



Mechanical Characterization Of Madhuca Longifolia Trunk Fiber Polyester Composites

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ABSTRACT

This paper investigates the mechanical properties of natural fiber-reinforced polymer composites using Madhuca longifolia trunk fibers as reinforcement in a polyester resin matrix. The trunk fibers were collected from readily available local sources, cleaned, cut into small lengths of around 5 mm, and sun-dried for an entire day prior to the creation of the composite. The composites were made using a manual hand lay-up technique with a 30% fiber weight fraction. Composite specimens were subjected to impact and flexural tests in compliance with standard testing procedures. The results show that the resulting composite has a flexural strength of 17.18 MPa and an impact energy of 0.2 J. The measured mechanical performance is caused by the Madhuca longifolia fibers' efficient dispersion and strong interfacial bonding with the polyester matrix. The findings indicate that Madhuca longifolia trunk fibers might be utilized as a useful, sustainable, and eco-friendly reinforcing material for polymer composites. These composites may find usage in lightweight and non-structural engineering applications.

Keywords: Natural fiber reinforced polymer composites, Madhuca longifolia, polyester resin, flexural strength, impact strength, hand lay-up.

1. INTRODUCTION:

Natural fiber-reinforced hybrid composites were made by hand layup using nonwoven glass fiber sheets and sugarcane bagasse/coir fiber mats as reinforcements. FTIR and SEM analyses were used to evaluate the chemical composition and tensile fracture morphology of the generated composites. The epoxy-based hybrid composite (GCSEC) outperformed the polyester-based composite (GCSPC) in mechanical performance, achieving tensile strength of 59.5 MPa, flexural strength of 110.56 MPa, and impact strength of 40.85 J. Although epoxy composites demonstrated higher overall properties, polyester resin composites offer a cost-effective alternative for producing low-cost

hybrid structural materials [1]. Natural fiber composites are gaining popularity as lightweight, energy-efficient alternatives to conventional synthetic materials for structural purposes. The tensile properties of manually extracted snake grass fibers are analyzed and compared with those of other readily available natural fibers in this work. Chopped snake grass fiber-reinforced composites were made using isophthalic polyester resin, and fracture behavior was evaluated using fiber pull-out observations. Experimental results show that raising the fiber volume percent significantly improves the composite's modulus, tensile strength, and flexural strength [2]. This study assesses the impact of oxalic acid, alkali, and combination chemical treatments on vacuum-infused ramie fiber-reinforced polyester composites. Tensile (36.19%), flexural (49.42%), interlaminar shear (56.06%), and impact strength (83.90%) were all considerably increased by the combination alkali–oxalic acid treatment. Thermal research revealed a higher decomposition temperature, suggesting that the treated composites had improved thermal stability. Better fiber surface roughness and greater fiber–matrix adhesion were demonstrated by SEM analysis, improving composite performance [3]. The vacuum infusion method was used to make hybrid polyester composites reinforced with unidirectional ramie fibers treated with alkali–oxalic acid and cellulose nanocrystals (0.5–1 weight percent). The optimal CNC loading of 0.75 weight percent significantly increased tensile strength (27.23%), flexural strength (39.41%), interlaminar shear strength (84.56%), and impact strength (49.53%). FE-SEM study confirmed strong interfacial adhesion between ramie fibers and the polyester/CNC matrix, which improved load transfer efficiency. Although the inclusion of CNCs had little influence on thermal stability, the resulting hybrid composites showed significant potential for lightweight structural applications [4]. Four-layered natural fiber composite laminates with stacking sequences of $0^\circ/90^\circ$, $45^\circ/45^\circ$, and hybrid orientations were made using Hibiscus vitifolius and Malva fiber matting. According to mechanical characterization carried out in compliance with ASTM standards, the Malva (MMMM) composite showed better tensile (118.13 MPa), compressive (129.73 MPa), and flexural strength (121.13 MPa). The hybrid MHMH laminate, which had the highest tensile strength of any stacking configuration, highlighted the effectiveness of fiber hybridization. The Hibiscus vitifolius (HHHH) composite demonstrated the lowest water absorption (0.853%) in comparison to Malva laminates, suggesting superior moisture resistance [5]. High-performance nano bio composites were made by compression molding unsaturated polyester resin reinforced with pre-treated short sun hemp (2 cm) fibers and 5 weight percent hydrophilic bentonite nanoclay. The inclusion of nanoclay significantly improved flexural strength when compared to untreated composites, showing increases of 165% for fibers treated with H_2O_2 and 148% for fibers treated with $KMnO_4$. It has been demonstrated that intercalation and exfoliation procedures utilizing sun hemp fibers, polyester matrix, and nanoclay enhance performance and provide a superior fiber–matrix interaction. The addition of nanoclay considerably reduced water absorption in H_2O_2 -treated nanobiocomposites from 11.86% (untreated) to 2.76%, indicating enhanced dimensional stability and suitability for automotive and aerospace applications [6]. Hybrid polymer matrix composites were made using kaolin waste and alkali-treated bamboo fibers (*Bambusa vulgaris*) as sustainable reinforcements in an isophthalic unsaturated polyester matrix. Composites containing 30 mm treated fibers and 30% kaolin showed superior flexural capabilities, achieving a flexural strength of 137.0 MPa and a flexural modulus of 19.27 GPa. Tensile strength rose

