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Moringa Oleifera (Drumstick) Fiber Reinforced Epoxy Composite – A Mechanical Characterization Study

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Abstract

The growing emphasis on sustainable and lightweight engineering materials has driven increasing interest in natural fiber–reinforced composites. Among potential fiber sources, Moringa oleifera (drumstick) offers high cellulose content and ease of extraction yet remains underexplored in composite reinforcement applications. This study aimed to fabricate and characterize a drumstick fiber–reinforced epoxy composite, evaluating its tensile, flexural, and impact properties, and comparing its mechanical performance with that of a conventional natural fiber (coir–epoxy) composite. Fibers were extracted from drumstick pods through water retting, cleaned, dried, and hand-woven into plate-shaped mats. Using the hand lay-up technique, four-layer laminates were fabricated with epoxy resin (LY556) and hardener (HY951) in a 10:1 ratio. Standardized ASTM specimens were prepared for tensile (D638), flexural (D7264), and Charpy impact (D5628) tests, performed using universal testing and impact machines. The composite exhibited tensile strength of 11.77 MPa, flexural strength of 41.03 MPa, and impact strength of 8.33 kJ/m², with elastic moduli of 1.21 GPa (tensile) and 25.7 MPa (flexural). Compared with coir fiber composites, the drumstick–epoxy system showed lower tensile and impact performance but notably higher flexural strength, indicating strong bending resistance but limited ductility. These findings suggest that drumstick fibers form adequate adhesion with the epoxy matrix but require chemical surface modification or fiber hybridization to enhance interfacial bonding and tensile properties. The composite's stiffness and biodegradability make it suitable for non-load-bearing components, interior panels, and lightweight applications where flexural stresses dominate.

Keywords
Drumstick (Moringa oleifera) fiber, Mechanical characterization, Natural fiber reinforcement composite, Hand lay-up fabrication and Epoxy composite.

1. Introduction
A composite is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure, differentiating composites from mixtures and solid solutions.

Composites are generally classified by the type of reinforcement materials they use. This reinforcement is embedded into a matrix that holds it altogether. Because of this, it becomes easy to achieve unique strength and stiffness properties along with the basic advantages of obtaining high strength to weight ratios. In general, the most common types of composites are metal composite, fiber reinforced polymer composite (FRPC), bio-degradable composite etc. The basic formation of FRPCs includes the use of synthetic fibers such as carbon, glass, aramid, Kevlar etc. Aside from high strength and high stiffness, these composites have long fatigue life and adaptability to the intended function of the structure.

In recent years, much attention has been paid to the research of natural fiber reinforced polymer composites. Natural fiber is considered as one of the environmentally friendly materials, which have good properties compared to synthetic fiber (May-Pat et al., 2013). In natural fiber reinforced composites, fibers are extracted from natural sources such as trees, leaves, pulp, animals etc. instead of using synthetic fibers. Composites with natural fibers have many advantages such as lower density, better thermal insulation and reduced skin irritation. Another beneficial side of using natural fiber is their biodegradability. Fibers such as glass, aramid, basalt, polycrylonitrile etc. are not biodegradable. In other words, using such materials as composite reinforcement results in affecting the environment as most of these are petroleum products, the resources which are depleting rapidly. Therefore, to decrease environmental damage, to reduce the greenhouse effects, to reduce pressure on fossil fuels, the use of natural fibers has caught the eyes of researchers.

Basically, the fiber phase of a composite is a high stiff and strong phase which is used for the load carrying purpose which indicates that the basic tensile strength is being provided by the fiber phase whereas the matrix phase provides uninterrupted bonding among fibers to distribute loads through the reinforcement uniformly and protect it from external situations in the environment such as temperature, pressure, moisture, chemical reactions etc. So, the fiber phase of the composite holds a heavy importance to enhance the mechanical properties. In most cases, the natural fibers used are Jute, Sisal, Kenaf, Flax, Banana plant etc. However, there are also some natural fibers which do not provide much strength to the composite. To overcome this, hybridization of the fibers is done.

1.1 Objectives

The research will mainly focus on the making of the drumstick fiber reinforced epoxy composite and investigate the mechanical properties of the composite. The specific objectives of this project are:

- To make the drumstick fiber reinforced epoxy composite.
- To determine the tensile, flexural and impact strength of the composite.
- To compare the mechanical properties of the drumstick fiber reinforced composite with another composite.

2. Literature Review

The estimated Figure for thermoset and thermoplastic composites for 1988 was in order of 1.1×109 kg for the United States alone (Mallick & Newman, 1990). Over 60% of which was estimated to be consumed by three industries alone: land transportation (25%), construction (20.1%), and marine (15.9%). The main growth areas for composites in marine and land transportation were recreational boats (e.g., 600,000 - 700,000 new boats are sold every year) and automobiles, respectively.

Composites are mainly classified based on structural constituents. On this basis, the classifications are: flake composites (i.e., composed of flat flakes with or without matrix), particulate composites (i.e., composed of particles with or without a matrix), filled (or skeletal) composites (i.e., composed of a continuous skeletal matrix filled with a second material), fiber composites (i.e., composed of fibers with or without a matrix), and laminar composites (i.e., composed of layer or laminar constituents). Other types of categorizations are by basic material combinations, by distribution of the constituents, by bulk-form characteristics, by function etc("Composite Materials Handbook," 1992). In material science, structural materials can be categorized into three types: ceramics, metals and polymers. It is difficult to give an accurate evaluation of the advantages and disadvantages of these three different types of materials, because each category includes entire groups of materials within which the variety of properties is often as wide as the distinctions between the three classes of material (Altenbach et al., 2004).

