Nazan Erdumlu,
Bulent Ozipek

Istanbul Technical University
Textile Technologies and Design Faculty
Textile Engineering Department
Istanbul, Turkey
E-mail: okurn@itu.edu.tr

Investigation of Regenerated Bamboo Fibre and Yarn Characteristics

Abstract
This article presents general characteristics and current applications of regenerated bamboo fibre in the textile industry. In the experimental part of the study, 100% regenerated bamboo yarns of six different counts (11.8, 14.8, 16.4, 19.7, 24.6 and 29.5 tex) were produced from bamboo fibre using ring yarn spinning technology. Subsequently, the physical parameters of related yarns produced in spinning mill conditions were tested, and the results were evaluated according to the parameters of 100% viscose rayon, as well as 100% carded and combed ring spun yarn in Uster statistics. In this way, the aim was to state the strength and weakness of bamboo fibre and to predict its future in the textile industry.

Key words: *bamboo fibre, fibre characteristics, ring-spun yarn, physical properties, Uster statistics.*

Introduction

With the growing demand for more comfortable, healthier and environmentally friendly products, efforts in research and development activities in the textile industry have focused on the utilisation of renewable and biodegradable resources as well as environmentally sound manufacturing processes in textiles. In this respect, a new kind of regenerated fibres, which are an alternative to conventional ones, and cotton have gained importance in apparel and home textile manufacturing. The most commonly known novel type of regenerated fibre is lyocell, which is produced from wood pulp by a viscose-like process but with a less hazardous environmental impact, as the compound (NMMO: N-methylmorpholine N-oxide) used in the lyocell manufacturing process for dissolving cellulose is organic and can be almost 99.5% recycled [1, 2].

One of the latest developments in new fibre researches is the use of bamboo fibre in various textile products that has been used in construction materials, decorating items, furniture and high performance composite materials for years. Regenerated bamboo fibre is obtained from the bamboo plant, which is an abundant and cheap natural resource. Bamboo grows in tropical climates and is harvested after 3 - 4 years . Bamboo is widespread throughout Asian countries, and the bamboo fibre used in textile applications is obtained from *Phyllostachys Heterocycla Pubescens*, a species known as Moso bamboo [3]. Regenerated cellulosic bamboo fibre was first manufactured in 2002 by Hebei Jigao Chemical Fibre Co. Ltd. in China [4]. Bamboo fibre is obtained from bamboo pulp, which is extracted from the bamboo stem and leaves by wet spinning, including a process of hydrolysis-alkalisation and multi-phase bleaching that is quite similar to that of viscose rayon fibre [5].

While the characteristics and usage of bamboo bast fibre in various applications have been widely investigated, researches on regenerated bamboo fibre for textile applications have so far remained quite limited. Wang and Gao examined the microstructure of natural bamboo fibre in order to obtain detailed information about bamboo fibre, and investigated the performance of bamboo fibre and evaluated it in comparison with ramie fabrics [6]. Olesen and Plackett examined the microscopic properties, chemical compositions and physical characteristics of plant fibres such as bamboo, flax, hemp and jute [7], and Liu et al. investigated the dyeing behaviour of bamboo fibre with reactive dyes as well as the performance of bamboo fibre in knitted goods [4]. Recently, Xu et al investigated the structure and thermal properties of bamboo viscose, Tencel and conventional viscose fibres comparatively in order to understand their physical, chemical and mechanical properties [8].

In this paper, information about the manufacturing process for regenerated bamboo fibre, application areas and characteristics is supported by investigations on yarn properties produced from regenerated bamboo fibre in the ring yarn manufacturing process with different counts.

Manufacturing process of regenerated bamboo fibre

The manufacturing process for regenerated bamboo fibre using hydrolysis alkalisation with the multi-phase bleaching principle is given below [9, 10]:

1. Preparation: Bamboo leaves and the soft, inner pith from a hard bamboo trunk are extracted and crushed.
2. Steeping: The crushed bamboo cellulose is soaked in a solution of 15% to 20% sodium hydroxide at a temperature of between 20 °C and 25 °C for one to three hours to form alkali cellulose.
3. Pressing: The bamboo alkali cellulose is pressed to remove excess sodium hydroxide solution.
4. Shredding: The alkali cellulose is shredded by a grinder to increase the surface area and make the cellulose easier to process.
5. Ageing: The shredded alkali cellulose is left to dry for 24 hours to be in contact with the oxygen of the ambient air. During this process, the alkali cellulose is partially oxidized and degraded to a lower molecular weight due to high alkalinity. This degradation is controlled to produce chain lengths short enough to produce correct viscosities in the spinning solution.
6. Sulfurization: In this stage, carbon disulfide is added to the bamboo alkali cellulose to sulfurise the compound, causing it to jell.
7. Xanthation: The remaining carbon disulfide from the sulfurisation is removed by evaporation due to decompression and cellulose sodium xanthogenate is the result.

