Open Journal of Composite Materials, 2015, 5, 70-78
Published Online July 2015 in SciRes. http://www.scirp.org/journal/ojcm
http://dx.doi.org/10.4236/ojcm.2015.53010

Flexural Properties of Long Bamboo Fiber/ PLA Composites

Shinji Ochi

Department of Mechanical Engineering, National Institute of Technology, Niihama College, Ehime, Japan
Email: s_ochi@mec.niihama-nct.ac.jp

Received 19 May 2015; accepted 30 June 2015; published 3 July 2015

Abstract

This paper describes the flexural properties of biodegradable composites made using natural fiber and biodegradable plastics. Biodegradable composites were fabricated from bamboo fiber bundles and PLA (polylactic acid) resin. In this research, effect of molding temperature and fiber content on flexural properties of bamboo fiber reinforced composites was investigated. The flexural strength of this composite increased with increasing fiber content up to 70%. The flexural strength of composites decreased at molding temperature of 180˚C. Biodegradable composites possessed extremely high flexural strength of 273 MPa, in the case of molding temperature of 160˚C and fiber content of 70%.

Keywords

Bamboo Fiber, PLA, Biodegradable Composites, Natural Fiber, Flexural Strength

1. Introduction

Recently, consciousness to recycling and zero emission is increasing. FRP (fiber reinforced plastics), including glass and carbon fiber reinforced plastics, have good characterizes, such as high strength, low density and corrosion resistance. Therefore, these FRPs are extensively used in a wide range of fields, including a exterior of a motorboat, automobile parts and sport goods, etc. However, these FRPs impact the environment. They are made from fossil fuels and they are non-biodegradable. From these perspectives, the usage and disposal of conventional FRP clearly contribute to the global concerns of recycling and zero-emissions and emphasis need to be placed on the involving FRP once they have been disposed.

In the past, bamboo was used as part of daily life (e.g., bamboo shoots for food and stalks for building materials). However, recently, bamboo forests have fallen into ruin because of the appearance of plastic products and the import of inexpensive bamboo shoots. The present study investigated whether bamboo can be effectively used to replace plastic and FRP materials.

How to cite this paper: Ochi, S. (2015) Flexural Properties of Long Bamboo Fiber/ PLA Composites. *Open Journal of Composite Materials*, **5**, 70-78. http://dx.doi.org/10.4236/ojcm.2015.53010

The use of natural fibers in FRP to replace glass and carbon fibers is receiving attention, because of advantages such as biodegradability, renewability, low cost and more over. Recent researches [1]-[10] have investigated the development of biodegradable composites using natural fibers such as flax [1] [2], hemp [3] [4], banana [5], jute [6] [7], ramie [8] and kenaf [9] [10] as a reinforcement for biodegradable plastics [11] [12].

The purpose of this work is to develop the material with the biodegradability and high strength with excellent mechanical properties comparable to GFRP. In this study, long bamboo fiber bundles were selected as a reinforcement of the biodegradable composites due to their high strength. In order to increase the fraction of fibers, emulsion type PLA was used for the matrix. The unidirectional fiber reinforced composites were fabricated by hot press method. And, their mechanical properties were investigated.

2. Experimental Procedures

2.1. Materials

In this research, fiber bundles of bamboo which have diameter of 100 - 300 μm and length of 100 mm were used. **Figure 1** shows macroscopic photograph of bamboo fiber bundles used in this work. Steam explosion method was used to take out bamboo fibers. Steam explosion is the method when the water contains in bamboo is heated under high temperature and pressure, then bamboo is rapidly released to the atmosphere, so that the water evaporate into steam, result of parenchyma inside the bamboo shattered.

In order to produce biodegradable composites that have high fiber content, an emulsion-type PLA (Miyoshi Oil & Fat Co., LTD.; PL-1000) was used (**Figure 2**). This resin contains fine particles of approximately 4.0 μm in diameter suspended in aqueous solution with a mass content of approximately 40%. The molecular weight of used PLA is around180,000.

