DEVELOPMENT OF HIGH STRENGTH BIOMASS COMPOSITES MADE FROM BAMBOO

H. Takagi[1]*, H. Mori[2], T. Mori[2], S. Sujito[3], and J. K. Pandey[1]
[1] Institute of Technology and Science, The University of Tokushima, Tokushima, Japan,
[2] Graduate School of Advanced Technology and Science, The University of Tokushima, Tokushima, Japan, [3] Faculty of Mathematics and Natural Sciences, University of Jember, Jember, Indonesia
*Hitoshi Takagi (takagi@me.tokushima-u.ac.jp)

Keywords: *Bamboo, Adhesion, Hot-pressing, Resinless, Shear strength*

1 Introduction

Recently there has been an increased public attention to the development and application of environment-friendly biomass–derived materials, which are made from natural resources such as trees, crops, and natural plant fiber [1-5]. The green composites are also made from biodegradable resins and plant fiber; in addition they show a fully decomposable character. However, most of the biodegradable resins made from starch-rich plants are more expensive than conventional plastics such as polypropylene and polyethylene. This cost disadvantages is regarded as one of the significant problems for the utilization of the green composites.

It is well known that wood can be deformed and consolidated under appropriate hot-pressing conditions [6, 7]. This technique can be applied to even wood flour, i.e. complex objects can be made from only wood flour without any synthetic adhesives. Miki et al. have succeeded in the fabrication of long rods by sequential extrusion of wood flour [7]. In the present paper, therefore we apply this hot-pressing technique to steam-exploded bamboo stripe and bamboo fibers to make biomass-based composites only from bamboo.

The objectives of this study are to fabricate the bamboo composites without any synthetic resins and to clarify their mechanical properties as well as the optimum forming conditions.

2 Experimental Methods

2.1 Bamboo Stem and Bamboo Fiber

Bamboo fiber was extracted by a steam-explosion method, which is described elsewhere [8]. Bamboo stripe was cut from the steam-exploded bamboo column. The length and diameter of the bamboo fiber obtained were approximately 300 mm and 200 μm, respectively. Many parenchyma cells are still attached on the bamboo fiber (approximately 30 vol.%). This parenchyma cell plays an important role in the fabrication process of this type of bamboo composite.

2.2 Preparation of Bamboo Composites

The bamboo fibers and stripes (Fig. 1) were cut into pieces of about 100 mm length with scissors and a circular sawing machine, respectively. These bamboo fibers or bamboo stripes were set into a pre-heated metallic mold in parallel with longitudinal direction and then hot-pressed under a predetermined conditions. The hot-pressing time was fixed to be 10 min. The dimensions of tensile and flexural specimens are about 10 mm × 100 mm × 0.7 mm and 15 mm × 100 mm × 1 mm, respectively. The hot-pressing conditions used are molding pressure from 10 to 100 MPa, and molding temperature from R.T. to 200°C.

Fig. 1 Photograph of steam-exploded bamboo stripes.

2.3 Mechanical Testing of Heat-Treated Bamboo Fibers

In this study, the tensile strength of bamboo fiber bundles was evaluated because it was extremely

difficult to extract a single fiber from a bamboo fiber bundle.

A heat-treated fiber bundle and non-treated fiber bundle were bonded to a paper sheet with alpha-cyanoacrylate adhesive (Cemedine, Loctite® Zero-time) as shown in Fig. 2 to avoid the fiber damage introduced during the setting the fiber specimen in a universal test machine. Tensile tests were performed at 1.0 mm/min and room temperature without an extensometer. The number of heat-treated fiber samples examined was 10 in each heat-treated condition.

