fibre has got inherent ability of providing high UV protection to the human skin[1]. So, as the bamboo content increases the UPF of the fabrics increases. Secondly, it can be observed that there is an increase in UPF after washing. The washing comprises 35 wash cycles. The increase in UPF may be attributed to the shrinkage of cellulosics on washing which results in blocking the pores in the fabric.

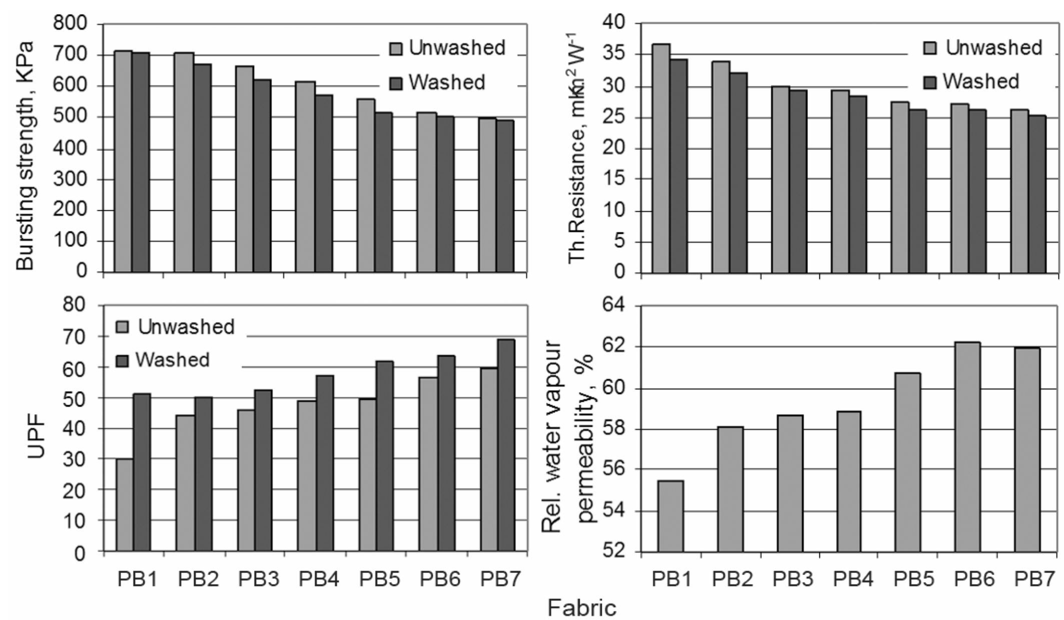

Fig. 1—Effect of blend % on bursting strength, thermal resistance, UV protection factor and water vapour permeability of fabrics

The UV transmittance of the blended fabrics also decrease with increasing bamboo content (both UVA and UVB) which further decreases after washing. The percentage of UVB blocking abilities of the fabric should be in 97- 99% range even after two years of wear and tear.

According to the labelling categories of UV protection for fabric and garments[11] it has been suggested that an UPF of more than 40 is considered to be excellent. The results show that all the blended fabrics are equally well UV protective.

3.2.4 Relative Water Vapour Permeability

Figure 1 shows that the water vapour permeability increases with the increase in bamboo content. As the blend comprises polyester and bamboo, it is clear that the increase in bamboo content will increase the water vapour permeability. It has also been mentioned in the literature[4,12] that the water vapour permeability of bamboo fibre is high. This is because the cross-section of the bamboo fibre is filled with micro-pockets providing amazing absorption and ventilation. With this unique microstructure, bamboo fibre apparel will absorb and evaporate human sweat very quickly.

3.2.5 Air Permeability

Air permeability of the fabrics decreases with increasing bamboo content (Fig. 2). This can be related to increasing hairiness. It has been observed that the hairiness increases with the increase in bamboo content. This increasing hairiness resists the air flow and hence decreases the air permeability with increasing bamboo content in the blends.

