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Original article

Properties of antibacterial bioboard from bamboo macromolecule by hot press

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A B S T R A C T

Bamboo macromolecules were pretreated with bamboo vinegar, which has an antibacterial property, and processed into antibacterial bioboard (ABB) by hot pressing. The ABB was then analyzed by conducting Fourier-transform infrared spectroscopy, thermogravimetric analysis and differential thermal analysis. Results showed that ABB samples had average density of 1.0 g/cm^3, which is appropriate for application. The physical and mechanical properties were best for the ABB sample pretreated with bamboo vinegar and hot pressed at 165 °C for 10 min. Fourier-transform infrared spectroscopy revealed that the optimum conditions for hot pressing were a temperature of 165 °C, duration of 10 min, and the addition of bamboo vinegar. Thermogravimetric analysis/differential thermal analysis curves indicated that the thermal degradation of the ABB was less than that of bamboo, revealing that hot pressing increased the thermal stability of ABB samples. Analysis revealed that pretreatment with bamboo vinegar improved the antibacterial property of the ABB.

1. Introduction

Bamboo is a renewable bio resource if the cycle of its plantation and use is not deliberately destroyed. Pyrolyzing bamboo under oxygen-limited conditions produces bamboo charcoal (Zhao et al., 2008; Xia and Li, 2016). Bamboo vinegar (BV) is a brown-red transparent liquid produced during the pyrolysis of bamboo charcoal and contains more than 200 chemical components, such as acetic acid, phenolic compounds, alkane compounds, alcohol compounds and aldehyde compounds, among which acetic acid is the main component. Nowadays, bamboo charcoal is used to adsorb Pb^{2+}, Cu^{2+}, $Zn^{2+}$and other ions from water in the removal of environmental pollutants (Mizuta et al., 2004). Meanwhile, BV has also attracted great attention and the commercial production of BV in China is increasing. Because of the acetic acid and phenolic compound contents, BV has various effective uses; e.g., it is used as a natural insecticide, natural fungicide, soil disinfectant, compost fermenting agent, plant growth regulator and microorganism activator (Kartal et al., 2004; Liu and Liu, 2010; Gao, et al., 2017). Currently, not enough is known enough about the structural transformations that occur during hot pressing and it is therefore not possible to improve important technologies for industrial production.

With the emergence of wood-based panels, there is increasing public demand for self-binding bio boards that can be produced without the large emission of formaldehyde and that can be made antibacterial (Liu et al., 2014). Self-binding bio boards are a class of bamboo-based panels with bamboo fiber bound together without urea formaldehyde resin under heat and pressure (Shao et al., 2008). Self-binding bio boards have been improved by activating the bamboo fibers before hot pressing (Lin et al., 2015; Mi et al., 2014). With the strong market demand for bio boards, a critical task is to find the self-binding mode of fibers and groups of fibers during hot pressing. Furthermore, it is important to make full use of BV such that bio boards have an antibacterial function. An antibacterial bio board (ABB) was thus prepared by hot pressing, and its properties were examined by conducting Fourier-transform infrared spectroscopy (FTIR), thermogravimetric analysis (TGA) and differential thermal analysis (DTA).

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2. Materials and methods

2.1. Experimental materials

Bamboo was collected from the Jinggangshan Forest region in China. The bamboo was then dried in air and crushed to the 20–60 mesh range (denoted B0). Industrial BV, a by-product of charcoal production from bamboo, was obtained from Jinggangshan Charcoal Co., China. The BV comprised 80–90% water, 7–11% organic acids, 6–8% phenols, 0.8–1% ketones, and 1–3% other substances. Potato dextrose agar medium, acetic acid and water used as reagents in the experiments were all analytical grade (Liu, 2012).

2.2. Experimental methods

2.2.1. ABB preparation

A 686-g quantity of bamboo powder was treated with 6860 ml BV at room temperature for 10–30 min, and dried at 90 °C for 16 h and stored at 15 °C. According to an orthogonal test method of the response surface (described in Table 1), the 686 g of treated bamboo powder was paved in the hand and processed into a 350 mm × 350 mm × 7 mm ABB by hot pressing with pressure of 3.5 MPa. The physical and mechanical properties were obtained according to Chinese standards for particleboard (**GB/T 4897–2015**).

2.2.2. FT-IR analysis

FTIR spectra of the samples were obtained using an FTIR spectrophotometer (IR100) and KBr discs containing 1.00% finely ground sample.

2.2.3. TGA/DTG analysis

Each sample was analyzed using less than 10 mg of powder (Atta et al., 2017). Thermogravimetric spectra were measured from room temperature to 750 °C using a TG20 thermal gravimetric analyzer (209-F1 TG, Netzsch, Germany) and a carrier gas (N_2) velocity of 40 mL/min. The heating rate was 20 °C/min.

2.2.4. Antimicrobial effect

The antimicrobial effect of ABB samples was measured according to the inhibition zone (Wen et al., 2013; Jin et al., 2016).

