Research on the properties of dope-dyed bamboo pulp staple fibers

Y J Zhang

Hebei University of Science and Technology, Shijiazhuang, Hebei

E-mail: zhangyongjiu1958@sohu.com

Abstract. In order to understand the properties of the dope-dyed bamboo pulp staple fibers, the moisture regains, tensile properties, friction properties and electrical conductivity of them and the white bamboo pulp fiber were tested, compared and analyzed. The results show that the moisture regains of the dope-dyed bamboo pulp fibers are smaller than the white bamboo pulp fiber's, whereas their friction coefficients, breaking strengths and elongations and mass ratio resistances are a bit larger.

1. Introduction

Bamboo fibers are classified into bamboo fiber directly from bamboo and bamboo pulp fiber according to their processing methods. The former is obtained to process bamboo by physical and mechanical methods. Its processing technology includes hydrolysis, steaming, boiling, softening, carding and so on [1-3]. The latter is made by chemical method and is a regenerated cellulose fiber with more than 93% of the regenerated cellulose which is made from bamboo as raw materials through special processes [4]. Currently, bamboo fiber used for textile processing generally refers to bamboo pulp one. Bamboo pulp fiber is not only purely spun, but also blended with other fibers such as cotton, hemp, silk, wool, viscose, Modal, Tencel and synthetic fiber. It can be produced by various styles of knitted fabrics, woven fabrics and so on. The fabrics are biodegradable, soft, cool and comfortable, and have many advantages like good drapability, high strength, good abrasion resistance and moisture permeability etc [5].

Dope dyeing is the green and environmental protection technology widely spread and applied in recent years and realizes the synchronous production of fiber and dyeing. The production of dope dyed fiber is to add an appropriate colorant into the dope during the polymerization or spinning of man
made fiber process. After spinning, the colorant is uniformly dispersed in the fiber. Dope dyeing process compared with the conventional dyeing has a lot of advantages such as continuously spinning, more uniform color, better color fastness, higher dye uptake rate, shorter production cycle, lower cost, less pollution and so on[6-13]. Dope dyeing technology is widely used in man-made fibers and a lot of dope dyeing patents have been granted in the world [14-16]. China textile industry vigorously promotes dope dyeing technology and dope-dyed fiber accounts for 5%-10% of the total fiber during the twelfth five year period [17].

Because the dope-dyed bamboo pulp staple fibers are new and the study on their properties is now in its infancy, further tests need to be done. Since fiber properties can affect the textile processing and dyeing etc, the characteristics of the dope-dyed bamboo pulp staple fibers should be deeply studied.

2. Experimental materials and methods

2.1. Materials

Two dope-dyed bamboo pulp staple fibers and one white bamboo pulp staple fiber from Jilin Chemical Fiber Group CO., LTD. were prepared for testing whose specifications are shown in Table 1.

| Specimen No. | Fineness/dtex | Length/mm | color              |
|--------------|---------------|-----------|--------------------|
| 1            | 2.11          | 38        | White( no dope-dyed) |
| 2            | 1.93          | 38        | yellow             |
| 3            | 2.10          | 38        | red                |

2.2. Test methods

2.2.1. Moisture absorption performance. Moisture absorption performance tests were performed on the apparatus—Model Y802A oven according to Chinese national standard “GB6503-2008 Testing method for moisture regain of man-made fibres”. Before drying the samples, condition the fibers in the standard atmosphere of 20°C and 60% RH (relative humidity) for a minimum of 24h, then weigh 10g fiber for each as \( W_1 \) (g) and put into the oven at 110°C to expose. When the samples were exposed for 2h, weigh the specimens without removing them from the oven. After that, the samples were weighed once every 10 min until the constant weight is recorded as \( W_2 \) (g). Moisture regains (%) of the samples were calculated by the following equation:

\[
\text{Moisture Regain} \% = \frac{W_1 - W_2}{W_2} \times 100
\]

2.2.2. Physical properties. Many forces such as friction, tensile and so forth can deform and do damage to fibers during textile processing. The mechanical properties of fibers are the abilities that the fibers...
bear all kinds of outer forces [18, 19]. Additionally, prior to testing, the samples were conditioned at the standard atmosphere (as mentioned above) for a minimum of 24h. The physical properties of the fibers were investigated as follows in this study:

Breaking Tenacity: Breaking tenacity was measured using a fiber strength tester YG004N according to Chinese national standard “GB/T14337-2008 Testing Method for Tensile Properties of Man-Made Staple Fibers”.

Friction Performance: The friction coefficients of the fibers were investigated with the use of a friction tester Y151 by using the winch method [20]. The friction coefficients between one fiber and metal roller, one fiber and its own fiber roller, and one fiber and rubber roller were respectively measured at 30 rpm, 75 cm/min and 100 mg pre-tension. Every hanging single fiber was repeatedly measured for 2–3 times. 5 identical rollers were demanded to use and each kind of fiber was tested for 6 times using each roller, so 30 values were obtained. The friction coefficients were calculated based on the following equation:

\[ \mu = \frac{\ln f_2 - \ln f_1}{\theta} \]  

Where \( f_1 \) is the fiber tension of the loose end of the winch, \( f_2 \) is the fiber tension of the tight ends of the winch, \( \mu \) is the angle between the fiber and the winch and \( \theta \) is the friction coefficients between the fiber and the winch.

