Modification of Bleached Bamboo Fiber using Cationic Guar Gum for Fiberboard

Wenjia Han,[a,*] Chuanshan Zhao,[a] Qining Sun,[b] Rendang Yang,[c] and Dongmei Yu [a]

In this work, a biodegradable fiberboard was prepared from modified bleached bamboo fibers. Cationic guar gum (CGG) was deposited onto the fibers, and the corresponding changes in physical properties of the composite were determined. Bleached bamboo fiber was modified by depositing cationic guar gum (CGG) onto the fibers. The treated fibers were then used to prepare biodegradable fiberboard. A 56.21% increase in tensile strength and a 54.40% increase in strain were obtained with the addition of 1.5 wt% of CGG. The bamboo fiber treated with CGG exhibited better thermal stability than the pure bamboo fiber. The surface morphologies of the unmodified and modified samples were analyzed using atomic force microscopy (AFM) in the tapping mode and scanning electron microscopy (SEM), which revealed differences in the fine structure of fibers, showing coarser surfaces spread across the fibers.

Keywords: Bleached bamboo fibers; Cationic guar gum; Modification; Mechanical properties; Morphology

Contact information: a: Key Lab of Paper Science and Technology of Ministry of Education, Qilu University of Technology, Ji'nan, China; b: Institute of Paper Science and Technology, School of Chemistry and Biochemistry, Georgia Institute of Technology, 500 10th Street, N.W., Atlanta, GA 30332-0620, USA; c: State Key Lab of Pulp and Paper Engineering, South China University of Technology, Guangdong Public Laboratory of Paper Technology and Equipment, Guangzhou 510640, China;
** Corresponding author: hwj200506@163.com*

INTRODUCTION

Considering the global energy crisis and looming environmental problems, green natural fiberboard and biodegradable additives have attracted growing interest in recent years for academic research and engineering applications. Their high specific strength and stiffness, low cost, and biodegradability give these renewable fiber composites and additives value above pure plastics in industries such as automotive and interior construction (Asasutjarit *et al*. 2009; Burgueño *et al*. 2004; John and Thomas 2008; Satyanarayana *et al*. 2009). However, the biggest limitation for most of the current applications of fiberboard is the addition of petroleum-based polymers, which make it not completely biodegradable (Ashori 2008). Most natural fiberboard contains two main components: the binder and natural fibers (Caṇigueral *et al*. 2009). In widely used polymer matrices, natural fibers play the role of filler or reinforcing fibers, while petroleum-based polymers such as polypropylene (PP), polyethylene (PE), polyvinyl alcohol (PVA), and modified maleic anhydride polypropylene (MAPP-PP) provide the physical properties (Robledo-Ortíz *et al.* 2010). Although several green adhesives such as modified starch, soy protein, polylactic acid (PLA), and poly (butylene succinate) (PBS) are used to improve the biodegradability of the fiberboard, petroleum-based binders are still needed to obtain sufficient surface performance, high density, and suitable

mechanical properties. Guar gum is a polysaccharide that originates from the ground endosperm of guar beans. It is made up of (1-4) residual bonds of D-mannose-beta with a side chain of associated (1-6) alpha-D-galactose and has a global ratio of mannose to galactose of about 2:1. The substitutions of galactose are distributed regularly along the mannose chain (Fatehi *et al*. 2009; Lee *et al*. 2006).

CGG is a cationic polymer prepared from GG by cationic modification (Pal *et al*. 2007). It can be treated as an environmental reinforcing agent in natural fiber composites. It is easier to attach to the fiber surface than GG, yielding high-performance composites. Therefore, the incorporation of CGG on natural fibers overcomes the limitations of untreated natural fibers by improving their poor fiber-matrix adhesion and low mechanical properties. These properties are of considerable technological importance for developing better green products (Huang *et al*. 2007; Lee *et al*. 2005; Müller *et al*. 2009).

