BAMBOO FIBER REINFORCED BINDERLESS GREEN COMPOSITES FROM STEAM-EXPLODED BAMBOO POWDER

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In this paper, we attempted to prepare the binderless green composite using bamboo fiber and steam-exploded bamboo powder as matrix. The influence of molding conditions on their tensile behavior was investigated by changing the molding temperature, pressure and time. Except for the composites molded at low temperatures from 100°C to 120°C, their tensile strength decreased with increasing the molding temperature. When the molding time increased, their tensile strength decreased. Average tensile strength of the binderless bamboo green composite molded at 120°C and 10 MPa for 10 min was 170 MPa. The decreases in tensile strength of binderless composites molded at temperatures higher than 120°C may be responsible for the strength drop of the reinforcing bamboo fiber derived from thermal decomposition. In order to obtain detailed information about the adhesion behavior of bamboo powder and bamboo fiber, photomicrographs were taken of the fracture surfaces of the composites. The results show that molding condition, especially molding temperature, has a great effect on the mechanical properties of bamboo fiber reinforced binderless green composites.

Keywords: Binderless composites; bamboo; green composites; steam-explosion.

1. Introduction

Nowadays we have been using variety of plastics and polymer composites, such as polypropylene, polyethylene, glass fiber reinforced plastics (GFRP), etc. for many applications. However most of these synthetic polymeric materials are made from petroleum and/or coal, which are typical of the fossil fuels and have serious supply challenges. From these circumstances the research and development of bio-based materials including green composites and bio-composites are conducting in North America^{1,2}, Europe^{3,4}, and East Asia⁵⁻⁹.

Typical of the green composites are composed of biodegradable resin and natural plant fiber. The higher cost of the biodegradable resin such as poly-lactic acid (PLA) and

polyhydroxyalkanoate (PHA) prevent from applying the green composites to commercial products. The use of natural fiber contributes not only to increase in the mechanical performance but also to decrease the total materials cost, because most of the natural fiber is not expensive. However, there is limitation to lower the cost of the green composites.

Therefore, the authors group has been researching on the development of new bio-based composites without using any synthetic resin¹⁰⁻¹². Mori and Takagi have developed resinless bamboo composites, in which the plastic deformable parenchyma cells attached on the bamboo fiber was utilized as a matrix phase^{10, 11}. In addition, Takagi *et al.* made all bamboo composites; namely resinless, from hot-pressed bamboo column¹². These results indicate that parenchyma cells of steam-exploded bamboo can be successfully used as matrix phase.

Now we are aiming to fabricate new biomass-based composites in which all raw materials are derived from bamboo. In this study we examined the effect of molding conditions on their mechanical properties.

2. Experimental Method

2.1. Materials

As a matrix material, we used steam-exploded bamboo powder. “Moso” bamboo (*Phyllostachys pubescens*) cultivated in Tokushima, Japan was steam-exploded in the following conditions: one time explosion after a steam treatment at 170°C and 980 kPa for 40 min., and then seven times explosions after a steam treatment at 170°C and 980 kPa for 6 min. Finally the steam-exploded bamboo powder was pulverized for 30 seconds by using a high-power blender (WB-1; Osaka Chemical Co. Ltd., Japan). This pulverization was repeated once again (totally one minute treatment).

Unidirectional bamboo fiber was used as reinforcement. The bamboo fiber was also extracted from “Moso” bamboo by using the steam explosion method⁵. The conditions for the steam explosion were the same as those of bamboo powder as described above.

2.2. Fabrication of composites

The unidirectional bamboo fiber reinforced green composites were fabricated by a hot-pressing method. The steam-exploded bamboo powder and bamboo fiber were alternately stacked in a metallic mold as follows: 0.5 g powder/0.3 g fiber/0.5 g powder/0.4 g fiber/0.5 g powder/0.3 g fiber/0.5 g powder. The sample size of composites molded was approximately 100.0 mm × 10.0 mm × 2.5 mm, and the volume fraction of bamboo fiber was 33%. In order to examine the effect of molding temperature on the mechanical properties of the composites, the molding temperature was changed from 100°C to 160°C. Other molding conditions; namely molding pressure of 10 MPa and molding time of 10 min., were determined from the results obtained in preliminary experiments.