2.2. Molding Method of Biodegradable Composites

First, preliminary composites were produced by putting the biodegradable resin on the surface of bamboo fibers

Figure 1. Photograph of bamboo fiber used in this work.

Figure 2. PLA of emulsion type.

and drying at 105˚C for 120 min in an oven. Next, biodegradable composite specimens were fabricated by hot pressing using a pressing machine. In this process, the preliminary composites were set in a metallic mold and heated to 120˚C, 140˚C, 160˚C, 180˚C and 200˚C with hot-press machine. The metallic mold was held at 120˚C - 200˚C for 5 min and specimens were hot-pressed at 10 MPa. The dimensions of the biodegradable composite specimens were 15 mm × 100 mm × 3 mm for flexural testing (**Figure 3**). The volume fraction of bamboo fiber in the specimens was varied from 0% to 70%. **Table 1** was showed molding condition in this research.

2.3. Method of Flexural Test

Three-point flexural tests were conducted using a testing machine (SIMADZU Model AG-250kNE), following JIS K7171 (plastics determination of flexural properties). Flexural tests were performed at a crosshead speed of 1 mm/min and a span length of 48 mm as shown in **Figure 4**. Five specimens were prepared and analyzed. A 95% confidence interval was calculated by statistical analysis.

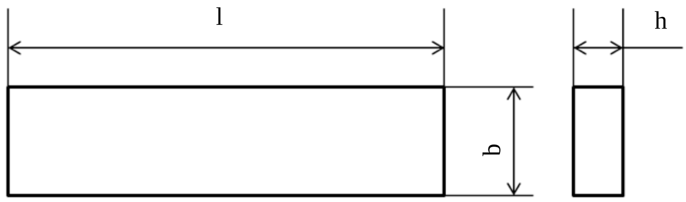


Figure 3. Shape and dimensions of flexural specimen (l = 100 mm, b = 15 mm, h = 3 mm).

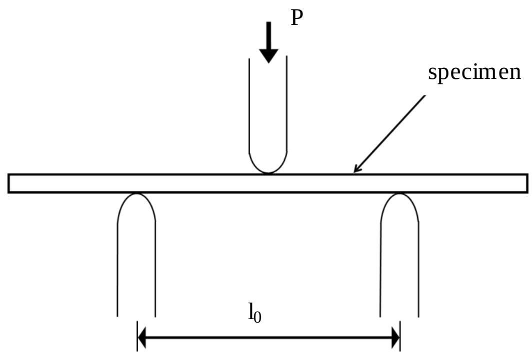


Figure 4. Method of three-point flexural test (l_0 = 48 mm).

Table 1. Molding condition (temperature, fiber content).

Molding temperature (˚C)	Bamboo fiber (%)	PLA (%)
120	50	50
140		
160	0	100
	30	70
	50	50
	70	30
180	50	50
200		

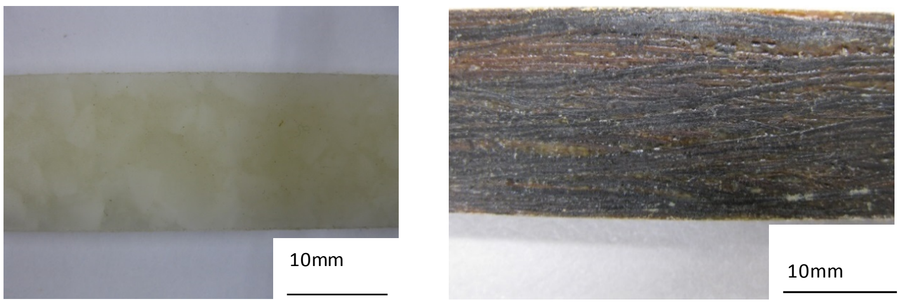
3. Results and Discussions

3.1. Fabrication of Composite Materials

The top view of the biodegradable composites with 0 and 70 % of fibers molded at 160˚C are shown in **Figure 5**. From this figure, a color of PLA specimen is milky. The other, it of bamboo fiber of 70% is dark brown. It can be observed that the distribution of fibers is parallel, and that there are no voids that would cause a decrease in strength. The novel technique presented herein, which uses an emulsion-type biodegradable resin, provides a suitable internal environment for achieving high fiber volume, in which voids are reduced in the composites.

