

Comparative Analysis of Different Mechanical Properties of Banana Pseudostem Fiber and Pineapple Leaf Fiber Reinforced Polymer Composite

Vishal Wankhade^{1,*}, Manoj Sharma², Rajeev Sharma³, Shashi Chandra Sharma⁴

Abstract

In this research, a hybrid natural fiber polymer composite is prepared using different combinations of banana pseudostem fiber and pineapple leaf fiber in a discontinuous reinforcement phase and epoxy polymer in a continuous matrix phase. For the preparation of the composite, the hand layup technique is used and important mechanical characteristics, namely tensile, flexural, and impact strength, are determined. The findings of this investigation represent that the highest values of tensile, flexural, and impact strength, 28.3 MPa, 57.1 MPa, and 55.9 J/m respectively, were obtained in 20% Hybrid (10% banana pseudostem fiber and 10% pineapple leaf fiber) as a reinforcement material and the rest of the epoxy polymer as a matrix material (20%HFPC). However, for 30% Hybrid (15% banana pseudostem fiber and 15% pineapple leaf fiber) as a reinforcement material and the rest of the epoxy polymer as a matrix material (30%HFPC), the tensile strength slightly declined to 25.2 MPa, although flexural strength (49.9 MPa) and impact strength (45.2 J/m) remained high. The 5% Hybrid (2.5% banana pseudostem fiber and 2.5% pineapple leaf fiber) as a reinforcement material and the rest of the epoxy polymer as a matrix material (5%HFPC) displayed the least results of tensile, flexural, and impact strength at 11.8 MPa, 25.1 MPa, and 39.7 J/m respectively. This research work focuses on sustainable natural fiber composite development using waste agricultural products.

Keywords: Banana pseudostem fiber, hand layup technique, matrix phase, pineapple leaf fiber, reinforcement phase

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INTRODUCTION

Banana and Pineapple are commercial fruit crops which are widely farmed in India and worldwide. After several fruit crops, and when Banana and Pineapple plants decline, they are removed from the farm and it becomes agricultural waste. To produce natural fibers from this agricultural waste, there is a sustainable method to dispose of the agricultural waste which helps in sustainable waste management [1].

The pseudostem of Banana plants is the leading contributor to developing natural fibers and these fibers are widely known as banana pseudostem fibers or banana fibers [2]. Banana fiber composites also offer favorable thermal characteristics when compared to their non-reinforced counterparts [3].

Thermogravimetric analysis (TGA) has confirmed that the degradation of these composites typically begins between 344°C and 358°C, which supports their use in standard thermoplastic processing environments [4]. Moreover, Differential Scanning Calorimetric (DSC) studies suggest that increasing fiber content tends to reduce the thermal transition point and reduce crystallization enthalpy, indicating restricted polymer chain dynamics. The incorporation of nanoclay into banana fiber-reinforced systems further elevates their thermal resistance and enhances residual char formation, making them suitable for thermally demanding applications [5].

Banana fiber and pineapple leaf fiber (PALF), both obtained from the foliage of tropical plants, are increasingly recognized as sustainable and high-performance reinforcements in polymer composite fabrication. Their favorable strength-to-weight ratios, thermal characteristics, and natural origin make them attractive alternatives to synthetic fibers in green composite applications.

Pineapple leaf fiber (PALF) polymer composites are emerging as eco-conscious and sustainable alternatives to traditional composites, formulated by embedding fibers derived from pineapple leaves into synthetic or biodegradable polymer matrices. These fibers, obtained from *Ananas comosus*, contain a high proportion of cellulose (about 70–82%), along with hemicellulose, lignin, and pectin. The high cellulose content imparts superior specific strength and low density, making PALF a strong candidate for reinforcement in polymer systems. Additionally, utilizing pineapple leaf waste supports environmental sustainability and adds value to agricultural by-products. Incorporating PALF into matrices, such as polypropylene (PP), epoxy, or polylactic acid (PLA) leads to enhanced thermal and mechanical characteristics of the final composites [6].

