Indian Journal of Fibre & Textile Research
Vol. 36, March 2011, pp. 18-23

Properties of ring-spun yarns made from cotton and regenerated bamboo fibres

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Received 29 April 2010; revised received and accepted 7 June 2010

The properties of ring-spun yarns made from cotton and regenerated bamboo cellulosic fibres and their blends have been studied. Three blend proportions (100% cotton, 50:50 cotton-bamboo and 100% bamboo) have been used to produce yarns of three different counts (20s, 25s and 30s) and these yarns are then tested for their diameter, tensile, evenness and hairiness related properties. It is found that the yarn diameter reduces as the proportion of bamboo fibre increases. The yarn tenacity first reduces and then increases but the elongation increases continuously as the proportion of bamboo fibre increases. The yarn unevenness is found to be maximum for 50:50 cotton-bamboo yarns. The 100% cotton and 100% bamboo yarns are having comparable unevenness except for 30s count. Hairiness of yarn in different length classes and mean hair length reduce continuously as the percentage of bamboo fibre increases. However, for the same blend proportion, mean hair length is found to be independent on the yarn count.

Keywords: Bamboo, Cotton, Hairiness, Ring spinning, Tenacity, Yarns

1 Introduction

Blending of different fibres is a very common practice in the spinning industries. The blending is primarily done to enhance the properties of resultant fibre mix and to optimise the cost of the raw material. The properties of blended yarns primarily depend on the properties of the constituent fibres and their compatibility. Moreover, the proportion of fibres in the blend also plays a significant role. It has been observed that the stronger component has to be mixed at least by a certain proportion in order to gain in terms of tensile properties[1].

Ratnam *et al.*[2] developed an expression to predict the strength of the blended yarn spun at optimum twist, in terms of the strengths of yarns spun from the two components at optimum twist. Good agreement between the predicted and the observed values was found over a range of cottons and counts. Zurec[3] experimented on the recovery of yarns made of viscose, acetate and polyamide fibres and of their blends and analysed them at various levels of strains. Based on the experimental results, he proposed the mechanics of elastic recovery of the blended yarns. Balasubramanian[4] investigated the migration behavior of fibres in the blended yarn structure. He reported that long and fine fibres have a definite tendency to migrate towards the core, while short and coarse fibres concentrate near the surface. He also found that strand width at the delivery nip has a significant effect on the arrangement of fibres in the yarn structure. Anandjiwala *et al.*[5] mixed high tenacity but low elongation Pima cotton with low tenacity but high elongation Upland cotton in the drawframe and blowroom stages. They found that 50:50 Pima-Upland mix, irrespective of stage of mixing, always gives lower tenacity than the yarns spun from 100% Pima or 100% Upland cotton. However, the blowroom mixing showed improved tenacity results as compared to drawframe mixing. Barella and Manich[6] found that the hairiness of cotton-polyester blended yarns increases with the increase in cotton fibre proportion. They attributed the reason to the short fibre content in the cotton fibre. Sett *et al.*[7] studied the tensile properties of jute-cotton and jute-viscose blended yarns spun on Dref-II and rotor spinning systems. They reported that the tensile and viscoelastic characteristics of rotor and friction (Dref-2) spun jute blended yarns depend partly on fibre alignment and partly on the noncompatibility of the tensile properties of their component fibres. Aghasian *et al.*[8] investigated various properties of rotor-spun yarns spun from polyester-cotton blends. They also tried to predict the properties of the blended yarns using the rule of mixtures (ROM). The experimental results of the yarn tenacity were also compared with Hamburger's[1] model and it was found that the tenacity of the yarns does not follow the Hamburger's model.

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Tenacity, work of rupture and hairiness were found to be decreased in blended yarns while the uniformity, thick places, and neps were increased. Several other researchers[9-11] have worked on the properties of blended yarns.

Bamboo textile products are having high demands in the market because of their antibacterial nature, biodegradable properties, high moisture absorption capacity, softness and UV protective capability. With its high moisture absorption capacity, breathability and fast drying behaviour, bamboo fibre ensures comfort in various applications. Currently, regenerated bamboo fibres are being used in apparels including undergarments, sports textiles, t-shirts and socks. It is also found to be suitable for hygienic products and sanitary materials such as sanitary napkins, absorbing pads, masks, bandages and surgical gowns.