Traditional ceramics such as aluminum nitride, silicon carbide, silicon nitride are prone to mechanical loads. It causes fracture in these materials. Ceramics matrix composites were primarily developed to eliminate the fracture problem. As the fractures in ceramics mainly start from the crack initiated at a preliminary stage, the main function of developing a ceramic matrix is to resist crack initiation. The use of long, multi-strand ceramic fiber has drastically increased the crack resistance of the composite and came up with some other new applications (Zoli & Sciti, 2017). In recent years, a new type of ceramic matrix composite (CMC) called Ultra-high Temperature Ceramic Matrix Composites

(UHTCMC) or Ultra-high Temperature Ceramic Composites (UHTCC) has been developed. As the name suggests, it can withstand very high temperature (Zoli et al., 2017). CMC has a wide range of applications, especially in aerospace. It is used as the heat shield for space vehicles which are open to more than 2000ºC during re-entry. Also, they are best used to make thermal shock or vibration components (Lazzeri, 2012).

Rohatgi et al. analyzed the damping properties of Al alloy composites reinforced by graphite and SiC. The result shows that the graphite/alloy composite damping capacity improved with the graphite volume percentage within the limit. On contrary, dispersion of silicon carbide in aluminum alloy has not made any obvious improvements in the damping capacity (Rohatgi et al., 1994). On the other hand, Srikanth and Gupta investigated the effect of SiC on the damping capacity of pure magnesium matrix. They found that the presence of SiC particulates improve the damping capacity in that case. Also, a better result was achieved by replacing the SiC particulates with SiC whisker. However, the use of SiC whisker is limited due to cost and health issues(Srikanth et al., 2005a). Srikanth et al. investigated the Al2O3 reinforced magnesium matrix composites in nanoscale and analyzed the damping capacity, elastic modulus and hardness which are shown in Table 1 (Srikanth et al., 2005b).

Table 1. Damping capacity, elastic modulus, and hardness of Mg and nano-Al2O3/Mg (Srikanth et al., 2005a).

Wt. % of Al_2O_3	Loss Factor, η	Dynamic Modulus (GPa)	Hardness (HV)
0.0	0.0085	39.52	39.6±2.1
1.0	0.0115	41.29	52.3±1.1

Since 1990s, many researchers began to focus on the manufacture and use of natural fiber reinforced polymer composites in response to the increasing demand for eco-friendly materials and the desire to reduce the use of traditional fibers such as glass fiber, carbon fiber, aramid etc. Aside from ecological consideration, these natural fibers exhibit many other advantageous properties which promote the replacement of synthetic fibers. Natural fiber polymer composites (NFPC) are defined as composites which have polymers as the matrix phase and high-strength natural fibers such as jute, banana, sisal, palm, kenaf, etc. as the reinforcement (KUMAR, 2021). Al-Oqla and Sapuan worked on finding the properties of jute and plastic composites such as crystalline, fiber modification, thermal stability, weather resistance, durability etc. They also worked on the suitability of using these composites in automotive industries through eco-motive design (AL-Oqla & Sapuan, 2014).

Kloykam et al. investigated the compatibility and composite properties of alkaline and silane-treated pineapple leaf and polyamide 6 composites. Effects of fiber surface treatment and fiber loading on the properties of the composites were investigated. From the results, it was found that alkali treatment is sufficient to improve compatibility and mechanical properties of the pineapple leaf fiber/polyamide 6 composites at fiber loading of 30% wt (Panyasart et al., 2014). Rajasekaran et al. examined the mechanical properties of drumstick and plastic resin of high strength-based composite. In his experiment, the fiber was treated with chemicals such as NaOH and HCl solutions. It is also clear from the results that flexibility of the fiber was extended to a greater extent by this process (Rajasekaran & Rajavikraman, 2024. M. Ashok Kumar et al. worked on glass fiber/drumstick fibers reinforced with epoxy hybrid composites using the rule of hybrid mixture. Properties such as impact strength, frictional coefficient, dielectric strength and chemical resistance were studied. Both treated and untreated drumstick fibers were used to compare the change in properties (Ashok Kumar et al., 2012).

Mohanty et al. studied the effect of jute fibers on the mechanical properties of pure bio-degradable polymer, the mechanical properties of the resulted composites, tensile strength, bending strength, impact strength. There was an increase in strength while compared to pure bio-degradable polymers. The tensile strength, bending strength and impact strength increased approximately 50%, 30% and 90% respectively (Mohanty et al., 2000). Mohd Hafiz Zamri et al. investigated the mechanical properties of jute/glass reinforced polyester hybrid composite with water absorption conditions. Three separate water conditions, distilled, sea and acidic water were used and effects of this water absorption on the compression and flexural strength were investigated. Finally, it gave the conclusion that jute fiber reinforced composite is unfit for underwater applications (Zamri et al., 2016).