In this study, we investigated the deposition of CGG onto bleached bamboo pulp under mild conditions. Our main interest was to study the effect of CGG deposition on the mechanical and thermal properties. In addition, the surface morphology of modified bamboo fiber was studied by AFM and SEM.

EXPERIMENTAL

Materials

Commercial ECF bleached chemical bamboo pulp with a beating degree of 15.0 °SR and a brightness of 84.5 ISO was provided by Sichuan Ya'an Pulp Co. Ltd. of Sichuan, China. The characteristics of the bamboo fibers are shown in Table 1, based on detection by FQA (Kumar *et al.* 2010). Commercial grade cationic guar gum (KEYU C-14S) with a substitution degree of 0.13 was purchased from Foshan Keyu New Composite Materials Co., Ltd of Foshan, China. The molecular weight was 9.5×10^6 g/mol. The viscosity of 1.0% CGG solution was about 3500 mPa·S.

Table 1. Characteristics of Bamboo Fibers

Property	Fiber Length (mm)	Fiber Width (um)	Fiber Curl (%)
Number average length(n)	0.49	13.21	24.26
Weight average length(l)	1.45	13.82	31.29

Bamboo Fiber Modification

The bamboo pulp was diluted to 5% w/v, and the pH was adjusted to 9.00. An aqueous 5% CGG solution was added to the pulp while stirring at 50 °C for 5 min with 0, 0.5, 1.0, and 1.5 wt.% added CGG on a dry basis. Higher amounts of CGG added will damage or soil the surface of the composites at high temperature and pressure due to the higher cohesiveness of CGG. Therefore, the amount of CGG used was less than 1.5% in this research. After cooling to room temperature, the CGG-modified pulp slurry was

diluted to less than 0.5% and was used as the raw material for preparing bamboo fiber composites. The control sample without CGG treatment was prepared in the same way.

Fabrication of Fiberboard

Bamboo fiber board specimens were prepared in a full-automatic fiber mold (EAMC-02, Hangzhou, China). In each composite, the modified bamboo fiber was kept at 0.5 wt%, and the slurry was filtered at a specific vacuum degree (Han *et al*. 2010). The thickness and base weight of samples were ~2 mm and ~1600 g/m^2, respectively.

Characterization of Fiberboard

Static tensile tests, including both tensile stress-strain and elastic modulus under static compression, were carried out with a computerized Universal Mechanical Testing Machine at a speed of 10 mm·min^{-1}. Conditions were at 25 °C and 50% RH. The length, width, and thickness of the samples were 100 mm, 20 mm, and 3 mm, respectively. Measurements were repeated three times and averaged.

The stiffness was tested by a K416 Bending Resistance Tester based on ISO 5628. The bending length and angle of the samples were 25 mm and 15°, respectively.

Thermogravimetric analysis (TGA) data were obtained from 25 to 600 ºC using a TGA with a NETZSCH TG209 Jupiter Thermal Analysis System in a nitrogen atmosphere with a heating rate of 20 ºC/min and a flow rate of 10 mL·min^{-1}.

Air-dried composites with untreated and treated bamboo fibers were fixed to a metal-base specimen holder using double-sided sticky tape and were then coated with gold by a vacuum sputter-coater. The surface morphology was observed in a scanning electron microscope (SEM) using a Hitachi S800 field emission SEM.

Atomic force microscopy (AFM) analysis was conducted to observe the morphology of the bamboo fiber surfaces using a Veeco Di Multimode SPM instrument. AFM scanning was carried out in air in contact AFM mode with a tip radius of curvature of 10 to 20 nm, a scanning rate of 1.969 Hz, a scan size of 5.000 µm, and a data scale of 1.733 V.

RESULTS AND DISCUSSION

Mechanical Properties of Bamboo Fiber/CGG Fiberboard

Figure 1a shows the effects of CGG on the stress-strain properties of the bamboo fiber/CGG fiberboard. In general, the mechanical properties of bamboo fiber-based fiberboard were improved with the addition of CGG. There were three stages in the stress-strain curves.

