Development of green composite consists of woodchips, bamboo fibers and biodegradable adhesive

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ABSTRACT

From the viewpoint of the effective utilization of waste wood, the green composite which is produced by solidifying woodchips has been developed [Miki M, Takakura N, Kanayama K, Yamaguchi K, Iizuka T. Effects of forming conditions on compaction characteristics of wood powders. Trans Jpn Soc Mech Eng C 2003;69(678):502–8 [in Japanese]; Miki M, Takakura N, Kanayama K, Yamaguchi K, Iizuka T. Effects of forming conditions on flow characteristics of wood powders. Trans Jpn Soc Mech Eng C 2003;69(679):766–72 [in Japanese]; Miki M, Takakura N, Iizuka T, Yamaguchi K, Kanayama K. Possibility and problems in injection moulding of wood powders. Trans Jpn Soc Mech Eng C 2004;70(698):2966–72 [in Japanese]]. Since the composite was solidified by the compressive load without the binder, it did not have the high strength and was very brittle, and it had no water resistance [Kinoshita H, Kaizu K, Koga K, Tokunaga H, Ikeda K. In: Proceeding of the Japan Society of Mechanical Engineers M&M2007; 2007. CD [in Japanese]]. In this study, to improve these defects, it was proposed that a biodegradable resin as an adhesive and bamboo fibers as reinforced fibers were applied to the woodchip composite. By using woodchips with two kinds of the particle size, bamboo fibers with three kinds of the length and the biodegradable adhesive, several kinds of specimens changed mixing ratio of those materials were produced by compression molding at the appropriate temperature. By examining the bending strength and impact strength of the composites, it was found that the high bending strength was obtained in the case where woodchips with the small particle size and long bamboo fibers were used, and the high impact strength was obtained in the case where woodchips with the large particle size and long bamboo fibers were used.

1. Introduction

Green composites are expected to be widely used in place of polymer composites made from fossil oil and to contribute to the maintenance of a sustainable productive society. Many green composites which consist of natural fibers as reinforcements and a biodegradable resin as a matrix material are proposed. Natural fibers such as bamboo [5], hemp [6] and kenaf [7] are light, strong, renewable and inexpensive. Many attempts which use the natural fibers practically have been performed. For example, in the case of automobile components, the natural fibers have been used instead of glass fibers [8]. The biodegradable resin is resolved into water and carbon dioxide by the microorganism. The green composites are environmental friendly materials.

Recently, the composite produced by solidifying woodchips has been developed for effective utilization of waste wood [1–3]. The composite does not damage the environment because it is composed of only the woodchips which is a natural resource. The waste woodchips generated by lumbering of the wood can be utilized effectively. The products with complicated shapes can be formed by compression molding of woodchips at the appropriate temperature. However, the composite which is produced by solidifying only the woodchips without the binder does not have the high strength, and it is brittle partially and its water resistance is bad. Therefore, to improve these defects, we used the biodegradable resin as an adhesive [4]. Moreover, to obtain the higher strength, we used the bamboo fibers as a reinforced fiber. The bamboo fibers have the high strength in comparison with other natural fibers. The supply of the bamboo fibers has been stabilized because the growth rate of the bamboo is very rapid. However, recently, the bamboo disrupts forest and the utilization of the bamboo also decreases due to the insufficient maintenance of the bamboo thicket. Excellent mechanical properties of bamboos should be effectively utilized from the viewpoint of the effective utilization of natural resources. All of woodchips, bamboo fibers and the biode-
gradable adhesive which we use as ingredients for the composite do not give the damage to the environment. Therefore, our proposed green composite are also friendly to the environment. It will be a great help in saving resources by using the waste woodchips and bamboo fibers.

