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Research Article

Study on Mechanical Properties of Banana Fiber-Reinforced Materials Poly (Lactic Acid) Composites

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Synthetic materials reinforced with natural fibers are attracting great attention of scientists and researchers. Sustainability and eco-friendly nature along with easy availability and low cost are the key reasons. In this work, a natural fiber such as a banana fiber was investigated to create bioavailable materials while enhancing mechanical properties. The banana fiber was extracted from banana sheath by the mechanical method combined with chemical treatment with NaOH 1, 2, 3, 4, and 5%. Treatment of the banana fiber with NaOH effectively removes other impurities from the fiber surface and the fiber surface becomes rough, increasing the compatibility and bonding between banana fiber and PLA. The reported optimum NaOH concentration was 5% banana fiber used for the material polylactic acid (PLA) composite/banana fiber. The composites (BF) were prepared by the hot melt mixing method. The results showed that 20% by weight of banana fiber gave good results and the mechanical strength values kept at the specified level (tensile strength: 52.57 MPa, flexural strength: 70.35 MPa, impact strength: 155.45 J/m and hardness: 23.8 Hv). SEM observations showed visual evidence that surface impurities were removed from the fiber by NaOH treatment.

1. Introduction

Natural fibers today play an important role as reinforcement in biocomposites due to their properties such as biodegradability, nontoxicity, recyclability, and light weight [1]. The most important components of natural fibers are hemicelluloses, cellulose, lignin, pectin, and waxes [2]. Natural fibers are, in general, available in leaves, fruits, seeds, grasses, silks, woods, lobes, and stems of plants [3]. Many research works are being done with natural fibers such as coir, bamboo, banana, flax, jute, hemp, kenaf, hemp, bagasse, straw, turpentine, rice husk, grass, rapeseed, pandan fiber, etc. M. Ramesh et al. studied to fabricate banana-hemp-glass hybrid composites to evaluate mechanical properties such as tensile strength, flexural strength, and impact strength [4]. Rahul K. et al. also studied the treatment and characterization of banana fibers reinforced with epoxy composites with a nano silica filler [5]. In addition, recent research activities show that biological compounds such as used coffee grounds [6], sisal fibers [7], lemon and lime peels [8], cellulose, and silk [9], various fillers obtained from the outermost skins of onions, potatoes, and carrots [10] are an approach that produce biomaterials with desired specific properties. A number of works have also studied and made environmentally friendly composite materials using green additives such as fly ash [11, 12], nanoclay [13] carbon nanotubes, and at the same time, by hybridizing them [14]. Banana fibers have been studied and used as reinforcement for petroleum-based plastic composites such as epoxy [15] and especially bioplastics such as PLA [16–18]. Banana fiber is used as a reinforcing material for epoxy-based composites; at the ratio of 50% banana fiber and 50% epoxy resin, the material can withstand higher loads than other ratios [19]. On the other hand, in order to improve the properties as well as expand the application of banana fibers, Manickam Ramesh and his colleagues continue to research and fabricate hybrid materials between the banana fiber and carbon fiber. Hybrid composites containing 20% carbon fiber and 80% banana fiber give high mechanical strength [20]. The banana fiber has also been studied in combination with a glass fiber and hemp fiber reinforcement for epoxy-based composites [21]. In addition, the study of the simultaneous combination of banana fibers and solid grass fibers for polyester-based composites can be applied in lightweight details and components such as car dashboards, soundproof panels, etc. [22]. The results show that the reinforcement with the natural-origin banana fiber has opened the future for a green, highly degradable material that promises many industrial applications. The objective of this study was to extract banana fibers from banana sheath by mechanical means combined with the use of the basic chemical NaOH. Initial assessment mechanical properties of PLA/banana fiber biomaterials at different banana fiber mass contents: 10 wt.%, 20 wt.%, and 30 wt.% banana fiber.