Xu *et al.*[12] analysed the properties of bamboo-viscose, Tencel and conventional viscose fibres to explain the similarity and difference in their molecular and fine structures. They reported that Tencel consists of longer molecules and has a greater degree of crystallinity, while bamboo-viscose fibre has a lower degree of crystallinity. All the three fibres resemble in thermal behavior with a two-step decomposition mode. Erdumlu and Ozipek[13] studied the properties of 100% regenerated bamboo yarns spun in six different counts using ring spinning technology. Subsequently, the physical parameters of yarns were tested and compared against the parameters of 100% viscose rayon as per the Uster statistics. Although some sporadic efforts have been made to investigate and analyse the properties of bamboo fibre blended yarns, there is dearth of detailed research on the gamut of bamboo yarn properties. Hence, in the present work an attempt has been made to study and analyse the properties of cotton, bamboo and cotton-bamboo blended yarns.

2 Materials and Methods

Ring-spun yarns of 20s (30 tex), 25s (24 tex) and 30s (20 tex) were spun in a spinning mill from 100% cotton, 50:50 cotton-bamboo and 100% bamboo fibres. The upper half mean length, bundle tenacity and micronaire of cotton fibre were 28 mm, 28.5 g/tex and 4.5 respectively. The length and denier values of bamboo fibre were 38 mm and 1.4 respectively. For all the yarns, the roving count was 1.05s (562 tex). The ring frame twist multiplier and spindle speed were 3.8 and 15500 rpm respectively. The 100% cotton fibres were processed through combing line. To maintain the length compatibility between cotton and bamboo fibres, in case of cotton-bamboo blend, cotton slivers were processed up to the combing stage and then the combed cotton slivers were blended with bamboo fibres in the blowroom stage.

The yarn samples were tested for their diameter using Projectina microscope. For each yarn sample, five cones were selected randomly and from each cone 10 readings of diameter were noted. The mean yarn diameter was calculated from the 50 individual readings. Tensile properties of yarns were evaluated using Instron tensile tester (Model 4301) at a crosshead speed of 300 m/min. For each yarn sample, 50 readings were taken and then averages were calculated. The unevenness and hairiness of yarns were measured by Premier unevenness tester. For each yarn sample, 3 cones were randomly selected and 1000 m length was tested from each cone at a testing speed of 400 m/min.

3 Results and Discussion

3.1 Yarn Diameter and Packing Fraction

Table 1 shows the yarn diameter for different yarn counts and blend proportions. It is observed that for the same yarn count as the proportion of bamboo fibre increases, the diameter of the yarn reduces. The

Table 1— Diameter and tensile properties of yarns

Yarn count Ne	Blend	Diameter mm	Tenacity g/tex	Elongation %	Modulus g/tex	Bending rigidity g.cm^2
20s	Cotton	0.260	14.90	5.17	313.0	0.00612
	Cotton-bamboo	0.242	10.98	6.27	253.4	0.00236
	Bamboo	0.213	12.47	12.48	231.5	0.00236
25s	Cotton	0.226	13.23	4.86	311.9	0.00328
	Cotton-bamboo	0.213	10.60	5.30	288.4	0.00268
	Bamboo	0.192	12.81	12.94	254.6	0.00265
30s	Cotton	0.213	13.03	4.60	316.8	0.00262
	Cotton-bamboo	0.192	11.03	4.89	315.6	0.00178
	Bamboo	0.179	12.67	11.21	254.9	0.00141

density of cotton and bamboo fibres is equal ($1.51\ g/cm^3$). Therefore, it is evident that bamboo fibres are better packed in the yarn cross-section as compared to the cotton fibres. Based on the linear density and diameter, the packing fraction of different yarns was calculated[14] and the results are shown in Fig. 1. It is found that as the proportion of bamboo fibre increases the packing fraction of the yarn is also rises concomitantly. The effect is more prominent when the bamboo fibre proportion is increased from 50% to 100%.

The bamboo fibres are having longer length (38 mm) than that of cotton fibres. Moreover, the bamboo fibres have lower bending and torsional rigidity. Therefore, they are packed better in the yarn structure than the cotton fibres. Scanning electron microscopic photographs (Fig. 2) also depict that fibres are more uniformly and compactly twisted in case of bamboo yarn, whereas the fibres are rather loose in case of cotton yarn. Lower diameter of bamboo yarns may lead to better air permeability and moisture vapour permeability of the fabrics.