In this study, by using woodchips with two kinds of the particle size, bamboo fibers with three kinds of the length and the biodegradable adhesive, several kinds of specimens changed mixing ratio of those materials were produced by compression molding at the appropriate temperature. With regard to our proposed green composite, a small quantity of the biodegradable resin is used and the matrix consists of the woodchips impregnated slightly with the biodegradable resin. The matrix of the composite is not made by burying woodchips in the resin. The biodegradable resin is used to coat woodchips for improvement of the water resistance and is also used to strengthen the adhesion of woodchips for improvement of the strength. In order to evaluate mechanical properties of the composite, we focus on the effects of the biodegradable adhesive and bamboo fibers on the bending strength and impact strength. Therefore, by the four-points bending test and Charpy impact test, the bending strength and impact strength of the specimens made under some conditions were examined. In addition, by Charpy impact tests using the specimens absorbed water, the effect of its water resistance on the impact strength was examined. From the experimental results, the effects of the biodegradable adhesive and bamboo fibers on the bending strength and impact strength of the proposed green composite were clarified.

2. Experiments

2.1. Specimens

Woodchips with two kinds of the particle size and three kinds of bamboo fibers, and the biodegradable adhesive were used as ingredients for specimens. Fig. 1 shows samples of woodchips and bamboo fibers used as ingredients for specimens. We used woodchips of the Japanese cedar. The woodchips have the particle size of 1 mm or less and 200 μm or less, respectively. The bamboo fibers [9] have 1 mm in diameter and the length of 10 mm, 20 mm and 30 mm, respectively. The mechanical properties of the wood and bamboo fibers used as ingredients for specimens are listed in Table 1. As the biodegradable adhesive, Landy CP-100 [10,11] was used. The biodegradable adhesive is the aqueous dispersion of starchy fatty acid ester (CORNPOL resin [12]) made from the cornstarch. Landy CP-100 is accessioned as “Green Plastics” by Japan bioplastics association [13]. The main mechanical properties of Landy CP-100 are listed in Table 2. The adhesive has the property that the adhesive strength is maximum between 120 ℃ and 140 ℃.

We made eight types of specimens using woodchips with two kinds of the particle size for the bending test and Charpy impact test, respectively, as listed in Table 3. Fig. 2 shows the forming process of the specimens. The specimens for bending tests were made by mixing woodchips and bamboo fibers with weight of 5 g in total, and the biodegradable adhesive with the weight of 4 g. The specimens have the length of 60 mm, the width of 18 mm and the depth of 5.6–8.5 mm in a rectangular cross section. The specimens for Charpy impact tests were made by mixing woodchips and bamboo fibers with the weight of 4 g in total, and the biodegradable adhesive with the weight of 3.2 g. The speci-
mens have the length of 55 mm, the width of 10 mm and the depth of 8.0–10.0 mm, and does not have notch. The specimens for bending tests were made by pressing at a pressure of 15 MPa using the universal testing machine and holding for 3 h at the temperature of 130 °C. Similarly, the specimens for Charpy impact tests were made by pressing at a pressure of 30 MPa and holding for 3 h at the temperature of 130 °C.

2.2. Experimental methods

Fig. 3 shows a schematic illustration of the four-points bending test. The tests were carried out using the universal testing machine (Simadzu AG-500A) at the crosshead speed of 0.5 mm/s. The maximum bending stress is given by the following equation:

\[ \sigma_f = \frac{3P(L-a)}{2bh^2} \]  

(1)

where \( P \) is the maximum load, \( L \) is the distance between lower supporting points, \( a \) is the distance between upper loading points, \( b \) and \( h \) are the width and the depth in a rectangular cross section of the specimen, respectively. Charpy impact tests were carried out in conformity to the Japanese Industrial Standards (JISZ2202).

3. Results and discussions

3.1. Microstructures of specimens

Fig. 4 shows examples of specimens with adhesive made for bending tests. The surfaces of specimens were polished and photographed. From Fig. 4(B), we can show some bamboo fibers in the matrix of the composite.

Fig. 5 shows microstructures of specimens observed by the substance microscope.