2. Experimental Procedure

2.1. Materials. Polylactic acid (PLA 4042 D, Mw: 1,65,000 g/mol), the MFI for PLA is 1 to 2 g/10·min (190°C, 2.19 kg) (Sigma-Aldrich Vietnam). The banana fiber is made from the bark of a banana tree (Vietnam), density (kg/cm^3): 1.39, cellulose: (wt%) 62.5–66.98, lignin (wt%): 4.5–5.0, hemicellulose (wt%): 10–18. NaOH (Sigma-Aldrich Vietnam). Physical properties of the banana fiber (see Table 1).

2.2. Methods

2.2.1. Sample Preparation and Characterization. Banana stems were collected from Tay Tuu Ward, Bac Tu Liem District, Hanoi City, Vietnam, and the banana stems were washed. We use a knife to separate each banana stem and wash it with clean water. Then, we separate the inner and outer sheaths. Dried banana stems were soaked in NaOH solution (at concentrations of 1, 2, 3, 4, and 5% by weight) for 24 h at room temperature. Then, the fibers were cleaned with distilled water to remove NaOH particles on the fiber surface. After being dried under sunlight for two days, the fibers were left in an oven at 90^{0}C–100 C for 24 hours to make sure that the water is completely removed from the fibers (see Figure 1).

The PLA/banana fiber biocomposite film (0 wt.%, 10 wt.%, 20 wt.%, 30 wt.% banana fiber) was fabricated using a film extrusion process. Initially, PLA pellets and banana fibers were dried at 80°C for 12 h in a hot air oven. Then, both PLA and banana fibers were manually mixed and the PLA/banana fiber mixture was then fed into an extruder to melt the mixture at a screw speed of 60 rpm, 10 min. The melting point is kept at 180°C. PLA-10: Base resin/banana fiber (PLA/banana fiber = 90/10), with the rate of 10% reinforced fiber and 90% plastic base. PLA-20: Base resin/banana fiber (PLA/banana fiber = 80/20), with the ratio of 20% fiber and 80% base resin. PLA-30: Base resin/banana fiber (PLA/banana fiber = 70/30), with the ratio of 30% reinforced fiber and 70% plastic base.

Table 1: Physical properties of the banana fiber [19].

S. No	Property	Range
1	Cellulose (%)	62.5–66.98
2	Hemicellulose (%)	18–19
3	Lignin (%)	4.5–5.0
4	Moisture (%)	10–11
5	Density (g/cm^3)	1–1.5
6	Elongation at break (%)	4.7–6.6
7	Young's modulus (GPa)	18.5–20.1
8	Microfibrillar angle (deg.)	11
9	Lumen size (mm)	5

2.2.2. Characterization. Tensile strength was determined according to an ISO 527-1993 standard on INSTRON 5582-100 kN machine (USA) with tensile speed 5 mm/min, temperature 250°C, and humidity 75%. Bending strength was determined according to ISO 178-1993 standard on an INSTRON 5582-100 kN machine (USA) with bending speed 5 mm/min, temperature 250°C, and humidity 75%. Izod impact strength was determined according to the ASTM D265 standard on the Tinius Olsen machine (USA). The hardness test is performed in the hardness tester according to the recommended standard by ASTM D2583 at Research Center for Polymer Materials, Hanoi University of Science and Technology. SEM of banana fiber-reinforced PLA resin composites treated with NaOH was analyzed by a scanning electron microscope JSM 6490 (JEOL-Japan) at the Material Damage Assessment Department, Institute of Materials Science – Vietnam Academy of Science and Technology with an acceleration voltage of 10 kV.

3. Results and Discussion

3.1. Research on Making Banana Fibers from Banana Tree Sheath. The fabricated banana fiber image is presented in Figure 2. Natural fiber composite materials have lower physical and mechanical properties than glass fiber and carbon fiber composites, namely, tensile strength, flexural strength, impact strength, and stiffness. The main reason is that natural fibers have many other impurities and especially hygroscopic properties. Therefore, it affects the adhesion between the fiber and the plastic. The quality of the fiber-resin interaction surface plays an important role in the use of natural fibers as reinforcing fibers for composites. Therefore, physical and chemical methods have been used to solve this problem, thereby improving the properties of the composite or overcoming the phenomenon of substandard reduction in strength.

