BANANA FIBER COMPOSITES FOR AUTOMOTIVE AND TRANSPORTATION APPLICATIONS

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Abstract

The purpose of this work was to establish and optimize a process for the production of banana fiber reinforced composite materials with a thermoset, suitable for automotive and transportation industry applications. Fiber surface chemical modifications and treatments were studied along with processing conditions for epoxy and eco-polyester banana fiber composites. Flexural tests show that banana fiber/eco-polyester composites have a higher flexural strength and modulus, due to improved fiber/matrix interaction. Environmental tests were conducted and the compressive properties of the composites were evaluated before and after moisture absorption. The resulting banana fiber/epoxy composites were found to yield a flexural strength of 34.99 MPa and compressive strength of 122.11 MPa when alkaline pretreated, with improved environmental exposure resistance. While the non alkaline pretreated banana fiber/polyester composites were found to yield a flexural strength of 40.16 MPa and compressive strength of 123.28 MPa, with higher hygrothermal resistance than pretreated fiber composites with the same matrix.

Introduction

Engineers and manufacturing companies are in constant search of new and/or improved materials and production processes to lower costs and improve profit margins [1]. The automotive and transportation industry benefits significantly from lighter materials and recyclable components due to improved energy efficiency. As a consequence, composite materials have been studied and used in these applications. As a result of the increasing demand for environmentally friendly materials there is a growing interest in bio-based or “green composites”, also referred to as natural materials [2-3].

Natural fibers are renewable and obtained from natural resources that present several advantages, including: low density, acceptable specific strength properties, good sound abatement capability, low abrasivity, low cost, high biodegradability and existence of vast resources [1-23]. In addition, at the end of their life cycle these can be incinerated for energy recovery, because they have a good calorific value [3]. Numerous researchers have exploited the reinforcement potential of kenaf, flax, hemp and jute for developing thermoplastic and thermoset composites using several different techniques; these composite materials have been successful in the semi-structural as well as structural applications [1-8]. Some uses of bio-based composites include internal door trim, seat-back trim, dashboard supports, rear shelves and exterior parts, such as transmission covers [4-5].

Banana fibers which are obtained from the dried stalk of banana trees, a waste product of banana cultivation, offer possibilities for engineering applications, including automotive. Banana fiber possesses good specific strength properties comparable to those of conventional materials, like glass fibers [9-10,25]. Furthermore, this material has a lower density than glass fibers [26]. However, banana fibers are associated with some challenges including high moisture uptake, low thermal stability and low bonding with polymers. Previous studies have shown that with appropriate surface treatments the mechanical properties (such as tension, flexure and impact) can be improved [9,11,23-25]. Alkali treatments have been proven effective in removing impurities from the fiber, decreasing moisture sorption and enabling mechanical bonding, and thereby improving matrix-reinforcement interaction [27].

The objective of this paper is to establish and optimize a production process for banana fiber composites suitable for automotive and transportation applications. For this purpose two different matrices have been evaluated: epoxy and soybean based polyester (referred to as eco-polyester). In order to increase environmental resistance and enhance the fiber polymer interface, a chemical treatment of the fiber surface with sodium hydroxide (NaOH) is used. It is also a concern in this study to characterize the resulting composites in terms of their mechanical properties and the influence of environmental effects, particularly moisture uptake on the resulting properties.

Materials and Methods

Banana fibers in the form of short non-woven fibers (4-9 mm) were used in this work. The fibers are separated mechanically from banana stalks and then dried in hot air.

Fiber Chemical Treatment

Banana fibers were immersed in 6% NaOH solution for 2 h at room temperature. After the alkaline treatment, the fibers were thoroughly washed by immersion in water tanks, followed by running water. The material is then filtered and dried at 80°C for 24 h.