3.2 Tensile Properties

The tensile properties of yarns are shown in Table 1. It is observed that as the proportion of bamboo fibre increases, the tenacity first reduces and then increases. For all the three counts, 50:50 cotton-bamboo blend is producing the weakest yarn. This may be attributed to the different breaking elongation of cotton and bamboo fibres. As the breaking elongation of cotton fibre is much lower than that of bamboo fibre, cotton fibres are expected to reach the rupture point earlier during tensile testing of cotton-bamboo blended yarns. Table 1 shows that the cotton-bamboo blended yarns are actually breaking at an elongation which is very close to the breaking elongation of 100% cotton yarns. Moreover, the breaking elongation of cotton-bamboo blended yarns is found to be around half or even less as compared to the breaking elongation of 100% bamboo yarns. The bamboo fibres, at the rupture point of cotton-bamboo blended yarns, will contribute partially towards the breaking load of the blended yarns. However, as soon as the cotton fibre constituents of the cotton-bamboo blended yarns rupture, the entire yarn structure collapses as the remaining constituents (bamboo fibres) cannot withstand the load which has already been generated at the rupture point of cotton fibres. This ultimately leads to the reduction in yarn tenacity with respect to the 100% cotton yarns. Similar behaviour of blend yarn tenacity, when the constituent fibres are having large difference in elongation, was also reported by Cheng *et al.*[15]. Yarns spun from 100% bamboo fibres show some improvement in tenacity with respect to the 50:50 cotton-bamboo yarns as all the bamboo fibres are expected to reach the rupture point simultaneously and thereby contributing more towards the yarn tenacity. To analyse the above hypothesis quantitatively, an attempt has been made to predict the tenacity of the blended yarns using the similar approach proposed by Hamburger[1]. The expression used for the prediction of blended yarn tenacity is shown below:

$$\text{Tenacity}_{\text{Blend}} = \frac{1}{100} \times \left[\text{Cotton }\%.\text{Tenacity}_{\text{Cotton}} + \text{Bamboo }\% \left\{\text{Tenacity}_{\text{Bamboo}} \cdot \frac{\varepsilon_{\text{Blend}}}{\varepsilon_{\text{Bamboo}}}\right\}\right] \quad \ldots (1)$$

where ε_{Blend} is the breaking elongation of the cotton-bamboo blended yarn; and ε_{Bamboo}, the breaking

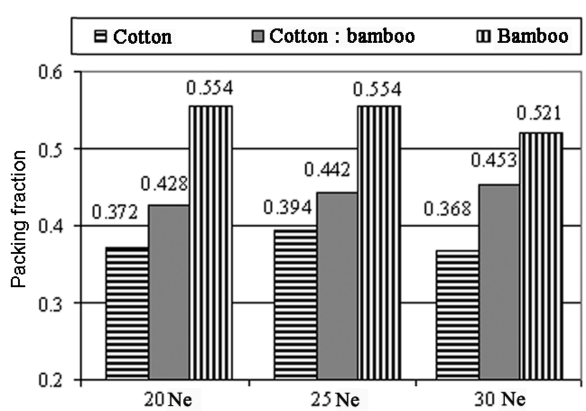

Fig. 1— Packing fraction of different yarns[14]

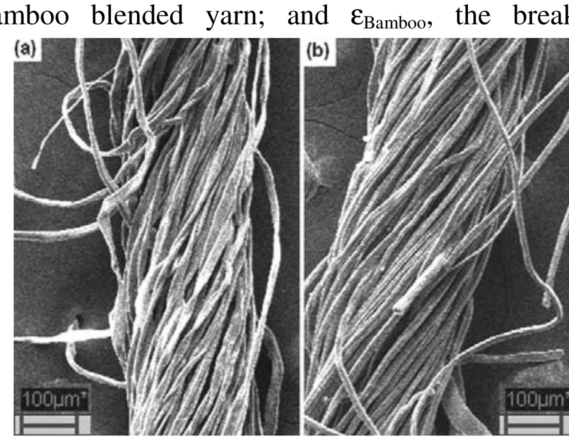

Fig. 2— SEM images (×150) of cotton (a) and bamboo (b) yarns of 25 Ne

elongation of the 100% bamboo yarn for the same count.

The predicted values of blended yarn tenacity are 10.58, 9.23 and 9.27 g/tex respectively for 20s, 25s and 30s counts. Table 1 shows that the corresponding experimental values of blended yarn tenacity are 10.98, 10.60 and 11.03 g/ tex. Although the Eq. (1) underestimates the tenacity of the cotton-bamboo blended yarns in all the three cases, it bolsters the experimental results that the tenacity of the cotton-bamboo blended yarn should actually be lower than that of 100% cotton or 100% bamboo yarns. Addition of bamboo fibre increases the elongation and reduces the tensile modulus as expected. Yarn count seems to have no distinct effect on the tensile modulus specially in case of cotton yarns.

