MECHANICAL PROPERTIES OF "GREEN" COMPOSITES BASED ON POLY-LACTIC ACID RESIN AND SHORT SINGLE BAMBOO FIBERS

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Abstract

This paper deals with the fabrication of short single bamboo fiber (BF) reinforced biodegradable emulsion-type Poly-lactic Acid (PLA) resin environmentally-friendly "green" composites. The "green" composite with BF loading from 15 to 75 mass % were prepared by hot-press molding at conditions of constant temperature of 140^{0}C, pressures of 10 MPa, and time molding of 10 minutes. The effect of BF contents on tensile and flexural properties was investigated. The measurement finding showed that the tensile and flexural properties were affected by the BF content. The best tensile and flexural properties were observed for the GC with 40 mass % BF content. Morphological BF reinforced "green" composites have also been investigated. The results obtained emphasize the applications of these fibers, as potential reinforcing materials in biodegradable based or "green" composites.

Keywords: *"Green" composite, Bamboo fiber, PLA, Mechanical properties*

1 Introduction

The use of natural fibers to reinforce biodegradable polymers as an alternative to synthetic or glass fibers has been and continues to be the subject of research and development. The potential advantages of using natural fibers and biodegradable polymers to produce "green" composites (GC) have been well documented and are generally based on environmental friendliness as well as health and safety factors [1]. Up to now, different natural fibers have been employed to fabricate GC such as bamboo [2-4], kenaf [5], flax [6], hemp [7], jute [8] and wood fibers [9]. In line with the use of bamboo fibers (BF) in fabrication of the GC, studies of effect of fiber length and fiber content on mechanical properties of randomly short BF reinforced starch-based resin GC have been carried out [2]. The samples were fabricated by hot press molding using short length BF bundles. Both tensile and flexural strength are considerably affected by fiber length and content. The maximum tensile and flexural strength of 45 MPa and 60 MPa are achieved for the BF length of 25 mm and 50% mass of fiber content.

One of the biodegradable polymers which had been highlighted because of its availability from renewable resources such as corn, wheat, sugar beets and tapioca is poly-lactic acid (PLA). PLA is a class of crystalline biodegradable thermoplastic polymer with relatively high melting point and good mechanical properties. Usually, PLA is synthesized by condensation polymerization of L-lactic acid or ring-opening polymerization of the corresponding lactic [10]. Unfortunately, PLA and also most of the biodegradable resins have relatively low strength, so it is impossible for biodegradable resins to be used as high strength structural components. Because of that the use of strong natural fiber such as hemp, ramie and bamboo as reinforcement materials on strengthening biodegradable resins to be attractive field of research. Generally, the mechanical properties of natural fiber reinforced biodegradable GC were significantly improved by using short single fibers.

In the present study, the investigation of the effect of fiber content on mechanical properties of the GC based on the PLA resin with short single BF reinforcement material have been conducted.

2 Experimental Procedures

2.1 Materials

Random short single BF as a reinforcement material with average diameter of 17-20 μm and 2.0-3.0 mm in length were obtained from chemically with sodium hydroxide (NaOH) and mechanically treatments of long BF bundles produced from steam explosion [3]. Long BF bundles were cut into 30-40 mm in length and dipped in aqueous solution of 5% (weight/volume) sodium hydroxide for 60 minutes and followed by mixed well for 20 minutes using a home-use mixer. This mixture then washed using flowing water followed by distilled water in several times. Subsequently drained and dried using a convection oven at temperature of 70^{0}C for 4 hours and obtained short single BF. Finally, the short single BF blended using home-use mixer to get randomness finer fiber which free from soft cells powder attached on the BF surface. Fig. 1 shows an SEM photograph of random short single BF reinforcement material used in fabrication of the GC.

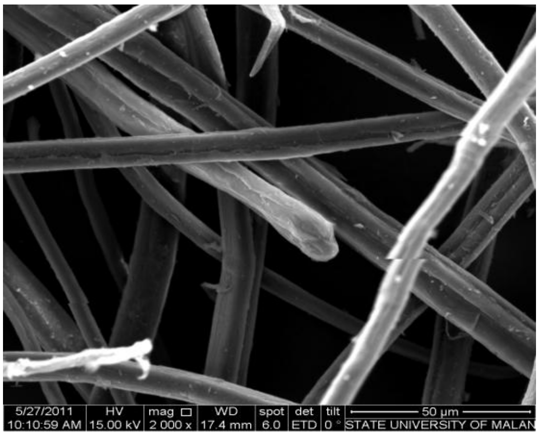

Fig.1. SEM photograph of random short single BF materials.

