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Study on the Chemical Agent Resistance Ability of Bamboo Pulp Fibers

Xiaohong Yuan*[a], Dongsheng Chen[a], Wei Yin[a], Mingxia Yang[b]

[a] Faculty of Clothing and Design, Minjiang University, Fuzhou 350121, China
[b] Textile College, Henan Institute of Engineering, Zhengzhou 450007, China
yxhong1981_2004@126.com

This paper aims to understand the chemical properties of bamboo pulp fiber, and to provide a theoretical basis for developing bamboo pulp fiber fabric. The chemical agent resistance ability of bamboo pulp fiber is therefore researched through analyzing and comparing the dissolution of the fiber at different concentrations and different temperatures of the chemical reagents. The results show that different concentrations of acid and alkali, oxidizing agents, and reducing agents affected the solubility of viscose and bamboo pulp fibers. Under a high concentration of acid and alkali, oxidant, or reducer solution, viscose and bamboo pulp fibers were easily dissolved. The solubility of viscose and bamboo pulp fiber decreased with a reduction in the concentration of the chemical reagent. The resistance of bamboo pulp fiber to strong acid is as poor as that of viscose fiber. However, the resistance of bamboo pulp fiber to weak acid is better than that of viscose fiber. The effects of acid on bamboo pulp fiber vary according to the type of acid, its concentration and the temperature it is at. The alkali resistance and oxidation resistance of bamboo pulp fiber is as high as that of viscose fiber, but bamboo pulp fiber is more resistant to reducing agents than viscose is.

1. Introduction

The chemical resistance of fiber refers to the ability of the fiber to resist various forms of chemical damage (Wang, 2010). In the textile dyeing and finishing process, fiber will be exposed to a range of chemical materials, such as acids, or alkali salts. At the same time, fiber can also be exposed to all kinds of chemicals in the course of its application, such as detergents, or finishing agents. Therefore, as textiles, fibers must possess a certain degree of chemical resistance and must satisfy the requirements of the textile dyeing and finishing process, as well as the use of various products. Only by understanding the chemical resistance of various textile fibers is it possible to select the most appropriate processing conditions and to use a variety of fiber products properly.

With the increase of consciousness concerning environmental protection, bamboo pulp fiber has sparked interest as a new type of green fiber (Zhu, 2012; Zheng and Zhu, 2011). China, known as ‘the kingdom of bamboo’, has the richest bamboo resources globally. Chinese bamboo species numbers, area, accumulation and yield are all among the highest in the world.

Bamboo fiber is a renewable resource and can be naturally biodegradable, which is helpful in terms of environmental protection and in realizing the sustainable development goals of human society (Guo and Deng, 2011; Liu and Ye, 2013). The cellulose fiber, which is made from bamboo, has incomparable advantages, such as good spinnability and coloration, a natural antibacterial health care function, and desorption. As a result, bamboo is known as ‘breathing fiber’ (Wan et al, 2004; Sun et al, 2003; Sun et al, 2011; Yang et al, 2008; Du et al, 2015). Bamboo fiber can be used pure in spinning, but can also be blended or interweaved with cotton, silk, linen, or synthetic fibers. It has wide applications in the production of products with special functions. For example, bamboo fiber can be used in products such as underwear, shirts, trousers, mats, gauze, masks, towels, bathrobes, or bedding and has very broad market prospects (Xue, 2007; Wang, 2014; He, 2012; Liu and Xu, 2014; Zhang et al, 2013).

The microstructure (Lei et al, 2015), performance (Nasrin & Alim, 2015; Wu & Wu, 2015; Alkhazaleh & Duwairi, 2015) and application (Li et al, 2015) of bamboo fibers have been recently studied by many

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researchers. Chen et al. (2015) reported the effect of hemicellulose removal on the structural and mechanical properties of the regenerated fibers. They found that the removal of the branched hemicelluloses, rather than the unbranched components, was the key to balancing different factors and to obtaining a stronger fiber. Wang et al. (2015) reported the sensitivity of bamboo fiber's longitudinal tensile properties to moisture content variation under the fiber saturation point. Mercerization was adapted to treat bamboo fibers and XRD was used to characterize their microstructure after treatment with NaOH. This was confirmed by Liu and Hu (2008). Wai et al. (1985) reported the results of beating pulp fibers from Bambusa polymorpha Munro. Li (2014) reported on the physical properties of bamboo fiber fabric, as well as its hygroscopicity, and its dyeing, antibacterial and moth-proofing properties. Tang (2013) investigated the structure, characteristics and purpose of bamboo fiber. Shen et al (2007) reported on the heat and moisture property of bamboo fiber fabric. Fan et al. (2007) described the thermo-comfortability of regenerated bamboo fiber fabric. Zhou (2004) reported on the structure and performance of bamboo fiber, as well as on the spinning and weaving process. Sui (2003) investigated the microstructure and the physical and chemical properties of bamboo fibers. There is, however, less research on the resistance ability of bamboo pulp fibers to chemical agents.