significantly by 66% and 54% with kaolin inclusion as compared to plain polyester, indicating the reinforcing effect of mineral waste fillers. SEM examination and ANOVA validation demonstrated effective fiber–matrix interaction and statistical reliability, highlighting the feasibility of bamboo fiber/kaolin waste hybrid composites for structural applications [7]. Polyester composites reinforced with crocheted miriti fibers (*Mauritia flexuosa*) were made by hand lamination and vacuum curing under different fabric grammages, fiber treatments, matrix viscosities, and post-curing conditions. The modulus of elasticity and tensile strength were significantly impacted by matrix viscosity and alkaline fiber treatment when mechanical parameters were evaluated using ASTM D3039. The greatest tensile strength (13.02 MPa) was achieved with alkaline-treated fibers, a viscous matrix, a higher fabric grammage (473.9 g/cm²), and post-curing at 60 °C. The greatest modulus of elasticity of composites with decreased fabric grammage and viscous matrix but no alkaline treatment was 1.59 GPa, demonstrating the combined impact of processing variables on mechanical performance [8]. Alkali-treated date palm fiber (DPF) and cleaned sheep wool were used in compression molding to produce hybrid polyester composites with fiber loadings of 0–30 weight percent. With a tensile strength of 27 MPa, a tensile modulus of 3.69 GPa, and a flexural strength of 35.4 MPa, the hybrid composite composed of 20 weight percent DPF and sheep wool had the best mechanical performance. The maximal impact strength (39.5 kJ/m²) and hardness (64 HB) at 20 weight percent fiber content showed effective stress transfer within the hybrid system. SEM analysis revealed strong interfacial adhesion between hybrid fibers and the polyester matrix, and the 30 weight percent hybrid composite had the lowest density (1.02 g/cm³), enhancing its lightweight qualities [9]. Oil-treated Ethiopian Highland bamboo fiber-reinforced polyester laminates with a 35:65 fiber-to-matrix volume ratio were made by hand layup. The oil-treated bamboo fiber composite had maximum tensile and flexural strengths of 193.3 MPa and 173.4 MPa, respectively. When compared to untreated bamboo fiber composites, oil treatment greatly enhanced the mechanical performance of the materials by raising their tensile and flexural strengths by 39.6% and 50.2%, respectively. The improved performance, which results in reduced brittleness and enhanced load-bearing capacity, is caused by fiber lubrication and increased strand flexibility because of oil treatment [10]. Polyester composites loaded with iron powder (IP) and reinforced with Timoho fiber (TF) were successfully produced with a constant 30 weight percent fiber content using the hot press method. While the TF10IP composite had superior impact toughness (126.74 kJ/m²) and compressive strength (155.72 MPa), the PTF composite had the highest tensile strength (119.26 MPa). Iron powder increased the modulus of elasticity from 4.14 to 4.94 GPa while decreasing elongation from 3.58% to 2.19%, indicating greater stiffness with less ductility. The use of IP filler, which improved flame resistance and thermal stability (TGA), corroborated the mechanical performance results. Additionally, fiber pull-out and vapor traces were visible in the fracture morphology [11]. Natural fiber-reinforced polymer composites have notable mechanical, thermal, and sustainability benefits, as the studied literature collectively shows. Important conclusions include the fact that epoxy matrices perform better mechanically than polyester matrices, the importance of fiber surface treatments in improving fiber–matrix adhesion, and the synergistic advantages of hybrid reinforcement techniques. Composite materials are becoming more and more practical for structural, automotive, and aerospace