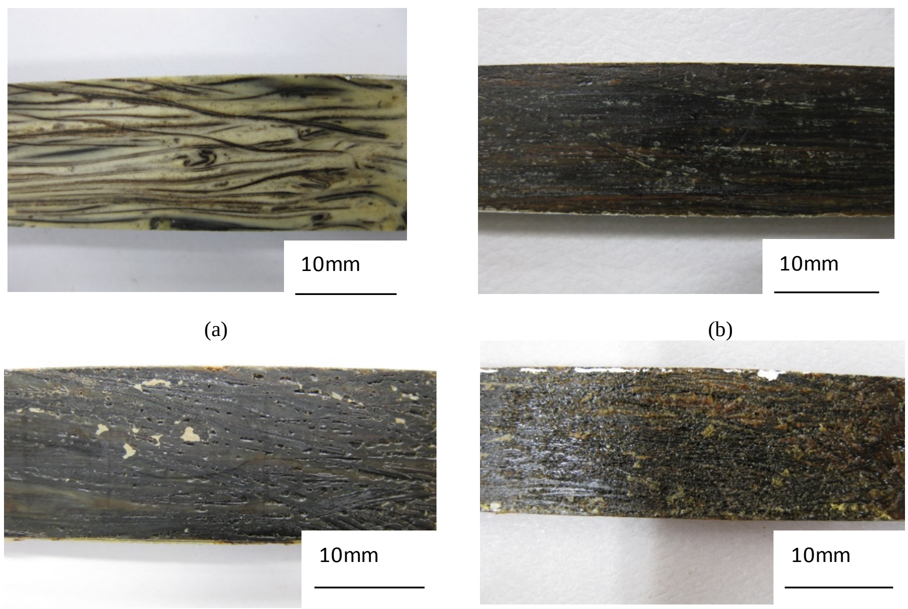
Figure 6 shows top views of biodegradable composites of 50% fiber content. **Figures 6(a)-(d)** indicate specimens molded at 120˚C, 160˚C, 180˚C and 200˚C, respectively. From **Figure 6(a)**, resin doesn't finish melting in case of 120˚C, and it's the turbid color. From **Figure 6(b)**, in the case of fiber content of 50% and molded at 160˚C, there are no voids because resin melted completely. From **Figure 6(c)**, in the case of 180˚C, voids have occurred to the surface. In the case of molding temperature of 200˚C, unevenness in the surface appears more conspicuously.

The relationship between the density of the composites of 50% fibers and molding temperature is shown in **Figure 7**. From this figure, the density of composites increased with rising molding temperature until 160˚C.



(a) (b)

Figure 5. Photographs of top view of composites. Fiber content of (a) 0% and (b) 70%.



(c) (d)

Figure 6. Photographs of top view of composites. Molding temperatures of (a) 120˚C, (b) 160˚C, (c) 180˚C and (d) 200˚C.

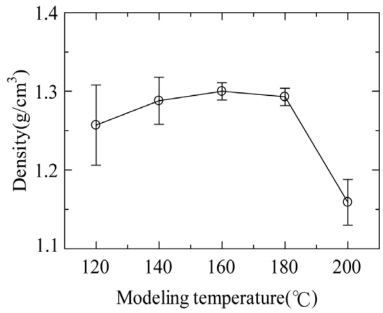


Figure 7. Relationship between density and molding temperature.

However, density decreased dramatically at 200˚C. This was expected as it was known bring many voids at temperatures above 200˚C, from **Figure 6(d)**.

