

3rd International Conference on Natural Fibers: Advanced Materials for a Greener World, ICNF 2017, 21-23
June 2017, Braga, Portugal

Improving the Properties of Banana Fiber Reinforced Polymeric Composites by Treating the Fibers

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Abstract

This study looks at two different chemical treatments designed to promote the interfacial bonding between banana fibers and an LDPE matrix: peroxide treatment and permanganate treatment. The effects of the treatments on the tensile properties of individual banana pseudo-stem fibers were explored, with peroxide treatment enhancing the tensile properties and permanganate treatment having an inconclusive effect. Some interesting results from composite processing are briefly explored, leading to peroxide treated fibers being excluded from composite testing. The flexural and tensile properties of untreated and permanganate treated injection molded composite parts were then explored. Untreated banana pseudo-stem fibers provided a measurable increase in composite properties, especially in tensile stiffness. Permanganate treated fibers provided little to no advantage in composite properties compared to their untreated counterparts, even with post-fracture analysis showing enhanced interfacial bonding.

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Peer-review under responsibility of the scientific committee of the 3rd International Conference on Natural Fibers: Advanced Materials for a Greener World.

Keywords: natural fibers, banana fibers, natural fiber composites, composite mechanical properties

1. Background

Many lignocellulosic fibers are well characterized in terms of composition and mechanical properties. All of these fibers will contain a combination of cellulose, hemicellulose, and lignin, although their relative amounts vary greatly between different species of plants [1], [2]. Mechanical properties of lignocellulosic fibers may also vary greatly, even from the same plant. This is due to several factors during the plant's life cycle, including the growing conditions, the ripeness of fibers during harvesting, the methods used to extract the fibers, and the transportation and storage of the fibers over time [3]. In general, however, plant fibers that come from the stems of their plant tend to exhibit better mechanical properties [4]. Bismarck et al. provides a valuable summary of the mechanical properties of several common natural fibers [5].

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Natural fiber-reinforced composites have many appealing features for consumer applications, especially in the automotive industry [2], [6]. Common applications include interior paneling for aircraft and automobiles, household tables and chairs, window frames, laptop cases, and other consumer items [7], [8]. Natural fiber-reinforced composites are valued for their sustainability and light weight compared to similar conventional composites, which is what makes them especially popular in the automotive industry [8].

One of the biggest obstacles to widespread adoption of banana fiber-reinforced composites is the relatively poor bonding between fiber and matrix. This poor bonding has to do with banana fibers' tendency to absorb moisture. When the hydrophilic fibers are combined with a hydrophobic thermoplastic matrix, the result is relatively inefficient bonding between fiber and matrix. [9], [10] There are a couple of methods that have been used before to help improve this bonding. One method involves roughening the surface of the fiber to provide mechanical anchoring sites for the polymer. Another method focuses on chemically changing the surface of the fiber to reduce its hydrophilicity, thereby increasing its compatibility with the matrix [2]. Some common chemical treatments used to achieve this are silane treatment, alkali treatment, peroxide treatment, permanganate treatment, isocyanate treatment, and a polymer coupling agent such as maleic anhydride [2], [9], [11]. For this study, the main chemical treatments explored were peroxide treatment and permanganate treatment.

Peroxide treatment is a treatment that has been studied with natural fibers, though not in the context of banana fiber/LDPE composites. A study led by Joseph et al. looked at the effects of several chemical treatments on the properties of short sisal fiber/LDPE composites, including peroxide treatment. It was found that randomly oriented peroxide treated fibers improved the tensile strength of the composite by as much as 50% [12]. It is believed this increase in strength is due to the peroxide initiated free radical reaction between LDPE and cellulose, as described in references [12], [13]. It is also believed that peroxide treatment promotes crosslinking within the LDPE by itself, which would also contribute to its increase in strength [13], [14].

A less common but still effective treatment used is permanganate treatment. Permanganate treatment modifies the surface of the fibers by interacting with highly reactive Mn^{3+} ions, which in turn induces the grafting of polyethylene onto the surface. The entire process is illustrated in reference [15]. In addition to improving interfacial bonding, the hydrophilicity of the fibers decreased after the treatment [15]. As permanganate concentration increases, the properties will at first increase and then suddenly decrease after a certain threshold is reached, indicating the degradation of cellulosic fibers [12]. Therefore, the concentration and time of exposure to the treatment is very important to the fiber properties.

2. Experimental Procedure

2.1 Chemical treatments

The procedures for the chemical treatment of banana pseudo-stem fibers follow the method described by Joseph et al. very closely [16]. For the peroxide treatment, untreated fibers are soaked in a 6% by weight solution of dicumyl peroxide in acetone for 30 minutes. The fibers were then decanted and allowed to air dry. For the permanganate treatment, untreated fibers were soaked in a solution of potassium permanganate in acetone (concentration varying from 0.005% to 0.2% by weight) for 1 minute. The fibers were then decanted and allowed to air dry.

Once the treatments were complete, fibers that were designated for thermal and single fiber testing were stored in a temperature and humidity controlled chamber. The fibers were maintained at 18 °C and a relative humidity of 62%. This was to ensure that all fibers contained the same moisture content. Fibers that were designated for composite processing were dried in an oven at 50°C overnight. This was meant to minimize swelling of the composite material during processing by expelling all moisture absorbed from the fibers.

2.2 Mechanical Testing

In order to test the effects that the chemical treatments have on the individual strength of banana fibers, a Dynamic Mechanical Analyzer (DMA) testing machine was used. With a tensile range of 0–18 N, the DMA allows for precise measurements of the loads subjected to individual banana fibers. For both treated and untreated cases, individual fibers were subjected to a tensile load from a constant rate of extension (0.5 mm/min) until fracture. The effects of idle time were also explored. Idle time refers to the amount of time treated fibers spent in storage in the temperature and humidity controlled chamber. Fibers with the same chemical treatment but different idle times were subjected to the same tensile test, and the results were compared. The cross-sectional area of a sampling of each type of treated fiber was then determined using SEM imaging and making measurements on those images. The fibers were not assumed to be always circular in cross-sectional areas. The areas were then averaged for each type of chemical treatment.

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