The evaluation of tensile testing based on different contents of CGG showed that the addition of CGG resulted in an enhancement in tensile properties of the fiberboard (Fig. 1b). The tensile stress increased from 26.06 to 40.71 MPa (56.21 % improvement) as the CGG addition increased from 0 to 1.5 wt.%. In addition, the effect of CGG addition on strain was observed. The strain of fiberboard first leveled off from 26.06% to 29.93% as CGG addition increased from 0 to 0.5 wt.% and then increased dramatically to 40.71% when the CGG addition was 1.5 wt.%. Correspondingly, the tensile modulus for the fiberboard reached 4.27 GPa, exhibiting a 19.2 % improvement with the 1.5 wt.%

CGG addition. The tensile strength of the bamboo fiber fiberboard was highly improved by adding the CGG, as denoted above.

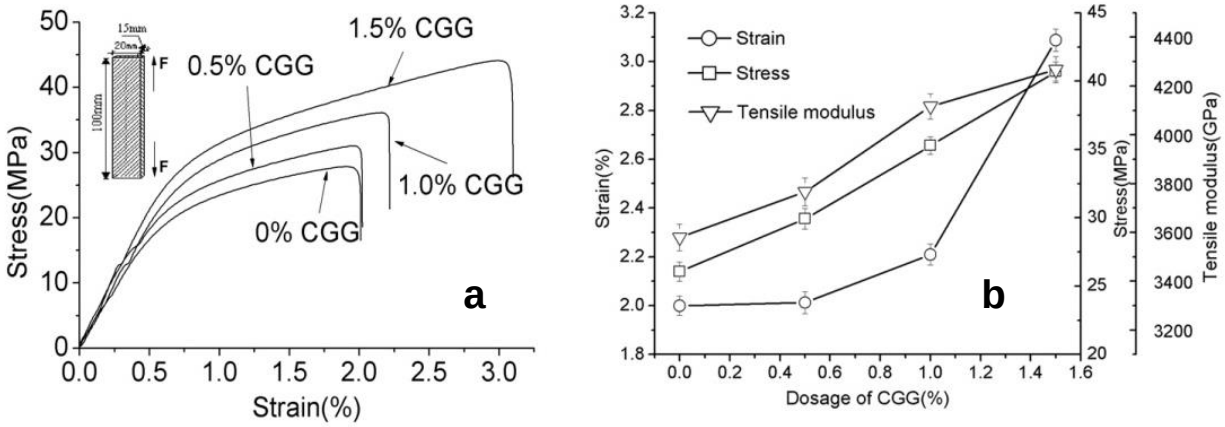

Fig. 1. Tensile stress-strain curves (a) and the effect of CGG on the tensile property (b) of bamboo fiberboard

Stiffness Properties

The stiffness of the fiberboard was tested, as shown in Fig. 2. It was found that CGG improved the stiffness of the sample from 4.23 to 5.73 N (35.46% improvement) when CGG was added from 0 to 1.5%. The improvements in the mechanical properties of bamboo fiberboard can be attributed to two aspects. One aspect is that both CGG and bamboo fibers contain free hydroxyl groups, which is the basis of a rigid hydrogen-bonded network. The other aspect is the crosslinking properties of CGG, which are important factors for improving the mechanical properties of bamboo-fiber composites.