The relationship between the density of the specimens molded at 160˚C and fiber content is shown in **Figure 8**. From this figure, density of specimen is increased with increasing fiber content until 50% of fibers. But, density decreased slightly at 70% of fibers. From this figure, resin isn't filled sufficiently inside the specimen. Therefore density decreased slightly at 70% of fibers.

The density of products molded at 0% and 50% of fibers are 1.24 and 1.31 g/cm^3, respectively.

3.2. Flexural Strength Bamboo Fiber/PLA Composite

Figure 9 shows the relationship between flexural strength and molding temperature. The flexural strength leveled off at molding temperature of 120˚C - 160˚C, but decrease after 180˚C. The strength of the mold product decreased because strength of fiber in itself decreased [13]-[15]. Therefore, it can be said that 160˚C is the most suitable molding temperature.

Figure 10 shows the relationships between flexural strength and fiber content molded at 160˚C. From this figure, it can be seen that flexural strengths increase linearly with increasing fiber content. The flexural strengths were 273 MPa, in the samples with a fiber content of 70%. This value is higher than the flexural strength of the bamboo reinforced material reported in the past [16] [17].

Figures 11-13 show fracture behavior after flexural testing. **Figure 11** shows specimen molded at 120˚C. The color of specimen is milky. In the case of the specimen molded at 120˚C there is no fracture of fibers, delamination can be seen between the fiber bundle and biodegradable resin, and bonding between the fiber bundle and the biodegradable resin is poor. In the case of molded at 160˚C (**Figure 12**), it's possible to observe fracture of fiber.

In the case of specimens molded at 200˚C (**Figure 13**), they explained that this cause was due to a lot of voids and low shearing stress between fiber and resin. Moreover, the strength of the mold product decreased because strength of fiber in itself decreased, from **Figure 9**. The composites molded at 200˚C brought many voids (**Figure 6(c)**). These voids caused the decrease of density and strength.

3.3. Flexural Modulus of FRP

Figure 14 shows the relationship between flexural modulus and molding temperature. In the case of 120˚C, flexural modulus indicated 3.2 GPa. Flexural modules increased at 140˚C, and remain constant thereafter. As the reason that the value of 120˚C indicated low value, from **Figure 11**, because adhesion force of fiber and resin is weak, it can think detaching has formed.

Figure 15 shows the relationship between flexural modulus and fiber content. From this figure, flexural modulus increases linearly with increasing fiber content. Unidirectional bamboo fiber/bamboo powder composites fabricated with fiber content of 70% and molding temperature at 160˚C have flexural modulus of 6.8 GPa.

3.4. Comparison with General Plastics

Table 2 shows mechanical properties of general plastic and FRP materials. The density of bamboo fiber reinforced PLA composites indicated 1.2 - 1.3 g/cm^3. The density of bamboo composite indicated same as value of PC (polycarbonate) and POM (polyacetal).

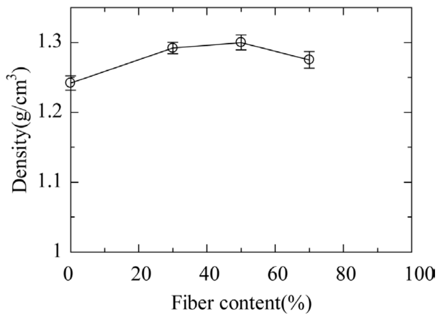


Figure 8. Relationship between density and fiber content.

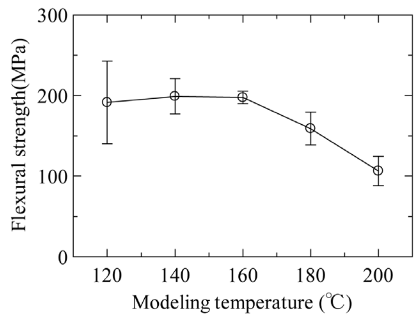


Figure 9. Relationship between flexural strength of biodegradable composites and molding temperature.