Processing

A compression molding press was used to prepare the banana fiber reinforced epoxy and eco-polyester composites. Measured quantities of SC-15 epoxy resin (supplied by Applied Poleramic Inc) and ENVIREZ 1807 polyester (supplied by Ashland Inc) were mixed with a catalyst (alkyl polyamine and benzoyl peroxide/ tert-butyl perbenzoate mixture, respectively). The mold was sprayed with Polytetrafluoroethylene (PTFE) release agent and a piece of Teflon® cloth was placed on the bottom. A pre-weighed quantity of short non-woven banana fiber (55% weight) was placed in the mold and the resin was poured on the fiber network, followed by a layer of Teflon® cloth. The mold was closed and the mixture was left to cure at 60°C (for epoxy) or 80°C (for polyester) and 2.43 MPa, for 3 h (epoxy) or 1.5h (polyester) in a hydraulic press. De-molding was done at 60°C for both types of composites.

Water Absorption

The effect of water absorption on banana fiber reinforced epoxy composites was investigated by subjecting the composites to an aggressive hygrothermal environment in order to obtain complete or near complete saturation levels. The compression test samples, containing different fiber fractions and treatments were immersed in a water bath at 90°C. After immersion for 3 h, the specimens were taken out of the water and all the surface water was removed by blotting with a clean dry cloth.

Mechanical Testing

Flexural Testing

The flexural strength and modulus of the composites was determined using the three point bending test method according to ASTM D 790-03, procedure B, using a SATEC T-500 screw driven machine. Samples were cut into rectangular sections of 19 mm width and L/d ratio of 36/1. The load was applied midway between the supports with a crosshead speed of 5.4 mm/s. Each sample was loaded to failure.

Compression Testing

The compressive strength of banana reinforced composites, before and after water immersion, was determined in accordance with ASTM D 695 – 96. The specimens were cut to 25mm x 25mm x plate thickness regular prisms and then ground with a 120 grit carbide sand paper at a 100 rpm in order to obtain smooth surfaces. The test was performed at a 1.3 mm/s strain rate in a universal testing machine; SATEC T-5000. For each type of the compressive strength is presented as the average value of 5 specimens.

Results and Discussion

Flexural Properties

Figure 1 and Table I represent the results obtained from flexural testing of the specimens. Banana fiber/ eco-polyester composites presented a flexural modulus of 2419.55 ± 129.48 MPa; whereas, banana fiber/ epoxy composites presented a modulus 4.19% smaller when compared to the banana fiber/eco-polyester composite. Accordingly, the elongation of the banana fiber/eco-polyester composite is higher than the elongation of the banana fiber/epoxy composite. This phenomenon occurs due to the difference in strain to failure of the two thermosetting matrices, as observed in Figure 1, the polyester composite strains more.

In flexural testing, stress is localized in the region of the applied load and hence, it will provide information about the fiber/matrix interaction [28]. It is reasonable to assume that enhanced fiber/matrix interaction will lead to an improved transfer of stress from the matrix to the fiber and thus, the flexural strength and modulus will increase. Data in Table I show that both the strength and modulus of the banana fiber/eco-polyester are higher in comparison to the other type of composite and therefore, the fiber/matrix interaction appears to be higher in the eco-polyester composite.

