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Influence of Banana Fiber on Mechanical Properties of Luffa Nanoparticles Epoxy Composite

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ABSTRACT

The rapid growing in technology as opened way for the utilization of eco-friendly resources, particularly the use of natural fiber for the creation of polymer composites. In the present work, banana fibers and the luffa were extracted from luffa plant and banana stem by manual stripping into strands. 60 nm luffa fiber was obtained after milling in a planetary ball milling machine and pre-impregnated into epoxy resin matrix. 2, 5, 10, 15, 20 and 25 wt.% short banana fiber were blended with the matrix for the production of composites using hand lay-up method. The hardness, tensile strength, and flexural strength of the produced composites were evaluated. The hardness, tensile and flexural strengths (47.5 – 52.6 Hv, 12.75 – 14.81 MPa and 143.93 – 165.83 MPa) of the produced composites were observed to increase with increasing short banana fiber content from 2 wt.% - 15 wt.% and decreased at 20 wt.%. Properties of the produced composites can be satisfactorily used in synergy as raw materials for composites manufacturing to widen its applications.

Keywords: Polymer Composites, Nanoparticle Luffa fiber, Short Banana fiber, Epoxy Resin

Aims Research Journal Reference Format:
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1. INTRODUCTION

Epoxy-based polymer composite materials are considered as significant materials due to their widespread applications across various industries as substitutes for conventional materials (Amir *et al.*, 2017 and Ahmad *et al.,* 2015). Recently, the use of natural fibers in composite formulation have gained significant attention from researchers and engineers owing to their unique combination of characteristics and eco-friendly nature (Adeyanju et al., 2021; Anbukarasi and Kalaiselvam, 2015). They have emerged as a key area of research in recent years, with researchers conducting numerous studies to explore their potential applications, fabrication processes and properties. This has led to a growing interest in utilizing available natural fibers as substitutes for artificial fibers in the fabrication of fiber epoxy-based polymer composites (FEPCs).

The low production costs of naturally occurring fibers, reduced densities, excellent mechanical properties, higher specific strengths, minimal environmental impact, lower health risks, and decreased energy consumption, make them better substitute over their artificial counterparts (Adeyanju et al., 2021; Alhijazi et al., 2020). Natural fibers such as hemp, banana, jute, coir, kenaf, flax, bamboo, luffa, snake grass, and sisal, are frequently used as reinforcing members in epoxy composites (Ramesha et al., 2014; Ramesh et al., 2013). These find applications in supporting structures, panel boards, particle boards, automobiles interior decoration, packaging commodities, home decors, animal feed, cosmetics, medicine and other biopolymers.

Luffa cylindrical, commonly known as sponge gourd, belongs to the cucurbitaceous species and is widely available across various regions (Das and Biswas, 2016). Upon dehydration, the intricate fiber structure of the luffa fruit typically forms interconnected mats. Besides, bananas are indispensable natural resources, present abundant in tropical and subtropical regions worldwide. It plants offer various usable parts, including the fruit, peel, leaf, pseudo-stem, and stalk (Pickering et al., 2016; Prasad et al., 2014). These components are useful in both food and non-food related items serving as sources of micro- and macro-nutrients, arts/handicrafts, high-quality textiles/fabric materials. Additionally, it contributes to livestock feed, provide fibers, bioactive compounds, and organic fertilizers. The banana pseudo-stem holds potential applications in pulp and paper production, textiles, and as fillers or structural reinforcements in composite materials (Ramesha et al., 2014; Ramesh et al., 2013).

Moreover, the characteristics of a natural fiber composite are important for ensuring its suitability for being implemented in industrial sectors. These include the physical properties (water absorption, density, porosity) and mechanical properties (hardness, tensile and flexural strength, impact and compression strength, etc.), taking into account its behaviour towards environmental conditions (Boopalan et al., 2013). The effect of fiber volume fraction on the tensile strength of banana fiber reinforced vinyl ester resin composites was analysed by Ghosh et al., 2011. An increasing in tensile strength with increment in banana fiber fraction after an initial dip was observed, and this leads to the concept of critical volume of fibers. The application of banana fibers at concentrations of 0, 5, 10, 15, and 20 wt.% in epoxy resin was studied by (Balaji et al., 2020). Increase in mechanical properties of the composite was observed up to 15 wt.% banana fiber content above which the mechanical properties decrease. Short (6mm) banana fiber with 30% volume fraction as a reinforcement in the natural rubber matrix was evaluated by (Kumar and Rajesh, 2016). Improvements in mechanical properties by alkalization and surface treatments of cellulose filler was reported.