8. Dissolving: A diluted solution of sodium hydroxide is added to the cellulose sodium xanthogenate, dissolving it to create a viscose solution consisting of about 5% sodium hydroxide and 7% to 15% bamboo fibre cellulose.
9. Spinning: After subsequent ripening, filtering and degassing, the viscose bamboo cellulose is forced through spinneret nozzles into a large container of diluted sulfuric acid solution which hardens the viscose bamboo cellulose sodium xanthate and reconverts it into cellulose bamboo fibre threads which are spun into bamboo fibre yarns.

The above-mentioned manufacturing process for regenerated bamboo fibre resembles that of viscose rayon fibre; consequently, regenerated bamboo fibre is also called bamboo viscose [8].

Bamboo fibre is also manufactured by a mechanical process. In the mechanical process, the woody parts of the bamboo plant are crushed and then natural enzymes are used to break the bamboo walls into a soft mass so that the natural fibers can be mechanically combed out and spun into yarn. Since this process is more labour intensive and costly, this type of manufacturing process of bamboo fibre for clothing is rarely used [10].

Properties of regenerated bamboo fibre

A cross sectional image of regenerated bamboo fibre obtained by a polarizan microscope is presented in ***Figure 1***. It is not circular, and it is also quite similar to that of regular viscose rayon fibre.

Cotton is the most widely used natural cellulosic fibre in apparel and home furnishing manufacturing due to its several advantageous aspects, such as comfort, and its absorbent and anti-allergenic properties. Primarily regular and modified rayon fibres as well as regenerated cellulosic fibres are the main substitutes for cotton in the aforesaid applications. Rayon was the first regenerated cellulosic fibre produced from wood pulp by viscose processes based on wet spinning. By modifying the chemical and/or physical manufacturing parameters, different types of rayon fibres with unique characteristics are obtained. High wet modulus rayon (modal) is a modification of regular viscose rayon with a higher tenacity [11].

In ***Table 1***, the physical parameters of regenerated bamboo fibre are presented in comparison with cotton and certain regenerated cellulosic fibres such as lyocell, viscose rayon, and modal. Soybean protein fibre is also included in the comparisons since it is an emerging renewable fibre type with a good mechanical and physical performance, as well as being comfortable with a natural antibacterial property similar to that of regenerated bamboo fibre. Particularly for cotton the fibre characteristics differ in a wide range, depending on the type and growth conditions. The figures displayed below are average values based on those presented in existing literature.

Viscose rayon has a lower dry and wet tenacity but higher elongation compared to cotton. Bamboo and viscose rayon fibre properties are similar in terms of dry tenacity, elongation at break, and moisture absorption; on the other hand, the wet tenacity value of bamboo seems slightly higher than that of viscose rayon. Bamboo also has a lower tenacity than cotton in both a dry and wet state. The low wet strength of bamboo fibre should be considered in pre-treatment, dying and finishing processes. Modal has a higher dry and wet tenacity than regular rayon and bamboo fibre. Contrary to cotton, the tenacity of all regenerated fibres decreases in a wet state.

Among all fibres subjected to comparative research, lyocell has the highest tenacity in both dry and wet states due to a higher degree of crystallinity and molecular orientation compared to bamboo and viscose rayon fibres. Moreover, as there are several voids in the cross section of bamboo and viscose rayon fibres, they have a higher moisture absorption capacity [8].

Soybean protein fibre is another kind of renewable fibre obtained from natural resources. Soybean-protein staple fibre is made from soybean residue that comes from the production of soybean oil. The residual cake left after oil is extracted from the soybean plant and the high polymer from soybean cake are used to obtain soybean fibre. After obtaining a protein spinning solution of certain concentration, a filament bundle of a single fibre of 0.9 - 3.0 dtex is spun by the wet spinning process. Next, the fibre performance is stabilised through hydroformylation, followed by winding, heat setting and cutting. In this way, soybean fibre of different lengths and specifications for spinning can be manufactured [17]. When compared to regenerated bamboo fibre, soybean protein fibre has a higher dry and wet tenacity, which is closer to that of lyocell fibre. On the other hand, the moisture absorption capacity of soybean protein fibre is lower compared with regenerated cellulosic fibres.