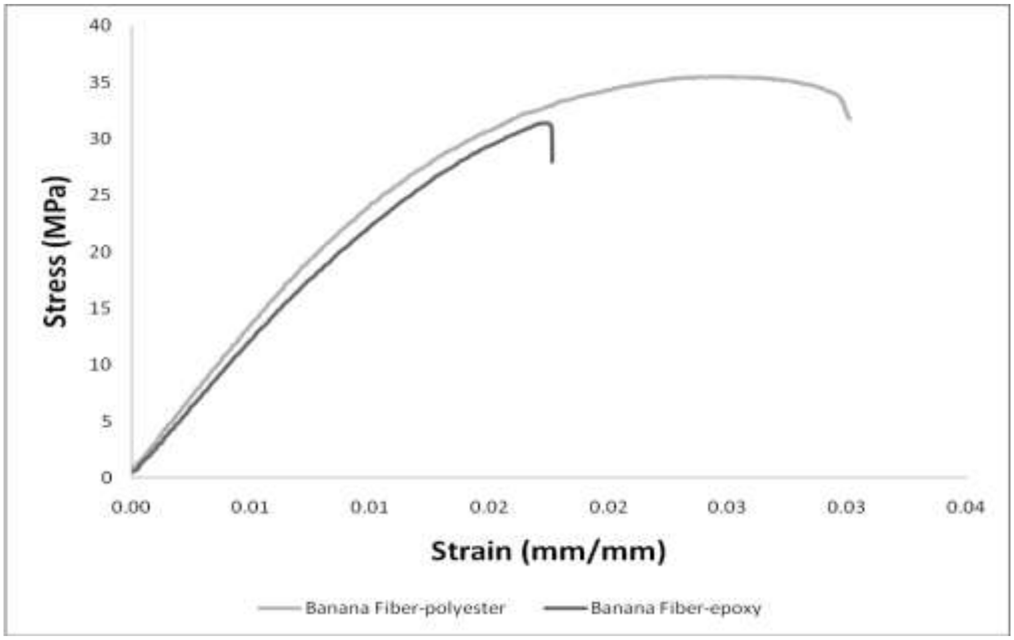

Figure 1: Flexural property curves of the different banana fiber composites studied.

Table I: :Average Flexural data for each type of Banana Fiber plate tested.

Type of sample	Flexural Modulus (MPa)	Flexural Strength (MPa)
Banana Fiber/Polyester	2419.55 ± 129.48	40.16 ± 1.99
Banana Fiber/Epoxy	2318.15 ± 335.96	34.99 ± 6.26

*Data in the table represents averages with a sample size of at least 4 specimens per sample.

Compressive Properties

The alkaline pre-treatment done on banana fibers showed different performances with the two different thermosetting matrices. Non-pretreated banana fiber/epoxy composites had a compressive strength of 88.26 ± 6.11 MPa and pretreated banana fiber/epoxy composites have a 122.11 ± 8.54 MPa compressive strength. Non-pretreated banana fiber/eco-polyester composites have a 122.88 ± 2.54 MPa compressive strength; while pretreated banana fiber/eco-polyester composites presented a 84.70 ± 5.12 MPa value for such strength. These results indicate that the fiber treatment is favorable for the epoxy matrix composites but not favorable in the case of the polyester matrix composites.

In addition, observation of the influence of the chemical pretreatment done to the fibers on plate consolidation shows that the alkalinization yields a 35.7% plate thickness increase in polyester resin composites and a 0.5% decrease for epoxy composites, when comparing each type of composite to its untreated fiber version. This observation and the compressive strength tendencies suggest that there is some phenomenon occurring, which results in the fiber/matrix interaction variations due to the difference in the chemical identities of the two matrices. When the fiber/matrix compatibility is high, the number of voids and flaws in the interface decreases [28]. As this happens the plates present an improvement in consolidation and thickness decreases.

Previous work revealed chemical treatment increases surface roughness and decreases the surface polarity [11, 29-30]. NaOH cleans the fiber's surface by removing impurities, waxes and part of the lignin; as lignin acts as a cementing substance that holds the fibrils together. Partial removal of lignin causes some debonding of the fibrils which leads to exposure or protruding of some of them. Such protrusion will produce mechanical bonding of the fibers and consequently, improve fiber-matrix interaction [27-28]. However, if the matrix and the fiber's surface do not possess similar polarities the two constituents will repel and there will be no effective bonding between them. This appears to be the reason why the alkaline treatment presents different effects for both the matrices, i.e. the epoxy and the eco-polyester respectively. The specific chemical make-up of the polymers has not been disclosed by the supplier. Considering the thickness variation and the compressive strength trends of the polyester composites, a possible explanation is that the polarity of the eco-polyester is compatible with the non-pretreated fiber, but not with the polarity of the chemically pretreated fiber. By alkaline treatment, the polarity is presumably altered, and hence the fiber-matrix interface compatibility for the eco-polyester system decreases, as can be observed in Figure 2. SEM analysis done on the fracture surfaces of the composites revealed higher density of voids between the fiber and the matrix for the pretreated fiber/ eco-polyester composites, when compared to the non-pretreated fiber/eco-polyester composites (See Figure 3, arrows point at some of these defects). The opposite effect is observed for the epoxy composites, i.e. fiber-matrix interface compatibility increases because of the pre-treatment (Figure 2). SEM analysis of the epoxy matrix composites indicates decreased void size and less number of voids for the fiber pre-treated system.