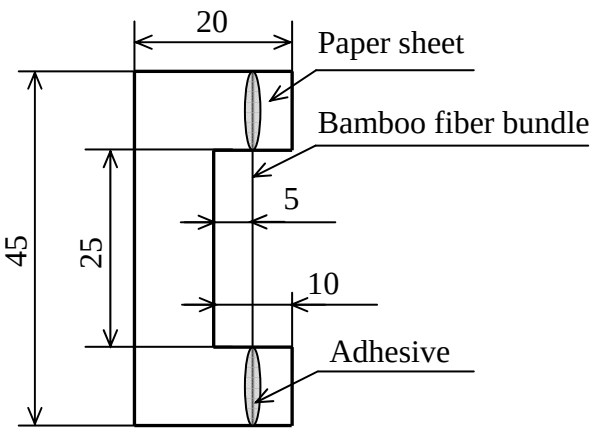

Fig. 2 Schematic illustration of bamboo fiber specimen for tensile testing.

2.4 Mechanical Testing of Bamboo Composites

Tensile tests for the bamboo composites were carried out using an Instron universal testing machine (5567) with extensometer (2620-602, Instron). Gauge length and testing speed were 25 mm and 1.0 mm/min, respectively. Aluminum tabs of 2 mm thickness were glued onto the both ends of the tensile specimen to avoid introducing gripping damages. The number of specimens examined was three in each hot-pressing condition.

Flexural tests were also performed in a 3-point bending mode with the same Instron 5567 testing machine. The flexural test speed was 1.0 mm/min, and the number of specimens investigated was three in each hot-pressing condition.

3 Experimental Results and Discussion

3.1 Tensile Test for Heat-Treated Bamboo Fibers

Figure 3 shows the relationship between the tensile strength of heat-treated bamboo fibers and heating temperature. The vertical lines are indicated the 95% confidence interval for the average tensile strength. It can be seen that the tensile strength of bamboo fiber heat-treated at low temperatures (below 120°C) shows the similar values and that the tensile strength tends to decrease with increasing the heat treatment temperature above 120°C [9]. This decrease in tensile strength is presumably related to the decreases in fracture elongation (embrittlement), which might be derived from the pyrolysis (thermal degradation) of bamboo fiber itself during the high-temperature heat treatment [10].

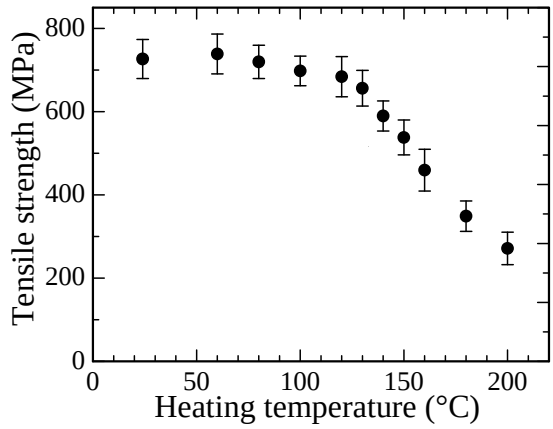

Fig. 3 Relationship between tensile strength of heat-treated bamboo fiber and heating temperature.

3.2 Tensile Test for Bamboo Fiber Composites

Figure 4 shows the relationship between tensile strength of bamboo fiber composites and molding temperature as a function of molding pressure. The tensile strength has considerably strong temperature dependence. The tensile strength of the bamboo fiber composites molded at 120–130°C is almost three times higher than that at room temperature. However the molding pressure has little effect on the strength. In addition, the effect of molding pressure becomes further small at higher temperatures above 100°C.

The tensile strength of bamboo fiber composites increases with increasing molding temperature below 120°C, and then decreases with increasing molding temperature above 140°C. This increasing trend is consistent with that in the samples' density (Fig. 5). On the other hand, the decrease in tensile

strength is consistent with that of the heat-treated bamboo fiber as shown in Fig. 3. In other words, the decrease in tensile strength at higher temperatures is derived from the lack of the strengthening effect in bamboo fiber itself due to the pyrolysis (thermal degradation) of the bamboo fiber.
The maximum tensile strength of the bamboo fiber composites molded at 120°C and 50 MPa is 636 MPa. The optimum molding temperature range seems to be from 120°C to 130°C according to these experimental results.