This paper mainly studies the chemical agent resistance ability of bamboo pulp fibers. For different lengths of time and under different temperature conditions, bamboo pulp fibers were immersed in different concentrations of acid, alkali, oxidant, or reducer solutions. The dissolution and appearance changes of the bamboo pulp fiber were then observed. The results obtained can provide a theoretical basis for developing bamboo pulp fiber fabric.

2. Experimental equipment and procedures

The materials used were bamboo pulp fibers and viscose fibers from Experimental Materials. The fineness of the bamboo pulp fibers and viscose fibers was 1.55 dtex.

The experimental reagents used were: hydrochloric acid at concentrations of 15% and 37%, sulfuric acid at concentrations of 40%, 60%, 70% and 98%; a 68% concentration of nitric acid; and a 5% concentration of sodium hydroxide; as well as ethyl acetate; sodium hypochlorite; and carbon tetrachloride.

The experiments required the following instruments: a thermometer (10-100 ° symbol); a constant temperature bath (20-100 ° symbol) with six holes; an electronic balance beaker; a wood clip; forceps; a glass rod; a measuring cylinder; a dropper; and an Instron series 3365 electronic universal strength testing machine.

The chemical resistance of the fiber was determined as follows: First, according to the demands of the experiment, the different concentrations of chemical reagent were configured. 0.5 grams of a sample was then weighed and added to the configured reagents (the amount of samples and reagents were at least at a ratio of 1 gram of sample to 50 grams of reagents). After 5 minutes, the contents were observed for dissolution and other changes. The Thermostatic Water Bath was used to regulate temperature and was set at 25℃ and 100 ℃.

In summary, to conduct the experiments, the following procedure was adhered to: configuring the different concentrations of reagents → regulating the temperature of the reagent → weighing the fibers and adding them into the reagents → timing the experiment, observing and recording the data → taking out the samples.

3. Results and discussion

The experimental results of the acid resistance of fibers are as follows:

The dissolving conditions of bamboo pulp fiber and viscose fiber under different temperatures and conditions of sulfuric acid are shown in Table 1.

Table 1: The dissolution of fibers in a sulfuric acid solution

Fiber	Concentration state	40%		60%		70%		98%	
		25°	100°	25°	100°	25	100°	25°	100°
Bamboo Pulp	Solution	I	SS	SS	SS	SS	S	S	S
Viscose	Solution	I	SS	SS	S	SS	S	S	S

Note: S-soluble; SS-slightly soluble; P-partially soluble; I-insoluble.

In Table 1, it can be seen that bamboo pulp fiber and viscose fiber have similar reaction conditions in strong sulfuric acid. They are only affected differently under 100℃ in a 60% sulfuric acid concentration. Here, the bamboo pulp fiber is slightly soluble, but the viscose fiber is soluble. This demonstrates that bamboo pulp fiber and viscose fiber have roughly the same sulfuric acid resistance. Under 25℃, the bamboo pulp fiber was insoluble in a 40% concentration of sulfuric acid and became slightly soluble at 60% and 70% concentrations of sulfuric acid. It was soluble in a 98% concentration of sulfuric acid. Under 100℃, bamboo fiber was found to disintegrate in different concentrations of sulfuric acid. The fiber was slightly soluble in 40% and 60% concentrations of sulfuric acid, and became soluble in 70% and 98% concentrations. The temperature and acid concentration therefore have an uncontrolled effect on the way in which fibers dissolve in sulfuric acid. As can be seen from the analysis of the results, the sulfuric acid resistance of bamboo pulp fiber was very poor.
The dissolving conditions of bamboo pulp fiber and viscose fiber at different temperatures and in different concentrations of hydrochloric acid are shown in Table 2.

Table 2: The dissolution of fibers in a hydrochloric acid solution

Fiber	Concentration state	15%		37%	
		25°	100°	25°	100°
Bamboo Pulp	Solution	I	I	SS	S
Viscose	Solution	I	SS	SS	S

Note: S-soluble; SS-slightly soluble; P-partially soluble; I-insoluble.