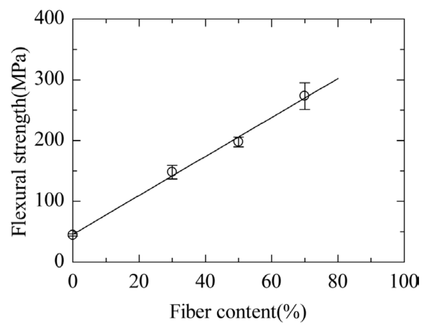


Figure 10. Relationship between flexural strength of biodegradable composites and fiber content. molding temperature of 160˚C.

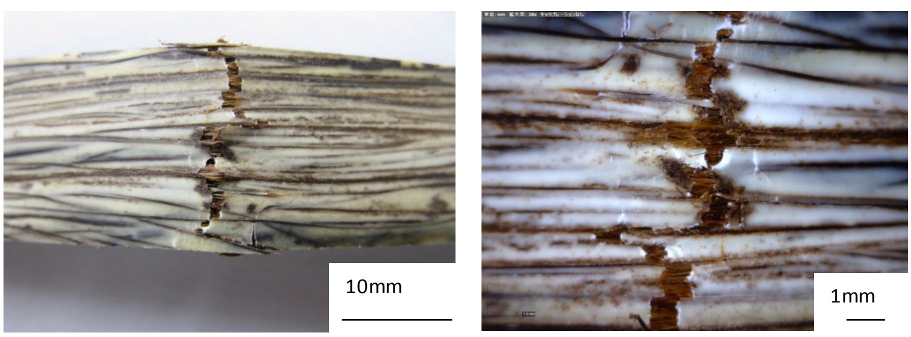


Figure 11. Fracture behavior of specimen after flexural test. Molding temperature of 120˚C. fiber content of 50%.

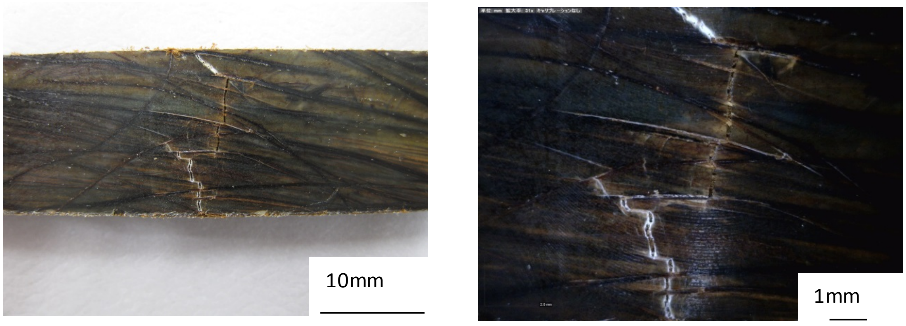


Figure 12. Fracture behavior of specimen after flexural test. Molding temperature of 160˚C. fiber content of 50%.

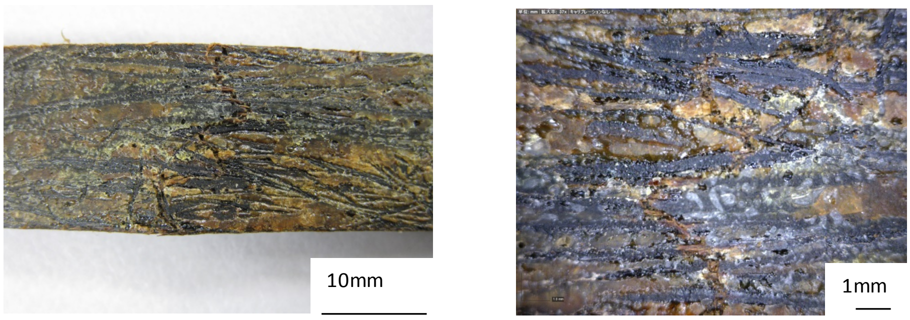


Figure 13. Fracture behavior of specimen after flexural test. Molding temperature of 200˚C. fiber content of 50%.