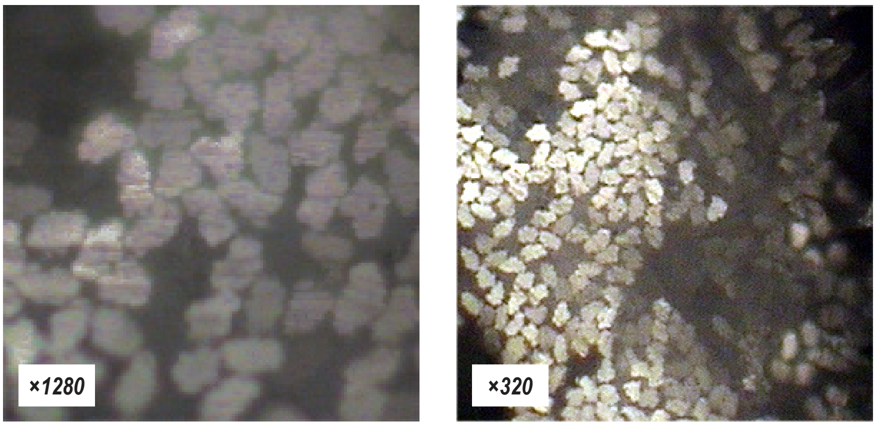

Figure 1. *Cross section of regenerated bamboo fibre.*

Table 1. *Various physical parameters of the fibres [2, 5, 11 - 16].*

	COTTON	BAMBOO	LYOCELL	VISCOSE RAYON	MODAL	SOYBEAN
Dry tenacity, cN/tex	20 - 43	22 - 25	37 - 45	18 - 26	24 - 36	38 - 40
Wet tenacity, cN/tex	27 - 56	13 - 17	30 - 39	9 - 15	12 - 24	25 - 30
Elongation at break, %	6 - 10	14 - 24	12 - 16	15 - 25	13 - 25	18 - 21
Moisture absorption, %	7 - 8	13	11 - 12	10 - 16	12 - 13	8 - 9

Table 2. Fibre characteristics.

Parameter	Measured value	Test method
Linear density, dtex	1.44	ISO 1973:1975
Dry tenacity, cN/tex	24.18	ISO 5079:1995
Elongation, %	26.9	ISO 5079:1995
Moisture absorption, %	12.5	ASTMD 1576

Table 3. Roving parameters.

	%U	CV_m	CV_m (1 m)	CV_m (3 m)
Mean	8.39	10.44	5.34	4.68
SD	1.50	1.67	2.60	2.89

Application areas of regenerated bamboo fibre

Because of the distinctive characteristics of regenerated bamboo fibre, such as its natural antibacterial and biodegradable properties, high moisture absorption capacity, softness, brightness as well as UV protective characteristics, bamboo textile products have started to edge into the textile market. With its high moisture absorption capacity, breathability and fast drying behaviour due to its unique microstructure, bamboo fibre ensures comfort in various applications. Currently, regenerated bamboo fibre is used in apparels including underwear products, sport clothes, t-shirts and socks. It is preferred in summer clothes, especially in garments for pregnant ladies and children to protect them from UV radiation. Its natural antibacterial nature makes it suitable for hygienic products and sanitary materials such as sanitary napkins, absorbing pads, masks, mattresses, bandages, surgical clothes, food packing bags etc. Since chemical additives are not needed to obtain antibacterial characteristics, such products are not believed to cause skin allergies. Moreover, regenerated bamboo fibre is used in home furnishings such as towels, bathrobes, bedding sets, blankets and curtains [5, 10, 16].

Experimental study

In this study, 100% bamboo rovings of 0.738 ktex were supplied by a bamboo yarn manufacturing company. Regenerated bamboo fibre bales were processed using a conventional short staple carded yarn spinning system. Then yarn samples of six different counts were produced in a ring spinning frame. In ***Tables 2*** and ***3***, experiment results of the bamboo fibre that was used in the production of the bamboo rovings as well as the roving parameters are presented, respectively.

To determine the yarn properties, a Zweigle L232 yarn count measuring device was used in the measurement of yarn counts, an ETT yarn twist measurement instrument was used for twist measurement. The yarns were tested for tenacity and elongation at break on a Premier Tensomaxx 7000, and for evenness and hairiness on an Uster Tester 4. Tests were carried out on nine cones for each yarn sample under standard atmospheric conditions due to scarcity of raw material. The average values of 45 test results are presented for yarn count, 90 test results for twist, 27 test results for irregularity, imperfections and hairiness, as well as 45 test results for tenacity and elongation at break. Moreover, the test results were compared with Uster statistics related to 100% viscose rayon ring spun cones, and 100% carded and combed ring spun yarn cones for knitted fabrics in order to estimate yarn quality.