Budrun Neher et al. analyzed the mechanical and physical behavior of palm fiber reinforced acrylonitrile butadiene styrene composites for three different weight percentages and reported that the tensile strength and flexural stress decreased with increasing fiber content in the PF-ABS composites except for 10% fiber content. Physical properties as a water absorption property show that water absorption decreases with the rise in fiber content in the composites (Neher et al., 2014). A detailed comprehensive literature review on natural fiber reinforced composite material is presented including different polymer, fiber dimensions and applications. It should be noted that natural fibers are abundantly available in developing countries like Bangladesh, India, Malaysia, Philippines, Indonesia and Korea but is not equally utilized.

3. Theoretical Aspects

3.1 Natural Fiber Reinforced Polymer Composites (NFRPCs)

In natural fiber reinforced polymer composites, one or more than one types of natural fibers are used as reinforcement and polymers are used as the matrix phase.

3.1.1 Natural Fibers

Fibers are a class of hair–like material that are continuous filaments or in discrete elongate pieces, like pieces of thread. They can be spun into filaments, thread, or rope. They can be used as a component of composite materials. They can also be matted into sheets to make products such as paper or felt. Natural fibers are those fibers which we get from nature. There are mainly two sources of natural fibers: Plant and animal (Figure 1).

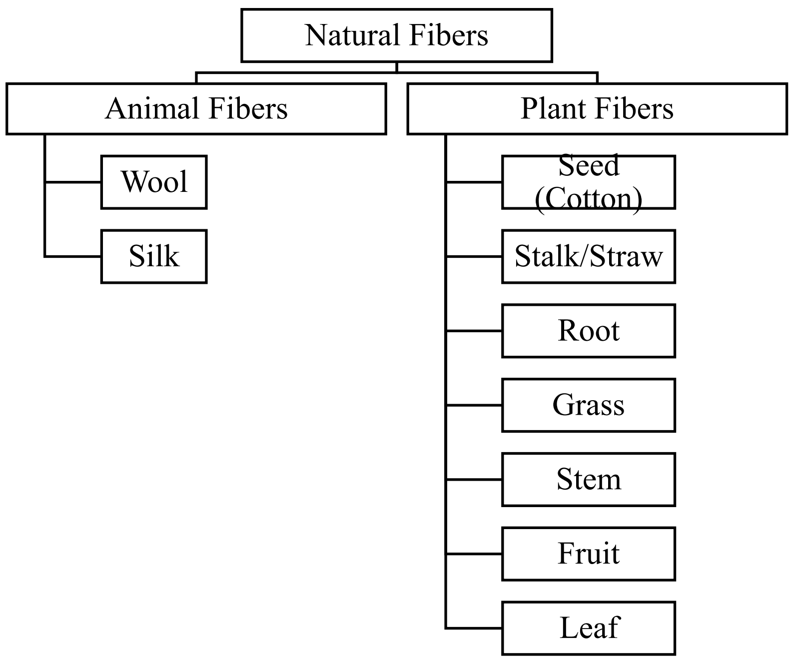


Figure 1. Natural fiber classifications

3.1.2 Resins

Resins are generally viscous substances which, through a curing process, turn into rigid polymers. Resins do occur naturally but are now also synthetically generated. Many synthetic resins have similar characteristics to natural resins in plants, but many are very distinct. There are various types of synthetic resins. Some are produced through the esterification process of organic compounds. Other resins are more like thermosetting plastics, in which case the term "resin" is applied simply to the reactant or component, or to both. One of the monomers of a co-polymer is called the "resin"; the other monomer is called “hardener”. The single monomer product is considered the "resin" for thermosetting materials that only have one monomer. For example, liquid methyl methacrylate is generally called the "resin" or "casting resin" when it is in a liquid or viscous state before it polymerizes and "sets." The resulting polymethyl methacrylate is often renamed acrylic glass or just acrylic.

3.1.3 Composite Production

The production of a composite material follows the following steps.

- Selection and collection/extraction of reinforcement material/fiber.
- Weaving fiber.
- Matrix phase/resin selection.
- Making Composite (Hand Lay-Up Technique).
- Chemical Treatment.

3.1.3.1 Fiber Extraction

Fiber extraction is an essential part of composite production. The strength of a composite mainly depends on the strength of reinforcement. All types of natural fibers are bounded by lignin and cellulose. Lignin is also a natural binder which is to be totally removed to get hair-like fibers. Lignin is generally removed by retting process. Most fibers get separated after being underwater for a couple of days. Sometimes, to increase the rate of rotting, some additives are used. The flowchart in Figure 2 shows the extraction process of fiber.

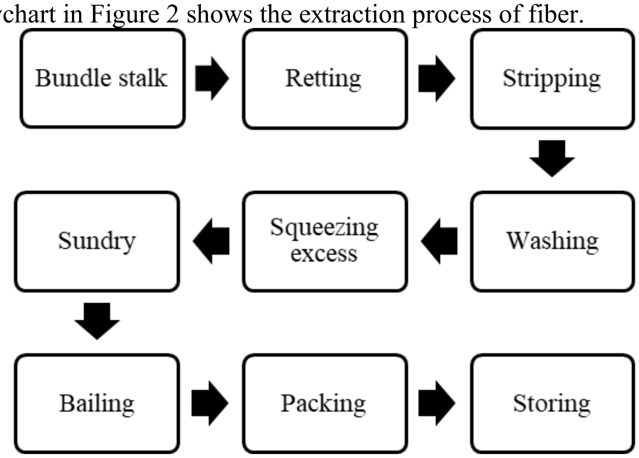


Figure 2. Fiber extraction process

3.1.3.2 Weaving of Fiber

Continuous reinforcement provides the best result in case of composites. When fibers are small, discontinuous reinforcement is used. But when fibers are long enough, continuous reinforcement can be allowed, which requires weaving of fibers. Weaving the fiber, a plate-like shape is produced. While making the composite, resin is poured over this plate. The machine in which weaving is carried out is called a loom. Sometimes, hand weaving is also done, but it is very time consuming and tough process. Also, the orientation of fibers gets disturbed.