applications thanks to sophisticated processes including nanoclay integration, CNC addition, and mineral waste fillers.

2. Experimental Work

2.1 Materials

Madhuca longifolia trunk fiber served as the main reinforcing material in this investigation. The material of the trunk was collected from locally accessible sources. The material was thoroughly cleaned under running water after collection to remove any unwanted contaminants, such as surface dust and soil particles, that had gathered during handling and transportation. The cleaned trunk material was then allowed to sun-dry outside for an entire day to reduce the moisture content. Once the trunk material had dried, the fibrous portion was removed. The extracted fibers were then cut into uniform lengths of around 5 mm using the appropriate cutting equipment to prepare them for composite production and specimen preparation. Polyester resin, which was acquired from a nearby industrial source, served as the matrix material. Methyl ethyl ketone peroxide served as the catalyst, and the resin was mixed with a suitable hardener to expedite the curing process and ensure adequate solidification of the composite.

2.2 Preparation of Composites

The conventional manual hand lay-up method was employed to create the composite laminates due to its simplicity and effectiveness in producing natural fiber-reinforced polymer composites. A flat wooden mold served as the casting surface for the composite's processing. The polyester resin mixture was aggressively stirred for two to five minutes to ensure that all the ingredients were dispersed uniformly and to initiate the curing reaction. Fibers from the trunk of Madhuca longifolia were cut into lengths of around 5 mm. The fibers were added to the resin matrix at a weight fraction of 30% and distributed randomly to achieve uniform dispersion. After applying a layer of resin to the mold's surface, fibers were progressively added. The leftover glue was then used to adequately soak and impregnate the fibers. The mixture was dispersed evenly to guarantee uniform thickness and minimize the formation of cavities in the composite. The produced composite laminate was allowed to cure at room temperature for a whole day to ensure complete solidification. After the composite had dried, it was gently removed from the mold. For flexural and impact testing, the laminate was sliced and trimmed into standard specimen dimensions after curing.

2.3 Mechanical Testing

2.3.1 Flexural Testing

The flexural behaviour of the developed Madhuca longifolia trunk fiber reinforced polyester composites was evaluated utilizing a three-point bending test employing a Universal Testing Machine (UTM) in accordance with ASTM D790 standards. The test specimens measured 100 mm by 13 mm by 3 mm (length × width × thickness). During testing, each specimen was positioned symmetrically on two supporting spans, and force was applied halfway until the specimen broke. The support span was maintained in compliance with standard parameters, and the crosshead speed was adjusted in line with

ASTM D790 standards to provide consistent loading circumstances. The flexural strength was determined using the specimen's maximum load prior to failure. To ensure the reproducibility and reliability of the results, at least three specimens were assessed for each sample, and the average values were provided. Care was taken throughout testing to minimize experimental errors and ensure that the specimens were correctly aligned.

2.3.2 Impact Testing

A pendulum-style Izod impact testing device was used to evaluate the impact strength of the produced composites in accordance with ASTM D256 criteria. The prepared specimens measured 65 mm by 13 mm by 3 mm. In this investigation, unnotched specimens were used to evaluate the composite material's inherent impact resistance. After each specimen was fixed vertically in the testing apparatus, a pendulum hammer was released to strike it. The energy absorbed by the specimen during fracture was recorded using the machine's calibrated dial. The impact strength was determined using the energy absorbed during the fracture process. Each impact test was conducted in an ambient laboratory environment at room temperature. To ensure homogeneity, at least three specimens were assessed for each composition, and the average values were reported. The obtained results provide insight into the durability and energy-absorbing capabilities of the produced composite.