Results and discussion

Physical parameters of the yarn samples are listed in ***Table 4***.

Apart from 19.7 tex, physical properties of bamboo yarn including breaking tenacity and elongation at break decrease as the yarn becomes thinner. These results are consistent with the results obtained in industrial researches [5]. As expected, the elongation values of bamboo yarn are relatively high. All results related to yarn samples of 11.8 tex far exceed those for other yarn counts. In particular, yarn irregularity deteriorates, to a large extent, in the finest yarn.

Tables 5 - 9 (see page 46) show comparisons between bamboo yarn samples and world level yarn quality related to 100% viscose rayon ring spun yarn cones, and 100% carded and combed ring spun yarn cones for knitted fabrics according to Uster Statistics 2007 [18].

In terms of irregularity, the quality level of bamboo yarn decreases markedly as

Table 4. Physical parameters of the yarn samples.

YARN COUNT, tex	29.5	24.6	19.7	16.4	14.8	11.8
Measured yarn count, tex	31.45	25.25	19.90	17.38	15.42	10.85
Twist, t.p.m.	590.09	669.13	805.87	881.16	945.53	1064.56
Tenacity, cN/tex	16.40	15.93	15.13	15.79	14.70	11.33
Tenacity, CV%	5.52	8.23	7.41	9.41	11.03	14.15
Elongation at break, %	16.81	16.24	15.29	15.57	14.34	11.30
Elongation at break, CV%	5.68	8.14	6.73	8.42	11.26	18.20
Work to break, cN·cm	2601.83	2046.99	1494.31	1297.93	1021.65	533.70
Yarn irregularity, CVm%	11.08	12.17	13.07	14.21	15.15	17.80
Thin places, -50%/1000 m	0.00	1.70	1.70	9.40	24.50	152.00
Thick places, +50%/1000 m	24.19	39.07	40.00	69.17	107.96	269.54
Neps, +200%/1000 m	36.02	51.57	67.87	90.46	110.19	352.69
Hairiness (H)	6.59	5.81	5.13	4.61	4.38	3.85
Hairiness (sH)	1.45	1.37	1.28	1.23	1.21	1.20

Table 5. Irregularity and thin place values of yarn samples according to Uster Statistics; NA refers to "not available".

	Uster quality level											
	Yarn irregularity (CV_m%)						Thin places (-50%/1000m)					
Yarn count (tex)	29.5	24.6	19.7	16.4	14.8	11.8	29.5	24.6	19.7	16.4	14.8	11.8
100% viscose rayon	27%	50%	62%	85%	95%	NA	14%	5%	5%	51%	80%	NA
100% carded cotton	5%	5%	5%	22%	38%	NA	42%	41%	24%	64%	81%	NA
100% combed cotton	39%	53%	58%	75%	84%	95%	69%	46%	35%	80%	92%	95%

Table 6. Thick places and nep values of yarn samples according to Uster Statistics; NA refers to "not available".

	Uster quality level											
	Thick places (+50%/1000m)						Neps (+200%/1000m)					
Yarn count (tex)	29.5	24.6	19.7	16.4	14.8	11.8	29.5	24.6	19.7	16.4	14.8	11.8
100% viscose rayon	73%	79%	68%	81%	92%	NA	45%	49%	49%	55%	57%	NA
100% carded cotton	18%	22%	12%	23%	30%	NA	5%	5%	5%	5%	5%	NA
100% combed cotton	64%	70%	59%	72%	79%	95%	71%	68%	58%	60%	56%	95%

Table 7. *Hairiness values of th yarn samples according to Uster Statistics; NA refers to "not available".*

	Uster quality level											
	Hairiness (H)						Hairiness (sH)					
Yarn count (tex)	**29.5**	**24.6**	**19.7**	**16.4**	**14.8**	**11.8**	**29.5**	**24.6**	**19.7**	**16.4**	**14.8**	**11.8**
100% viscose rayon	37%	29%	22%	12%	8%	NA	20%	24%	26%	28%	31%	NA
100% carded cotton	5%	5%	5%	5%	5%	NA	5%	5%	5%	5%	5%	NA
100% combed cotton	18%	10%	5%	5%	5%	5%	5%	5%	6%	7%	12%	52

Table 8. *Tenacity values of yarn samples according to Uster Statistics; NA refers to "not available".*