The inclusion of PALF in polymer composites has demonstrated substantial enhancement in mechanical attributes like tensile, flexural, and impact strength, as well as stiffness. For example, PALF-reinforced PLA composites fabricated through injection molding showed considerable improvements in strength when treated with sodium carbonate, especially at fiber contents of 20–30% and fiber lengths near 4 mm [7]. Similarly, epoxy laminates reinforced with woven PALF exhibited superior tensile and flexural performance along the fiber's warp direction, attributed to efficient stress transfer and fiber orientation [8]. From a thermal standpoint, PALF composites are suitable for processing under conventional conditions. Thermogravimetric analysis (TGA) revealed that PALF-reinforced PLA composites maintain thermal stability up to elevated temperatures, ensuring compatibility with standard fabrication processes [9]. Enhanced thermal resistance has also been observed in PALF-based composites using polybutylene succinate (PBS), particularly when fiber alignment is introduced. This alignment contributes to improved char residue formation and resistance to heat [10]. Furthermore, PALF blended with date palm fibers has shown promise in insulation and packaging applications due to its favorable thermal insulation properties [11].

The randomly oriented fiber composites are composed of short or discontinuous fibers dispersed throughout the matrix without a specific alignment. While they exhibit relatively lower mechanical strength compared to aligned fiber composites, they offer nearly isotropic properties. This makes them advantageous in applications where uniform mechanical response in all directions is desired, such as panels, casings, or non-critical load-bearing structures [12]. The randomly oriented fiber composites are increasingly being adopted in non-structural and semi-structural applications, such as automobile door panels, interior trims, furniture, packaging, and construction boards due to their sustainability and adequate mechanical performance [13,14]. The hybrid design enables tailoring of the composite's physical and mechanical characteristics by intelligently combining fibers with complementary behaviors [15]. For example, banana fiber possesses high tensile strength but lacks thermal resistance, while pineapple leaf fiber (PALF) offers superior rigidity and better thermal stability. Together, they can deliver well-rounded improvements in strength, stiffness, and resistance to thermal and impact loading. Moreover, hybrid composites offer additional benefits, such as weight reduction, lower material cost, and increased applicability in lightweight structural components [16].

Sustainability and Performance Attributes of Banana and Pineapple Leaf Fibers in Polymer Composites

Banana fiber and pineapple leaf fiber (PALF), both obtained from the foliage of tropical plants, are increasingly recognized as sustainable and high-performance reinforcements in polymer composite fabrication. Their favorable strength-to-weight ratios, thermal characteristics, and natural origin make them attractive alternatives to synthetic fibers in green composite applications [17].

Mechanical Characteristics

Banana fibers exhibit tensile strengths in the range of 400–600 MPa and Young's modulus between 12–22.5 GPa, which provides a good mix of rigidity and strength, making them suitable for moderate to high-load applications [18].

PALF, on the other hand, offers higher stiffness (22–34.5 GPa) and comparable tensile strength (400–700 MPa), showing strong potential in structural composite materials where greater rigidity is required [19].

Thermal Performance

These fibers possess thermal degradation limits compatible with thermoset polymers. Banana fibers degrade between 270–320°C, and PALF ranges from 270–330°C, which overlaps well with the stability range of resins like epoxy (~300°C) [20]. This similarity in thermal behavior ensures that both fibers can be effectively used in environments where elevated temperatures are encountered during service.

Fiber Morphology and Bonding Efficiency

The coarse and uneven surfaces of banana and PALF contribute positively to their adhesion with epoxy matrices, as the rough texture encourages mechanical interlocking [17].

Their cellulose-rich composition (60–65% in banana, 70–81% in PALF) supports not only mechanical integrity but also thermal endurance [18,19].

Moisture Sensitivity and Treatment Potential

Both fibers are moderately sensitive to moisture (banana: 10–12%, PALF: 9–11%), which may affect composite dimensional stability. However, surface modification techniques, such as alkali and silane treatments have proven effective in reducing this susceptibility, thereby improving composite reliability in humid environments [18,20].

