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Development and characterization of a laminate composite material from polylactic acid (PLA) and woven bamboo fabric

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ABSTRACT

This article presents the development and mechanical characterization of a composite material fabricated from both renewable resources and biodegradable materials: bamboo woven fabric as reinforcement and polylactic acid (PLA) as resin matrix. The laminate composites were produced using a film stacking method. The physical, thermal, and, mechanical properties of bamboo fabric, PLA matrix, and laminate composites were investigated. It is shown that the breaking force of the plain woven bamboo fabric in the weft direction was greater than in the warp direction. Further, the tensile, flexure, and, impact properties of PLA increased when weft direction bamboo fabric reinforcement is used. In addition, scanning electron microscopy examination of laminate composite showed good bonding between bamboo fiber and PLA resin. In summary, laminated composites based on polylactic acid and bamboo fabric display excellent energy absorption capability, which can be exploited for the development of engineering structural applications.

1. Introduction

As a result of the increasing environmental awareness, the concern for environmental sustainability and the growing global waste problem, over the past decades there has been a fast growth in the use natural fibers instead of traditional fibers as reinforcements in composite materials [1–3]. Natural fibers have been used to reinforce thermoplastics due to their advantages, such as low cost, low density, acceptable specific strength, good thermal insulation properties, biodegradability, and renewability [4–7]. Recent advances in the use of natural fibers (e.g., jute, flax, sisal, kenaf, henequen, fique, coconut and bamboo) in composites have been reviewed by several authors [8–16]. In the vast majority of studies, however, the resin used was petrochemical-based. Therefore, the development of composites materials based on fibers and matrix resins originate from renewable raw materials has been subject of great interest for both ecological and engineering perspective [17].

Among biodegradable polymers, polylactic acid (PLA) has a special interest as a matrix in natural fiber composites for many reasons. Fist, PLA is a versatile thermoplastic produced from lactic acid monomer coming mainly from the fermentation of corn, potato, sugar beet, and sugar cane [18]. Second, the commercially attractive features of PLA includes its degradability in a short period of time (0.5–2 years) in contrast to conventional plastics like PS, PE, etc., which need 500–1000 years [19]. Third, PLA has good mechanical properties that are similar to those of polystyrene. Even though PLA has a high cost, it has been used in industrial packaging field and medical applications [20]. At last, PLA can be melt – processed with standard processing equipment at temperatures below those at which natural fibers start to degrade [21].

Some research on PLA – natural fiber composites materials have been undertaken, for example, Oksman et al. [22] reported that PLA – flax composites had better mechanical properties than PP(polypropylene) flax composites. Plackett et al. [23] combined PLA films with jute fiber mats to generate composites by a film stacking technique. They found that tensile properties of composites produced at temperatures in the 453–493 K range were significantly higher than those of polylactide alone.

On the other hand, bamboo fiber is also a good candidate as reinforcement in composite materials because it is an abundant natural resource available in many countries and one of the fastest growing grass plants [24,25]. Also, bamboo has excellent specific mechanical properties because its fibers are aligned longitudinally [26].

Even though it is difficult to extract bamboo fiber from the plant, different extract techniques have been studied [27]. Okubo et al. [28] reported that steam explosion technique is an effective method to extract bamboo fibers for reinforcing thermoplastics. Tokoro et al. [29] illustrated that mechanical performance of PLA/Bamboo Fiber composites improved by using steam-exploded filament, due an increase of interfacial strength between PLA and steam-exploded filament.

Although there are many research studies in the literature concerned to develop green composites, most of them use short

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natural fibers as reinforcement material. Few studies developed woven fabric reinforced composites using natural fibers and biodegradable matrices, exploiting the benefits of the load carrying capacity of long fibers to manufacture composites for structural applications.

In this article, it is presented the development and mechanical characterization of an environmental friendly composite material manufactured from woven bamboo fabric and polylactic acid (PLA). The evaluation of physic, thermal and mechanical properties of bamboo fabric, PLA matrix and laminate were determined. The specimens were prepared using techniques according to the ASTM standard.

2. Experimental

2.1. Materials

The PLA polymer used in this work was a commercial polylactide granulate identified as PLA2002D from Quimicoplasticos S.A., Bogota, Colombia. A thermoplastic resin designed for extrusion/thermoforming applications produced by Natural Works Company.

The plain woven bamboo fabrics were manufactured with a counterbalanced loom using bamboo fiber yarns produced by China Bambro Textile Co., Ltd. This company produces the bamboo fiber by steam explosion technique.