From Fig. 5(A), it is found that the specimen with the woodchips size of 1 mm or less has more voids between the particles than the specimen with the woodchips size of 200 μm or less. Also, from the comparison of the specimen of only the woodchips without the biodegradable adhesive in Fig. 5(A) and the specimen with the biodegradable adhesive in Fig. 5(B), it is found that the number of voids between the particles considerably decreases in the case where the biodegradable adhesive is added to the woodchips. It seems to be a cause that the adhesion between particles is intensified by adding the adhesive. From Fig. 5(C), it is also found that the bamboo fibers have been buried in the particles of the woodchips. The fibers bend and a part of fibers overlap each other.

3.2. Bending strength

Fig. 6 shows comparison of the bending strengths obtained by four-points bending tests. The symbols of • and ■ shown in Fig. 6 express the average of five samples of the bending strengths and the error bars which show the standard deviation. First, we examine the influences of the biodegradable adhesive on the bend-
ing strength. From the results of comparing the No. 1 specimen (the specimen is composed of only the woodchips without the biodegradable adhesive) with the No. 2 specimen (the specimen is composed of the woodchips with the biodegradable adhesive), it is found that the bending strength remarkably increases by addition of the biodegradable adhesive.

Second, we examine the influences of the bamboo fibers on the bending strength. The bending strengths of the No. 3–8 specimens composed of the woodchips with the particle size of 200 μm or less and the bamboo fibers are higher than that of the No. 2 specimen composed of only the woodchips. And the bending strength increases as the fibers become longer and the content of the fibers increases. On the other hand, the bending strengths of the specimens composed of the woodchips with the particle size of 1 mm or less and the bamboo fibers increase except for the No. 3 specimen with the fiber length of 10 mm and content of 10%. From those results, it is found that the bending strength increases remarkably by mixing long bamboo fibers with woodchips.

Third, we examine the influences of the particle size of woodchips on the bending strength. For the No. 1 specimens composed of only the woodchips without the biodegradable adhesive, their bending strengths are low in both particle sizes and the effect of the particle size is not found in those results. On the other hand, with regard to specimens with the biodegradable adhesive, the bending strengths of the specimens composed of the woodchips with the particle size of 200 μm or less are higher than those of the specimens composed of the woodchips with the particle size of 1 mm or less. Particularly, the bending strengths of the specimens composed of the woodchips with the particle size of 200 μm or less and bamboo fibers with the length of over 20 mm are very high. From those results, it is found to be a cause that the voids in the specimen decrease since the particle size is small, and the adhesion of woodchips becomes firm. From the results, it is clarified that the bending strength of the specimen composed of woodchips with the small particle size, long bamboo fibers and the biodegradable adhesive is very high.

