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Development of eco-composites using natural bamboo fibers and their mechanical properties.

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Abstract

This paper presents the development of eco-composites using natural bamboo fibers and their basic mechanical properties.

Tensile strength of the bamboo fiber bundles reinforced composites (BFRC) was measured as well as that of bamboo fiber bundles. The bamboo fibers bundle was selected into 125~210μm in diameter by a sifter machine from the bamboo chips. The BFRC were fabricated by the hot press molding using a maleic anhydride modified polypropylene as a matrix.

The experimental results showed that the specific modulus of bamboo fiber bundles was as high as that of conventional glass fibers. The test result means that the bamboo fibers have a potential to be applicable as the reinforcement of eco-composites. The optical photographs of the material cross section showed an existence of many voids in the BFRC. The SEM photographs of the fractured surface of the specimen also indicated that the resin impregnation into the reinforcements was still insufficient at the bundle crossing point.

Then, in this study, the steam explosion method was applied to extract bamboo fibers from the natural bamboo. The single bamboo fibers (BFc) were mechanically separated using a cooking mixer. The tensile strength of BFRC using BFc (BFcRC) increased about 1.5 times of MAPP. It was also found that Young's modulus of BFcRC increased about 300% of the resin. The impregnating state of resin into the BFc showed that the voids in the specimen drastically were decreased by using the steam explosion. It was also found that the size of voids in BFcRC is remarkably smaller than that of BFRC. If Bamboo was used as a reinforcement of the thermal plastics, bamboo fiber bundles should be modified into the "cotton shape".

Introduction

Natural cellulosic fibers are being focused as a substitution of glass fiber, because these fibers have adequate mechanical properties in spite of low density. These natural fibers have been abundant and available material. Many studies on the natural fiber reinforced composites have been reported. [1-4]. If the total cost including the disposal to be the waste was considered, the natural fibers are more economical than conventional glass fibers.

Natural bamboo is an abundant natural resource in Japan. The bamboo has several advantages, such as high growth speed, high strength with low density. The high specific strength of bamboo in comparison with its weight is derived by its fibers longitudinally aligned in its body. As this high specific strength, natural bamboo fiber is called "natural glass fiber" [5].

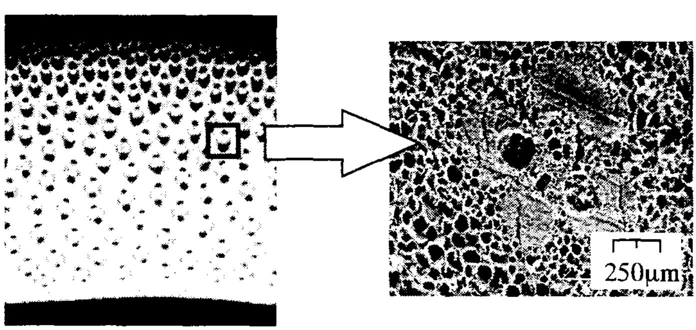
To use advantages of the bamboo or bamboo fiber, it is necessary to reveal their mechanical properties. It is also important to establish the available process of bamboo. However, few reports of bamboo or bamboo fiber reinforced composites have been published as authors known.

The objectives of the present study are to develop eco-composites using the natural bamboo fiber and to show the mechanical properties of them. The available process was also proposed for fabricating the bamboo fiber composite.

2. Materials

2-1. Bamboo fibers

Figure1 (a) (b) show a cross-section of bamboo. The bamboo consists of many vascular bundles with xylem. A vascular bundle consists of four sheaths of fibers, two vessels and some sieve tubes. The xylem surrounds each vascular bundle. The sheath consists of many single fibers. The average diameter of single fibers is 10~20 μm. The primary chemical constituents of the bamboo fibers and the xylem are cellulose and lignin respectively. In this study, the bamboo fibers bundle was selected into 125~210μm in diameter by a sifter machine. Figure 2 shows the selected bamboo fiber bundles used in this study.



(a) (b)

Fig.1 Cross-section of bamboo.