In recent years, lots of research work is going to engineer sustainable composites by utilizing natural fibers. It is also investigated that some natural fiber composites show equivalent or enhanced properties over synthetic fibers [21,22]. Previous research has not extensively explored the mechanical behavior of hybrid natural fiber composites, fabricated by using isotopically distributed short banana pseudostem fiber and pineapple leaf fiber in the reinforcement phase. This study is tried to address this gap. In this research work, a hybrid randomly oriented natural fiber polymer composite is prepared using a different combination of banana pseudostem fiber and pineapple leaf fibers in the discontinuous reinforcement phase and epoxy polymer in the continuous matrix phase and investigation of mechanical performance is done for these fabricated composites.

METHODOLOGY

Materials

Reinforcement Materials

In this study, two types of natural fibers, banana pseudostem fiber and pineapple leaf fiber, are used (Figure 1a and b). These fibers were purchased from the local market, washed with water, and dried thoroughly under sunlight.



Figure 1. Banana pseudostem fiber

Pineapple leaves fibers



Figure 2. Epoxy polymer resin and hardener.

According to previous studies, fibers with a length of 20 mm show better mechanical properties compared to 5 mm, 10 mm, 15 mm, and 25 mm short fibers. Therefore, in this research, 20 mm length fibers are used [23].

Matrix Material

In this research work, epoxy polymer resin (Lapox Matalam System B) and hardener (Lapox Matalam System B) made by Atul Ltd. are being used consistently in the ratio of epoxy to hardener of 2:1 as shown in Figure 2.

Sample Preparation

In this research work, tensile test samples are fabricated as per the specifications of ASTM D638-Type I, flexural test samples are fabricated as per the specifications of ASTM D790, and Izod impact test samples are fabricated as per the specifications of ASTM D256 by using the equal proportion of banana pseudostem fiber and pineapple leaf fiber at varying weight percentage with epoxy polymer as shown in Figure 3a, b, and c. Epoxy polymer and hardener are being used in the ratio of epoxy to hardener of 2:1. The test specimens are prepared as:

- 5% Hybrid (2.5% banana pseudostem fiber and 2.5% pineapple leaf fiber) as a reinforcement material and the rest of the epoxy polymer as a matrix material (5%HFPC).
- 10% Hybrid (5% banana pseudostem fiber and 5% pineapple leaf fiber) as a reinforcement material and the rest of the epoxy polymer as a matrix material (10%HFPC).
- 20% Hybrid (10% banana pseudostem fiber and 10% pineapple leaf fiber) as a reinforcement material and the rest of the epoxy polymer as a matrix material (20%HFPC).
- 30% Hybrid (15% banana pseudostem fiber and 15% pineapple leaf fiber) as a reinforcement material and the rest of the epoxy polymer as a matrix material (30%HFPC).

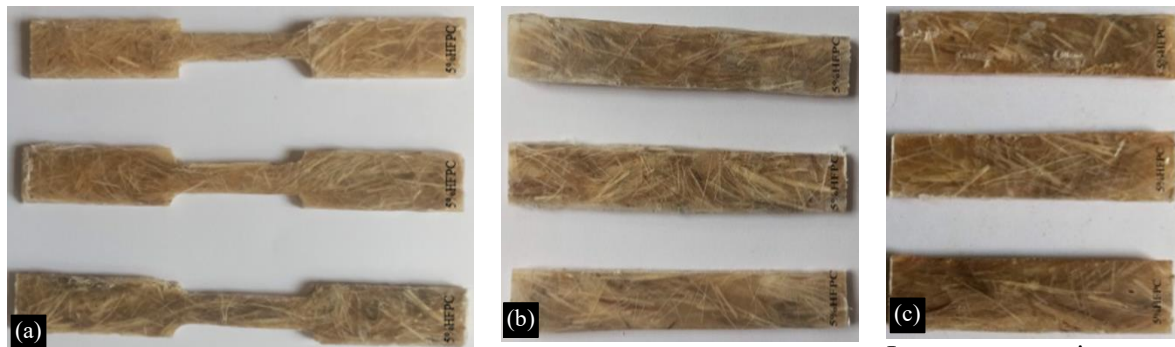


Figure 3. Tensile test specimen

Flexural test specimen

Impact test specimen

Mechanical Testing

Tensile Testing

In this study, tensile experimental samples were produced and evaluated in accordance with the test specification of ASTM D638 TYPE I. The tensile test was carried out at the Central Institute of Plastics Engineering & Technology (CIPET), Bhopal, according to the specification of ASTM D638 TYPE I using a Retrofitting Universal Testing Machine (UTM) (Make - LLOYD). A load of 5.0 kN was exerted at a uniform cross-head movement of 5 mm/min and the results of the tensile test are mentioned in Table 1.