The stress transfer at the interface between the two fiber–resin phases is determined by the degree of adhesion, which is essential for effective stress transfer and load distribution on the system across the interface phase split. Therefore, in order to have good mechanical properties of this composite material, the improvement of the interaction on the phase division surface becomes the main concern of cellulose fiber application studies. One of the simple, effective and, economical methods is to use common chemicals such as NaOH to extract and at the same time pretreat

Figure 1: Retreatment process of Banana fiber (BF).

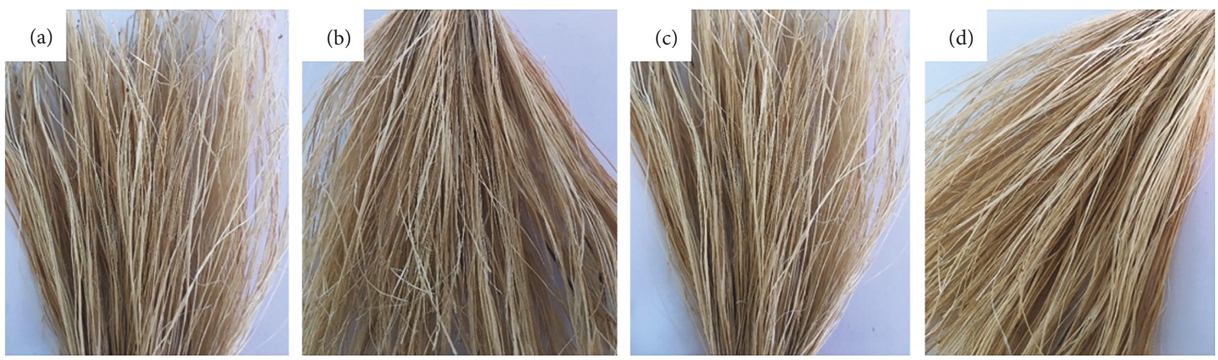


Figure 2: Image of a banana fiber extracted from the banana stem, treated with NaoH solution at different concentrations: (a) -NaoH 1%, (b) -NaoH 2%, (c) -NaoH 4%, and (d) -NaoH 5%.

the fiber surface. NaOH treatment of fibers effectively removes noncellulose fibers and other impurities from the fiber surface and makes the fiber surface smooth. This leads to a better alignment on the interface with the base material, the degree of fiber-resin compatibility, and enhanced wetting characteristics.

3.2. Mechanical Properties of Treated and Untreated BF. In this work, different concentrations of NaOH were used (1%, 2%, 3%, 4%, and 5% mass). The results show that the fabricated fibers have the characteristics of a uniform structure, toughness, and relatively uniform size (Figure 3).

Study on the influence of NaOH content on the properties of banana fibers when using reinforcement for composites based on the PLA resin. The results are presented as shown in Figure 3. When banana fibers are treated with NaOH, chemicals such as lignin, cellulose, hemicelluloses, and wax are removed using fibers after being treated with reinforced NaOH for PLA plastic composites. The test results are shown in Figure 3 and show that with 5% NaOH, the mechanical properties are higher than the remaining contents. Figure 3 shows that the mechanical properties such as tensile strength, flexural strength, impact strength, and hardness have decreased but not much.

Among them, the material in which the banana fiber is treated at 4% by mass of NaOH has higher and reduced mechanical properties compared to the base resin but remains at the specified level (tensile strength: 52.57 MPa, strength bending: 70.35 MPa, impact strength: 155.45 J/m and hardness: 23.8 Hv). Usually, the quality of a fiber-reinforced composite is significantly dependent on the fiber-matrix interface because a well-formed interface allows for a better stress transfer from the matrix to the fiber.

Therefore, good interface adhesion between matrix and fiber is essential to improve the mechanical strength in composites. It is clear that surface treatments enhance the strength impact of biological materials significantly. When treating banana fibers with NaOH solution at different concentrations (1, 2, 3, 4, and 5 wt.%), components such as hemicellulose, lignin, etc. are removed. Research results show that treating banana fibers with 5% NaOH solution gives the best roughness.