An emulsion-type biodegradable PLA (Miyoshi Oil & Fat Co., Ltd.; PL-2000) resin was used as the matrix. This resin contained fine particles approximately 2.2 μm in diameter suspended in aqueous solution with a mass content of approximately 40%. Typical physical and mechanical properties of the PLA (PL-2000) resin are shown in Table 1.

Table 1
Typical physical and mechanical properties of PLA (PL-2000) resin are used as matrix.

Density (gram/cm^3)	1.26
Tensile strength (MPa)	11.5
Young’s modulus (GPa)	1.1
Particle diameter (mm)	2.2

2.2 Sample Preparations

Predetermined short single BF was mixed with water diluted emulsion biodegradable PLA resin using home-use mixer for 20 minutes. This mixture then poured in a shallow plate and then dried in a convection oven at temperature of 70^{0}C for 12 hours to obtain preformed sheet. The preformed sheet was cut into small sizes with dimensions of 100.0 mm in length and 10.0 mm in width. These preformed sheets were stacked to obtain pre-specimens GC.

The GC specimens were fabricated by hot pressing using a metallic mold and a pressing machine. In this process, the pre-specimens were set in the metallic mold and heated to 140^{0}C. The specimens were hot-pressed at 10 MPa for 10 minutes. The dimensions of the specimens of 100.0 mm in length, 10.0 mm in width, and 2.0 mm in thickness were made and used for tensile testing. While, the dimensions of specimens of 100.0 mm in length, 10.0 mm in width, and 4.0 mm in thickness were fabricated used for flexural testing. The BF content in the specimens was 15%, 25%, 40%, 50%, 60% and 75% of mass.

2.3 Sample Characterizations

Mechanical (tensile and flexural strength) properties of the GC specimens reinforced with randomly oriented short single BF fabricated in this work were carried out using an Instron universal test machine (Model 5567). The tensile test of the specimens was conducted at crosshead speed of 1.0 mm/min and a gauge length of 30.0 mm. Meanwhile, the flexural tests of the specimens were also performed at a crosshead speed of 1.0 mm/min using a 3-point bending test with a span length of 50.0 mm. In this study, internal microstructures and fracture surfaces of the specimens were observed using an INSPECT S 50 scanning electron microscope (SEM).

3 Experimental Results and Discussion

Tensile stress-strain and flexural stress-crosshead displacement all of the specimens are shows similar behavior. Both of them are tremendously affected by the BF content on the specimens. The tensile stress and flexural stress are increases with increasing an applied loading up to the maximum of elongation and deflection were reached, respectively.

Figs. 2 and 3 show the relationship between BF content with tensile and flexural properties, respectively. From both figures it can be seen that the tensile and flexural properties have similar dependence on the BF content.

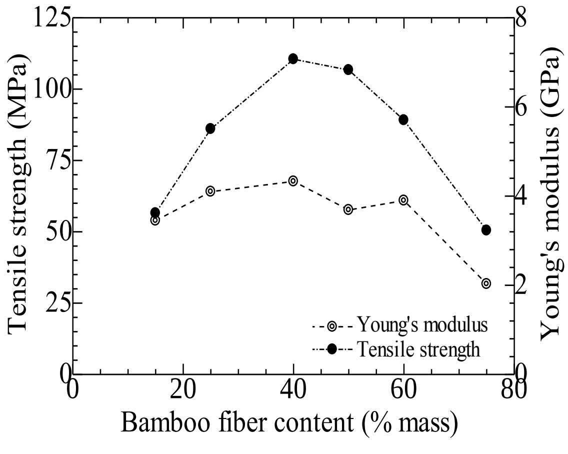

Fig.2. Relationship between tensile (strength and modulus) properties and bamboo fiber content.

In the region in which the BF content less than 40 mass %, both tensile properties and flexural properties are increases with increasing BF content. This increasing tendency in the tensile and flexural properties, however, decreases with increasing the BF content in the region in which the BF content more than 40 mass %.