Flexural Testing

In this study, flexure test specimens were fabricated and tested according to the ASTM D790 standard for a 3-point flexure test. The flexural performance was assessed at CIPET, Bhopal, as per the ASTM D790 3-point flexure test standard using a Retrofitting Universal Testing Machine (UTM) (Make - LLOYD). A load of 5.0 kN was exerted at a uniform cross-head travel speed set to 5 mm/min and findings of the flexural test are mentioned in Table 1.

Impact Testing

In this study, impact test samples were fabricated as per the specification of ASTM D256, and the impact test is done using a Charpy impact setup at CIPET, Bhopal. The findings of the impact test are presented in Table 1.

RESULTS AND DISCUSSION

The results of tensile, flexural, and impact tests are tabulated as:

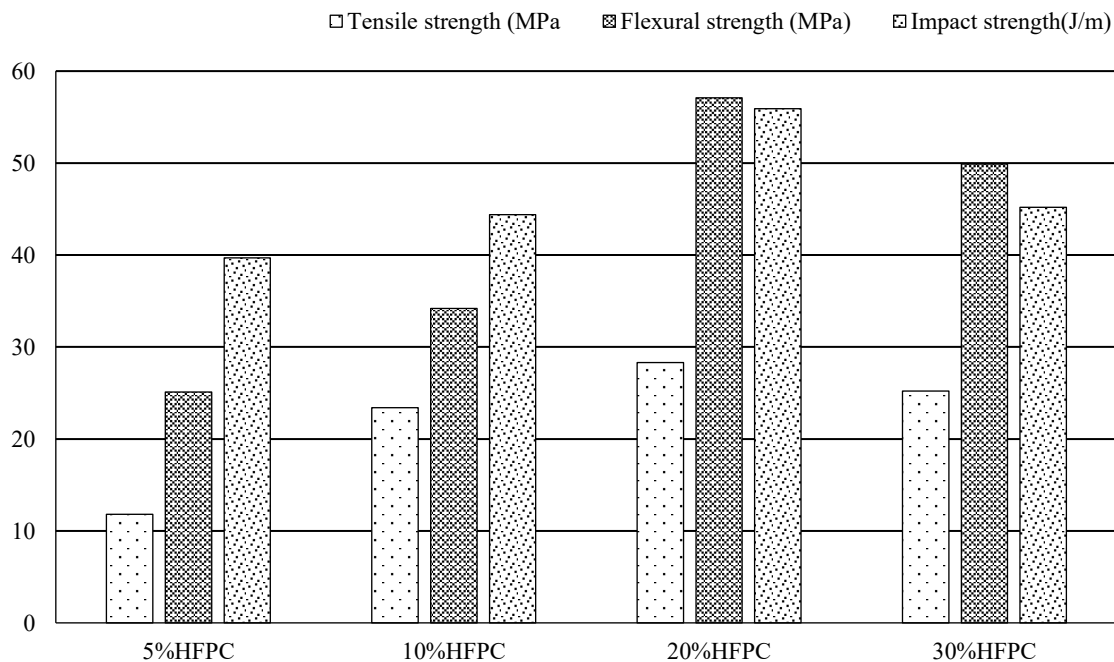
The outcomes of this research demonstrate a clear correlation between the percentage of reinforcement fiber content and the mechanical properties of the composite material. With the increase in the reinforcement fiber content, considerable variations were observed in tensile, flexural, and impact strength. These findings indicate that composites containing higher reinforcement fiber (ranging from 5% to 20%) exhibit improved mechanical characteristics (Figure 4).

Tensile Strength

Findings from this investigation reveal that the amount of fiber contained in the reinforcement phase increases the tensile properties. The composite with 20% of fiber in the reinforcement phase shows the highest tensile strength of 28.3 MPa. This highest tensile strength may be due to the very uniform load transfer between the composite. Similar trends of results were observed in the research by Xie et al. (2019), who reported that a significant rise in tensile strength was observed with higher fiber content, especially between 5% to 20%. At 5% reinforcement fiber content, the tensile strength was at its minimum (11.8 MPa), and a similar trend was also observed by Kim and Kim (2018), showing that lower reinforcement fiber content results in diminished tensile strength.