There are many other factors like weave and thickness which affect the air permeability but all of these being nearly same in the tested fabrics. Hence, blend variation is the only reason for the air permeability to reduce. The results when compared with respect to washed and unwashed samples it can be observed that the air permeability decreases with 35 cycles of wash. The amount of reduction of air permeability is more with the increase in bamboo content. Washing causes cellulosics to shrink. Therefore, the air permeability decreases after washing and the difference in air permeability before and after washing is more with the increase in cellulosic contents in the blend.

3.2.6 Wicking

Figure 2 shows that the wickability increases with increase in bamboo percentage. Bamboo fabric retains the water absorption properties of the plant. Bamboo is a highly water absorbent plant, able to take up three times its weight in water. The cross-section of the bamboo fibre is filled with micro-pockets and channels that give the fibre very high wicking properties. The bamboo fibre have got very good wickability often better than polyester[1]. Therefore, wickability of the fabrics increases with the increase in bamboo fibre content.

It can also be observed here that the wickability is more in wale-wise direction as compared to that in course-wise direction. This is due to the fact that the transfer of water is easier in wale- wise direction, due to the better capillary action in wale-wise direction.

The transverse wickability of the fabrics increases with increasing bamboo content in the blend (Fig. 2).

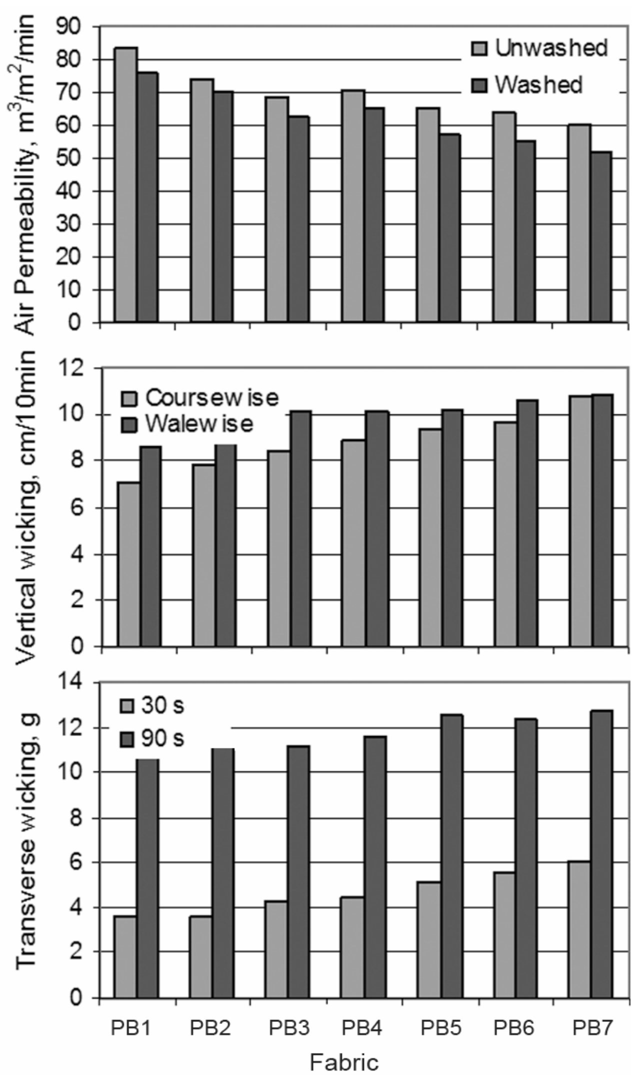

Fig. 2—Effect of blend % on fabric air permeability, vertical wicking behaviour and transverse wicking behaviour