3.1.3.3 Resin Selection

Thermoset polymers are frequently used in natural fiber reinforced polymer composite production. The single biggest advantage of thermoset polymers is that they have a very low viscosity and can thus be introduced into fibers at low pressures. Thermosets are processed using basic processing techniques such as hand laying and spraying, compression, transfer of resin, infusion, and molding operations. After curing, the thermoset cannot return to its initial state. Due to its ease of handling, good balance of mechanical, electrical and chemical properties and relatively low cost, unsaturated polyester resins are the most used thermosets in industrial, mass-production applications.

3.1.3.4 Hand Lay-Up Technique

The simplest molding technique, hand lay-up, is used in the making of large objects of low volume, e.g. parts of wind turbines, concrete shapes and radomes. For a high-quality coating, a pigmented gel coat is poured onto the mold. When the gel coat is cured, the glass mat and/or woven roving is put in the mold and the catalyzed resin is poured, rubbed or sprayed. Manual rolling then extracts trapped air, compacts the fiber, and completely wets the resin with the reinforcement. Additional layers are applied for consistency of mat or woven roving and resin. Curing in the resin system is initiated by a catalyst or accelerator that enhances the composite without external heat.

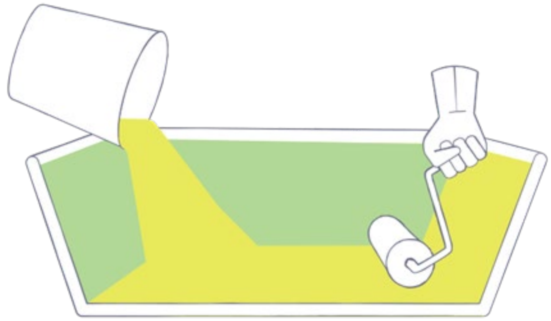


Figure 3. Hand lay-up molding process

3.1.3.5 Chemical Treatment

Sometimes, natural fibers are chemically treated to enhance their properties. The most common types of chemical treatments are:

- Alkaline Treatment
- Silane Treatment
- Acetylation of Natural Fibers
- Benzoylation treatment
- Acrylation and Acrylonitrile Grafting
- Peroxide Treatment
- Isocyanate Treatment

4. Experimental Procedure

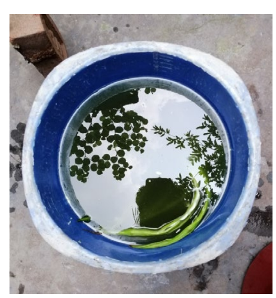
4.1 Material Collection

In this experiment, drumstick fiber was used as the reinforcement material and epoxy resin was used as the polymer matrix material. The materials were collected and processed for composite fabrication.

