Research of morphology structure and properties of bamboo charcoal acrylic fiber

Yongjiu Zhang\(^1\) and Aifen Feng

Hebei University of Science and Technology, Shijiazhuang, Hebei

E-mail: zhangyongjiu1958@sohu.com

Abstract. In order to understand the properties of bamboo charcoal acrylic fiber, the tensile properties, friction properties and hygroscopicity of it, the bamboo charcoal acrylic fiber and the ordinary acrylic fiber were tested, compared and analyzed. The burning behaviors of the two kinds of fibers were observed by burning test, and their cross-sectional and longitudinal morphology was observed with scanning electron microscope (SEM). The SEM pictures showed that there are the uneven sizes of microspores on the surface of bamboo charcoal acrylic fiber and in it. It was found that the friction coefficients of the bamboo charcoal acrylic fiber are smaller and its tensile and moisture absorption are better than those of the ordinary acrylic fiber. However, there are no obvious differences of the burning behaviors between the two fibers.

1. Introduction

Acrylic fiber has obtained the considerable development and has become an indispensable part of synthetic fibers since its industrialization production in the 1950s [1]. In China's acrylic fiber market, the conventional acrylic fiber is saturated, but large quantities of differentiated and functional acrylic fibers, such as composite, superfine, noncircular cross-section, antibacterial fibers and more, are needed to import [2]. Therefore, it is necessary to develop functional acrylic fibers in order to adapt to the market demand.

The advent of bamboo charcoal fiber meets the people's increasing demand for functional textiles, and it has been paid attention to in the textile industry widely. It is a new kind of fiber following original bamboo fiber and bamboo pulp fiber made from bamboo and enjoys "Black Diamond" reputation [3]. The fabrics manufactured from bamboo charcoal fiber has good adsorption, deodorization, moisture absorption, heat storage, warm, antibacterial property, mould proof and anti-ultraviolet. Also they can emit far infrared rays and release negative ions. Therefore they can be used to made high-grade underwear, sportswear, coats, jackets and others [4].

Bamboo charcoal acrylic fiber is a new type of functional fiber and developed by Jilin Chemical Fiber Group CO., LTD. It has good heat storage and heat insulation functions. The fabrics made from bamboo charcoal acrylic fiber and general acrylic fiber were tested by Swiss Company SGS. The results show that the temperature of the fabric made from the bamboo charcoal acrylic fiber was 18.5°C higher than that of the fabric made from the general acrylic fiber when the fabrics were irradiated by the certain heat source. This shows that the fabric made from the bamboo charcoal

\(^1\) Address for correspondence: Yongjiu Zhang, Hebei University of Science and Technology, Shijiazhuang, Hebei. E-mail: zhangyongjiu1958@sohu.com.
acrylic fiber can reflect human body’s heat radiation, store heat energy and prevent heat loss. Therefore, the fabric can meet the requirements of winter clothing with beauty and warm. The fabrics made from the blended yarns of the bamboo charcoal acrylic fiber with viscose, bamboo fiber, Tencel, cotton fiber have hygroscopic heat efficiency with the average temperature up to 3.7°C and the highest up to 6.7°C. This efficiency makes people feel warmer and more comfortable. The fiber can also radiate far infrared rays which produce resonance with the human body cell molecular and go into the skin and subcutaneous tissue to improve the body’s microcirculation, promote its metabolism and delay its fatigue. The normal emission rate of the fiber’s far infrared rays is up to 0.87 and is durable. The fiber has good warm retention property, air permeability and comfort, and is suitable for underwear, sweaters, wadding, socks, gloves, scarves, blankets, bedding, and so on [5].

Because the bamboo charcoal acrylic fiber is a new type of fiber, the research on its properties is now in the initial stage. As is known to all, fiber properties have important influences on the textile processing, dyeing and finishing. Therefore it is necessary to research its characteristics.

2. Experimental details

2.1. Materials

1.67dtex bamboo charcoal acrylic fiber and normal acrylic fiber from Jilin Chemical Fiber Group CO., LTD.