2.2.3. Electrical conductivity. Fiber mass ratio resistance was evaluated by using YG321 Fiber Mass Ratio Resistance Tester according to Chinese national standard “GB/T 14342-1993 Testing method for specific resistance of synthetic staple fibres”. In addition, prior to testing, condition the samples at the standard atmosphere (as mentioned above) for a minimum of 24h. Fiber mass ratio resistance was evaluated by the following equation:

\[ \rho_m = R \frac{m}{l^2} \]  

where \( R \) is the averaged resistance of the fiber (\( \Omega \)), \( m \) is the mass (g) of the fiber and \( d \) is the density (g/cm\(^3\)) of the fiber.

3. Results and discussion

3.1. Evaluation of the moisture absorption of the fibers

Table 2 indicates that the moisture regains of 3 fibers are large, while the moisture regain of no dope-dyed (white) bamboo pulp fiber is larger than yellow fiber’s and red fiber’s. The reason the moisture regains of the dope-dyed bamboo pulp fibers are smaller is that some water-absorbent groups combining with the dyes, can reduce the number of fiber water-absorbent groups.
Table 2. Moisture regain of fibers

| Specimen No | Moisture regain/\% |
|-------------|--------------------|
| 1           | 13.91              |
| 2           | 13.43              |
| 3           | 11.06              |

3.2. Analysis of the physical properties of the fibers

The results of the breaking strength of the fibers are as in table 3.

Table 3. Tensile properties of the fibers.

| Specimen No | Breaking Tenacity/ cN \cdot dtex\(^{-1}\) | Breaking Elongation/ % | Dry breaking Tenacity/ CV |
|-------------|------------------------------------------|-------------------------|--------------------------|
|             | Dry | Wet | Dry | Wet |             |
| 1           | 1.86| 1.06| 18.60| 21.96| 25.25       |
| 2           | 2.24| 1.18| 21.70| 24.08| 17.34       |
| 3           | 2.19| 1.25| 22.60| 24.96| 14.94       |

The dry and wet breaking strengths and elongations of the dope-dyed bamboo pulp fibers are larger than those of white bamboo pulp fiber as shown in table 3, whereas the coefficients of variation (CV) of the formers are smaller than the latter’s. This shows that the strengths of the bamboo colored fibers are larger and more constant, which is helpful for the textile dyeing, finishing processing and fabric durability and quality.

The friction performance of fibers not only influences textile processing, but also affects the feeling and style of the products made from them. Additionally, friction can cause fibers to wear and deform, lead to mass transfer, and produce heat and static electricity [21, 22].

The friction coefficients of 3 fibers are shown in table 4. Generally speaking, the friction coefficients of two dope-dyed bamboo pulp staple fibers are a little larger than those of the white bamboo pulp staple fiber. The reason that the friction coefficients of two dope-dyed bamboo pulp fibers are larger is that their some groups combining with the dyes, can lead to their surfaces rough.

The larger fiber’s dynamic friction coefficient, static friction coefficient and the differences between them are, the stiffer the fiber is, and vice versa. Therefore, two dope-dyed fibers are stiffer than the white bamboo pulp fiber.

Fiber’s handle, spinning process and yarn qualities are all affected by its friction coefficients. The large friction coefficient among fibers, especially the static friction coefficient, can help the fiber aggregation in the spinning process, prevent fiber diffusion, and increase its yarn’s evenness degree and strength [23]. The dynamic friction coefficients of two dope-dyed fibers are smaller than their
corresponding static friction coefficients, which is helpful for their spinning process. The static and
dynamic friction coefficients between each fiber and the rubber bar are the largest, and those between
each fiber and its bar are the smallest. That the formers are large is helpful for the jaw to hold the card
sliver during the drawing, but in the opening & carding, it is difficult to transfer fibers and it often
happens to form the strikes. The difficult fiber transfer and strikes will do damage to fiber and will
make yarns and machine parts abrade. The friction coefficient of two dope-dyeing fibers should be
decreased with appropriate measures to ensure the spinning smoothly.

3.3. Electrical conductivity analysis
The mass ratio resistances of specimens 1-3 are 1.54×10⁹, 3.83×10⁹ and 6.36×10⁹Ω·g/cm²
respectively. The mass ratio resistances of the dope-dyed bamboo pulp fibers are obviously larger than
the white fiber’s. The moisture regains of 2 dope-dyed fibers are smaller than the white fiber’s and
their friction coefficients are larger with poor smooth, so they are easy to produce static electricity
which affects production and processing. Even after adding some oil, provided that the temperature,
humidity and spinning condition are not suitable, they can still produce static electricity easily which
will lead to the fiber and the rubber roller or roller attracted to each other resulting in blocking the
coiler, to make matter even worse, form hair on the surface of yarn, increase the flowers, even damage
the rubber roller, influence carding machine output to a certain extent, and form yarn defections and so
on. To make the dope-dyed fibers spin smoothly, anti-static measures should be taken to control their
mass ratio resistance under 10⁹Ω·g/cm².