It is also observed from Table 1 that as the proportion of bamboo fibre increases, the bending rigidity of the yarn reduces. As the diameter and tensile modulus of bamboo yarns are lower than that of equivalent cotton yarn, the bending rigidity of the former is expected to be lower than that of the latter. Bending rigidity can be expressed using the following equation:

Bending rigidity = $E.I$

For circular cross-section: $$I = \frac{\pi d^4}{64} \quad \ldots (2)$$

where E is the tensile modulus; I, the area moment of inertia; and d, the diameter of yarn.

Lower bending rigidity of bamboo yarns will not only make the loop formation easier during the knitting process but also produce softer handle in the final fabric.

3.3 Yarn Unevenness

Table 2 shows the results of yarn unevenness and imperfections. It is observed that 50:50 cotton-bamboo blended yarns are showing higher unevenness values than the 100% cotton or 100% bamboo yarns. The 100% cotton and 100% bamboo yarns are having comparable unevenness values in case of 20s and 25s counts. When the bamboo fibre is blended with cotton, the difference in their lengths causes floating fibres and thereby increases the unevenness. The higher unevenness value of 50:50 cotton-bamboo blend may also be responsible for the lower yarn tenacity in that particular blend. Irrespective of blend, the yarn unevenness increases as the yarn becomes finer, as expected.

3.4 Yarn Hairiness

Table 3 shows the yarn hairiness (per 100 m)in

Table 2— Unevenness and imperfections of yarns

Yarn count Ne	Blend	Unevenness %	Thin places km^{-1}	Thick places km^{-1}	Neps km^{-1}
20s	Cotton	8.23	0	4	6
	Cotton-bamboo	8.40	4	5	6
	Bamboo	8.34	0	6	12
25s	Cotton	8.82	0	11	12
	Cotton-bamboo	9.44	2	13	10
	Bamboo	8.73	0	6	13
30s	Cotton	9.21	0	9	17
	Cotton-bamboo	10.13	1	28	52
	Bamboo	9.83	2	11	18

Table 3— Hairiness results of yarns

Yarn count Ne	Blend	Hairs				
		3 mm	4 mm	5 mm	6 mm	7 mm
20s	Cotton	2078 (73.376)	637 (22.493)	101 (3.566)	15 (0.005)	1.0
	Cotton-bamboo	1559 (78.977)	359 (18.186)	48 (2.432)	7 (0.004)	1.0
	Bamboo	915 (87.309)	124 (11.832)	8 (0.008)	1 (0.001)	0.0
25s	Cotton	1812 (73.153)	555 (22.406)	93 (3.755)	15 (0.006)	1.7
	Cotton-bamboo	1013 (80.717)	212 (16.892)	27 (2.151)	4 (0.003)	0.0
	Bamboo	749 (88.221)	94 (11.071)	6 (0.007)	0 (0.000)	0.0
30s	Cotton	1444 (73.523)	434 (22.097)	74 (3.768)	12 (0.006)	1.0
	Cotton-bamboo	723 (82.629)	133 (15.200)	16 (1.829)	3 (0.003)	0.3
	Bamboo	519 (87.817)	67 (11.337)	5 (0.009)	0 (0.000)	0.0

Values in parentheses indicate hairiness percentage in different classes.