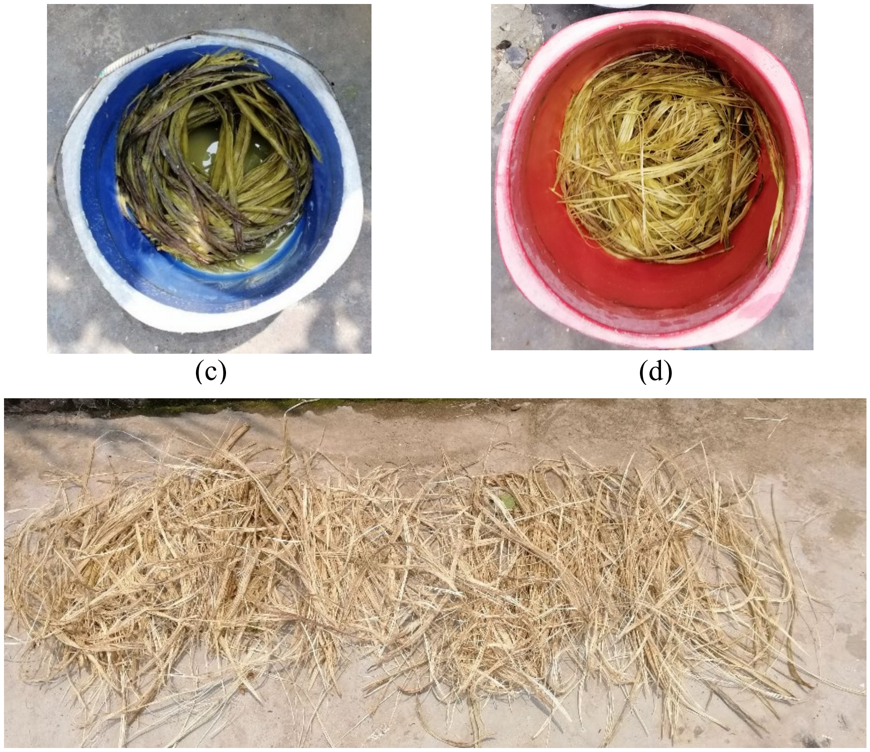
4.1.1 Extraction of Fiber

As drumstick is not a regular fiber like jute or banana fiber, it is not readily available in the market. The fiber extraction was done at home from drumsticks. It was a very easy and simple but lengthy process. The drumsticks were collected from the local market. There are two types of drumsticks (Moringa oleifera and Moringaceae) available in the local market. To extract fiber, total 18 kg of drumsticks (Moringa oleifera) were bought. Filthy water was collected from the nearest gutter. Collected drumsticks and dirt water are shown in Figure 4(a). First the drumsticks were smashed and then kept under filthy water for 14 days at ambient conditions. On the 15th day, the drumsticks were taken out and flashed with clean water properly until most of the pulps had been detached from the fiber. Figure 4(b) shows drumsticks under filthy water just after smashing. Figure 4(c) shows rotten drumsticks after keeping them under filthy water for 14 days. After washing, the drumsticks pulps were almost gone and most of the fibers were remaining. The washed fibers are shown in Figure 4(d). Once the fibers were extracted, they were kept under the sun for two days in ambient conditions. After drying in bright sunlight for two days, the fibers were then tilted by hands so that the remaining pulps fell off from the fibers. Thus, the fibers were obtained which were almost 1 to 1.2 feet tall. In Figure 4(e), dry drumsticks fibers are shown.

(a)



(b)



(c) (d)

(e)

Figure 4. (a) Drumsticks and dirt water, (b) Drumsticks under the water, (c) Rotten drumsticks, (d) Fibers after washing the pulps, (e) Fibers after drying

4.1.2 Fiber weaving

After extraction, the fibers were in a disordered shape, so at first, they were straightened. Then they were weaved in a plate-like shape. A piece of cloth was used to ease the weaving. Hand weaving procedure was followed. At first, the fibers were taken on a piece of cloth. Then they were sewed in a hand sewing machine. The fiber plate on cloth is shown in Figureureure 5(a). After weaving, the cloth was cut down. Thus, the fiber plate was achieved. In Figureureure 5(b), fiber plate after removing cloth is shown.

(a) (b)

Figure 5. (a) Fibers after sewing, (b) Plate-like shape of extracted fibers

4.1.3 Resin Selection

For the composite fabrication, epoxy resin (LY 556) at room temperature and hardener (HY 951) were selected. This resin was chosen because of its accessibility and compatibility with natural fibers. Good moisture resistance, chemical resistance, electrical properties, increased mechanical and fatigue strength, impact resistance, long shell life, absence of volatile organic compounds, low shrink during cures make epoxy resin popular than others available in market.

4.2 Production Process

For composite production, hand laminating process was followed. At first the resin was poured into a bowl to mix the resin and hardener. The resin-hardener mixing ratio was 10:1. A mold plate of 300mm×300mm was used as the mold plate which is shown in Figure 6(a). The plate was first covered with smooth grease and polyethylene. A layer of resin was poured onto it and brushed on the whole surface. The pouring and brushing process is shown in Figure 6(b).

(a) (b)

Figure 6. (a) Mold Plate, (b) Layer of resin over the plate

After pouring resin on the plate, and brushing it over the whole plate area, a plate of fiber was placed on it. After that, the plate was laminated with a hand mower which is shown in Figure 7(a). Then again resin was poured onto the fiber plate, and another plate of fiber was placed on it. The procedure was continued for four fiber plates and shown in Figure 7(b). At the end, another mold plate was placed over the fibers. Finally, these laminas were kept in press, for over 24 hours and allowed to cure and harden so that perfect shape and thickness can be achieved. The composite plate under heavy load is shown in Figure 7(c).

(a) (b) (c)

Figure 7. (a) Laminating the fiber plate, (b) Pouring resin over fiber plate, (b) Specimen under heavy weight

4.3 Specimen Processing

After being pressed by heavy weight for 24 hours, the composite plate is formed in proper thickness. The prepared composite plate is shown in Figure 8(a). To give proper shape to the composite, excess material was cut down by a grinding machine. Then, standard specimens for tensile, flexural, and impact strength testing were cut down from the composite plate. The specimens were prepared using a saw machine. The specimen cutting procedures are shown in Figure 8(b) and Figure 8(c).

(a) (b) (c)

Figure 8. (a) Prepared composite, (b) Grinding excess material, (b) Specimen preparation

5. Testing Procedure

5.1 Tensile Test

Tensile tests determine the materials behavior under tension load. In the simplest case, a material is elongated to its breaking point to find out the ultimate tensile strength of that material. The basic measuring criteria are the applied force and elongation. Very often, the material properties are denoted by stress and strain. Stress is achieved by dividing force by the cross-sectional area and strain is the ratio of elongation to the initial length. Other properties that are determined from tensile testing are modulus of elasticity, yield strength, Poisson's ratio, and strain hardening. For tensile testing, dog-bone shaped specimen was made. This is because, in a tensile test, the specimen is gripped between the jaws of the machine; then variable load is applied. The dog-bone shape provides better grip for the jaws. The specimens were cut according to ASTM D638 Standard and shown in Figure 9(a). Three identical specimens were tested. The machine and test setup for tensile testing are shown in Figure 9(b) and Figure 9(c).