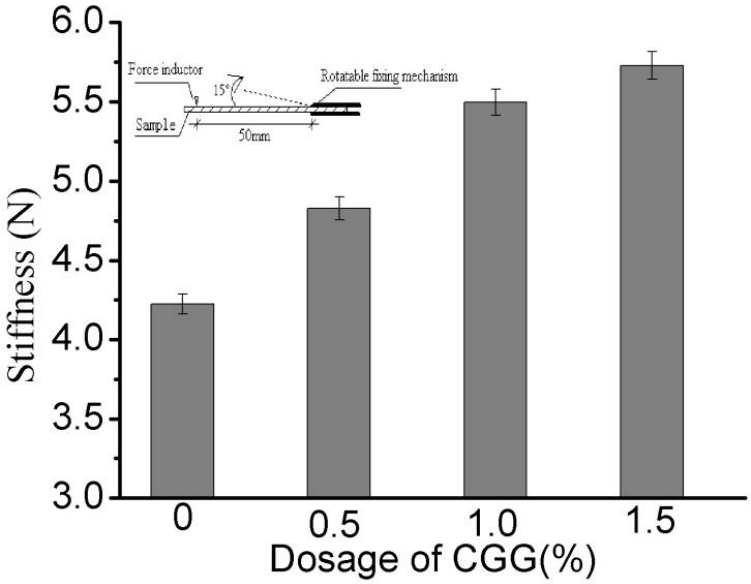

Fig. 2. Effect of CGG on stiffness properties of bamboo fiber fiberboard

Thermal Characteristics of Treated Bamboo Fiber

Figures 3(a) and (b) show the thermal properties of bamboo fiberboard in a nitrogen atmosphere, and the results are summarized in Table 2.

Table 2. Parameters of Thermal Weight Loss of Untreated and CGG-Treated Bamboo Fiber

Samples	Thermal Weight-Loss Rate /%			DTG Peak Temperature (°C)
	30 ~ 150 °C	150 ~ 400 °C	400 ~ 600 °C	
Untreated fibers	7.11±0.2	80.01±0.2	3.45±0.3	365
Treated fibers	8.29±0.1	73.22±0.3	4.57±0.1	362
CGG	10.72±0.2	56.37±0.4	5.79±0.2	311

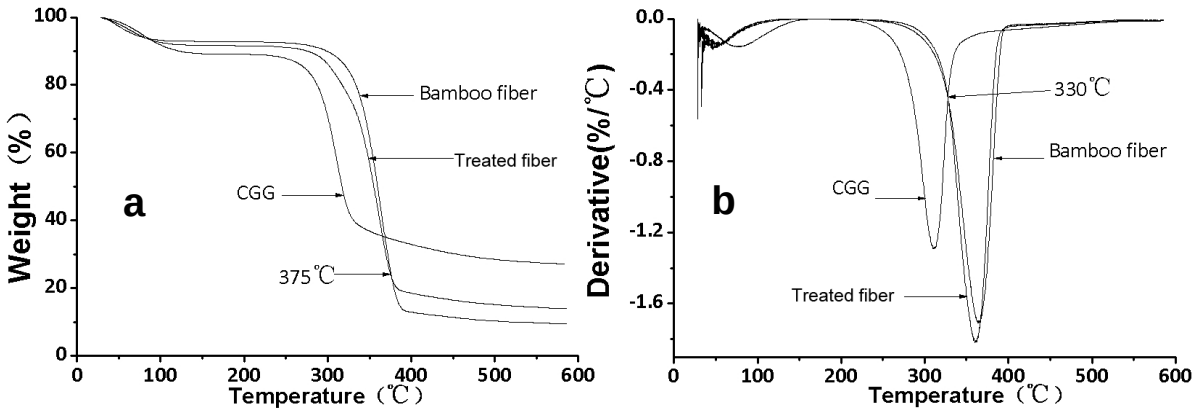

Fig. 3. TGA (a) and DTG (b) curves of untreated and treated bamboo fiber

As shown in Fig. 3, there were three decomposition stages: The first one was between 100 °C and 300 °C and was due to the loss of water and the condensation reaction among hydroxyl groups; the second one was between 300 °C and 400 °C and was due to the main decomposition; and the third was between 400 °C and 600 °C. The major weight losses for CGG, bamboo fiber, and treated fiber were 53%, 75%, and 80%, respectively, when heating from 220 °C to 360 °C. The ~30% residue in CGG was due to CGG carbonization in nitrogen.