2.2. Methods

2.2.1. Burning performance. The test is according to the textile industry standard FZ/T 01057.2-2007 “Test method for identification of textile fibers—part2: Burning behavior”. Use tweezers to clip a small bunch (about 50 ~ 100mg) fiber, and carefully observe the fiber in the proximity of alcohol lamp flame and in flames, the burning state of the fiber being removed from the flame, the generated order during its burning and its burning residue characteristic.

2.2.2. Microstructures. According to the textile industry standard FZ/T 01057.2-2007 “Test method for identification of textile fibers—part 3: Microscopy”, the cross-sectional and longitudinal morphology of the fibers was observed by Hitachi S450 scanning electron microscope made in Japan. The monofilament and sampled thin cross-section of fibers are respectively stuck on the object loading platform by the conductive glue, and the platform is put into a vacuum tank and is evacuated. Under the conditions of the scanning electron microscope with test voltage of 15 kV, the magnification of 1500 times and the resolution of 1.0nm, the morphology of the fibers are detected to observe by adjusting brightness and contrast being the best, and the most suitable pictures are selected.

2.2.3. Mechanical properties. Fibers can deform and even destroyed under a variety of external forces such as tensile, bending, torsion, compression, friction and so on in textile processing. The characteristics of fibers bearing all kinds of external forces are called mechanical properties [6, 7]. The mechanical properties tested include the breaking tenacity and friction performance of fibers. The samples had been conditioned at the temperature of 20°C and the relative humidity of 41% for 24h, and then were tested.

Breaking Tenacity: The instrument of YG004N electronic single fiber strength tester is used. The breaking tenacity of the fibers was tested at the drawing speed of 100mm/min and the length of the specimen of 15 mm according to the national standard “GB/T14337-2008 Testing Method for Tensile Properties of Man-Made Staple Fibers”. Each fiber was tested 20 times and the results were averaged. Friction Performance: The test instrument of type Y151 friction coefficient tester is used to test the friction coefficient of the fibers. The winch is used to be measured [8]. The friction coefficients of the two kinds of acrylic fibers respectively with metal roller, fiber roller and rubber roller were tested. The test is under the conditions of which the speed of friction roller is 30 rpm, the line speed of 75 cm/min,
and pre-tension is set to 100 mg. Each hanging single fiber was demanded to repeat the measurement operation for 2–3 times. Each roller was tested for 6 of each fiber and 5 rollers of the same types are used to obtain 30 values which were recorded. Based on the values, the friction coefficients of each fiber are calculated according to the formula of the friction coefficient.

2.2.4. Moisture absorption performance. The test is according to the national standard “GB6503-2008Testing method for moisture regain of man-made fibres”. The moisture regains of two fibers were tested by using typeY802A eight-basket constant temperature oven at the working voltage of 220 V and the heating power of 2.75 KW. After the fibers had been conditioned at the temperature of 20°C and the relative humidity of 41% for 24 h, 10 g fiber for each was weighed and then put into the 110°C oven to expose for 2 h.

3. Results and discussion

3.1. Burning performance analysis
The burning characteristics of two kinds of acrylic fibers are as shown in table 1.

| Fiber                  | Close to the flame | In the flame | After leaving the fire | Smell during burning | Combustion residue |
|------------------------|--------------------|--------------|------------------------|----------------------|--------------------|
| Bamboo charcoal acrylic| Contracting        | Burning with yellow flame and a lot of black smoke | Continue to burn rapidly | Slight smell of burning paper | Crisp, black and fragile lumps |
| Normal acrylic         | Contracting and slight melting | Melting and burning with white and very bright, and a little of black smoke | Continue to burn slowly | Pungent smell | Crisp, black and fragile lumps |

The burning behaviors of the bamboo charcoal acrylic fiber are similar to those of the normal acrylic fiber without a significant difference as shown in table 1. The bamboo charcoal acrylic fiber contracted when it was close to the flame; it was continuing to burn after it had left the flame with a burning speed more rapidly than the normal acrylic fiber; and there was a lot of black smoke to produce and a slight smell of burning paper during the burning process. A lot of black smoke by the bamboo charcoal acrylic fiber maybe because there is some bamboo charcoal powder to add into the fiber. The burning residues of two fibers are crisp, black and fragile.

3.2. Morphological analysis
Figure 1 shows the scanning electron microscopy images of the cross-section and longitudinal surface morphology of the bamboo charcoal acrylic fiber and the normal acrylic fiber.