(a) (b) (c)

Figure 9. (a) Tensile test specimen, (b) Universal testing machine, (b) Breakage occurring during tensile test

The flex or bending strength of a material is determined by the flexural test or three-point bending test. It is initiated by placing a specimen between two supports and applying a load by the third point. The most common purpose of a flexure test is to measure flexural strength and flexural modulus. Flexural strength is defined as the maximum stress at the outermost fiber on either the compression or tension side of the specimen. Flexural modulus is calculated from the slope of the stress vs. strain deflection curve. These two values can be used to evaluate the sample materials' stability to withstand flexure or bending forces. For flexural tests, uniform rectangular specimens were made. Specimens were cut according to ASTM D7264 Standard, and the specimen is shown in Figure 10(a). Three identical specimens were tested.

Figure10. (a) Flexural test specimen, (b) Three-point bending test

The flexural test was performed in 3-point bending test machine. The test setup is shown in Figure 10(b).

5.2 Charpy Impact Test

Impact tests are used to determine a materials ability to withstand impact force. It is also the indicator of materials toughness. A materials toughness basically depends on its energy absorption ability. Brittle materials low toughness is due to their lower amount of energy absorption during plastic deformation. Also, the impact strength of material depends on the temperature. Generally, at higher temperature, the impact energy of material is increased. During impact test, a little notch is cut in the specimen. It can be V-notch, U-notch or keyhole-notch. In our test, V-notch was cut. The specimen was cut according to ASTM D5628 Standard and is shown in Figure11(a). The testing setup is shown in Figure 11(b) and the broken specimen after impact is shown in Figure 11(c).

Figure11. (a) Impact test specimen, (b) Charpy impact testing machine, (c) Broken specimens

6. Results and Discussion

6.1 Tensile Test Result

In this work, the service properties of epoxy resins were improved by reinforcing with drumstick fiber. The experimental results from tensile test are provided in Table 2. From this data, we get an overview of the tensile property of the composite.

Table 2. Tensile test results

Specimen no.	Area (mm^2)	Load (KN)	Tensile Strength (MPa)	Standard Deviation
01	155.4336	1.747	11.24	0.875
02	154.6454	1.976	12.78	
03	154.3752	1.743	11.29	

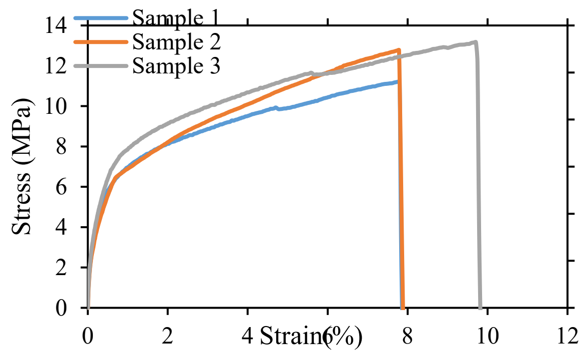


Figure 12. Tensile behavior of the three specimens

The stress-strain behavior of tensile test of the three specimens is shown in the following graph in Figure12.

The tensile test results, illustrated in the stress–strain curves for the three specimens, show a consistent pattern of elastoplastic behavior, yet with notable variations in mechanical performance. All samples exhibit a rapid initial increase in stress at low strain, characteristic of elastic deformation, followed by a gradual strain hardening region. Sample 3 demonstrates the highest overall performance, reaching a peak stress of approximately 13.5 MPa at around 9.5% strain, which is slightly greater than Sample 2's maximum stress of about 13 MPa near 8% strain and distinctly higher than Sample 1's peak of roughly 12 MPa at a similar strain range. The abrupt drop in Sample 2's curve indicates premature failure, contrasting with the more extended ductility of Sample 3. These trends align with the numerical tensile strengths in the table, where Sample 2 achieves the highest value (12.78 MPa), followed by Sample 3 (11.29 MPa) and Sample 1 (11.24 MPa). The relatively small standard deviation (0.875 MPa) suggests moderate variability among the specimens, although the visible differences in curve shapes imply that Sample 3 is comparatively more ductile, whereas Sample 2, despite its higher strength, fails earlier, and Sample 1 consistently exhibits the lowest stress response across the loading regime.

6.2 Flexural Test Result

In case of flexural tests, generally two types of failure modes can be observed; they are the failure in outer edge or inner edge. The outer edge fails from tension, whereas the inner edge fails from compression. The experimental results from flexural test are provided in Table 3.

Table 3. Flexural test results

Specimen no.	Span Length, L (mm)	b×t^2 (mm^2)	Force (N)	Flexural Strength (MPa)	Standard Deviation
01	80	2121.9825	650.5012	36.79	5.784
02	80	2223.13	882.2918	47.62	
03	80	2044.26	659.1797	38.69	

The stress-displacement behavior of the flexural test of three specimens is shown in the following graph in Figure13.

