Fabrication and characterization of Short Single Bamboo Fibers Reinforced Poly-lactic Acid (PLA) Green Composites (GC)

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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°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.

Index Term—Green composite, Bamboo fiber, PLA, Tensile Strength, Flexural Strength

I. 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 fiber length and fiber content effect 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 [11] have relatively low strength, so it is impossible for these resins to be used as high strength structural components. Because of that the use of strong natural fibers 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 resins 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.

II. MATERIALS AND METHOD

2.1 Materials

Long BF bundles, as shown in Figure 1, were produced from steam explosion process [3]. The long BF bundles, then were, cut were cut into 30-40 mm in length and dipped in aqueous chemical solution of 5% (weight/volume) sodium hydroxide (NaOH) for 60 minutes and followed by mechanically treatment by hand and followed mixed well using a home-use mixer for up to 20 minutes. This BF then washed using flowing water followed by distilled water in several times to get randomness finer fiber which free from soft cells powder attached on the BF surface. Then poured into deeped in distilled water with dimensions of 100x100 mm to obtain random orientation of short single BF as a reinforcement material with average diameter of 17-20 μm and 2.0-3.0 mm in length. Subsequently drained and dried using a convection oven at temperature of 70°C for 24 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. Figure 2 shows SEM photograph of random orientation short single BF reinforcement material used in the fabrication of the GC.
specimens were set in the metallic mold and heated to 140°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 GC Characterizations

Characterization of tensile and flexural strength properties of the GC specimens reinforced with randomly oriented short single BF was 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 three 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 S50 scanning electron microscope (SEM).

### III. RESULTS AND DISCUSSIONS

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 and flexural strengths were increases with increasing an applied loading up to the maximum of elongation and deflection were reached, respectively.

Figure 3 (a) and (b) shows the relationship between bamboo fiber content of the specimen with the tensile strength and Young’s modulus, respectively. From these both figures, it can be seen that the tensile strength and Young’s modulus have similar dependence on the BF content. In the region in which the BF content less than 40%, both the tensile strength and Young’s modulus are increases with increasing the short single BF content. This increasing tendency in the tensile strength and Young’s modulus, however, it does not apply to specimens with bamboo fiber content more than 40%. The results are supported by the results from the flexural strength and modulus measurements of these specimens, as shown in Figure 4.

The maximum value of the tensile strength (82.47±2.65) MPa and Young’s modulus (4.33±0.14) GPa were attained for specimen with 40% of BF content, as can be observed in Figure 3. From Figure 4, it could be also observed that the maximum value of flexural strength and flexural modulus were (164.47±11.34) MPa and (9.93±1.37) GPa, respectively, for 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

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In the mean time, 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 I.

<table>
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<th>Properties of PLA (PL-2000) resin were used as a matrix.</th>
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<tr>
<td>Density (gram/cm³)</td>
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<td>Tensile strength (MPa)</td>
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<td>Young’s modulus (GPa)</td>
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<td>Particle diameter (mm)</td>
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### 2.2 GC Fabrication

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

The GC specimens were fabricated by hot pressing machine using a metallic mold and a pressing machine as has been done previously [12]. In this process, the GC pre-
nearly 1000% and 100% higher than those of neat PLA and the bamboo fiber-reinforced PLA composites. In this study, the optimum concentration of the BF reinforcement material was obtained 40% of mass. The results are consistent with results of previous studies [12].

As we know that the tensile strength of plant based fibers is lower than that glass fibers, so it is necessary for the 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. 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.

Figure 5 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 (Figure 5a). The specimen with 40 mass % BF content, the BF were nearly spread evenly (Fig. 5b). 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% and 40% BF contents are depicted in Figure 5a and 5b, respectively. The micrographs in the Figure 5a shows the availability of fiber pull-out on the fracture surfaces, which is indicate weak interface bonding in this GC. As we can see from Figure 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.
IV. CONCLUSION

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 % of 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 used in many applications, likes for panels for indoor and outdoor applications, secondary structural applications in automotive and housing.

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REFERENCES


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