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2-2. Maleic Anhydride Polypropylene

Maleic anhydride polypropylene (MAPP) is effective material for cellulose-PP system. The maleic anhydride in the MAPP not only provides polar interactions but also can covalently link to the hydroxyl groups on the cellulose fiber [6-8]. In this study, the maleic anhydride polypropylene (Umex 1001; Sanyo Chemical Industries, Ltd.) /polypropylene (Novatec PP; Japan Polychem Corporation) mixture (5/95 in weight; MAPP) was used as matrix of BFRC (Bamboo Fiber Reinforced Composites).

3. Experimental Method

3-1. Tensile test of Bamboo fiber bundle

Figure 3 shows dimensions of the specimen. Tensile strength of the bamboo fiber bundle was measured using a small-capacity type tensile testing machine (ASG-H/Ez Test-500: shimadzu). The crosshead speed of the testing machine was 1mm/min. To compare the strength of the natural fibers, the tensile strength of the jute fiber was also measured.

3-2. Molding Method of BFRC

It has been known that the interfacial adhesion between matrix and fiber is degraded due to water absorption [9]. To remove the moisture, the bamboo fiber bundles were dried for 3 hours at 120℃ in a drying machine. For fabricating BFRC, thin films of the MAPP and the scattered bamboo fiber bundles in random were alternatively stacked, and then they were hot pressed at 190℃ under 2MPa for 30 minutes. The weight content and the volume fraction of bamboo fiber bundle were about 51% and 41% respectively.

3-3. Tensile test of BFRC

Figure 4 shows the dimensions of the specimens. Tensile strength of BFRC was measured using a universal testing machine (AUTOGRAPH: shimadzu). The crosshead speed was 1 mm/min. To evaluate an impregnation of resin into the bamboo fiber bundle, the polished surface of the specimen was observed using an optical microscope. The fractured surfaces were also observed by a scanning electron microscope (SEM).

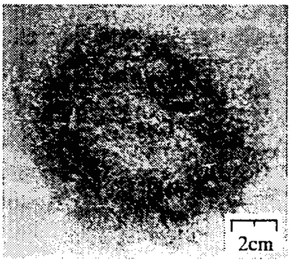

Fig.2 Selected bamboo fiber bundle using a shifter machine.

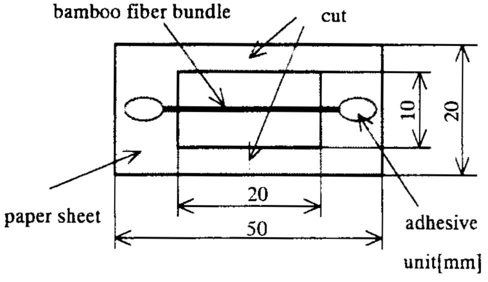

Fig.3 Dimensions of specimen for the tensile test of fibers.

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4. Results and discussion

4-1. Strength distribution of Bamboo fiber bundle

Figure 5 shows the tensile strength distribution of the bamboo fiber bundles and the jute fibers. The mechanical properties of them are listed in Table 1. Table 1 also shows typical mechanical properties of E-Glass fiber.

It was measured that the tensile strength of bamboo fiber bundle was as high as that of jute fiber. The bamboo fiber bundle and jute fiber had low Young's modulus compared with conventional glass fibers. The specific density of these natural fibers is remarkably lower than that of glass fiber. The bamboo fiber bundle has a specific Young's modulus greater than glass fibers. These results indicate that the bamboo fiber bundle have a potential as the reinforcement of polymer matrix.

4-2. Tensile strength of the BFRC

Figure 6 shows a typical tensile stress-strain curve of the BfRC. It was found that elastic modulus of the BFRC increased about 2.6 times of the MAPP. Figure 7 shows a cumulative probability of the BFRC with respect to the tensile strength. A bold solid line in this figure indicates the average strength of the MAPP. It was confirmed that the tensile strength of BFRC was 1.36 times of that of MAPP. It is also found that Young's modulus of BFRC increased about 135% of the MAPP. It can be said that the bundle of bamboo fiber works as reinforcement in BFRC.

Table 1 Mechanical properties of bamboo fiber bundles.