Table 5—Anti-bacterial properties of polyester/bamboo blended fabrics

Fabric	AATCC 147 (unwashed)		AATCC 100 (UFC) after 35 cycles of laundering					
	Growth on contact	Zone of inhibition, mm	‘0’ time (approx 1 min)	30 min	1 h	6 h	24 h	% reduction
PB1	Yes	0	4100	3900	4400	72000	>5,50,000	0
PB2	Yes	0	3700	3800	4100	65000	>4,80,000	0
PB3	Yes	0	3900	4000	4000	59000	>3,00,000	0
PB4	Yes	0	3500	3900	3700	40000	>1,00,000	0
PB5	Marginal	0	1800	2000	2800	10000	40,000	0
PB6	No	4	200	800	300	64	19	>80
PB7	No	6	25	38	31	22	21	>90

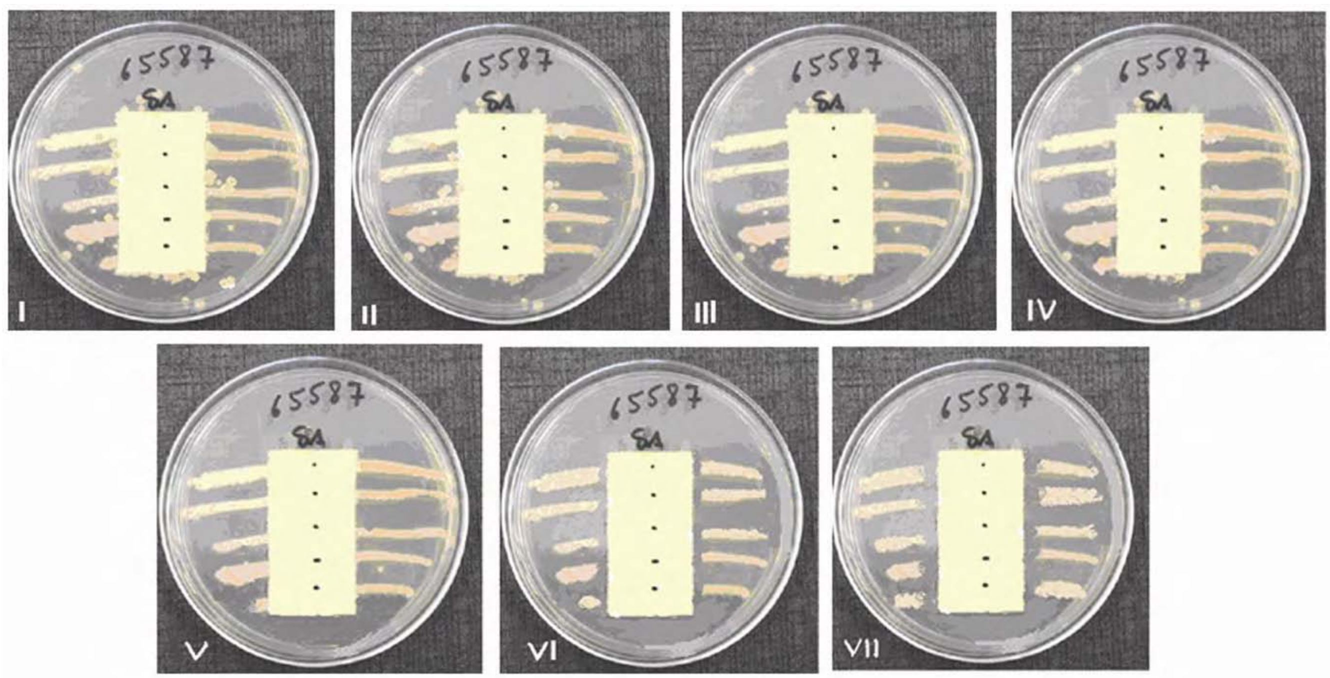

Fig. 3—Anti-bacterial activity of polyester/bamboo blended unwashed knitted fabrics [(I) PB1, (II) PB2, (III) PB3, (IV) PB4, (V) PB5, (VI) PB6 and (VII) PB7]

This may be attributed to the micro channels present in the fibres as well as the higher absorbency of the bamboo fibres. Also the absolute values of amounts of wicked water in all the fabrics are very high suggesting a very good moisture absorbing capacity of the fabrics.