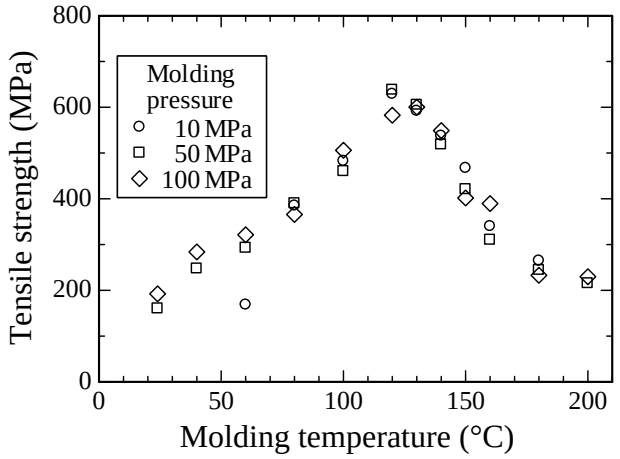

Fig. 4 Relationship between tensile strength of bamboo fiber composites and molding temperature.

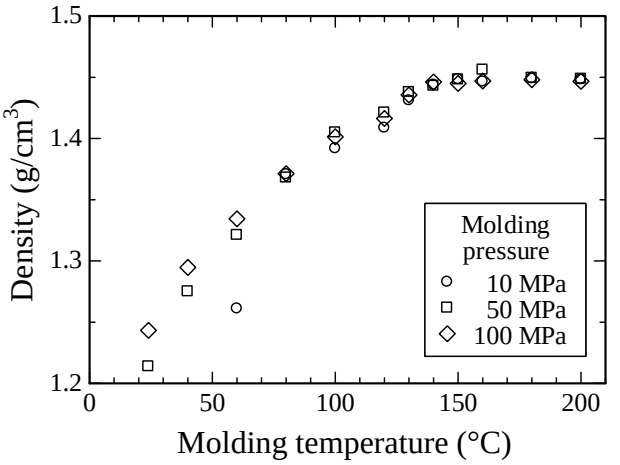

Fig. 5 Relationship between density of bamboo fiber composites and molding temperature.

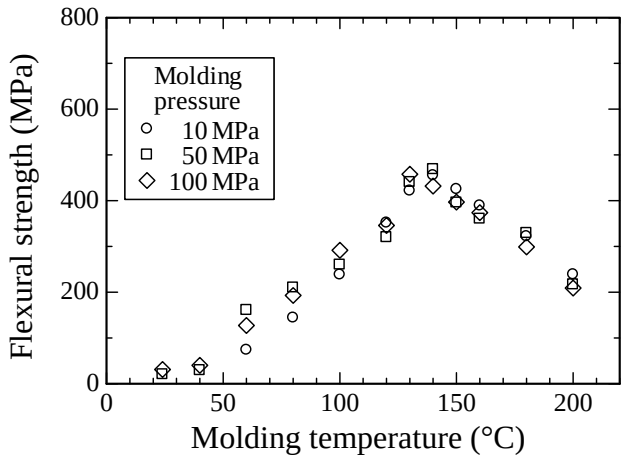

Fig. 6 Relationship between flexural strength of bamboo fiber composites and molding temperature.

The variation of flexural strength is shown in Fig. 6, and showing the similar molding conditions dependence.

3.3 Tensile Test for Bamboo Stripe Composites

Similar relationship between tensile strength of bamboo stripe composites molded at 10 MPa and molding temperature is indicated in Fig. 7. The tensile strength has also considerably strong temperature dependence. The peak temperature is slightly higher than that of bamboo fiber composites as shown in Fig. 4. The maximum tensile strength is approximately 450 MPa. This value is lower than the tensile strength of bamboo fiber composites.