Type of fiber	Physical properties		Mechanical properties				
	Specific gravity	Diameter [μm]	Young's modulus [GPa]	Tensile strength [MPa]	Failure strain [%]	Specific modulus [GPa]	Specific strength [MPa]
Bundle of bamboo	1.2	10.0~30.0	35.9	441	1.3	29.9	367.5
Jute	1.3	30.0~50.0	22.7	370	1.4	17.5	284.6
E-glass	2.55	7.8~14.1	68.5	1330	1.7	26.9	521.6

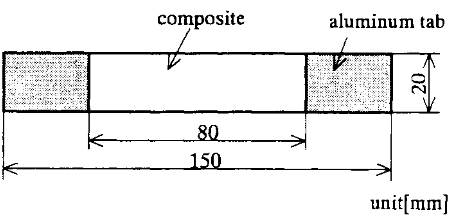

Fig.4 Dimensions of specimen for the tensile test of BFRC.

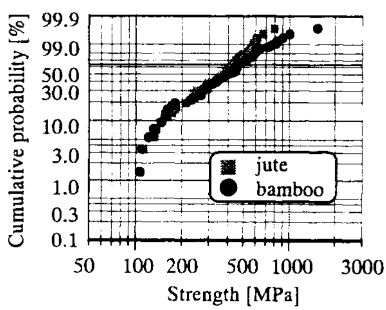

Fig.5 Strength distribution of the bamboo fiber bundles and jute fibers.

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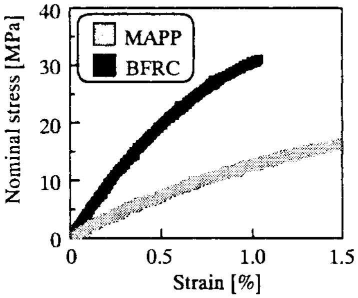

Fig.6 Stress-Strain curves of BFRC and MAPP.

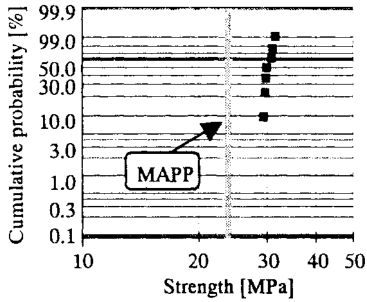

Fig.7 Strength distribution of BFRC.

4-3 The impregnating state of resin.

Figure 8 shows impregnating state of resin into the bamboo fiber bundles using the optical microscope. This photograph shows the existence of many voids near the sides of the bamboo fiber bundle. Fractured surface of the specimen is shown in Figure 9. It was observed that big vacant spaces existed at the fiber cross over points. When the bamboo fiber bundles were stacked, they may make the vacant spaces at the crossing over points because the bamboo fiber bundles have a high flexural rigidity.

Therefore, the impregnation of the MAPP into the vacant space was insufficient for fabricating the applicable BFRC. In addition, MAPP resin has high viscosity. To remove voids in the BFRC, it is necessary to decrease the diameter of fiber. If the fiber bundle can be separated into single fibers, the resin impregnation should be well obtained. However, it is difficult to separate the fiber bundle due to their high adhesive strength in conventional fabrications.

In this study, the steam explosion method was applied to degrade the adhesion between the bamboo fibers. The conditions of the steam explosion method are listed in Table 2. It is said that the steam explosion method is an easy method to separate the lignin and the cellulose from the woody materials [10].

Figure10 shows that SEM photograph of the surface of the extracted bamboo fiber bundle using steam explosion method. This photograph indicates that the bundles of bamboo fiber were not still separated into the single fibers and the lignin remains on the surface of the fiber bundle. To separate the bamboo fiber bundle into the single fiber, the fiber bundles were mechanically rubbed using a cooking mixer. Figure 11 shows a SEM photograph of the rubbed bamboo fiber bundle. These fibers look like cotton and it should be called the BFc (Bamboo Fiber Cotton). The diameter of BFc was 10~30μm and rignin is almost removed in it. It can be said that cotton shaped fibers are obtained by the steam explosion and rubbing process.

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Table 2 Conditions of the steam explosion method.

contents	time [min]	temperature [°C]	pressure [MPa]	the number of times
bamboo	100	170	0.8	8

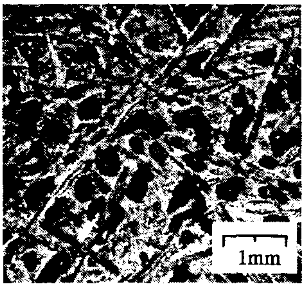

Fig.8 Resin impregnation state into bamboo fiber bundle.