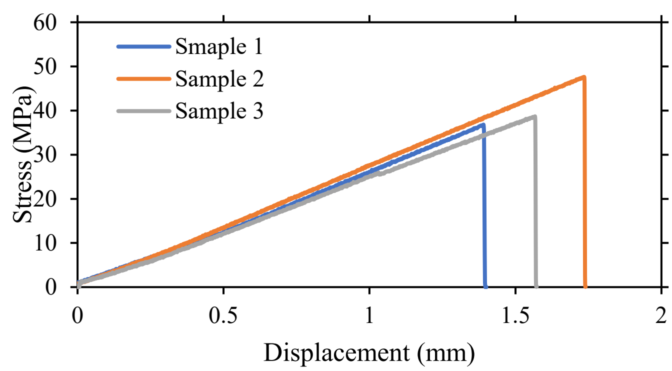


Figure 13. Flexural behavior of the three specimens

The flexural test results, as depicted in the displacement–stress curves, reveal a predominantly linear elastic response for all three specimens, followed by an abrupt failure characteristic of brittle or limited-ductility materials. Among the samples, Sample 2 consistently exhibits superior flexural performance, sustaining the highest stress of approximately 48 MPa at a displacement near 1.75 mm, which is noticeably higher than Sample 1, failing at roughly 37 MPa and 1.45 mm, and Sample 3, failing at about 39 MPa around 1.55 mm. These graphical trends correspond closely with the numerical flexural strengths in the table, where Sample 2 again records the maximum value (47.62 MPa), surpassing Sample 3 (38.69 MPa) and Sample 1 (36.79 MPa). The moderate standard deviation (5.784 MPa) suggests some variability between specimens, yet the comparative behavior clearly indicates that Sample 2 not only withstands greater force (882.29 N) but also maintains stiffness longer before fracture, whereas Samples 1 and 3 show earlier failure and lower stress capacities, reflecting comparatively weaker flexural resistance.

6.3 Impact Test Result

The Charpy impact test procedure followed. From the impact test result, how the material will perform under impact force can be guessed. The following table provides the result for impact test on the composite (Table 4).

Table 4. Charpy Impact test results

Specimen no.	Mass (kg)	h_1 (cm)	h_2 (cm)	Impact energy (KJ/m^2)	Standard Deviation
01	15	143	137.5	8.1	0.404
02	15	143	137	8.8	
03	15	143	137.5	8.1	

The Charpy impact test results indicate relatively consistent energy absorption behavior across the three specimens, although Sample 2 demonstrates a somewhat superior impact resistance. All specimens were tested under identical conditions using a 15 kg pendulum mass released from an initial height (h_1) of 143 cm, with the post-impact heights (h_2) ranging narrowly between 137 cm and 137.5 cm. Correspondingly, the calculated impact energies reveal that Sample 2 absorbs the highest energy at 8.8 kJ/m², which is moderately greater than the values for Sample 1 and Sample 3, both measuring 8.1 kJ/m². This difference suggests that Sample 2 exhibits slightly enhanced toughness or resistance to sudden fracture compared with the other specimens. The low standard deviation (0.404 kJ/m²) further confirms that the samples behave in a generally uniform manner, with only minor variation in impact performance, while still highlighting Sample 2 as comparatively more energy-absorbing.

6.4 Modulus of Elasticity

The tensile modulus of elasticity and flexural modulus of elasticity were calculated. The results are shown in the following Table 5.

Table 5. Experimental results for tensile and flexural Modulus of Elasticity

Type of Test	**Modulus of Elasticity (MPa)**
Tensile	1211.1 ± 206.88
Flexural	25.66 ± 1.44

The experimentally derived modulus of elasticity values reveals a pronounced contrast between the tensile and flexural responses of the material, highlighting the influence of loading mode on stiffness behavior. The tensile modulus, measured as 1211.1 ± 206.88 MPa, is substantially higher than the flexural modulus, which is only 25.66 ± 1.44 MPa, indicating that the material exhibits far greater resistance to deformation when subjected to uniaxial tension compared with bending. This substantial discrepancy, where the tensile modulus is nearly 47 times greater than the flexural modulus, suggests that the internal structure of the material mobilizes its stiffness more effectively under direct axial loading, while its response in flexure is comparatively compliant due to the combined effects of tension and compression occurring simultaneously across the cross-section. The relatively larger deviation in the tensile modulus also implies a higher degree of variability among tensile specimens, whereas the flexural values appear more consistent.

6.5 Comparison of Properties

The tensile, flexural and impact strength of the drumstick fiber reinforced epoxy composite was compared to another natural fiber composite which is coir fiber reinforced epoxy composite (Harish et al., 2009). The comparison is shown in the following Table 6.

Table 6. Comparison of tensile, flexural, and impact strength

Fiber	**Tensile Strength (MPa)**	**Flexural Strength (MPa)**	**Impact Strength (KJ/m^2)**
Drumstick	11.77 ± 0.875	41.03 ± 5.784	8.33 ± 0.404
Coir	17.86±2.32	31.08±6.01	11.49±0.99

For a better understanding, the comparison of strengths is shown in bar chart. In Figure 14(a) – (c), the bar charts show the comparison of tensile, flexural and impact strength respectively.