The decomposition temperatures for untreated and treated bamboo fiber and the CGG were 365 °C, 362 °C, and 311 °C, respectively. The treated fibers showed a slightly lower degradation temperature (362 °C) than the untreated ones due to CGG degradation. CGG may lead to a faster thermal degradation rate of treated bamboo fiberboard in the low temperature region (<360 °C) when compared with that of untreated bamboo fiber. However, the treated bamboo fiber obtained a lower thermal weight-loss rate in the main pyrolysis stage, from 327 °C to 365 °C, when compared with the untreated sample. The residual weight percentages that occurred above 500 °C were higher for treated bamboo fibers (13.97%) than for untreated ones (9.43%). As a result, bamboo fiber treated with

CGG exhibited different thermal properties, which can be attributed to the changes in fiber bonding causing the bulk changes of fiberboard.

Morphology Analysis

Figures 4(a) and (b) show the SEM micrographs of untreated and treated bamboo fibers, respectively. In Fig. 4(a) the untreated bamboo fibers showed a better, smoother appearance, with fewer fibrils sticking out. In Fig. 4(b), bamboo fibers treated with CGG became coarser, and the fibrils became much more structured, indicating that CGG partially improved the adhesion of fibers. CGG with a better side chain structure (as shown in Fig. 4(b)) increased the effective surface area and strengthened bonding ability, thereby improving the mechanical and thermal properties.

AFM analysis was used to further explore the fundamental interactions between bamboo fiber and CGG. The phase images obtained from the untreated fiber and CGG-treated fiber are shown in Figs. 4(c) and (d). In contrast to the relatively smooth surface of untreated bamboo fiber shown in Fig. 4(d), the adsorption and re-organization of CGG on the surface of bamboo fiber affected its topography and finally resulted in the complex and rough surface of the ultra-microstructure, with more pronounced hills and valleys, as shown in Fig. 4(c).

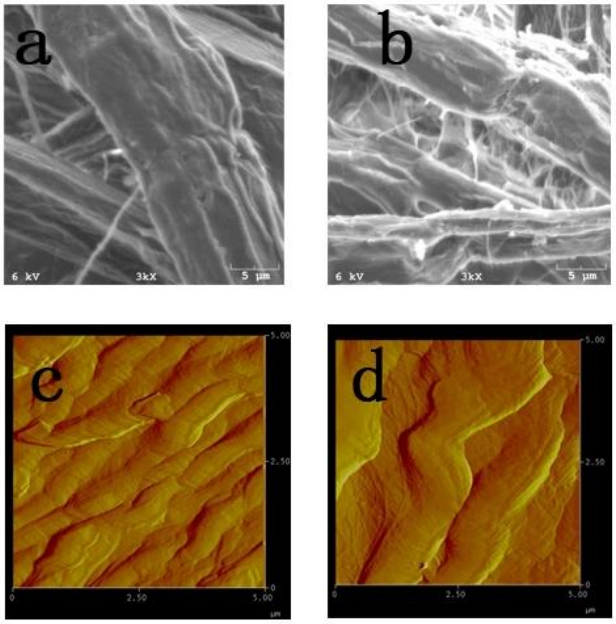

Fig. 4. SEM micrograph of bamboo fiberboard made from bamboo fibers (a) and made from bamboo fibers treated with 1.5% CGG (b), and AFM ultra-microstructure analysis of fiber treated with CGG with 1.5% CGG (c) and untreated bamboo fiber (d)

CONCLUSIONS

1. Biodegradable bamboo fiberboard samples were manufactured from bamboo fiber (bamboo pulp) and cationic guar gum (CGG) by wet-hot pressure technology.
2. The tensile strength, stiffness, and thermal stability of fiberboard samples were improved to different extents by treatment with CGG.

3. SEM and AFM analyses revealed that the surfaces of the untreated bamboo fibers had a rather smooth appearance, with fewer fibrils sticking out, and the surface structure was markedly coarser after CGG treatment, indicating that the main aggregation resulted from the ionic interactions between the fiber and CGG.

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