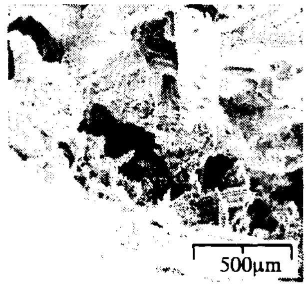

Fig.9 Fractured surface of BFRC.

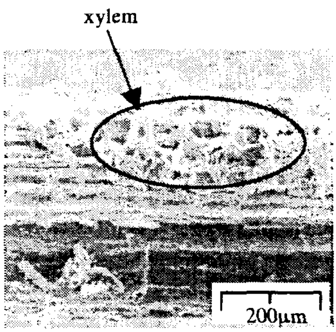

Fig.10 Surface of the extracted bamboo fiber bundle using the steam explosion method.

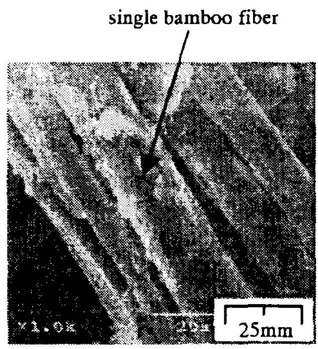

Fig.11 Surface of separated bamboo fiber using a cooking mixer.

The tensile strength of BFRP using BFc (BFcRC) was measured. A typical tensile stress-strain curve and the tensile strength distribution of BFcRC and BFRC are shown in Figure 12 and Figure13, respectively. Table 3 shows the average ultimate strength and the Young's modulus of BFcRC, BFRC and MAPP. Tensile strength of BFcRC increased about 1.15 times of BFRC. It is also found that Young's modulus of BFcRC increased about 130% of the BFRC.

Figure 14 shows impregnating state of resin into the BFc observed using the optical microscope. This photograph shows that the voids in the specimen can be drastically decreased for using BFc. It was also found that the size of voids in BFcRC is remarkably smaller than that of BFRC.

If Bamboo was used as a reinforcement of the thermal plastics, bamboo fiber bundles should be modified into the "cotton shape".

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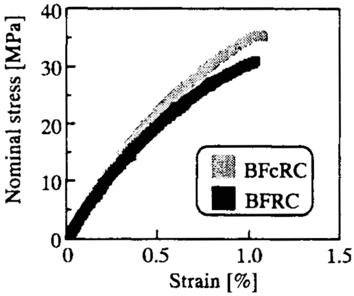

Fig12. Stress-Strain curves of BFcRC and BFRC.

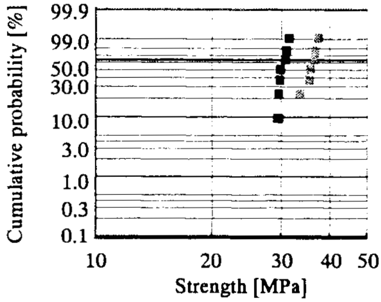

Fig.13 Strength distributions of BFcRC and BFRC.

Table 3 Mechanical properties of BFcRC, BFRC and MAPP.

Type of composite	Strength [MPa]	Young's modulus [GPa]	Failure strain [%]
BFcRC	35.1	4.69	1.18
BFRC	30.3	3.66	1.21
MAPP	22.5	17.6	-

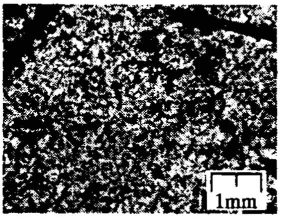

Fig.14 Resin impregnation state into bamboo fiber bundle in the BFcRC.

Conclusion

1. The bamboo fiber bundles have the potential to apply to the reinforcement of polymer matrix. The tensile strength of the bamboo fiber bundle is as high as that of jute fiber.
2. The strength of BFcRC was 1.5 times as high as that of MAPP. The Young's modulus of BFcRC was 3 times as high as that of MAPP.
3. For using BFc, The number of void in the specimen could be decreased, remarkably.
4. If Bamboo was used as a reinforcement of the thermal plastics, fiber bundles should be modified into the "cotton shape".

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