	Uster quality level											
	Tenacity, cN/tex - Tensorapid						Tenacity, cN/tex - Tensojet					
Yarn count (tex)	**29.5**	**24.6**	**19.7**	**16.4**	**14.8**	**11.8**	**29.5**	**24.6**	**19.7**	**16.4**	**14.8**	**11.8**
100% viscose rayon	50%	58%	69%	60%	76%	NA	73%	82%	95%	90%	95%	NA
100% carded cotton	67%	76%	88%	79%	94%	NA	87%	93%	95%	95%	95%	NA
100% combed cotton	54%	66%	82%	72%	95%	95%	84%	95%	95%	95%	95%	95%

Table 9. *Elongation at break values of yarn samples according to Uster Statistics; NA refers to "not available".*

	Uster quality level											
	Elongation at break, % - Tensorapid						Elongation at break, % - Tensojet					
Yarn count (tex)	**29.5**	**24.6**	**19.7**	**16.4**	**14.8**	**11.8**	**29.5**	**24.6**	**19.7**	**16.4**	**14.8**	**11.8**
100% viscose rayon	5%	5%	6%	5%	20%	NA	7%	8%	16%	6%	24%	NA
100% carded cotton	5%	5%	5%	5%	5%	NA	5%	5%	5%	5%	5%	NA
100% combed cotton	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%

Table 10. *Work to break values of the yarn samples according to Uster Statistics; NA refers to "not available".*

	Uster quality level											
	Work to break, cN.cm - Tensorapid						Work to break, cN.cm - Tensojet					
Yarn count (tex)	**29.5**	**24.6**	**19.7**	**16.4**	**14.8**	**11.8**	**29.5**	**24.6**	**19.7**	**16.4**	**14.8**	**11.8**
100% viscose rayon	11%	16%	26%	31%	45%	NA	33%	33%	42%	43%	58%	NA
100% carded cotton	5%	5%	5%	5%	5%	NA	5%	5%	5%	5%	5%	NA
100% combed cotton	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%

the yarn becomes finer when compared to the levels of all three types of yarn taken into consideration. Apart from thin places, the quality of bamboo yarn is more satisfactory in relation to the level of 100% carded ring spun yarn. With regard to thin places, bamboo yarn has a higher level of quality in relation to 100% viscose rayon ring yarns.

The hairiness indices of the bamboo yarn samples are of comparable quality: between 5 and 37% of the world level for viscose rayon and carded and combed cotton ring spun yarns.

As the fibre elongation value influences yarn elongation to a great extent, a high elongation value of regenerated bamboo fibre results in a high yarn elongation value. Elongation at break values of the bamboo yarn samples are within 5% of the world level in terms of carded and combed ring spun yarns, and corresponds to between 5 and 25% of the world level where 100% viscose rayon ring spun yarns are considered. With regard to breaking tenacity, yarn samples had values 50% above the world level.

The results regarding work to break values are the same as the world level for the elongation at break results of the yarn samples. However, the level of quality decreases in terms of work to break according to 100% viscose rayon ring spun yarn statistics, which can be attributed to the low quality level of the bamboo yarn samples in terms of tenacity.

Conclusions

- The results of the experimental study reveal that 100% bamboo yarns which are finer than 16.4 tex will not be able to meet acceptable levels of quality, and therefore it is suggested to use it in blends with other fibres, taking into consideration the stress-strain characteristics. On the other hand, the inconsistency between the roving count and yarn count for 11.8 tex and 14.8 tex might have caused this adverse result.

- The high elongation value and moisture absorption capacity of bamboo fibre can result in high shrinkage after refurbishing.

- The fibre and yarn characteristics of bamboo fibre are quite similar to those of viscose rayon fibre. On the other hand, its natural antibacterial characteristic, high air and moisture permeability, ensuring breathability in particular knitted goods, are distinctive characteristics of bamboo. For this reason, world leading sports clothing brands are extremely interested in bamboo fibre.

- The selling price of 1.67 dtex - 38 mm bamboo fibre is nearly 2.43 USD/kg. Although the price is high compared to viscose rayon or other cellulosic fibres, it is expected that bamboo fibre will have a large share of the market in a short period of time due to its distinctive characteristics, as mentioned above. Annual bamboo fibre production is nearly 40,000 tons, and as demand increases, the price of the fibre is expected to decrease in conjunction with an increase in amount of fibre production. In such a case, bamboo has the potential to become a strong rival for viscose [19].

- Existing information about bamboo fibre mostly consists of commercial papers by bamboo fibre producers expressing only the advantages of this new cellulosic fibre. Further researches should focus on the investigation of the performance of bamboo fibre of different blend ratios with other fibres, such as cotton, viscose rayon, modal, lyocell…etc. Another research topic may be the investigation of the performance of knitted and woven bamboo fabric and its behavior in dying and finishing processes, which will be determining factors for bamboo fibre in terms of producibility and performance of use.

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