3. Results and discussion

The static bending strength (MOR), elastic modulus (MOE), thickness swelling rate (TS), internal bond strength (IB) and density (ρ) were measured; values are given in Table 1.

3.1. Physical and mechanical properties of ABB

It is often desirable for bioboard to have ρ of 0.6–0.3 g/cm^3. Table 1 shows that ABB samples had ρ of 0.63–1.23 g/cm^3 and average density of 1.0 g/cm^3. The density of the ABB was thus appropriate. According to analysis and data statistics, effects of various factors on physical and mechanical properties of the ABB are shown in Fig. 1. For $R_{BVPT} = 5.43 > R_{Temperature} = 5.19 > R_{Time} = 2.30$, the BV pretreatment time significantly affected the MOR of the ABB. The MOR of the ABB decreased and then increased with increasing BV pretreatment time, increased with the rise in temperature and decreased with the extension of time (Viju et al., 2013). For $R_{Temperature} = 1101.59 > RR_{BVPT} = 695.36 > R_{Time} = 246.42$, the temperature significantly affected the MOE of the ABB. The MOE of the ABB followed the same trend as the MOR. For $RR_{BVPT} = 0.37 > R_{Time} = 0.23 > R_{Temperature} = 0.09$, the BV pretreatment time significantly affected the IB of the ABB. The trend of the IB of the ABB was the same as that of the MOR. For $R_{BVPT} = 34.22 > R_{Temperature} = 32.74 > R_{Time}$=14.52, the BV pretreatment time significantly affected the TS of the ABB. The TS of the ABB followed the same trend as the MOR. The best ABB sample was produced from BV and bamboo by hot pressing at a temperature of 165 °C for 10 min.

3.2. FT-IR analysis

FTIR spectra were taken to study the structural groups of bamboo and MDBLB. For comparison, the spectra of the samples described above are shown in Fig. 1. For the bamboo, O—H stretching, —C—H stretching, unconjugated C═O stretching, C═C stretching, C—C (in-ring) stretching, aromatic ring C—H stretching, C—H bending stretching, C—C stretching, methylene C—H stretching and C—I stretching are visible at 3430, 2920, 1716, 1605, 1500, 1431, 1360, 1241, 1043 and 569 cm^{-1}, respectively. All spectra had similar patterns except for the different intensities of infrared absorptions. The most intense bands (1716, 1500, 1431 and 1360 cm^{-1}) represent aromatic regions of BV. The transmitted intensities of all peaks in ABB were greater than those of the bamboo sample. This suggests that hot pressing enrichens the groups at 150, 165 and 180 °C. As the hot-press temperature increased from 150 to 165 °C, the transmitted intensities of all peaks increased gradually. As the hot-press temperature increased from 165 to 180 °C, the transmitted intensities of all peaks did not change greatly. The groups were thus enriched as the temperature increased. As the hot-press time increased from 10 to 20 min at a hot-press temperature of 165 °C, the transmitted intensities of peaks at 3430, 2920, 1716, 1605, 1500, 1431, 1360, 1241, 1043 and 569 cm^{-1} first decreased and then increased; i.e., a hot-press time of 10 or 20 min provided better results. As the hot-press temperature increased from 150 to 180 °C for a hot-press time of 10 min, the transmitted intensities of peaks at 3430, 2920, 1716, 1605, 1500, 1431, 1360, 1241, 1043 and 569 cm^{-1} increased gradually, demonstrating that the hot-press temperature of 165 °C gave the best results. As the hot press temperature increased from 150 to 180 °C for a hot-press time of 20 min, the transmitted intensities of peaks at 3430, 2920, 1716, 1605, 1500, 1431, 1360, 1241, 1043 and 569 cm^{-1} first increased and then decreased, again demonstrating that the hot-press temperature of 165 °C is preferred. In particular, the transmitted intensities of all peaks of the B13 sample are the greatest. According to the changes of groups, the optimum conditions for hot pressing are a temperature of 165 °C, duration of 10 min and the addition of BV.

3.3. TGA/DTG analysis

ABB is used widely in many applications in which it is exposed to high temperature, and its thermal stability is thus important. A controlled hot N_2 environment was used to measure the loss of mass of bamboo and ABB by oxidation, dehydration, hydration, reduction and decomposition (Ishaq and Jafri, 2017). Samples B1, B4, B9, B13, B16 and B0 were used for TGA between room temperature and 750 °C. The TGA and differential thermogravimetry curves are shown in Fig. 2. Thermal degradation of the three samples proceeded over a wide temperature range (100–745 °C). At 5.00% and 60.00% mass loss, the decomposition temperature was respectively 250 and 362 °C for the B0 sample. At 8.00% and 70.00% mass loss, the decomposition temperature was respectively 300 and 371 °C for the B9 sample and 308 and 372 °C for the B16 sample. At 15.00% and 70.00% mass loss, the decomposition temperature was respectively 256 and 370 °C for the B1 sample. At 8.00% and 75.00% mass loss, the decomposition temperature was respectively 306 and 373 °C for the B13 sample. At 8.00% and