Ortega et al., 2020 studied the fire resistance of polymer composites reinforced with natural fiber fabric, using magnesium hydroxide as flame retardant for the polymeric matrix and alkali treatment for the fiber. It was concluded that the composites reinforced with linen fabric have the best mechanical properties, but banana nonwoven with 60% additive has the best fire behaviour. The effect of 10%, 20%, 30%, 40% and 50% luffa fiber and ground nut reinforced epoxy resin matrix composites were developed and analysed by (Panneerdhass et al., 2014). Optimum mechanical properties were obtained at 40% fiber volume fraction of treated fiber composites and the fractures shows the pull out and de-bonding of fiber. Ramesh et al., 2017 fabricated a 50% banana fiber and 50% epoxy resin composite material that can withstand higher loads when compared with other combinations. This was proposed as an alternative to conventional fiber-reinforced polymer composites.

The effect of banana fiber contents of 10, 15, and 20 wt.% on mechanical properties of glass fiber-reinforced epoxy resin was analysed by (Ramesh et al., 2013). Higher mechanical properties were obtained at 20 wt.% banana fiber compared to the remaining samples. Additionally, Vidya et al., 2021 worked on the strength characterization of banana-sisal fibers reinforced composites, and found that both addition improves the strength of concretes.

2. EXPERIMENTAL DETAILS

2.1. Materials

The materials used for fabrication of composite material are:

(i) Short banana fibers: Banana fibers utilized in the study were obtained from banana stems, and the fiber strands were extracted by slicing the stems several times. These fibers underwent a soaking process in NaOH solution, sun dried to eliminate any free water, dirt, and other impurities present in the fibers. Subsequently, the dried fibers were cut into 5 mm lengths.

(ii) Luffa fibers: Dried luffa fibers used in this work were obtained from a luffa plant collected from Ogbomoso district in Oyo State, Nigeria. The fiber strands were cut uniformly to remove the seeds, washed, sun dried, and grounded in 60 nm particle size.

(iii) Epoxy resin: Araldite LY 556 epoxy resin from bisphenol-A, density - 250 °C, 1.15-1.20 gm/cm^3, Flash point - 1950 °C, supplied from Ciba Geigy India Ltd.

(iv) Curing agent: Triethyltetramine (HY-951) hardener, boiling point 207 °C, purity 99%, density 955 kg/m^3, also supplied from Ciba Geigy India Ltd.

The physical properties of the banana fiber is presented in Table.1. Similarly, Luffa fiber exhibits notable strength, energy absorption capacities, and stiffness when compared to other commonly utilized natural materials within a similar density range. Accordingly, luffa fiber contain cellulose of 55 to 90 wt.%, lignin content of 0-23 wt.%, hemicellulose content of 8–22 wt.%, extractives 3.2 wt.%, 0.4 wt.% ash and density 0.82–0.92 g/cm^3 (Ramesh et al., 2017).

2.2 Composite fabrication

In the present study, the composites were prepared by hand lay-up technique. Initially, the banana and luffa fibers were treated separately with 10% NaOH solution for 20 minutes. The fibers were then removed from the solution, washed with water for 2 hours and dried at 30 °C for 72 hrs. Banana fiber of 2 ± 0.5 mm thickness and 5 mm length were used. Subsequently, the luffa fiber strand was grounded into 60 nm particle size in 87002 LIMOGES planetary ball mill, model 28A20 92 at Ceramic Department, Federal Industrial Institute of Research, Oshodi (FIIRO), Lagos, Nigeria. The epoxy resin (LY 556) and the curing agent (HY-951) were mixed in the ratio 10:1 (v/v). HY-951 is the hardener mixed with epoxy resin to give effective binding. Wooden mold was machine to a suitable dimension 140 mm × 10 mm × 5 mm for the composite developed. The luffa nanoparticle was pre-impregnated with epoxy resin, stirred at a low rate and degassing of the mixture were carried out.