Similar studies on flax and hemp/polypropylene and banana fiber/polyester composites have been reported [15, 31]. These report that the consequence of decreased polarity compatibility is a poor wetting of the fiber in the matrix and thus, a deteriorated fiber/matrix interaction which produces lower mechanical properties. This explains why the alkaline treatment causes a decrease in compressive properties for the banana fiber/eco-polyester composites, while it increases the properties for banana fiber/epoxy composites.

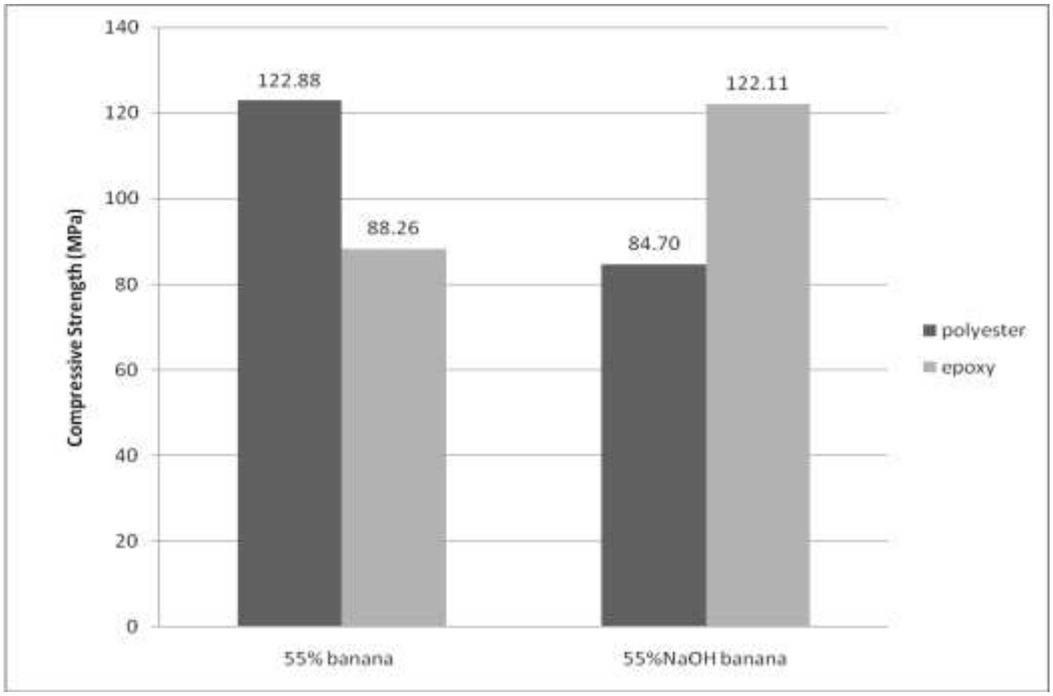

Figure 2: Compressive strenght for 55% pretreated and non-pretreated banana fiber reinforced polyester and epoxy.