There is much honeycomb microspore in the cross-section of the bamboo charcoal acrylic fiber with irregular section being similar to the round or oval as shown in figure 1. The longitudinal surface of the fiber has many grooves and is slightly rough. Therefore, in the process of spinning, the cohesion between the fibers will be increased, the fibers are not easily slip, and the yarn strength will increase. Because of the porous structure of the surface and internal of the fiber, the yarns and fabrics made from it not only have good moisture absorption and moisture absorption properties, thermal properties and good air permeability, but also have a certain absorption performance. The light undergarments, such as T-shirts, underwear, sportswear and casual wear, made from the fiber can quickly absorb skin moisture and sweat from the body’s skin and spread into the surrounding air quickly because of its porous structure. Therefore to wear the light undergarments made from the fiber can keep the skin dry, and allow the wearer to keep dry and comfortable. The weight products, such as quilts, warm clothing, coats, socks and gloves for winter, can prevent the invasion of cold air and are warm and light because
there is a lot of static air in the fiber’s microspore.

Figure 1. Scanning electron micrographs of fibers: (a) Cross-section morphology of bamboo charcoal acrylic fiber, (b) Longitudinal surface morphology of bamboo charcoal acrylic fiber, (c) Cross-section morphology of normal acrylic fiber, (d) Longitudinal surface morphology of normal acrylic fiber.

3.3. Mechanical properties’ analysis

Table 2 shows the results of the breaking strength of the fibers.

| Fiber Type          | Fineness/dtex | Breaking Strength/CN | Breaking Elongation/mm | Breaking Tenacity/cN•dtex⁻¹ | Rate of Breaking Elongation/% |
|---------------------|---------------|----------------------|------------------------|----------------------------|-------------------------------|
| Bamboo charcoal acrylic | 1.67          | 5.72                 | 4.05                   | 3.4                        | 27.02                         |
| Normal acrylic      | 1.67          | 4.64                 | 4.25                   | 2.7                        | 25.07                         |

The breaking strength and elongation of the bamboo charcoal acrylic fiber are larger than that of the normal acrylic fiber as shown in Table 2. This may be because the nanometer bamboo charcoal powder to add into the fiber causes the internal microstructure of the fiber changed, which influences the tensile properties of the fiber.

Fiber friction performance affects not only spinning and weaving processing, but also the handle and style of finished products. What is more, friction will lead to fiber wear and deformation, and produce mass transfer, heat and electrostatic phenomena [9, 10].

Table 3 shows the friction coefficients of two fibers. The friction coefficients of the bamboo charcoal acrylic fiber are a little smaller than those of the normal acrylic fiber. The differences between the static friction coefficient and the dynamic friction coefficient of each fiber are very small. Because the cross section of the normal acrylic fiber is round, and its surface is smooth, the contact area is smaller when relatively sliding, which causes its friction coefficients slightly higher. The surface of the bamboo charcoal acrylic fiber with bamboo charcoal powder is rougher, so the contact...
area is larger when relatively sliding, which causes the friction coefficients can reduce.

| Fiber                     | Static friction coefficient $\mu_s$ | Dynamic friction coefficient $\mu_d$ | $\mu_s - \mu_d$ |
|---------------------------|-------------------------------------|-------------------------------------|-----------------|
| Bamboo charcoal acrylic to metal bar | 0.3165                              | 0.2762                              | 0.0403          |
| Bamboo charcoal acrylic to its bar    | 0.3342                              | 0.2838                              | 0.0504          |
| Bamboo charcoal acrylic to rubber bar | 0.5124                              | 0.4288                              | 0.0836          |
| Normal acrylic to metal bar          | 0.3252                              | 0.2838                              | 0.0414          |
| Normal acrylic to its bar            | 0.3434                              | 0.2917                              | 0.0517          |
| Normal acrylic to rubber bar         | 0.5459                              | 0.4413                              | 0.1046          |

The static friction coefficients of two fibers are respectively higher than their dynamic frictional coefficients. Fiber’s dynamic and static friction coefficients and the differences between them affect its handle. The smaller they are, the softer they are, and vice versa. Therefore, the bamboo charcoal acrylic fiber compared to ordinary acrylic fiber is softer according to the results.