Table 1. Physical properties of banana fiber

Property	Range
Cellulose (%)	63-64
Hemi cellulose (%)	6-19
Lignin (%)	5-10
Moisture content (%)	10-11
Density (g/cm^3)	1-15
Elongation at break (%)	4.5-6.5
Young's modulus (GPa)	27-32
Tensile strength (MPa)	529-914
Microfibrillar angle (deg.)	11
Lumen size (mm)	5

Sources: (Idicula *et al*., 2005; Joseph *et al*., 2005; Pothan, and Thomas, 2003)

The banana fibers are mounted on the mixture placed in the wooden platen, and then it is completely filled with the epoxy resin. Pressure was then applied from the top and the mold was allowed to cure at room temperature for 72 hrs. Before placing the fiber and the matrix, releasing agent polyvinyl chloride was sprayed in the mold cavity for easy removal of the composite samples. After 72 hrs the samples were taken out of the mold. Five such samples were prepared with the same lengths but different volume fractions. A neat resin composite sample was also made with the above dimension without any reinforcement. Samples were prepared into the required size for mechanical testing and analysed. The morphology of the fabricated composite developed was carried out by scanning electron microscope model EVOMA 10 LaB6 Analytical VP-SEM at 20 KV. The objective of this research work was to develop and analyse the effect of short banana fiber-reinforced nanoparticle luffa fiber epoxy resin matrix with different concentrations: 5wt.%, 10 wt.%, 15 wt.%, 20 wt.%, and 25 wt.% respectively. Some mechanical properties and morphological structure was investigated by the SEM.

3. MECHANICAL TESTING

(i) Micro-hardness measurement was done using a Lecco Vickers Hardness (LV 700) tester. A diamond indenter in the form of a square-based pyramid with an angle 136° between opposite faces subjected to a load of 10 kg.
(ii) The tensile strength of the prepared specimen was determined according to ISO 527-1993 standard on Universal Testing Machine (INSTRON H10KS) with a span length of 40 mm, constant strain rate of 2 mm/min, and 10 kN load cell at room temperature.
(iii) The flexural strength was determined according to ISO 178-1993 on Universal Testing Machine (INSTRON H10KS) with a bending speed of 5 mm/min at room temperature. The compression tests are conducted on the same equipment as per ASTM D638 standards.
(iv) The impact energy test was carried out based on ASTM D256-93 standard, on the notched samples of dimensions 60 mm x 10 mm x 10 mm using the Avery Denison Universal Impact – Testing Machine (Model 2E) operating at maximum Speed 1200 rev/min.

4. RESULTS AND DISCUSSION

4.1 Micro-hardness test analysis

The distribution of short banana fiber (5 mm length) within 60 nm luffa fiber epoxy resin matrix significantly influences the mechanical properties and the resulting microstructure. The hardness results of the composite samples are shown in Figure 1. The maximum hardness 51.8 Hv and 52.3 Hv are obtained for the sample reinforced with 15 wt.% and 20 wt.% short banana fibers, compared to composite without reinforcement. This is due to the better and strong short banana fiber interfacial bonding between the matrix and reinforcement, and hence a close packing of the material.

