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Enhancing the morphological and mechanical properties of bamboo fibers

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The properties of bamboo fibers treated with alkaline solutions of various concentrations are investigated using scanning electron microscopy, IR spectroscopy, and tensile testing.

In recent years, increasing environmental awareness has resulted in natural fibers gaining widespread attention as realistic alternatives to synthetic fibers in composite materials for construction and automotive industry applications.[1,2] In addition to being sustainable and biodegradable resources, some of these biomaterials have properties that outperform traditional fossil fuel-derived fibers.[3,4] Bamboo fibers, for example, are known as nature's fiberglass for their outstanding mechanical properties.[5] Thus, polymer composites with bamboo fiber reinforcements are currently emerging as potentially useful materials for industrial purposes.[6,7]

Most natural fibers, including flax, jute, and bamboo, have a lignocellulosic structure—they are primarily composed of lignin and cellulose—and are highly hydrophilic as a result of the hydroxyl groups present in this structure. Additionally, in many cases pectin and waxy materials cover the fiber surface, hindering the adhesion of the fibers to a polymer matrix. These features can adversely affect the interaction of the fibers with hydrophobic matrix materials, resulting in negative consequences such as debonding in the composite materials.[8] For this reason, bamboo fibers have not completely replaced conventional fiber reinforcements.

One method of resolving these incompatibility problems is to pre-treat the natural fibers with an alkali, such as sodium hydroxide (NaOH). Although many attempts have been made to investigate the effects of alkali treatment on the properties of natural fibers,[9,10] detailed studies are lacking that compare the properties and performance of bamboo fibers after treatment with alkaline solutions at a range of concentrations. Here, we present the results of our investigation into the microstructure and mechanical properties of bamboo fibers treated with aqueous solutions containing either 1, 4, or 7% by weight (wt%) NaOH for one hour at room temperature.

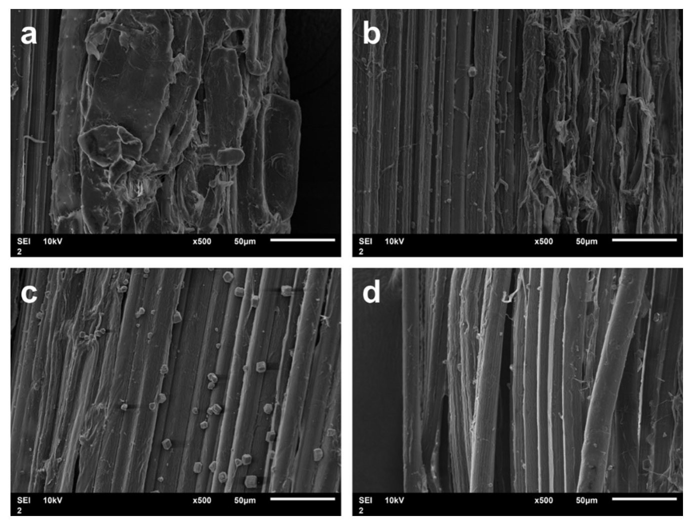

Figure 1. *Scanning electron microscopy images of the surface morphologies of bamboo fibers treated with sodium hydroxide (NaOH). (a) Untreated, (b) 1% by weight (wt%), (c) 4wt%, and (d) 7wt% NaOH solution.*

We characterized the surface morphologies of the untreated and treated bamboo fibers using scanning electron microscopy (see Figure 1). The resulting images show that NaOH treatment removes the mesh-like structure surrounding the fibers. In addition, we used IR spectroscopy to follow the alkali-induced structural and chemical changes in the bamboo fibers (see Figure 2).[11,12] The IR peak at 1733cm^{-1} is assigned to carbonyl (C=O) groups present in hemicellulose, and hence the decrease in peak height with increasing NaOH concentration suggests the removal of hemicellulose from the fibers. Furthermore, the decrease in intensity of the IR peak at 1243cm^{-1}—attributed to the acetyl groups in lignin—with increasing NaOH concentration suggests lignin is also removed from the fiber bundle.[13,14]

Continued on next page

Plastics Research Online
10.2417/spepro.006925 Page 2/3

We investigated the mechanical properties of the untreated and treated bamboo fibers using tensile strength tests (see Figure 3). Compared with the untreated fibers, there is an improvement in the average tensile strength of the fibers treated with a 4wt% NaOH solution. We attribute this result to the exposure of areas of cellulose during treatment (which, when used in composite materials, may produce effective bonding with a polymer matrix). Treatment with a 7wt% NaOH solution, however, results in a lower average tensile strength than that of the 4wt% NaOH-treated fibers.[15] This data indicates that in the case of the higher concentration NaOH treatment the removal of binding materials may include the partial removal of cellulose, negatively affecting the tensile strength of the bamboo fibers. Our overall results suggest that an appropriate alkali treatment is a key technology for enhancing the properties of natural fibers.[16,17]

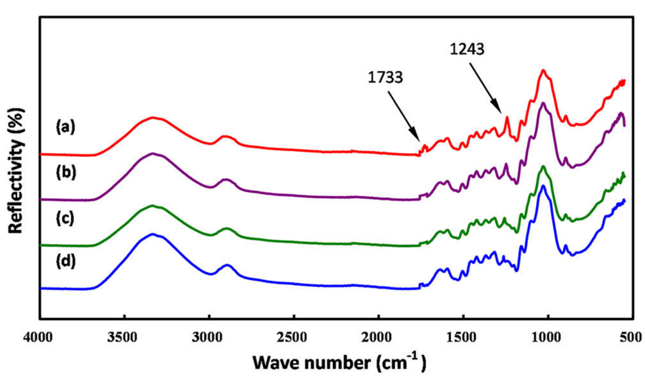

Figure 2. *IR spectra of NaOH-treated bamboo fibers. (a) Untreated, (b) 1wt%, (c) 4wt%, and (d) 7wt% NaOH solution.*

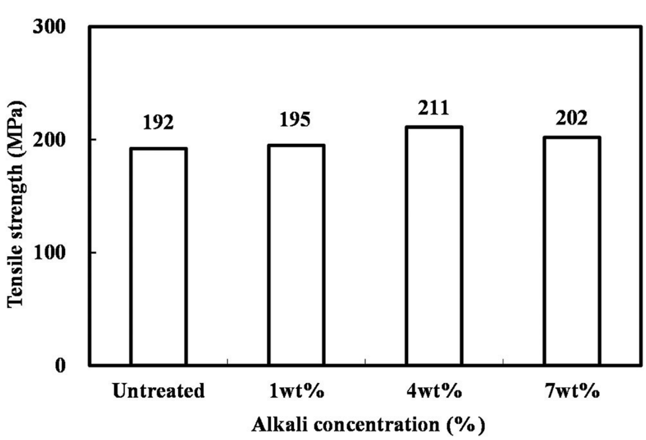

Figure 3. *Tensile strength measurements of NaOH-treated bamboo fibers.*

In summary, we have investigated the morphological and mechanical properties of bamboo fibers treated with NaOH solutions of various concentrations. The IR spectroscopy results suggest that NaOH treatment removes hemicellulose and lignin from the fibers, and the tensile strength tests indicate 4wt% is the optimum concentration for NaOH treatment. Our future work in this area will include investigating the thermo-mechanical performance of composite materials reinforced with alkali-treated bamboo fibers.

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The authors are interested in multiscale modeling of damage evolution and failure in composite materials reinforced with bamboo fibers. They are currently using experimental observations and micromechanical damage analysis to investigate the tensile behavior of these materials. Fang Wang's other research interests include multiscale analysis and computational approaches to probabilistic fracture and fatigue.

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