The compatibility between natural fibers and fibers is one of the major determinants of the mechanical and thermal properties of synthetic materials. The adhesion of fiber and plastic is clearly shown in Figure 4; under the effect of force, it is difficult for banana fiber to be released from the plastic substrate. Visually, it can be seen that the bond between the fiber and the resin is high. Adhesion or wetting ability on the banana fiber-PLA interface surface achieves high compatibility.

Figures 4(b) and 4(c): the banana fiber clearly bonded very well to the PLA resin. After the surface is broken, there is still a part of the banana fiber protruding on the plastic surface. It proves that the banana fiber adheres well and is very compatible with PLA plastic. The SEM image further revealed that the surface was even and smooth and there were no significant defects on the cracked surface. Thus, the proposed SEM microimage shows that chemical treatment tends to remove impurities from the surface of the banana fiber and thus can generate more functional groups to bind and improve wetting properties.

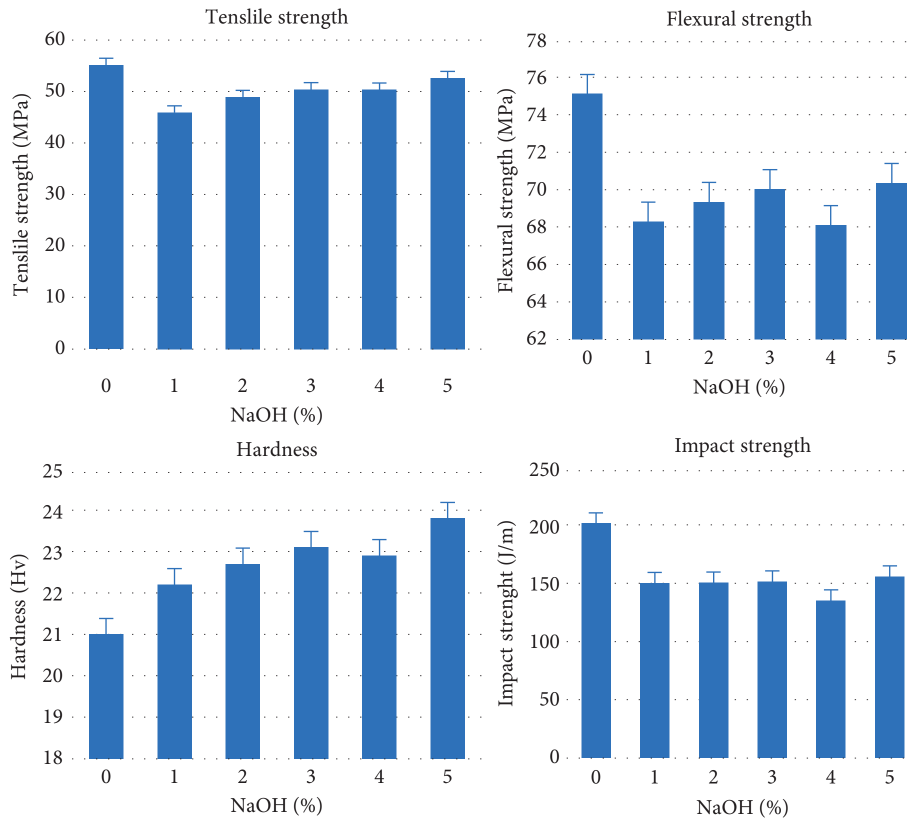
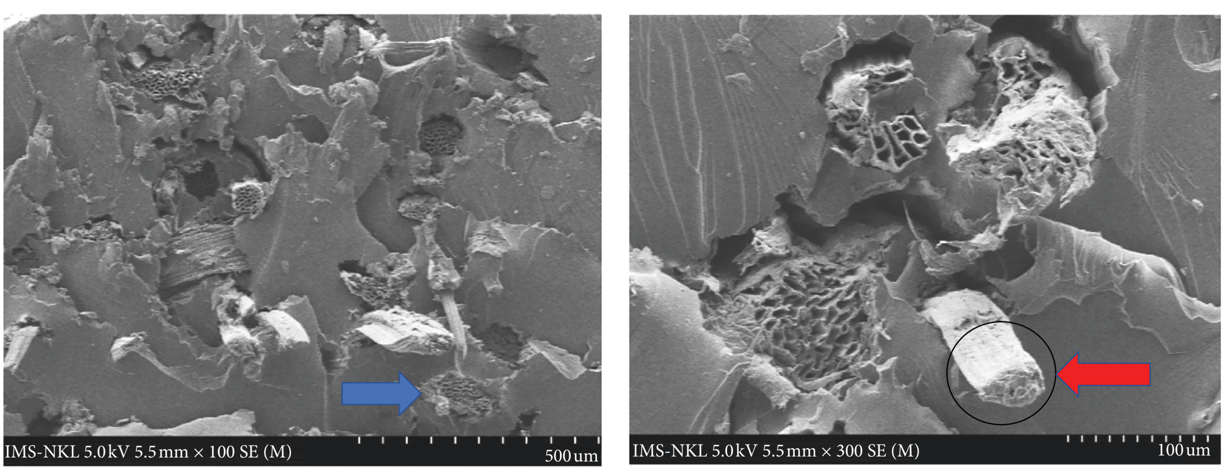