3. Results and Discussion

3.1 Flexural Strength

Figure 1 displays the flexural performance of the *Madhuca longifolia* trunk fiber reinforced polyester composites as assessed by three-point bending tests. The results showed a considerable variation in the flexural strength of the specimens under examination. Flexural strength is 17.18 MPa on average. Variations in the composite's fibre dispersion, resin impregnation, and interfacial bonding can account for this disparity.

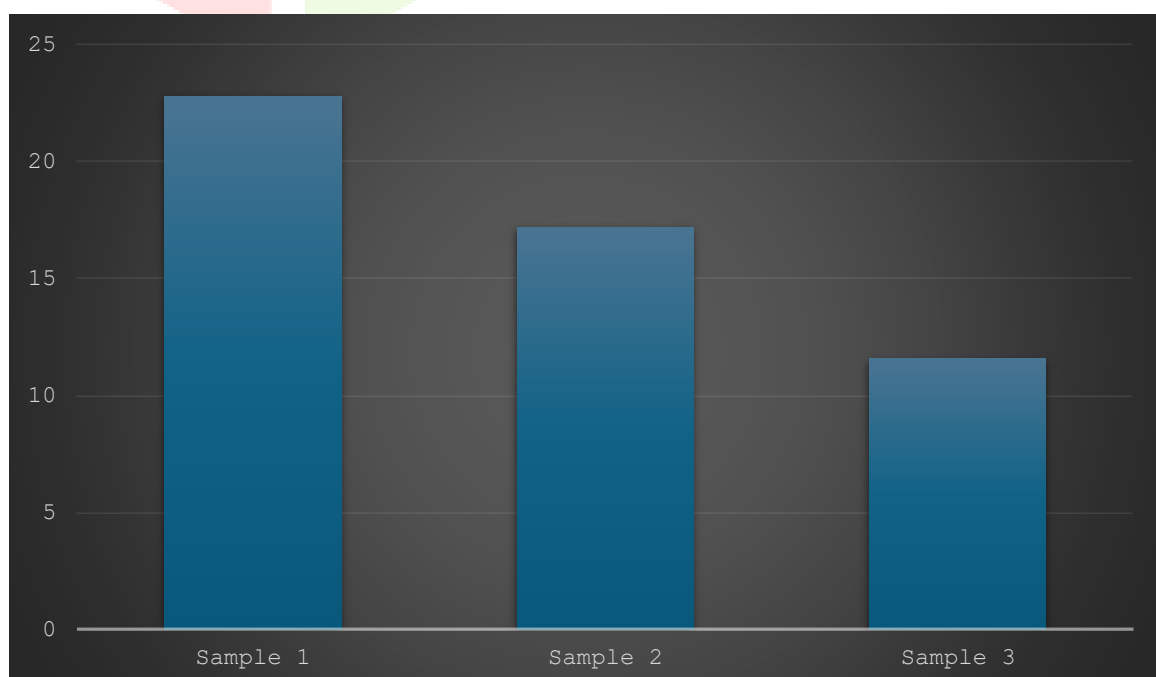


Fig 1: Flexural Strength

Improved stress transfer between the matrix and fiber when bending loads are applied. Furthermore, enhanced stiffness and load-bearing capacity result from better adhesion and uniform fiber dispersion. However, minor defects like as voids or uneven fiber alignment might be the reason for reduced strength. Overall, the results are consistent with the notion that proper manufacturing and fiber-matrix interaction play a major role in determining flexural behaviour.

3.2 Impact Strength

Figure 2 displays the *Madhuca longifolia* trunk fiber reinforced polyester composites' impact strength as determined by unnotched Izod impact testing. The results reveal an average impact energy of 0.18 J, indicating consistent energy absorption behaviour and homogeneous composite fabrication. Impact performance is significantly impacted by the fibers' ability to tolerate fracture initiation and propagation under dynamic loading conditions. The implanted trunk fibers promote energy-dissipating processes such localized fiber breakage, interfacial debonding, and fiber pull-out by functioning as effective barriers. These procedures aid in increasing the toughness of the composite and delaying the development of fractures.