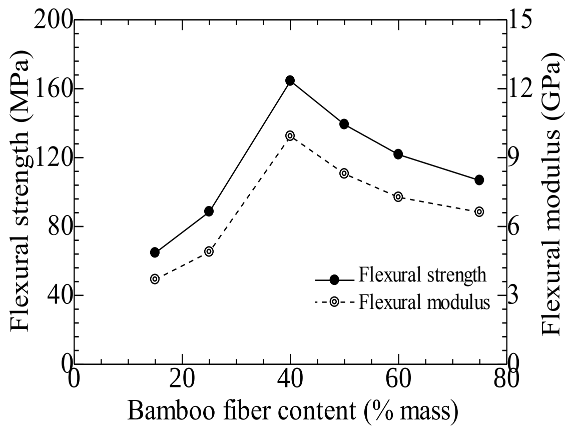

Fig.3. Relationship between flexural (strength and modulus) properties and bamboo fiber content.

The maximum value of tensile strength ((110.47±5.35) MPa and Young's modulus (4.33±0.27) GPa were attained for specimen with 40 mass % BF content, as can be observed in Fig. 2. In the meantime, from Fig. 3 it could be also observed that the maximum value of flexural strength and flexural modulus were (164.47±43.34) MPa and (9.93±2.67) GPa, respectively, in the same specimen. As compared to the tensile strength of neat PLA (11.5 MPa) and according to the result obtained by other researchers, the tensile strength of bamboo fiber reinforced PLA are 45 MPa [4] and 54.6 MPa [8], respectively. The tensile strength of the GC resulting from the current study is nearly 1000% and 110% higher than those of neat PLA and the bamboo fiber-reinforced PLA composites, respectively. In this study, the optimum concentration of the BF reinforcement material was obtained 40 mass %.

As we know that the tensile strength of plant based fibers is lower than that glass fibers, so it is necessary for GC to have higher fiber content in order to obtain high strength composite materials. However, generally composite materials with higher fiber content are difficult to fabricate. In the meantime, as already discussed earlier [2], decrease in the strength properties of the GC materials has been attributed to two situations such as the existence of defects, such as voids and weak adhesion force between matrix and reinforcement materials.

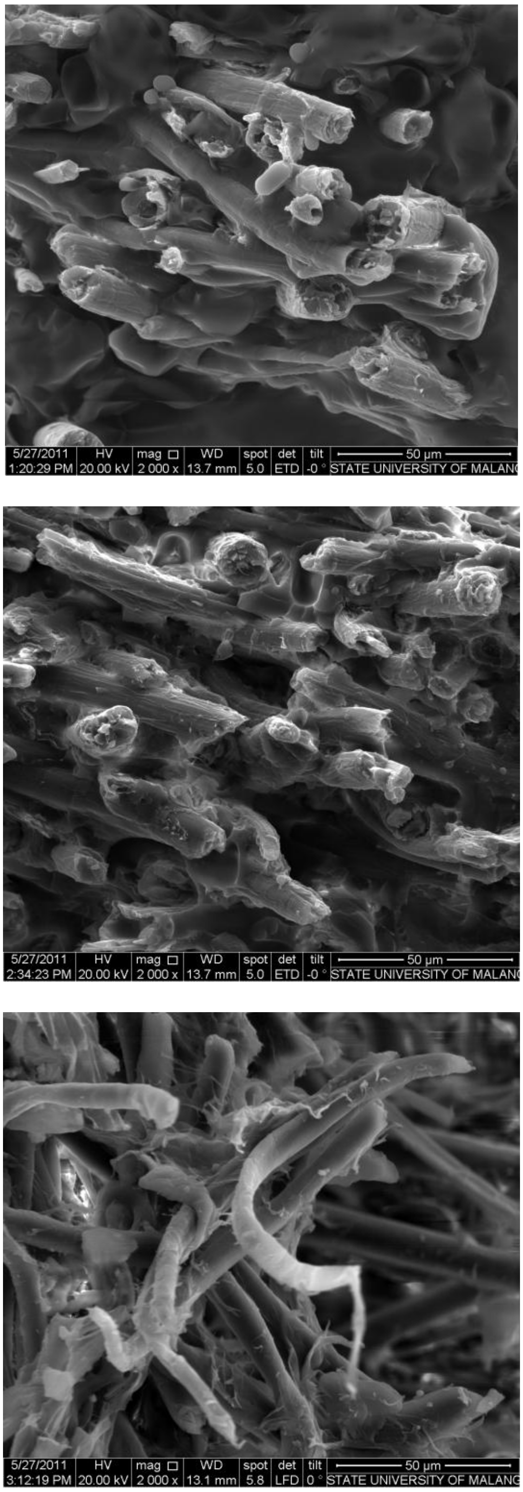

Fig.4. SEM micrographs of BF reinforced PLA GC containing: (a) 25 mass % of the BF; (b) 40 mass % of the BF; and (c) 75 mass % of the BF.