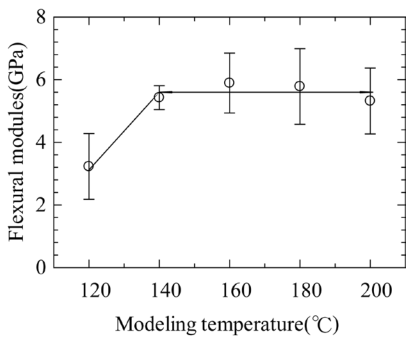


Figure 14. Relationship between flexural modulus and molding temperature. Fiber content of 50%.

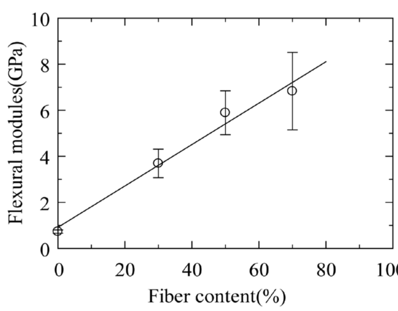


Figure 15. Relationship between flexural modulus and fiber content. Molding temperature of 160˚C.

Table 2. Characteristics of general plastics and FRP [18] [19].

	Density (g/cm^3)	Flexural strength (MPa)	Flexural modulus (GPa)
Bamboo fiber 50% 120˚C	1.26	191.52	3.23
Bamboo fiber 50% 140˚C	1.29	199.00	5.43
Bamboo fiber 50% 160˚C	1.30	197.60	5.89
Bamboo fiber 50% 180˚C	1.29	158.97	5.78
Bamboo fiber 50% 200˚C	1.16	106.38	5.32
Bamboo fiber 0% 160˚C	1.24	44.50	0.73
Bamboo fiber 30% 160˚C	1.29	148.08	3.69
Bamboo fiber 70% 160˚C	1.28	273.28	6.83
PE	0.94	34 - 39	1.00 - 1.55
PP	0.90	41 - 55	1.17 - 1.73
PS	1.05	23 - 69	1.10 - 2.69
PC	1.20	83 - 97	2.28 - 2.35
POM	1.41	94 - 110	2.62 - 3.38
GFRP (cross ply 54%)	1.65	274	
GFRP (random 25%)	1.48	140	7.45
GFRP (random 50%)	1.63	222	13.52

The flexural strength of common plastic materials, PP (polypropylene) is 41 - 45 MPa. Measurements of the press molded product of PLA resin of 100% indicated strengths nearly identical to that of PP. Measurements (197.6 MPa) of composite of 50% fibers and at molding temperature of 160˚C indicated a flexural strength nearly identical to that of GFRP (random). The flexural strengths (273 MPa) of the specimen of the fiber of 70% fabricated at 160˚C exceeded the flexural strengths of GFRP (cross ply).

Based on these results, it is consider possible that bamboo fiber/powder composites could substitute effectively for conventional FRP products.

4. Conclusions

High strength biodegradable composites were made using an emulsion-type PLA resin as the matrix and bamboo fiber bundles as the reinforcement. The results obtained are as follows:

1) Density of composites indicated about 1.2 - 1.3 g/cm^3. This value is numerals value compare as PC and PP and low density than GFRP.

2) Unidirectional biodegradable composites fabricated using an emulsion-type biodegradable resin and bamboo fiber bundles with a fiber content of 70% at 160˚C have high flexural strengths of 273 MPa and flexural modulus of 6.8 GPa.

3) The flexural strength and modulus increased linearly with increasing fiber content up to 70%. Thus excellent mechanical properties are achieved for composites fabricated by the novel technique proposed in this study in which the composites are fabricated with an emulsion-type biodegradable resin.

4) The flexural strengths were exceeded the general-purpose engineering plastics and FRP such as POM and GFRP.

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