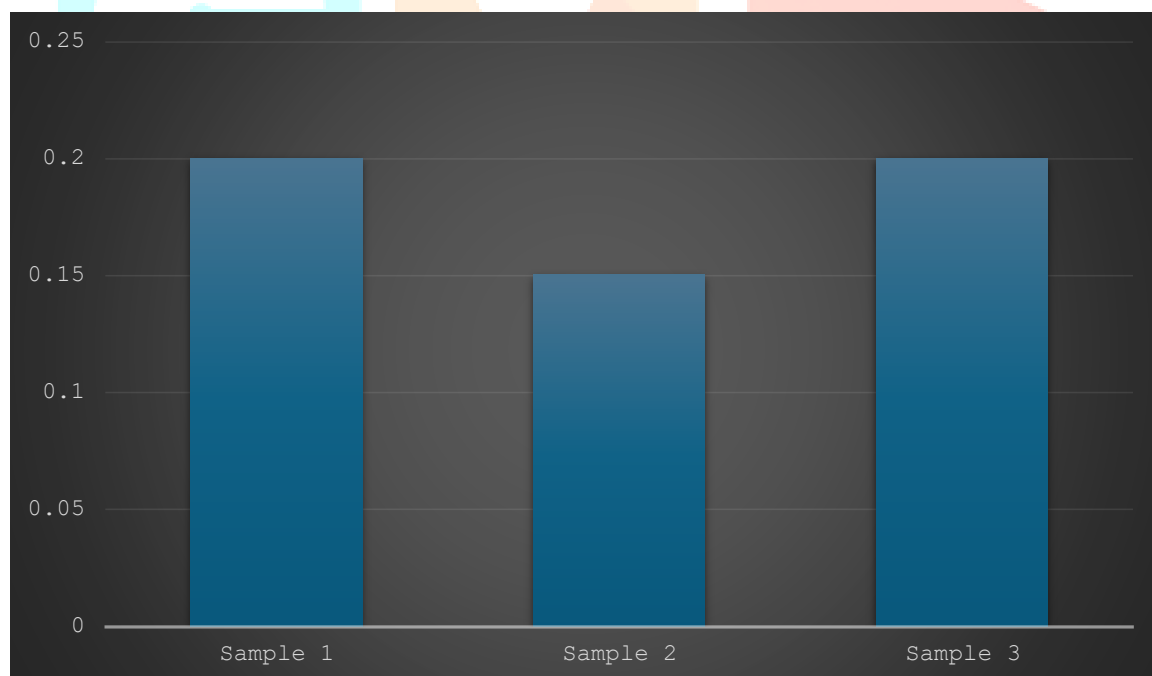


Fig 2: Impact Strength

Additionally, the uniform dispersion of short fibers inside the polyester matrix guarantees effective stress distribution upon impact. Despite the variable fiber orientation, sufficient fiber-matrix adhesion and suitable resin impregnation result in uniform and repeatable impact performance across the specimens. However, the relatively low impact energy value indicates moderate toughness, which is characteristic of short-fiber reinforced polyester composites. Overall, the results confirm the constant impact resistance

of the suggested composite, with fiber reinforcing playing a key role in improving resistance to sudden loading scenarios.

4. Conclusions

Madhuca longifolia trunk fiber reinforced polyester composites were built using the hand lay-up method, and their mechanical performance was evaluated. The inclusion of fibers at a weight percentage of 30% significantly increased the composite's flexural strength of 17.18 MPa and impact energy of 018 J. The improvement in mechanical behaviour is caused by efficient stress transfer, uniform fiber dispersion, and adequate interfacial bonding between the fiber and matrix. Minor variations in results might be caused by small differences in production, such as resin impregnation and fiber distribution. Even though the impact strength indicates modest toughness, the composite performs steadily throughout a range of loading conditions. With a 30-weight percent fiber content providing the optimal mechanical property balance for lightweight and non-structural applications, the results generally support the use of Madhuca longifolia trunk fibers as an affordable and sustainable reinforcing material.

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