Consequently, the discrepancy of the tensile and flexural strength in the specimens with BF content less and more than 40% may also be attributed to voids and low fiber-matrix interface adhesion force.

Fig. 4 shows SEM micrographs of fracture surfaces and internal microstructure of three specimens BF reinforced GC. Internal microstructure of the specimen with 15 mass % BF content has extensive BF-rich and BF-poor regions (Fig. 4a). The specimen with 40 mass % BF content, the BF were nearly spread evenly (Fig. 4b). In contrary, the specimen with 75 mass % of BF content, the BF the neighboring fibers make contact with each other without having any resin between them. On the other hand, the fracture surface of tensile specimens with 15 mass % and 40 mass % BF contents are depicted in Fig. 4a and 4b, respectively. The micrographs in the Fig. 4a show the availability of fiber pull-out on the fracture surfaces, which is indicate weak interface bonding in this GC. As we can see from Fig. 4c that almost all of fibers were pull-out without fiber fractures. This indicates that the interface adhesion force in this GC weaker than the others.

4 Conclusions

It has been successfully fabricated short single bamboo fiber (BF) reinforced emulsion-type poly-lactic acid (PLA) resin "green" composites (GC). The tensile and flexural properties of these GC were investigated. Both tensile and flexural properties are strongly affected by the BF content. The experimental values of the tensile strength and flexural strength have been found maximum for the GC with 40 mass % BF content. This indicates that the fiber/matrix interface adhesion force of this GC was higher than the other GC fabricated in this study. It may be use in many applications, likes for panels for indoor and outdoor applications, secondary structural applications in automotive and housing.

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References

[1] M. Avella, A. Buzarovska, M.E. Errico, G. Gentile and A. Grozdanov, “Review-eco-challenges of bio-based polymer composites”. *Materials*, Vol. 2, pp 911-925, 2009.

[2] 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 Intl. J.*, Series A, Vol. 47, No. 4, pp 551-555, 2004.

[3] H. Takagi and R. Takura, “The mechanical properties of bamboo fibers prepared by steam-explosion method”, *Zairyo*, Vol. 52, pp 357-361, 2003.

[4] S. Lee, and S. Wang, “Biodegradable polymers/bamboo fiber bio-composite with bio-based coupling agent”, *Composites Part A: Appl. Sci. and Manufact.*, Vol. 37, No. 1, pp 80–91, 2005.

[5] S. Ochi, “Mechanical properties of kenaf fibers and kenaf/PLA composites”, *Mechanics of Material*, Vol. 40, No. 4-5, pp 446–452, 2008.

[6] E. Bodros, I.Pillin, N. Montrelay and C. Baley, “Could biopolymers reinforced by randomly scattered flax fibres be used in structural applications”, *Compos. Sci. Technol.* , Vol. 67, No. 3-4, pp 462-470, 2007.

[7] M. García, I. Garmendia and J. García, “Influence of natural fiber type in eco-composites”, *J Appl. Polym. Sci.*, Vol. 107, No. 5, 2994-3004, 2008.

[8] R. Hu and J-K. Lim, “Fabrication and mechanical properties of completely biodegradable hemp reinforced PLA composites”, *J. Compos. Mater*, Vol. 41, No. 13, pp 1655-1669, 2007.

[9] M.S. Huda, L.T. Drzal, A.K. Mohanty and M. Misra. “Wood-fiber-reinforced poly(lactic acid) composites: Evaluation of the physicomechanical and morphological properties”, *J. Appl. Polym. Sci.*, Vol. 102, No.5, pp 4856-4869, 2006.

[10] D.A. Garlota, Literature Review of Poly(lactic)Acid, *J. Pol. Env*., Vol. 9., pp 63-84.