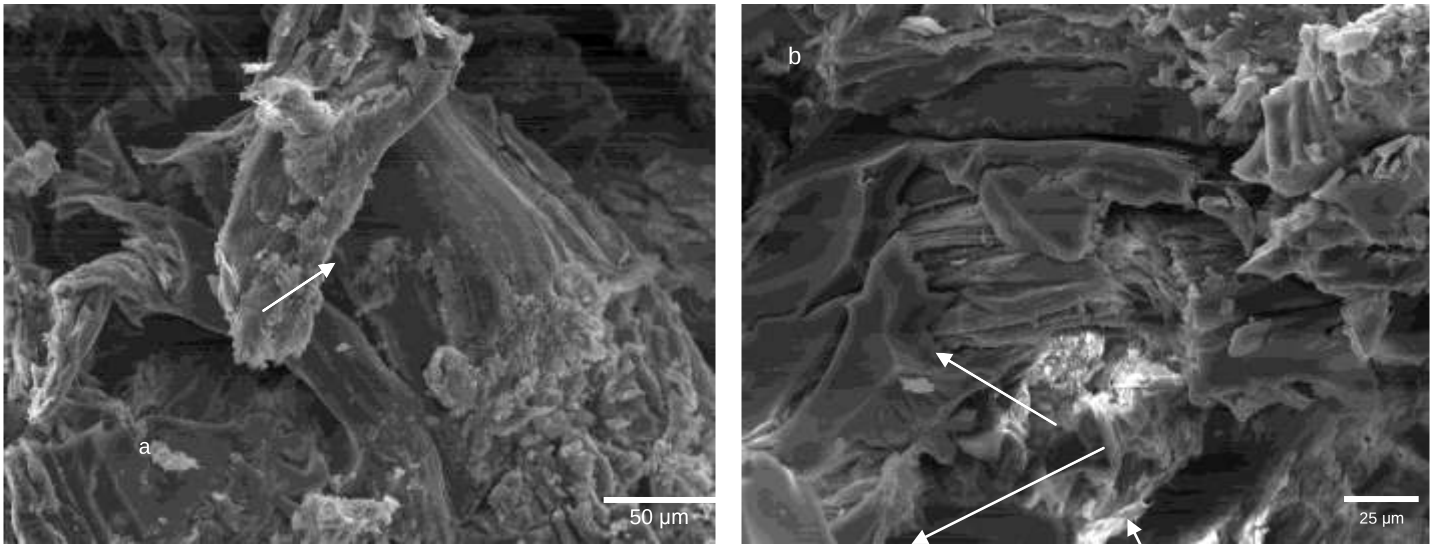

Figure 3: SEM micrographs of fracture surface of a) non-pretreated banana fiber/eco-polyester composites and b)pre-treated banana fiber/eco-polyester composites.

Effect of Water Absorption on Compressive Properties

Moisture uptake was quantified for each of the composites with and without fiber pre-treatment. Non-pretreated banana fiber/epoxy composites had a moisture uptake of 11.32% and pretreated banana fiber/epoxy composites had an 8.94% mass gain in moisture; while non-pretreated banana fiber/polyester composites showed a 13.82% moisture uptake and pretreated banana fiber/polyester presented a 40.76% uptake. In the case of the epoxy matrix the alkaline pre-treatment resulted in a decrease in moisture absorption, while for the polyester matrix an increase in moisture absorption occurred. Such phenomenon is also caused by the polarity compatibility of the resin's molecules with the fiber's surface.

As mentioned in the previous section wetting is affected by such compatibility and poor wetting is known to increase the number of flaws and voids between the polymer and the fiber [28]. Hence, water molecules can penetrate the composite easier and reach the fibers, thus causing swelling of the fibers. As the fiber and the matrix do not expand at the same rate, microcracking will occur in the matrix around fibers, which leads to a decrease in mechanical properties [28]. In addition, the polyester composites' moisture absorption is higher than that of the epoxy composites. This may be caused by the fact that 25% of the polyester resin is soy bean based and some bio-based resins have been found to have a higher compatibility with water [13]. Absorption of water by the matrix leads to a reduction in mechanical properties [32].

Figure 4 shows the compression strength for the different composites before and after hygrothermal exposure, illustrating the decrease in mechanical properties with water absorption. Non-pretreated banana fiber/eco-polyester composites resulted in a 27.24% decrease in strength while non-pretreated banana fiber/epoxy composites had a 43.21% decrease. Similarly, pre-treated banana fiber/polyester composites exhibited a 44.33% reduction in compressive strength and pre-treated banana fiber/epoxy composites a 25.63% decrease. The improvement in environmental exposure resistance with alkaline pre-treatment in banana fiber/epoxy composites can be explained in the improved fiber/matrix interactions; just as the decrease in environmental exposure resistance with the NaOH treatment in banana fiber/eco-polyester composites is due to the degradation of the fiber/matrix interaction due to the changes in the polarity of the fiber's surface.