2.3. Tensile tests and observation of composites

Quasi-static tensile tests were carried out using a universal test machine (Model 5567; Instron Corp., USA) to evaluate the mechanical properties of the composites as well as heat-treated bamboo fiber. The tensile speed for composites and bamboo fiber was 1.0 mm/min., and the gauge lengths of composites and bamboo fiber were 30.0 mm and 25.0 mm, respectively. The details of fiber tensile tests are reported elsewhere¹³. Their fracture surface was observed using a digital microscope (VHX-600; Keyence Corp., Japan).

3. Results and Discussion

Figure 1 shows typical stress-strain curves of bamboo fiber reinforced binderless green composites molded at different temperatures from 100°C to 160°C. It can be seen that their stress response depends on the molding temperature and that the maximum stress is closely related to fracture strain. In addition, there is a nonlinear relationship, indicating a knee point around 50 MPa.

Fig. 1. Typical stress-strain curves of bamboo fiber reinforced binderless green composites.

From these curves, tensile strength and Young's modulus were measured, and plotted against the molding temperature as depicted in Figs. 2 and 3. There is a peak at 120°C, and the tensile strength decreases with increasing molding temperature above 120°C. On the other hand, Young's modulus increases linearly, indicating that the stress transfer between bamboo fiber and matrix is enhanced as the molding temperature increases. Similar results were also reported for resinless bamboo fiber composites¹¹.

In order to examine the strength dependence on molding temperature, we carried out tensile tests for the bamboo fiber heat-treated at different temperatures. The typical stress-strain curves of the bamboo fiber are shown in Fig. 4. It could be observed from the results that strength and fracture strain of composites were significantly altered by the heat treatment temperature. However, Young's modulus was found to be independent of heat temperature and did not change markedly.

Fig. 2. Variation of tensile strength of the binderless green composites with molding temperature.

Fig. 3. Variation of Young's modulus of the binderless green composites with molding temperature.

Fig. 4. Typical stress-strain curves of heat-treated bamboo fibers.

Fig. 5. Variation of tensile strength of heat-treated bamboo fiber with heating temperature.

Figure 5 shows the variation of tensile strength of heat-treated bamboo fiber. The bamboo fiber was heat-treated for 10 min. at every temperature. Although an appreciable data scattering is observed, the tensile strength is almost invariable below 100°C, however decreases with increasing heat-treatment temperature above 100°C. The tensile strength of bamboo fiber heat-treated at 160°C is only 160 MPa, which is about 40% of the strength at room temperature. Similar strength drop after heat treatment above 100°C was also reported in hemp fiber¹³. Thus strength drop in composites fabricated at higher temperature as shown in Fig. 2 is responsible for the strength drop in reinforcing bamboo fiber.

Fig. 6. Fracture aspects of binderless green composites; (a) molded at 120°C/10 min./10 MPa and (b) molded at 160°C/10 min./10 MPa.

The fracture surfaces of the bamboo fiber reinforced binderless green composites molded at 120°C and 160°C are shown in Fig. 6, showing long pull-out bamboo fiber (Fig. 6(a)) and brittle fracture of bamboo fiber in the composites molded at higher temperature (Fig. 6(b)). This brittle fracture manner is also reported in resinless bamboo composites as well as heat-treated bamboo fiber¹¹.

4. Conclusions

Bamboo fiber reinforced binderless green composites were fabricated by using bamboo fiber and steam-exploded bamboo powder, and their mechanical properties were investigated. The major results obtained are summarized as follows:

- (i) It can be seen that the stress response of binderless green composites depends on the molding temperature and that there exists a tensile strength peak at 120°C.
- (ii) The drop in tensile strength of binderless green composites molded at higher temperature is closely related to the decrease in tensile strength of bamboo fiber.
- (iii) Fracture behavior of binderless green composites is also changed by molding temperature, and brittle fracture mode was observed in the composites molded at higher temperature.

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