Figure 3: Effect of treated NaOH content on mechanical properties of BF.



(a) (b)

Figure 4: Continued.

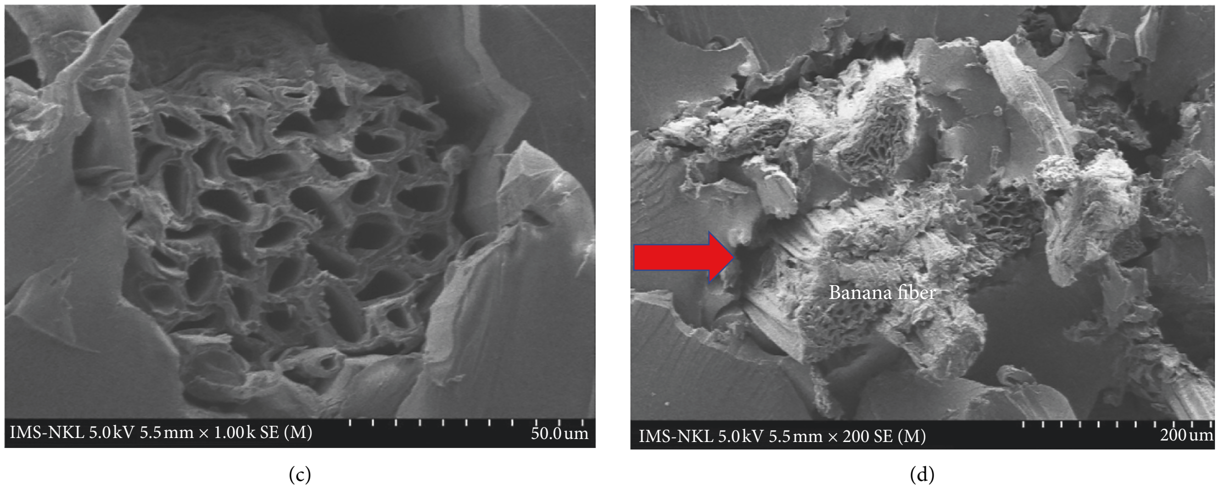


Figure 4: SEM of PLA/banana fiber composites: (a) – 10 wt.%, (b, c) – 20 wt.%, (d) -30 wt.% banana fiber.