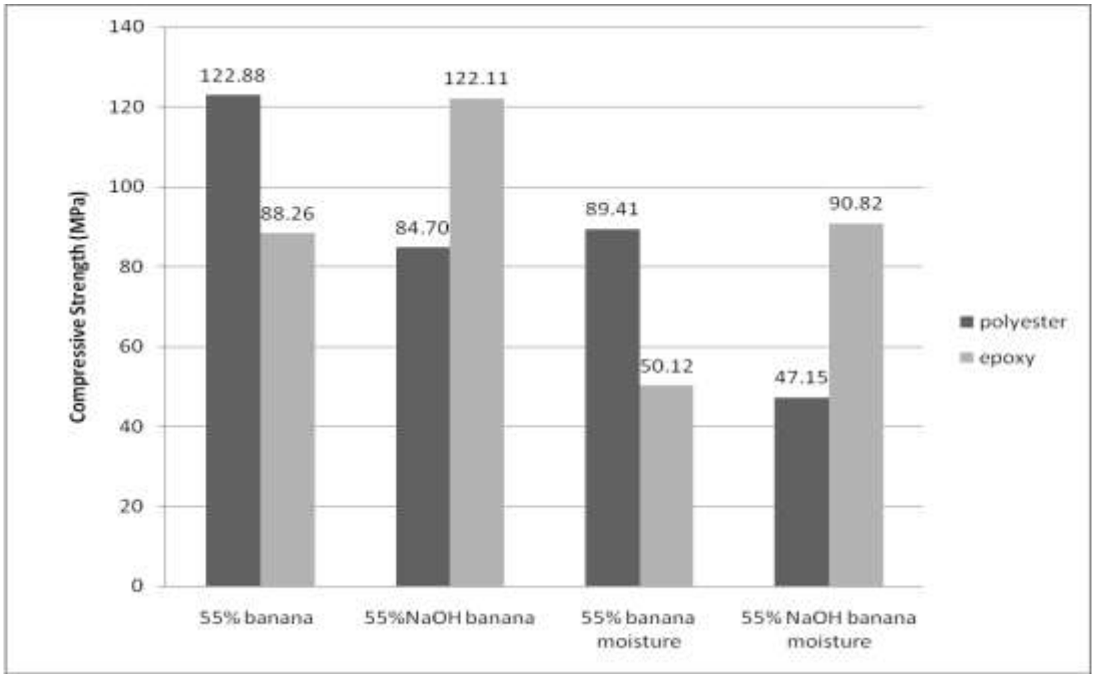

Figure 4: Compressive strength of banana fiber composites with and without fiber pretreatment before and after hygrothermal exposure.

Summary

The flexural strength of banana fiber/eco-polyester composites is 40.16 MPa, which is 14.78% higher than the strength of banana fiber/epoxy. The higher flexural strength and modulus observed in the banana fiber/eco-polyester composites is related to improved fiber/matrix interaction. Compressive properties were also found to be dependent upon the fiber/matrix interactions, which improve with alkaline pretreatment for an epoxy matrix and degraded with such treatment in the eco-polyester matrix. Thus, the highest compressive strength of 122.11 MPa of the banana fiber/epoxy composite is attained after fiber pretreatment and is 38.35% higher than the observed strength without the treatment. On the contrary the highest compressive strength in banana fiber/eco-polyester composites is 122.88MPa and is achieved without fiber pretreatment; the use of alkaline substances yields 31.07% lower properties. Water absorption is also dependent upon the fiber/matrix interactions but with the additional factor of increased water absorption by the biobased resin; therefore, moisture absorption is higher for eco-polyester matrix composites. It was observed that environmental resistance is higher in banana fiber/epoxy composites with alkaline pretreatment, followed for banana fiber/polyester composites without any treatment. This is due to improvement in fiber/matrix interaction with the fiber chemical pretreatment in epoxy composites and to deterioration of the interphase in polyester composites.

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