Table 1. Mechanical testing results.

S no	Designation of composite Specimen	Tensile strength (MPa)	Flexural strength (MPa)	Impact strength(J/m)
1	5%HFPC	11.8	25.1	39.7
2	10%HFPC	23.4	34.2	44.4
3	20%HFPC	28.3	57.1	55.9
4	30%HFPC	25.2	49.9	45.2

**Figure 4.** Comparison of tensile, flexural and impact strength.

Flexural Strength

Flexural strength exhibits a similar trend as the tensile strength; it shows an appreciable increase with higher reinforcement fiber content. The composite with 20% fiber contained in the reinforcement phase displayed the highest flexural strength (57.1 MPa), which suggests that the reinforcement fibers contributed to enhancing the composite's bending resistance. A similar investigation was done by Patel et al. (2020), who investigated that fiber content affects the flexural strength due to the fibers' role in effective load bearing during bending. At 30% fiber content, the flexural strength experienced a slight decrease to 49.9 MPa. This decline was also investigated by Li et al. (2017), who observed a reduction in flexural strength when reinforcement fiber content exceeded the optimal percentage, possibly because of poor fiber dispersion or a reduction in the matrix's ductility.

Impact Strength

A similar trend was seen for impact strength; the composite content of 20% reinforcement fiber shows the highest value of Impact Strength (55.9 J/m). This enhancement may be due to the capacity of fibers to absorb and distribute impact energy, which results in enhancing the toughness of the composite. Zhang et al. (2018) investigated a similar pattern where improvements in impact strength occur when fiber content is increased between 5% and 20%. Beyond 20% of reinforcement fiber content, a reduction in impact strength was observed. At 30% reinforcement fiber content, the impact strength was noted as 45.2 J/m. This slight reduction may be attributed to diminished interfacial interaction among the reinforcement fibers and the matrix at elevated fiber concentrations, leading to poorer energy dissipation.

Overall Trends

The enhancement in mechanical properties observed in several studies while incorporating reinforcement fiber up to 20% (, e.g., Yadav et al., 2017). Composites within this level of fiber content exhibit better strength and toughness. A decline in mechanical properties was observed at 30% fiber content. This performance at higher fiber contents is typically associated with factors, such as weak fiber-matrix bonding, fiber agglomeration, non-uniform fiber dispersion, or due to a rise in the brittleness of the composite, as stated by Xie et al. (2020).

CONCLUSION

The precise results of hybrid banana pseudostem fiber and pineapple leaf fiber reinforced epoxy polymer composite show a significant rise in mechanical properties in the range of fiber weight percentages from 5% to 20% and from 30% fiber weight percentages the mechanical properties get declined. The reduction in tensile, flexural, and impact strength observed in 30% Hybrid (15% banana pseudostem fiber and 15% pineapple leaf fiber) as a reinforcement material and the rest of the epoxy polymer as a matrix material (30%HFPC) sample may be due to higher fiber content; there may be uneven distribution and misalignment of fibers thereby weakening their reinforcement effect. The poor interfacial bonding among the reinforcement fibers and the epoxy matrix may lead to fiber pull-out. Higher fiber content can also introduce more voids, which disrupt the composite's integrity and reduce load-carrying ability. Furthermore, excessive fiber content can cause the matrix to be insufficiently filled, resulting in poor load distribution. Lastly, the fibers may interfere with each other at higher concentrations, destabilizing the composite and lowering its tensile strength, although flexural and impact strengths remain strong.

FUTURE SCOPE

In the present research, randomly oriented short banana pseudostem fiber and pineapple leaf fiber are used in the fiber length of 20 mm. By varying the length of the fiber and orientation, we can develop further research. There is also scope to change the matrix material and chemical treatment of the fibers. In the present research, banana pseudostem fibers and pineapple leaf fibers are taken in a 1:1 ratio in the reinforcement phase. There is scope to vary the proportion of the fibers in the reinforcement phase within prospects.

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