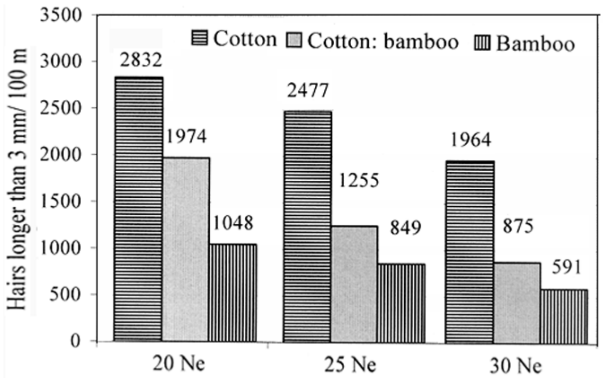

Fig. 3— Effect of bamboo fibre proportion on yarn hairiness

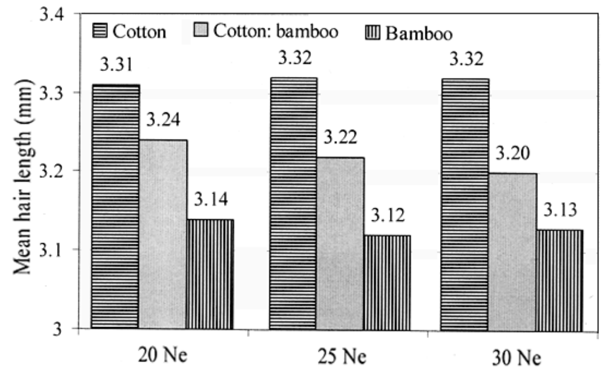

Fig. 4— Effect of bamboo fibre proportion on mean hair length

different length groups starting from 3 mm to 7 mm with an interval of 1 mm. The number of hairs longer than 3 mm has also been shown in Fig. 3. It is observed from Table 3 and Fig. 3 that as the proportion of bamboo fibre increases the hairiness in all the length classes decreases. Bamboo fibres are having longer length than the cotton fibres. Moreover, short fibres are totally absent in the bamboo fibre. The flexural and torsional rigidity of bamboo fibre is also lower than that of cotton fibre. Therefore, bamboo fibres are wrapped very easily in the main yarn body when they emerge from the spinning triangle and thus the hairiness reduces with the increase in bamboo fibre proportion. It is interesting to note that 100% bamboo yarn does not have any hair longer than 6 mm in case of 25s and 30s. Besides, 100% bamboo yarns do not have any hair longer than 7 mm in case of 20s count.

Figure 4 depicts the mean hair length of different yarns. It is observed that as the proportion of bamboo fibre increases, the mean hair length reduces. It is also evident that, for the same blend proportion, mean hair length does not change with the yarn count.

As the yarn becomes finer, for the same blend proportion, the number of hairs reduces and probably this reduction happens in equal proportion in different length groups and therefore the relative frequency of hairs in different length groups remains unaltered. As a consequence, the mean hair length does not really change with the yarn count. To prove this hypothesis, the percentage of hairs in different length groups was calculated and the results are shown in Table 3. It is interesting to note that for 100% cotton yarn, irrespective of yarn count, the proportion of hairs in 3, 4 and 5 mm length categories is around 73, 22 and 4 % respectively. For the 50:50 cotton-bamboo blended yarns the proportion is around 80, 16 and 2% respectively, although some variations has been noticed with yarn counts. For 100% bamboo yarns, irrespective of yarn count, the proportion of hairs in 3, 4 and 5 mm length categories is 88, 11 and 0.008% respectively. The above results also prove that as the proportion of bamboo fibre increases, the percentage of hairs in 3 mm category increases sharply and the percentage of hairs in longer length category (4 mm and 5 mm) declines drastically. Therefore, mean hair length reduces with the increase in bamboo fibre proportion. Figure 4 clearly shows that as the proportion of bamboo fibre increases, the mean hair length reduces consistently.

4 Conclusion

Regenerated bamboo fibre blended yarns are having lower diameter than the equivalent cotton yarns. The tenacity of yarns spun from 50:50 cotton-bamboo blend is lower than that of 100% cotton or 100% bamboo yarns. This happens due to the large difference in breaking extension between cotton and bamboo fibres which leads to the lower load sharing by the bamboo fibre component when the cotton fibre component reaches the rupture point. The breaking elongation of yarn increases and initial modulus reduces as the proportion of bamboo fibre increases. The 50:50 cotton-bamboo yarns are having marginally higher breaking extension than that of 100% cotton yarns. Bending rigidity of yarn also reduces as the percentage of bamboo fibre increases.

The yarn unevenness of 50:50 cotton-bamboo yarns is higher than that of 100% cotton or 100% bamboo yarns. The hairiness of bamboo yarns is much lower than that of equivalent cotton yarns. The mean hair length also reduces as the proportion of bamboo fibre increases in the yarn. The addition of bamboo fibres increases the percentage of hairs in the shorter length groups (3 mm) and reduces the percentage of hairs in longer length groups (4 mm and 5 mm). However, the mean hair length is independent on the yarn count if the blend proportion of yarn is the same. The analysis of relative frequency of hairs in different length classes shows that it is independent of yarn count and thus the mean hair length remains almost same with the change of yarn count.

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