From Table 2 it can be seen that, in a 15% concentration of hydrochloric acid under 100℃, bamboo pulp fiber was insoluble and viscose fiber was slightly soluble, but the coloration and luster of the fiber were changed. Bamboo pulp fiber and viscose fiber were both dissolved in a 37% concentration of hydrochloric acid. Under 25℃, bamboo pulp fiber and viscose fiber had the same solution condition in different concentrations of hydrochloric acid. They were both insoluble in a 15% concentration and slightly soluble in a 37% concentration. Therefore, the hydrochloric acid resistance of bamboo pulp fiber was also very poor.
The dissolving conditions of bamboo pulp fiber and viscose fiber at different temperatures and in different concentrations of nitric acid are shown in Table 3.

Table 3: The dissolution of fibers in a nitric acid solution

Fiber	Concentration state	68%	
		25°	100°
Bamboo Pulp	Solution	I	SS
Viscose	Solution	I	S

Note: S-soluble; SS-slightly soluble; P-partially soluble; I-insoluble.

In Table 3, it can be seen that, under normal temperatures, bamboo pulp fiber and viscose fiber were both insoluble in a 68% concentration of nitric acid. However, bamboo pulp fiber was slightly soluble and viscose fiber was soluble at 100℃.
From tables 1, 2 and 3, it can be seen that the nitric acid resistance of bamboo pulp fiber was higher than its resistance to sulfuric acid, or hydrochloric acid.
The experimental results of the alkali resistance of fibers are as follows:
The dissolving conditions of bamboo pulp fiber and viscose fiber under different temperatures in a 5% concentration of sodium hydroxide and ethyl acetate are shown in Table 4.

Table 4: The dissolution of fibers in a sodium hydroxide and ethyl acetate solution

Fiber	Concentration state	5% Sodium Hydroxide		Ethyl Acetate	
		25°	100°	25°	100°
Bamboo Pulp	Solution	I	I	I	I
Viscose	Solution	I	I	I	I

Note: S-soluble; SS-slightly soluble; P-partially soluble; I-insoluble.

As can be seen from Table 4, under normal temperature and heating conditions, both bamboo pulp fiber and viscose fiber were insoluble in a 5% sodium hydroxide and ethyl acetate solution. The results also show that the alkali resistance of viscose and bamboo pulp fiber was almost the same. When investigating the dissolving conditions of viscose and bamboo pulp fiber in an ethyl acetate solution at higher temperatures, the ethyl acetate beaker must be heated in a closed electric furnace, with the fuming cupboard kept fuming throughout. This will prevent the solution or solvent from burning or exploding. According to the results analysis, the alkali resistance of bamboo pulp fiber was good.
The experimental results of the oxidation resistance and reducing agent resistance of fibers are as follows:
The dissolving conditions of bamboo pulp fiber and viscose fiber under different temperatures in carbon tetrachloride and sodium hypochlorite are shown in Table 5.

Table 5: The dissolution of fibers in an oxidation and reducing agent solution

Fiber	Concentration state	Carbon tetrachloride		13% Sodium hypochlorite	
		25°	100°	25°	100°
Bamboo Pulp	Solution	I	I	I	I
Viscose	Solution	I	I	I	SS

Note: S-soluble; SS-slightly soluble; P-partially soluble; I-insoluble.

In Table 5, it can be seen that both bamboo pulp fiber and viscose fiber were undissolving, irrespective of temperature or heating, in carbon tetrachloride. Hence, the viscose fiber and bamboo pulp fiber were more resistant to oxidation. Under the same conditions, as the temperature rose from normal to heating in a sodium hypochloride liquid, the bamboo pulp fiber remained insoluble, whereas the viscose fiber changed from being insoluble to being slightly soluble. It is possible to see from the experiment results that heating can cause viscose to dissolve more quickly. Bamboo pulp fiber and viscose fiber therefore reacted differently under the maintained conditions, for the former was insoluble, while the latter became slightly soluble. The results demonstrate that the reducing agent resistance of bamboo pulp fiber was better than that of viscose fiber.

4. Conclusions

The concentration and temperature of an acidic solution can affect the solubility of viscose and bamboo pulp fiber: the higher the concentration and temperature, the greater the solubility of both fibers. The sulfuric acid resistance and hydrochloric acid resistance of bamboo pulp fiber was poor, but its alkali resistance was good. The acid resistance of bamboo pulp fiber was better than that of viscose fiber. Whether at room temperature, or in a heating-boiling state, the viscose and bamboo pulp fibers were not dissolved in different kinds of alkali, hence, the alkali resistance of both materials was rather better than their acid resistance. The oxidative resistance and reducing agent resistance of viscose and bamboo pulp fibers were both good, but the reducing agent resistance of bamboo pulp fiber was better than that of viscose.

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