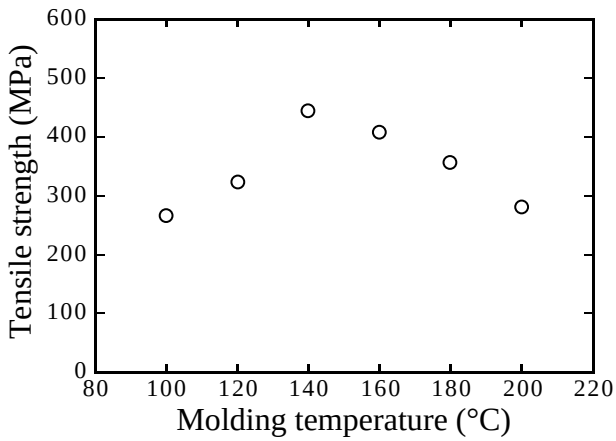

Fig. 7 Relationship between tensile strength of bamboo stripe composites and molding temperature.

This decrease is responsible for the smaller volume fraction of bamboo fiber in the bamboo stripe composites. As compared with the bamboo fiber composites, however the hot-pressing of bamboo stripe composite becomes much easier because of easiness of sample handing.

4 Conclusions

(1) Tensile strength of the bamboo composites strongly depends on pressing temperature. Their strength increases with increasing molding temperature up to approximately 130˚C. This increase in strength might be achieved by improved adhesive property of parenchyma cell phase.

(2) Mechanical properties of bamboo stripe composites are lower than that of bamboo fiber composites. This lower strength might be derived from lower fiber content in bamboo stripe composites. However the hot-pressing of bamboo stripe composite becomes much easier because of easiness of sample handing.

Acknowledgements

This study was partially supported by The University of Tokushima and the High Technological Research Project on “Research and Development Centre for Advanced Composite Materials” of Doshisha University and Ministry of Education, Culture, Sports, Science and Technology, Japan.

References

[1] B.S. Kim, J.W. Yi, J.R. Ha, S.K. Kim and J.I. Song, “Interfacial optimization of acetate taffeta fabric/PLA composites”. *Polymers and Polymer Composites*, Vol. 19, No. 2-3, pp 87-90, 2011.

[2] K. Takemura, “Effect of surface and heat treatment on tensile properties of jute fiber reinforced composites”. *WIT Transactions on The Built and Environment*, Vol. 112, pp 167-175, 2010.

[3] K. Tanaka, H. Miyabe, T. Katsura, T. Katayama and K. Uno, “Impact properties of jute fabric reinforced PLA composites”. *WIT Transactions on The Built and Environment*, Vol. 112, pp 207-217, 2010.

[4] H. Takagi and Y. Ichihara, “Effect of fiber length on mechanical properties of "green" composites using a starch-based resin and short bamboo fibers”. *JSME, International Journal, Series A*, Vol. 47, No.4, pp 551-555, 2004.

[5] H. Takagi and A. Asano, “Effects of processing conditions on flexural properties of cellulose nanofiber reinforced "green" composites”. *Composites Part A*, Vol. 38, No.4, pp 685-689, 2008.

[6] H. Imanishi, N. Soma, O. Yamashita, T. Miki and K. Kanayama, “Effect of production conditions of wood powder on bending properties of wood powder molding material without adhesive”. *JSME International Journal, Series A*, Vol. 48, No.4, pp 432-436, 2005.

[7] T. Miki, N. Takakura, T. Iizuka, K. Yamaguchi and K. Kanayama, “Production of long rods by sequential extrusion of wood powders”. *J. of Materials Processing Technology*, Vol. 140, pp. 407-412, 2003.

[8] H. Mori and H. Takagi, “Influence of molding conditions on mechanical properties of resinless bamboo fiber green composite”. *Proceedings of International Conference on Advanced Technology in Experimental Mechanics*, pp OS16-3-2-1-5, 2007.

[9] S. Ochi, H Takagi and R. Niki, “Mechanical properties of heat-treated natural fibers”. *Journal of Society of Materials Science, Japan*, 51-10, pp 1164-1168, 2003.

[10]The Cellulose Society, Japan, “*Dictionary of Cellulose”*, Asakura Publishing Co., Ltd., Tokyo, pp 79-118, 2000.