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Mechanical properties of polylactic acid composites reinforced with cotton gin waste and flax fibers

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Abstract

Interest in biodegradable polymers and sustainable materials has grown significantly in the last decade. Value addition of byproducts generated in agricultural processing systems is on the rise. Similarly, there is growing concerns with cotton ginners as the disposal of cotton gin waste (CGW) is becoming both financially expensive and an environmental concern. Therefore, this study investigated the possibility of producing environment friendly composites using biodegradable Polylactic acid (PLA) matrix reinforced with 10 to 30 wt. % of cotton burr and stem fibers from CGW. For comparison, hybrid composites were also prepared using CGW and stem fibers from flax residue of 100:0, 67:33, 33:67 and 0:100 ratios, while overall fiber weight fraction was fixed as 30%. The composites were produced by compression molding technique and the flexural property test was carried out following ASTM D790 standard. The test results showed that the flexural modulus increased by 42% with the addition of 30 wt. % of CGW as compared to neat PLA. Furthermore, the improvement of modulus of elasticity of composites containing 30 wt. % of CGW is comparable to hybrid composites reinforced with different percentage of flax fibers. However, the addition of fiber filler moderately altered the brittleness and reduced the flexural strength as compared to neat PLA. Nevertheless, the improvement of modulus of elasticity, and strain shows the possibility of using these composites as construction materials in low load or non-structural applications.

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1. Introduction

Due to the depletion of petroleum resources and growing environmental concerns, the industries are seeking environment friendly materials that are independent of fossil fuels. Polylactic acid (PLA) is the most extensively researched and utilized biodegradable polymer which has proven potential to replace petroleum based polymers [1]. However, PLA production has historically been limited due to its high cost. Although in the recent years, the cost has fallen but the demand of PLA has risen such that supply constraints are the more recent restriction [2]. Therefore, until PLA are more extensively available and affordable, incorporation of fibers into the PLA matrix can not only reduce the amount of PLA needed but also create composites with wide range of mechanical properties which can open doors to variety of applications.

Many researchers have studied the performance of PLA with different types of fibers such as flax fiber [3], cordenka rayon fiber [3], abaca fiber [4], hemp [5] and kenaf [5] to improve their mechanical and thermal characteristics. While many of these studies have shown the potential of using natural fiber as reinforcement for PLA composites, there has been limited studies performed on reinforcing PLA with agricultural waste fiber which can be cost effective. The aim of this paper is to study the suitability of using agricultural byproducts, cotton gin waste, and flax fibers in PLA composites. Cotton is planted on a large scale in many countries such as United States, Australia, China, Brazil and India. The cotton production in the world and in the United States was 116.7 and 23 million bales, respectively, in the 2004-2005 harvesting season [6]. It is estimated that, there are over 2.25 million tons of cotton waste generated every year in United States [7].

Cotton gin waste (CGW), a by-product of the ginning process, presents a significant waste disposal problem as the production of cotton is increasing. One of the efforts to meet this challenge is to use CGW as a fiber filler for composites. Bajwa et al. [8] had conducted a study to evaluate the suitability of using residual plant fibers from agricultural waste streams as reinforcement in thermoplastic composites. They found out that plant fibers from cotton gin byproducts hold great potential as fillers in thermoplastic composites with the major benefit of lower specific gravity. Similarly, Holt et al. [9] conducted experiments on composite boards made from agricultural residues. Their study showed that cotton burrs can be used as alternative agricultural fiber in blended composites. These studies showed the possibility of using CGW as a potential natural fiber for polymers.

This study investigated the effect of addition of 10-30 wt. % of cotton gin waste on the flexural property of PLA composites. Using relatively inexpensive and alternative sources of fiber filler for expensive PLA matrix can be long-term financial solution for the composites industry. However, the introduction of CGW in PLA matrix can reduce its mechanical properties [10], therefore to combat this issue, this research focused on developing hybrid composites prepared using CGW and stem fibers from flax residue of 100:0, 66:33, 33:67 and 0:100 ratios, while overall fiber weight fraction was fixed as 30%. Finally, the flexural property of the hybrid composites were evaluated to identify if the addition of flax fiber in hybrid composites can improve their mechanical properties.

2. Experimental Program

2.1 Specimen preparation

The polylactic acid, natural fiber (cotton bur stem and flax fiber, particle size 0.25-0.40 mm) and 2 wt. % of maleic anhydride polypropylene (MAPP) were dried in an oven at 80 °C for 24 hr, and manually blended and extruded into pellets using a twin screw co-rotating extruder (Leistritz Micro 18 GL 40D, USA). The screw rotation was set at 150 RPM and the temperature was ranging from 154 to 171 °C. The composite strand was chopped into small pellet of 5-10 mm for compression molding. These pellets were placed in an oven for drying at the temperature of 60 °C for 24 h. The dried composite pellets were compression molded into 150 by 150 mm plates with a nominal thickness of 4 mm using Carver compression molding hot-press. The mold temperature and applied load was set to be 185 °C and 11.33 metric ton, respectively. The plates were cut into the desired length and width using a table saw. Table 1 presents the formulation of specimens with the addition of fiber and MAPP.