3.2.7 Abrasion and Pilling

The abrasion and pilling test show poor results with poor rating for most of the fabrics. This may be due to the fact that the fabric under test is knitted one. The yarns used for knitting is single yarn and is given low twist of 16tpi. So, this may be the reason for poor abrasion and pilling resistance. Pilling resistance does not show much of variation in its grade. In the case of abrasion resistance the trend is not clear but at many points it is observed that the resistance to abrasion is increasing with the increase in bamboo fibre in the blend. Actually, both bamboo and polyester are equally good in terms of abrasion resistance because of their high elasticity. So replacing on fibre with the other will not make a difference in the fabric abrasion resistance[12].

Comparing the two properties with respect to washed and unwashed samples the changes observed in abrasion as well as pilling resistance are not much, even after 35 cycles of wash given to the fabrics.

3.2.8 Anti-bacterial Property

The anti-bacterial activity is qualitatively and quantitatively evaluated against ***Staphylococcus aureus*** (AATCC 6538), a Gram positive organism, according to AATCC 147 and AATCC 100 test method. The results (Table 5 and Fig. 3) show that no antibacterial activity is observed for fabrics with less than 70% bamboo fibres in it. But some anti-bacterial activity and considerable anti-bacterial activity are observed for fabrics having 80 % and 90 % bamboo fibres respectively (both unwashed and washed). According to literature[2], 100% bamboo fibre fabric exhibits excellent anti-bacterial activity, but this is not the case with the various blends of bamboo polyester studied over here. As per the study, the content of bamboo in a blend should be greater than 70% in order to retain anti-bacterial property in the fabric. So it can be concluded that the in order to retain the anti-bacterial activity of bamboo blend the blend composition should comprise more than 70% (preferably 80%) of bamboo fibres. So, this adds to the limitation of blending polyester with bamboo.

4 Conclusion

4.1 As the bamboo content of the yarn increases the yarn hairiness and unevenness increase along with a decrease in tenacity. Special attention has to be given during spinning of polyester/bamboo blended yarn with appropriate drafting system in order to achieve proper integration of fibres in yarn and to achieve better yarn properties.

4.2 The increase in bamboo content in the P/B blended fabric causes the UV protection factor and water vapour permeability to increase. The fabrics also exhibit increase in wickability (vertical as well as transverse wicking) with the increase in bamboo content. These all add to the advantages offered by the fabrics and make it suitable for being used in summers.

4.3 On the other hand, with the increase in bamboo content there is a decrease in bursting strength, air permeability, thermal resistance and whiteness index. Although the air permeability and thermal resistance decrease with the increase in bamboo content, the values obtained individually are within comfortable range for the human skin.

4.4 The fabric looses its anti-bacterial property when bamboo is gradually replaced by polyester. This is a major drawback of blending polyester with bamboo. The findings of the study suggest that P/B blends must contain greater than 80% of bamboo fibres in order to retain the anti-bacterial property of bamboo fibres in the fabrics. But considering the cost of both the components (bamboo and polyester), it is clear that by replacing 20% of bamboo with polyester the total cost of a garment can be reduced substantially without affecting its properties drastically.

4.5 After assessing the properties of the blended fabrics, the results thus obtained suggest that P/B blended fabrics made of high bamboo percentage are suitable for summer clothing especially in countries near the tropical region as they exhibit good water vapour permeability, and wicking and high UV protection ability. Also the values of thermal resistance and air permeability are within the comfort level of human skin.

Due to its UV protecting and anti-bacterial abilities, this fabric may soon find its way into many retail outlets and will be used in hospitals and sanitary clothing. If organic clothing made from bamboo becomes popular, it will lead to more bamboo plantations, more photosynthesis and less green house gas effects. Thus, one of the critical problems facing mankind will become easier to solve.

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