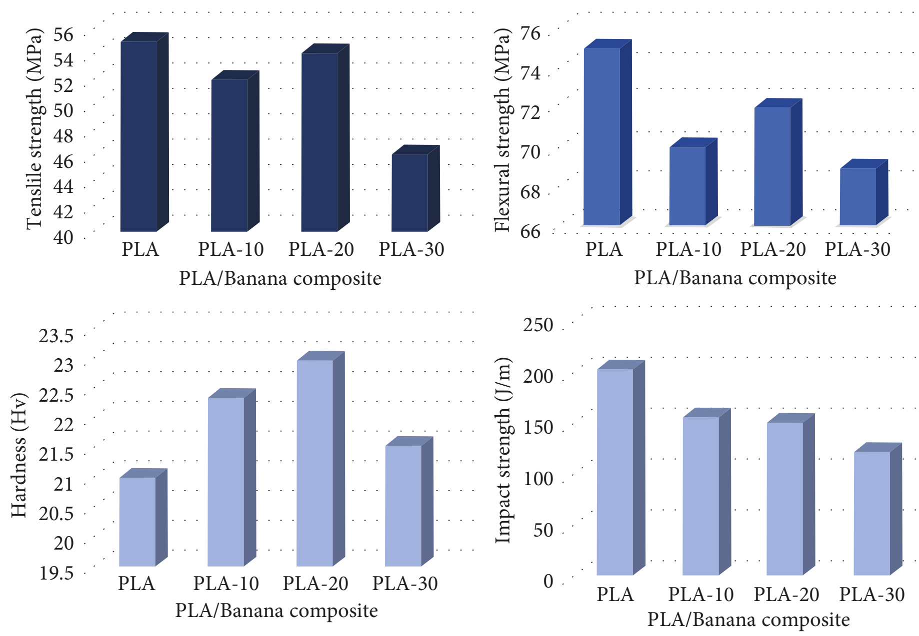


Figure 5: Mechanical properties of PLA/Banana fiber composites, with different contents: 10 wt.%, 20 wt.% and 30 wt.% Banana fiber.

3.3. Mechanical Properties of Composites. Effects of the banana fiber content on the mechanical properties of PLA/banana fiber composites are presented in Figure 5. We found that when adding 10%, 20%, and 30% banana fiber to PLA, respectively, the tensile strength tends to decrease. At 30% of banana fibers, the quality decreased the most; it can be explained that at this rate the combination or in other words, the degree of compatibility is not good leading to a decrease in compatibility. At 20% weight of the banana fiber, the tensile strength decreased, but not much, still kept at the specified level.

When 10%, 20%, and 30% banana fiber were added to PLA, respectively, the flexural strength tended to decrease. At 30% of banana fibers, the decrease in properties was the greatest; it can be explained that at this ratio, the combination or in other words, the degree of compatibility is not good, leading to a decrease in compatibility. At 20% weight of banana fibers, the flexural strength decreased, but not much, still kept at the specified level. At 10% mass of banana fibers, the impact strength decreased, but not much, still kept at the specified level.

The above results show that the chemical change has changed the surface topology of banana fibers and played an important role in the mechanical properties of biosynthetic materials. The results of the mechanical properties in Figure 5 are consistent with the structural morphological characteristics in Figure 4. During hydration, NaOH removes some amount of lignin, pectin, and wax from the surface of fibrous cell walls, thereby increasing surface roughness. This resulted in improved adhesion between the banana fiber surfaces to the biocomposite of PLA. Therefore, the mechanical properties of the natural fiber reinforced materials are not reduced much, still meeting the requirements within the technical limits.

4. Conclusions

NaOH treatment of banana fibers effectively removed other impurities from the fiber surface and made the fiber surface smooth. This results in a better bond on the fiber-resin interface, improved fiber bonding, and improved wetting characteristics. In addition, a strong hydrogen bond was noticed on the treated fibers, which facilitates better mechanical properties. The optimal NaOH concentration is reported to be 5%; this is mainly due to the reduction of the amorphous components of the fiber.

The results are based on the investigation of mechanical strengths: tensile strength, flexural strength, impact strength, and hardness (tensile strength: 52.57 MPa, flexural strength: 70.35 MPa, impact strength: 155.45 J/m, and hardness: 23.8 Hv). PLA/banana fiber composites were successfully fabricated with different banana fiber contents: 10%, 20%, and 30 wt%. Biocomposites with 20% by weight of fiber showed better mechanical properties than the other contents. Banana fiber-reinforced composites are a green material with potential for future engineering applications.

Great availability, cheaper, and good mechanical properties of banana fiber-reinforced banana fiber composites to make lightweight materials that can be used in the automotive sector as well as for household purposes.

Data Availability

The main table and figure data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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