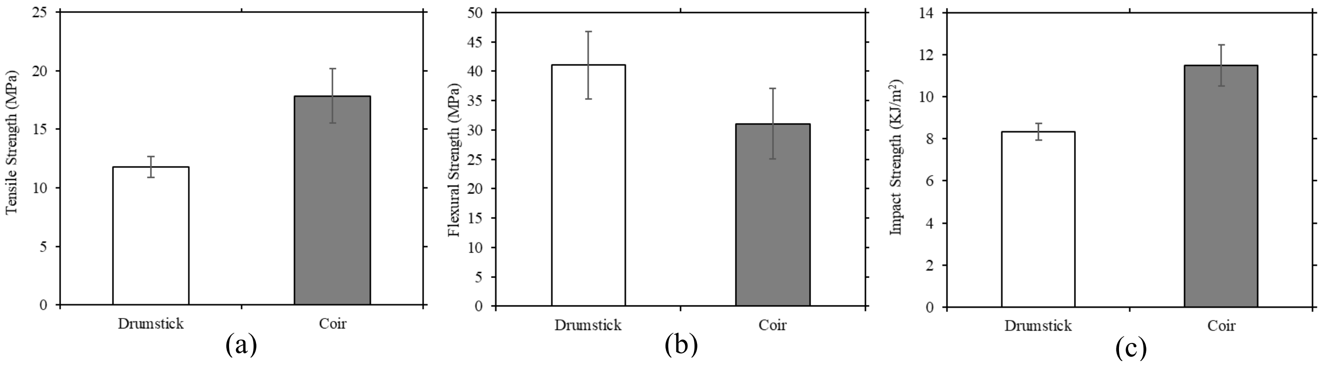


Figure 14. (a) Comparison of tensile strength, (b) Comparison of flexural strength, (c) Comparison of impact strength

The comparative mechanical performance of drumstick and coir fibers, as illustrated in the tensile, flexural, and impact strength graphs, reveals distinct differences in their load bearing and energy-absorbing capabilities. Coir consistently outperforms drumstick in both tensile strength and impact strength, achieving 17.86 ± 2.32 MPa compared with 11.77 ± 0.875 MPa for drumstick, and 11.49 ± 0.99 kJ/m² compared with 8.33 ± 0.404 kJ/m², respectively; this indicates that coir fibers possess greater resistance to axial fracture and superior toughness under sudden loading. Conversely, drumstick exhibits a noticeably higher flexural strength, reaching 41.03 ± 5.784 MPa, which surpasses the 31.08 ± 6.01 MPa recorded for coir, implying that drumstick fibers are comparatively more effective at sustaining bending stresses. Overall, while coir demonstrates greater strength in tension and impact—suggesting enhanced ductility and toughness—drumstick fibers display superior stiffness under flexural loading, highlighting a trade-off in mechanical performance depending on the mode of deformation.

7. Conclusion

This study successfully developed and evaluated a drumstick (Moringa oleifera) fiber reinforced epoxy composite through the hand lay-up fabrication method. Mechanical testing revealed that the composite possesses a tensile strength of 11.77 MPa, flexural strength of 41.03 MPa, and impact strength of 8.33 kJ/m², with respective tensile and flexural moduli of 1.21 GPa and 25.7 MPa. The results indicate that while the composite exhibits moderate tensile and impact performance, its high flexural strength demonstrates good load-bearing capability under bending.

Compared with coir fiber reinforced epoxy composites, the drumstick fiber composite displayed lower tensile and impact resistance but superior flexural behavior, suggesting stronger bending stiffness but limited ductility. The interfacial bonding between the natural fiber and epoxy matrix was adequate for structural integrity, though chemical surface modification or hybridization with other fibers could further enhance mechanical performance.

Overall, Moringa oleifera fiber shows strong potential as a renewable, low-cost reinforcement for polymer composites in lightweight, non-load-bearing, and semi-structural applications where flexural properties are critical. This work contributes to expanding the use of biobased fibers in sustainable composite development, opening pathways for environmentally friendly materials engineering. The following points describe the properties of the composite:

- Drumstick fiber reinforced composite has a comparatively low tensile strength.
- Drumstick fiber reinforced composite has quite a high value for flexural strength.
- In case of impact force, drumstick fiber reinforced composite cannot withstand high force.
- This composite can be a useful material for designs where less tension and impact force act.

8. Future Recommendations

This project prompts some recommendations. Some future work can be carried out on this project, and the properties of the composite can be modified.

- The fibers can be chemically treated to enhance their properties.
- The drumstick fiber can be used in hybridization with other fibers.
- Instead of stitching the fiber manually, looms can be used so that the fiber remains uniform inside the composite.

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Biographies

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Nurul Hasnat is a graduate of the Department of Mechanical Engineering at Khulna University of Engineering & Technology (KUET), Bangladesh. During his undergraduate studies, he gained research experience in composite laminate fabrication, finite-element and representative volume element (RVE) analysis of composite structures, and exploratory work on geopolymer-based cementitious materials. He was a former member of a Formula Student recognized team, overseeing aerodynamic package development and fiber reinforced vehicle body construction, and also worked as an Administrative Assistant for an engineering journal, supporting editorial and review workflows. His current research interests include composite materials, solid mechanics, and the development and characterization of advanced structural and cementitious materials.

Muhammad Jawad Zin Noor is a Mechanical Engineering alumnus (or former student) of KUET, Bangladesh. During his time at KUET, he was actively involved in extra-curricular engineering-related projects: for instance, he served as Suspension System Expert for a project team under KILO FLIGHT and did voluntary work under the KUET Automobile Club. Jawad is passionate about computational and experimental fluid mechanics, heat transfer and thermal management, and fluid-structure interaction. He is leaning towards more real-world applications of fluid mechanics and thermal management, especially in the field of product design, in a direction in which he is currently pursuing his career. Jawad is particularly passionate about bridging the gap between industry and academia.

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In addition to research, Tanvir has industrial engagement experience: he has worked as a Sales Engineer at Atlas Copco, which suggests he aims to blend academic expertise with industry-level applications. Beyond academics and work, Tanvir is likely motivated by bridging theoretical engineering and practical solutions, especially in materials engineering, sustainable composites, and mechanical design, offering promise for contributions in research or industrial sectors.