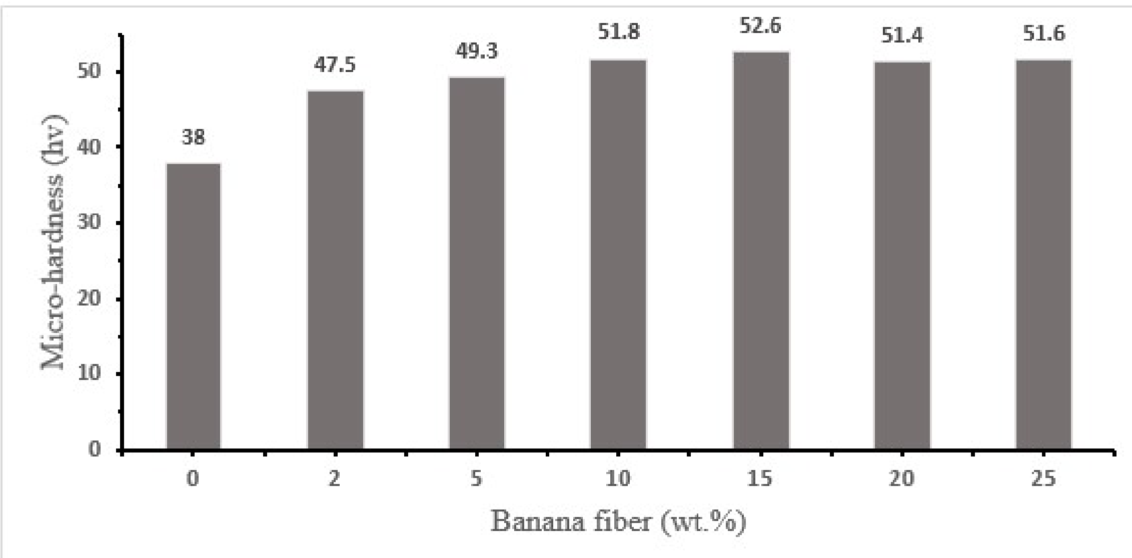

Figure1. Micro-hardness (Hv) against banana fiber (wt.%)

4.2. Tensile strength analysis

The tensile strength of the produced composite samples as shown in Figure 2, varied from 12.75 – 12.47 MPa. The tensile strength was observed to increase with the addition of short banana fiber contents up to 15 wt.% which clearly showed that the application of short banana fiber created a reinforcing effect that was responsible for the increase in tensile strength, and thereafter decreases. This trend was confirmed by Pickering et al. [16] who shows that good fiber dispersion promotes good interfacial bonding, reducing voids thereby positively impacted the tensile strength of the composites. The highest tensile strength was observed at 15 wt.% short banana fiber loading and could be explained by better fiber distribution in matrix material. Additionally, the large surface area of banana fibers can form a strong physical bond with the epoxy resin matrix make it harder by impeding matrix motion along the stress direction. Figure 3 shows the tensile modulus of the developed composites having similar trend has observed in Figure 2.

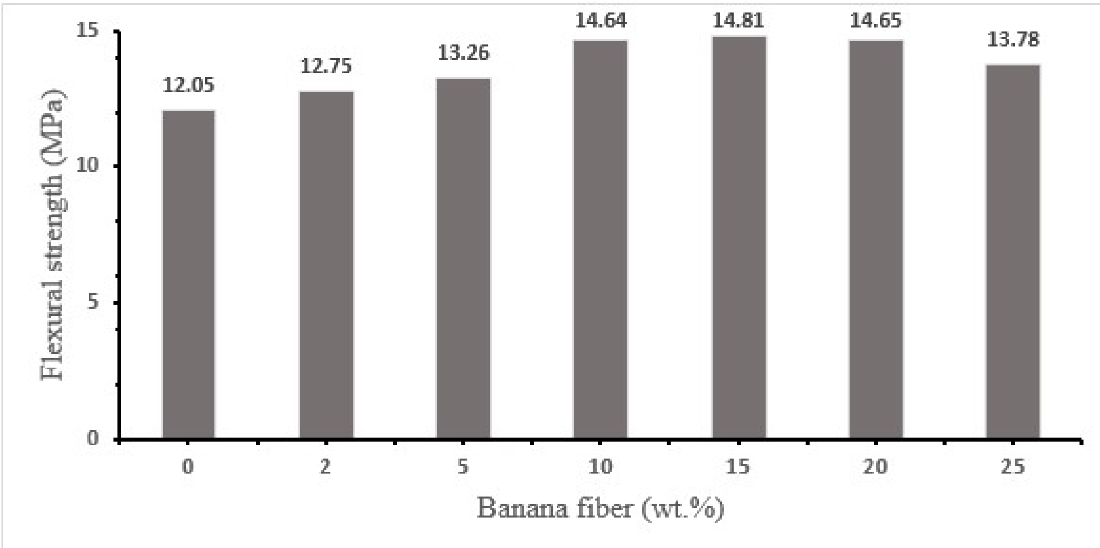

Figure 2. Effect of banana fiber (wt.%) on tensile strength (MPa)