2.2. Fiber testing

2.2.1. Thermogravimetric analysis (TGA)

Thermogravimetry (TG) technique was used to analyze the thermal stability of bamboo fiber yarn. The measurements were carried out using Thermal Analyzer Netzsch Sta 409 equipment in nitrogen atmosphere. Sample weights were approximately 20 mg. The test was conducted in a programmed temperature range from 20 to 700 °C at a heating rate of 15 °C/min.

2.2.2. Moisture content and density

Moisture absorption was determined by the weight gain relative to the dry weight of the samples, according to ASTM D1348. The moisture content (MC, %) of a sample was computed as follows:

$$WC(\%) = \frac{W_m - W_d}{W_d} * 100 \quad (1)$$

where, *Wm* is the moist weight and *Wd* is the dry weight. The average of replicates is taken for further statistical analysis. Ten specimens were tested.

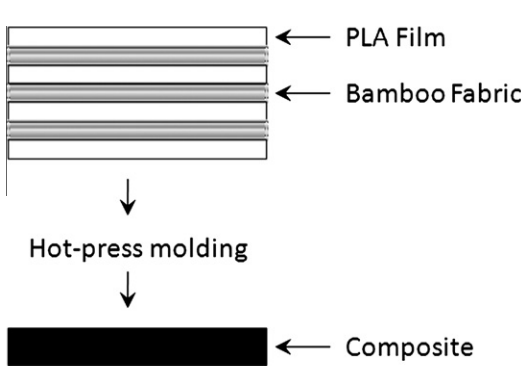

Fig. 1. Schematic of process for fabricating PLA/Bamboo fabric composites.

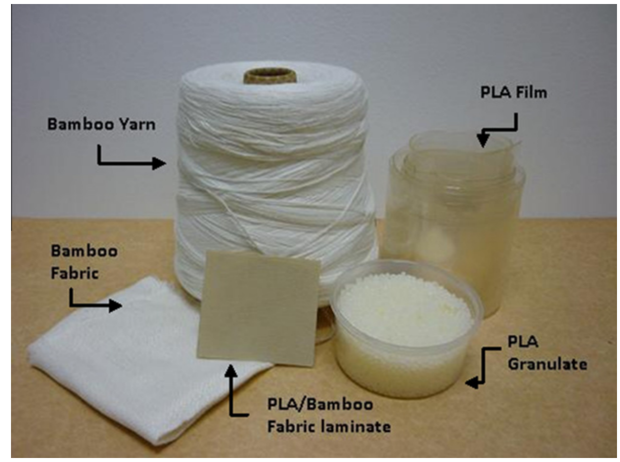

Fig. 2. Materials and PLA bamboo fabric laminate.

2.2.3. Density

The density of fibers yarns was measured by Arquímedes method with isopropyl alcohol using ASTM D3800 and an electronic balance (Sartorius A210P model) was used to weight yarns. Weights were measured to the nearest 0,0001 g. Ten specimens were tested.

2.3. Composite preparation

The PLA granulate was dried for 2 h at 90 °C to reduce their moisture content and was converted into a film approximately 0.35 mm in thickness using a Brabender Plasticorder 331 single-screw extruder. Extruder temperatures were set at 180 °C (zone 1), 190 °C (zone 2), 200 °C (zone 3) and 210 °C (die). The PLA film was collected on rolls and stored in the laboratory under ambient conditions prior to use.

Composites panels (51% fiber volume fraction) were produced using a film-stacking procedure, the layers of bamboo fabrics and PLA were piled up alternately as shown schematically in Fig. 1. Layers of PLA films and bamboo fabrics all oriented at same direction (weft/warp) were compression molded with a conventional compression molding press (Dake Press, model 44–251). The mold temperature was 160 °C and the pressure was about 556.7 kPa. Fig. 2 shows the materials and PLA/Bamboo fabric laminate.

2.4. Mechanical properties

2.4.1. Tensile test

2.4.1.1. Fabrics. Bamboo fabrics were tensile tested according to ASTM D 5035–06 on Instron tensile tester, model 3367. Fabric specimens prepared by the raveled strip method (50 mm × 150 mm) were characterized in both warp and weft directions. Tensile tests were performed at a gauge length of 75 mm and a crosshead speed of 300 mm/min. Five specimens were tested to obtain average tensile properties.

2.4.1.2. Polylactic acid (PLA). Tensile testing was carried out on an Instron tensile testing machine (model 3367) according to the ASTM D638–08, with a crosshead speed of 5 mm/min and a gauge length of 50 mm. Five specimens were tested to obtain average tensile properties.

2.4.1.3. Composite. Tensile properties of fabric-reinforced composites were characterized in accordance with ASTM D3039/3039M-08. Tensile tests were carried out using a universal mechanical testing machine (Instron model 3367). The machine was operated