4. Conclusions
In this study, two dope-dyed bamboo pulp staple fibers and one white bamboo pulp staple fiber were
tested. The moisture regains of the dope-dyed bamboo pulp staple fibers are smaller than the white
bamboo pulp staple fiber’s and their mass ratio resistances are larger, so it is necessary to keep relative
humidity in the workshop to ensure spinning smoothly. Their breaking strengths and breaking

| Specimen No. | Static friction coefficient/μs | Dynamic friction coefficient/μd | μs-μd |
|-------------|-----------------------------|-------------------------------|-------|
| 1 to metal bar | 0.2878 | 0.1904 | 0.0974 |
| 1 to its bar | 0.2207 | 0.1846 | 0.0361 |
| 1 to rubber bar | 0.4228 | 0.3578 | 0.0649 |
| 2 to metal bar | 0.4052 | 0.2271 | 0.1781 |
| 2 to its bar | 0.2578 | 0.2207 | 0.0371 |
| 2 to rubber bar | 0.4894 | 0.3729 | 0.1165 |
| 3 to metal bar | 0.3728 | 0.2337 | 0.1391 |
| 3 to its bar | 0.2762 | 0.2578 | 0.0184 |
| 3 to rubber bar | 0.4414 | 0.3628 | 0.0786 |
elongations are higher, which make their durability better. Their friction coefficients are larger, so it is requisite to add some oil to decrease friction forces when they are spun and woven.

References
[1] Liu J F 2007 Green natural fiber—bamboo Chin. Insp. Quara. 8 64
[2] Xue X C 2007 Properties and application of bamboo fiber Chem. Fiber. Text. Tech. 2 30-33
[3] Le Y C and Wang G H 2004 Structure and properties of bamboo fiber and its product development Sichuan Silk 4 10-12
[4] Song Y H and Zuo Z E 2009 Development of the bamboo fiber knitted loop transfer net fabric Knit. Inds. 7 6-7
[5] Liang H X, Wang H Z and Zhang Y 2005 The exploitation and significance testing of the original bamboo fabric Prog. Text. Sci. Tech. 5 39-40
[6] Xie S C, Qi Y H , Liu T, et al. 2013 Development of denim fabric with spun-dyed staple fibre yarn Chin. Text. Leader 11 38-41
[7] Fu S H, Zhang K, Sun G H, et al. 2010 Development of dope dyeing technology for cellulose fibre yarn Chin. Text. Leader 5 73-75
[8] Chen L H, Kong F R, Xu R C 2014 Research on the tensile properties of the liquid coloring viscose fiber J. Henan Inst. Eng. 26(1) 19-21
[9] Wu S Q 2015 Development and application of dope dyed polyester fiber used for automotive Knit. Inds. 11 6-9
[10] Guo Q, Li J X and Ma Y J 2014 Study on the solvent carrier type PET before spinning dope colored fiber PES Ind. 27(3) 27-29
[11] Gao Y , Liu J J , Du W H , et al. 2015 Production technology of dope-dyed PAN fiber Synth. Fiber Chin. 44(1) 31-33
[12] Dobbelstein H 2004 Soiling behavior and processability of solution-dyed PA 6 BCF yarns Chem. Fibers Int. 13 Franzen I and Masterbatches C. 2009 Solution dyed yarn vs. conventionally dyed yarn and fabric AFMA 1-38
[14] Mcintosh S A, H Y, Bailey B J et al. US Patent 6358458, 2002 Spinning and stability of solution-dyed nylon fibers
[15] Kobayashi S and Sugata Y US Patent Application 20020114917 Methods of coloring solution-dyed nylon
[16] Pacifici J A and Sims D G US Patent Application 20050144732 Process for providing dyed nylon fibers with resistance to staining and fading
[17] Zhu S 2013 The Countermeasures Probe into the Ecological Environment Rule of Dope-Dyed Polyester Fiber Chin. Fiber Insp. 5 46-48
[18] Jiang Y X and Qin F. 2005 An Introduction to Textile (Beijing: China Textile & Apparel Press)
[19] Yu X F 2004 Experimental Technology of Textile Materials (Beijing: China Textile & Apparel Press)
[20] Zhao S J 2007 Textile Material Experiment Tutorial (Beijing: China Textile & Apparel Press)
[21] Bowden F P and Tabor D 1964 The Friction and Lubrication of Solids, Part II (London: Oxford University Press)
[22] Rabinowicz E Friction and Wear of Materials 1965 (New York: Wiley)
[23] Li R Z, Zheng Y S and Ao L M 2010 Research of silver plated fiber friction property and spinning oil Cotton Text. Tech. 38 432-3