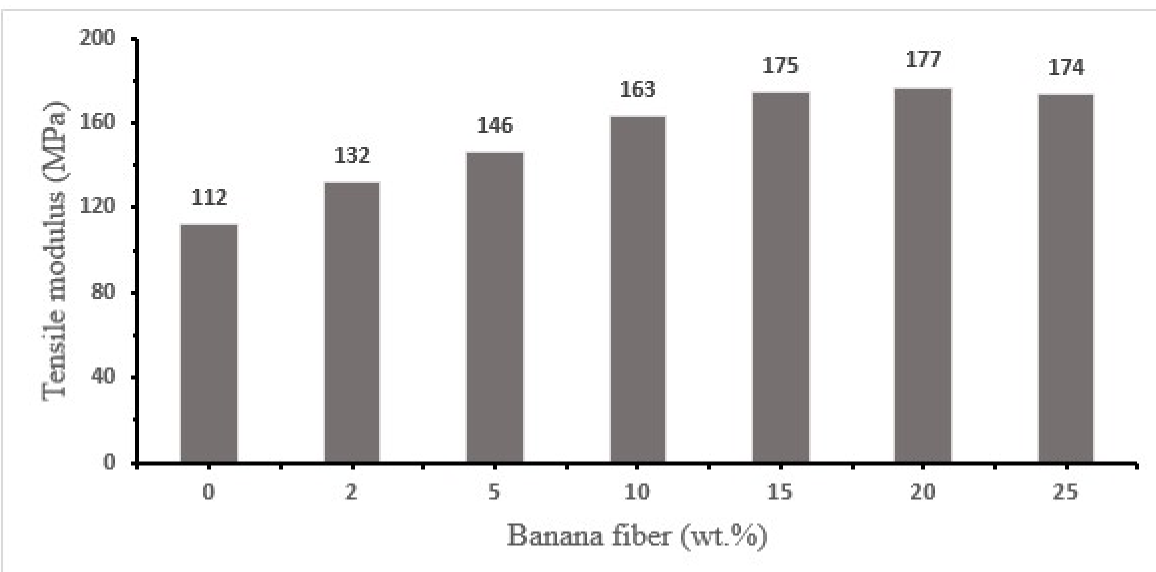

Figure 3: Effect of banana fiber (wt.%) on tensile modulus (MPa)

4.3 Flexural strength analysis

Figure 4 shows the variation of flexural strength with the different weight percent short banana fiber. From the result, it is concluded that sample reinforced with 15 wt.% banana fiber having higher flexural strength of 165.83 MPa. An increase in flexural strength may be due to even distribution of banana fiber, as the length to diameter ratio result in stacking properties of the composite and thereby increases the flexural strength.