### 3.3. Impact strength

Fig. 7 shows comparison of impact energy by Charpy impact test. The symbols of • and ■ shown in Fig. 7 express the average of five samples of impact energy and the error bars which show the standard deviation. From the results for the No. 1 specimen composed of only the woodchips without the biodegradable adhesive and the No. 2 specimen with the biodegradable adhesive, the impact strength increases slightly when only the biodegradable adhesive is added to the woodchips. Namely, it is found that the biodegradable adhesive is not effective for the improvement on the impact strength. When both the bamboo fibers and the biodegradable adhesive are mixed with the woodchips, the impact strength is higher than that of the specimen composed of only the woodchips. As well as the case of the bending strength, the impact strength is improved as the length of the bamboo fiber becomes longer and the content of the bamboo fiber increases. Particularly, the impact strengths of the No. 6 and No. 8 specimens are very high. In the case of those specimens, the bamboo fibers with the length of 20 mm or 30 mm are mixed with content of 20%. From those results, it is found that bamboo fibers have a good effect on the improvement of the impact strength, and long bamboo fibers increase remarkably the impact strength. Fig. 8 shows examples of fractured specimens after Charpy impact tests. They are No. 2 and No. 8 specimens with the particle size of 1 mm or less, respectively. It seems to be a cause of the improvement for the impact strength that the crack extension resistance increases by bridging of bamboo fibers as shown in Fig. 8. In regard to the influences of the particle size of woodchips on the impact strength, the impact strengths in the cases where woodchips with the particle size of 1 mm or less were used are higher than those in the cases where woodchips with the particle size of 200 μm or less were used. From experimental results of the bending strength in Fig. 6 and the impact strength in Fig. 7, it is found that the specimen with the small particle size of the woodchips has the high bending strength and the specimen with large particle size of the woodchips has the high impact strength. When the small particles for woodchips are used, the adhered interfaces between the bamboo fibers and the woodchip particles increase. When the large particles for woodchips are used, the adhered interfaces between the
bamboo fibers and the woodchip particles decrease, but the bamboo fibers are bent by the large particles from Fig. 5(C). In the case of the bending test at the quasi-static load, the composite is fractured by the crack extension in the woodchip matrix as the tensile stress increases. Therefore, it is considered that the effect of the adhesive strength between the woodchip particles on the bending strength is bigger than the effect of the bamboo fibers. On the other hand, in the case of the impact test, the composite is also fractured by the crack extension in the woodchip matrix as the tensile stress increases, but the bamboo fibers show the effect of the reinforcement after fracture of the matrix. The resistance for pulling out the bamboo fibers in the composites with the large woodchip particles is larger than that of the composites with the small woodchip particles because the bamboo fibers are bonded to the woodchip particles in the condition that the fibers are complicatedly bent. Therefore, the reinforcement by bamboo fibers remarkably influences the impact strength.

3.4. Water resistance

To examine the water resistance for produced specimens, Charpy impact tests using the specimens absorbed water were carried out. The impact tests were carried out using the No. 1–No. 8 specimens composed of woodchips with the particle size of 1 mm or less as shown in Table 3. Also, the specimens with the water absorption of about 50% which were obtained by soaking them in the water and the specimens dried to about 0% after they were soaked in the water to the water absorption of about 50% were used for the tests. Fig. 9(A) shows comparison of impact energy of the specimens with the water absorption of about 50%. Fig. 9(B) shows comparison of impact energy of the specimens with the water absorption of about 0%. The symbol of  shown in Fig. 9(A) and (B) expresses the average of samples and the error bars which show the standard deviation. From Fig. 9(A), it is found that the No. 1 specimen without the biodegradable adhesive which absorbed water dose not have the impact strength at all. On the other hand, it is also found that No. 2–No. 8 specimens that the biodegradable adhesive is added keep having the strength, respectively, though the impact strengths become lower by absorbing water. Particularly, the specimens with long bamboo fibers have the high impact strengths. From Fig. 9(B), it is found that the impact strengths of No. 2–No. 8 specimens recover considerably by drying after soaking. The water resistance is improved by the biodegradable adhesive and the long bamboo fiber. They are effective in the case where the woodchip matrix is deteriorated by the water.

4. Conclusions

To improve the strength and water resistance for the composite made of only the woodchips, the composite composed of woodchips as the matrix material, bamboo fibers as the reinforced fiber and the biodegradable resin as the adhesive was proposed, and its strength and water resistance were examined. The results obtained from the experiments are as follows:

1. The bending strength increases by adding the biodegradable adhesive to woodchips, and it increases remarkably by adding long bamboo fibers in addition.
2. The impact strength increases slightly when only the biodegradable adhesive is added to the woodchips, and the impact strength increases remarkably and the water resistance is also improved when long bamboo fibers are added in addition.
3. The bending strength is high when the woodchips with the small particle size and long bamboo fibers are used. On the other hand, the impact strength is high when the woodchips with the large particle size and long bamboo fibers are used.
4. The proposed composite composed of woodchips, long bamboo fibers and the biodegradable adhesive has the high strength, and the practical application for the composite can be expected.

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