Fiber’s friction coefficients not only influence its handle, but also affect its spinning process and its yarn quality. The larger the friction coefficient among fibers is, especially the static one, the larger the cohesion among fibers. Larger cohesion contributes to the fiber aggregation in the process, prevents fiber diffusion, and improves the yarn’s quality and strength [11]. The static friction coefficients of the bamboo charcoal acrylic fiber are larger than its corresponding dynamic friction coefficients, which is beneficial to the fiber winding, pressurization, anti-adhesion etc. The friction coefficients of the fiber to its bar are larger than those of it to the metal bar but smaller than those of it to the rubber bar. Large friction coefficient between the fiber and the machine parts is good at holding the strip grip by the jaw in the drawing process. However, in the opening and carding process, the fiber transfer will be difficult and form the strikes repeatedly, which results in fiber damage and causes the wear of yarns and machine parts. Therefore, in order to ensure the spinning smoothly, proper measures should be taken to reduce the friction coefficient between the fiber and the parts.

### 3.4. Moisture absorption analysis

Usually, the ability for fiber to absorb water from the atmosphere or Release water to the atmosphere is called hygroscopicity [6]. The level of the moisture absorption of textile materials usually is represented by the moisture regain. The larger the moisture regain of a textile material is, the better its moisture absorption is.

Based on the results, the moisture regain of the bamboo charcoal acrylic fiber is higher than the normal acrylic fiber’s, respectively 1.71% and 1.52%. There is a lot of microspore on the surface of bamboo charcoal acrylic fiber and in it which makes it have good moisture absorption and liberation, warmth retention property and air permeability. In addition, the bamboo charcoal particles in the fiber have the adsorption function which makes the fiber has better moisture absorption and increase its moisture regain. The increased moisture regain of the fiber not only helps its textile processing and reduces static electricity, but also improves the wearing comfort being suitable for work clothing, sportswear, underwear and other clothing.

### 4. Conclusions

There is a lot of microspore with many sizes distributed unevenly on the surface of the bamboo charcoal acrylic fiber and in it. This structure can increase the cohesion among the fibers and improve the quality of yarn, fabric moisture permeability, air permeability, puff performance, coverage, and warmth. Therefore the bamboo charcoal acrylic fiber can be used to produce sportswear, work clothes and other products whose comfort will be improved. The breaking strength and breaking elongation of
bamboo charcoal acrylic fiber are higher than the normal acrylic fiber’s, so its durability is better too. The friction coefficients of the bamboo charcoal acrylic fiber are a little smaller than the normal acrylic fiber’s, so its handle feels softer. The moisture regain of the bamboo charcoal acrylic fiber is larger than the normal bright acrylic fiber’s, so it is easy to process in spinning and weaving, and its products are comfortable to wear.

References
[1] Lu Dong, Li Qingshan and Yang Xiuzhen 2006 Present situation of China acrylic fiber industry Synthetic Fiber 6 28-29
[2] Jin Lichen 2007 Development of China acrylic fiber industry China Synthetic Fiber Industry 30 56-59
[3] Wang Xianfeng, Pan Fukui, Luo Jiali, etc. 2006 Performance and application of bamboo charcoal fiber Shandong Textile Science & Technology 6 54-56
[4] Li Wang, Li Xiaorong and Cao Qiuling 2006 Bamboo charcoal and its development and application in textiles China Textile Leader 2 36-7
[5] Jilin chemical fiber: Vigorously promote laima and heat storage fibers http://www.tteb.com:2012-8-24
[6] Jiang Yaoxing and Qin Feng 2005 An Introduction to Textile (Beijing: China Textile & Apparel Press)
[7] Xufen Yu 2004 Experimental Technology of Textile Materials (Beijing: China Textile & Apparel Press)
[8] Zhao Shujing 2007 Textile Material Experiment Tutorial (Beijing: China Textile & Apparel Press)
[9] Bowden F P and Tabor D 1964 The Friction and Lubrication of Solids, Part II (London: Oxford University Press)
[10] Rabinowicz E Friction and Wear of Materials 1965 (New York: Wiley)
[11] Li Ruizhou, Zheng Yuansheng and Ao Limin 2010 Research of silver plated fiber friction property and spinning oil Cotton Textile Technology 38 432-3