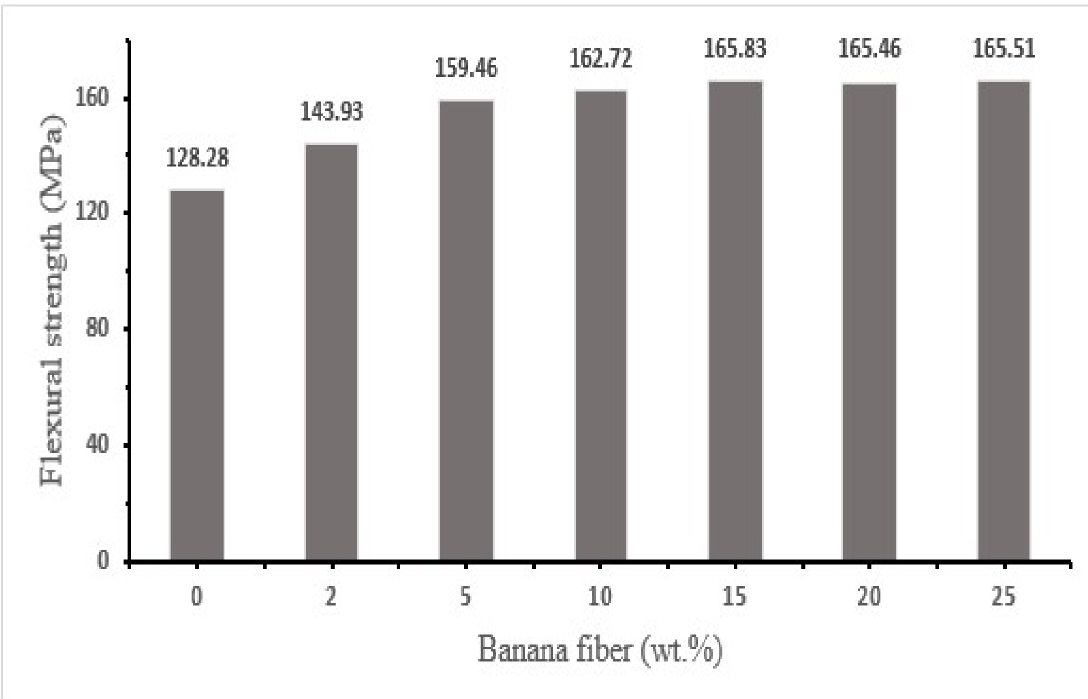

Figure 4. Effect of banana fiber (wt.%) on flexural strength (MPa)

4.4 Scanning Electron Microscopy (SEM) analysis

The SEM micrograph of the developed composite samples showing the dispersed 10 wt.% and 15 wt.%, short banana fiber in epoxy resin matrix is presented in Figure 5. At 10 wt.% short banana fiber, reduced void cavity were observed. This phenomenon tends to increase the load characteristics of the composite.

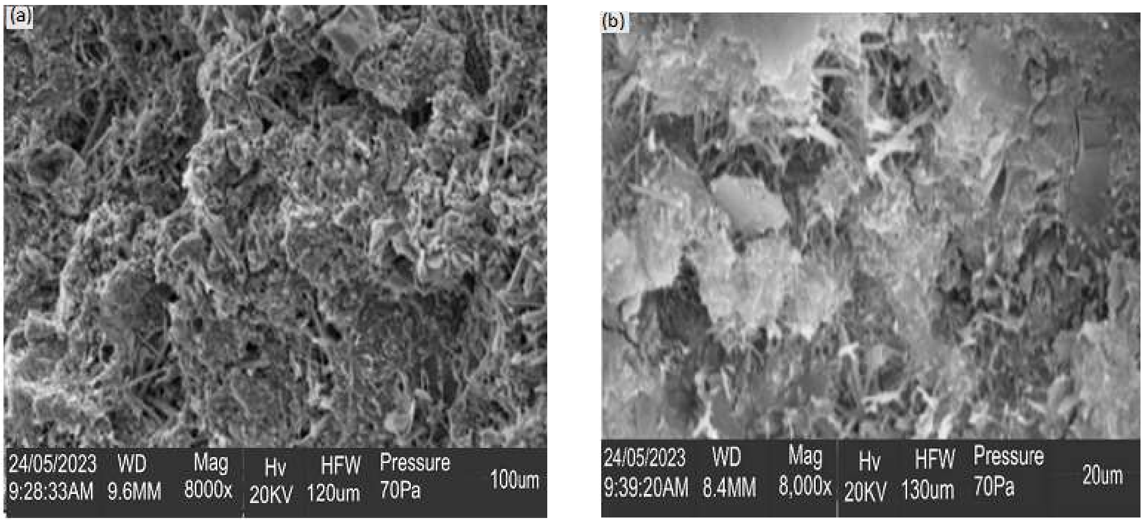

Figure 5. SEM image of nanoparticle luffa fiber epoxy composite/short banana fiber (BF) materials: (a) 15 wt.% BF, (b) 20 wt.% BF

5. CONCLUSIONS

The present study examined the effect of 5 wt.% - 25 wt.% short banana fiber reinforcement nanoparticle luffa fiber epoxy resin composite. The study confirmed that the pre-impregnated of nanoparticle luffa fiber in epoxy resin is possible with low-cost manufacturing techniques. Decreasing the size of natural fiber reinforcements in epoxy resin composites offer several compelling justifications, including enhanced mechanical properties, lightweight design, cost-effectiveness, and environmental sustainability.

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