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# Acalypha Indica Root Fibre in Polymer Composite: Mechanical Characterization

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***Abstract***

*The mechanical characteristics of Acalypha Indica root fibre reinforced epoxy resin composites, including tensile strength, tensile modulus, percentage of elongation, flexural strength, and impact strength, were studied. Composites were fabricated using epoxy glue and randomly oriented fibres of 3 mm length in varying weight ratios of 10%, 20%, 30%, and 40%. The hand layup method was followed by compression moulding to construct the composites. The study aimed to determine the optimal quantity of Acalypha Indica root fibre in the epoxy matrix to achieve the best mechanical properties. Mechanical tests revealed that composites with 30% fibre content exhibited superior performance compared to other weight percentages. Scanning Electron Microscopy (SEM) images indicated good fibre-matrix adhesion up to 30% fibre content. However, beyond this level, the interaction between the fibre and the epoxy matrix weakened. The tensile strength and modulus of 30% fibre-reinforced composites were found to be 12.50 MPa and 869 MPa, respectively. In composites containing more than 30% fibre, fibre pull-out and debonding were observed due to incompatibility between the fibre and the matrix.The percentage of elongation for composites with 30% fibre content in the epoxy matrix was recorded as 1.648%. When 30% fibre content was incorporated, the peak flexural strength and modulus values were 27.87 MPa and 1320.56 MPa, respectively. Excessive fibre content beyond 30% led to fibre-to-fibre contact, resulting in poor interfacial bonding between the fibre and matrix. The impact strength of the composites ranged from a minimum of 0.89 J/cm² at 10% fibre content to a maximum of 1.67 J/cm² at 30% fibre content. Due to their enhanced mechanical properties, these composites have potential applications in the automotive, aerospace, and biomedical industries.*

**Keywords:** Acalypha indica, composites, epoxy, tensile strength and flexural strength

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## INTRODUCTION

The world urgently requires environmentally friendly materials, leading many analysts to focus on materials that improve product environmental quality. The increasing demand for green materials has shifted attention toward natural resource-based materials, replacing artificial fibre composites with natural fibre composites. Natural fibres benefit from an established manufacturing framework in many developing countries, helping sustain employment for rural workers. These fibres can be obtained from various plant parts, including roots, leaves, bark, and fruits.

Key advantages of natural fibres include biodegradability, recyclability, improved energy recovery, cost-effective manufacturing, lightweight properties, high strength, a superior specific modulus, and minimal health risks. Additionally, they have lower density, reduced equipment abrasion, and minimal dermal and respiratory irritation. Due to these benefits, natural fibres have been widely used in sectors such as aerospace, construction, sports equipment, food packaging, maritime, and automotive industries. However, despite their many advantages, these fibres have some drawbacks, primarily due to their hydrophilic nature.

Root fibres serve as effective reinforcement materials in various polymer matrices. Their key attributes include low density, cost-effectiveness, availability, environmental friendliness, and favorable chemical and mechanical properties. These qualities make natural fibres suitable for reinforcing both thermosetting and thermoplastic matrices. Based on these characteristics, Acalypha Indica root fibre was selected as a novel reinforcement material for this study. To date, no research has explored the use of Acalypha Indica root fibre as an effective reinforcement in plastic composites. Therefore, this study investigates the fibre's properties and its potential as a reinforcement material.

The term "polymer" refers to a long-chain molecule composed of numerous repeating units with identical structures. In Polymer Matrix Composites (PMC), the matrix material can be either thermoplastic or thermosetting plastic. Synthetic fibres commonly used in composites include glass, carbon, Kevlar, and asbestos. Fiber Reinforced Plastic (FRP) composites are created by reinforcing fibres with a polymer matrix and are also known as advanced composite materials. These composites are lightweight, easy to shape into complex forms, and possess high strength and rigidity. However, they have certain drawbacks, such as causing abrasion to processing machinery, being non-recyclable, and contributing to $CO_2$ emissions.[1]

Natural fibres, on the other hand, are well known for their eco-friendliness, recyclability, and cost-effectiveness. Studies have shown that the mechanical properties of composites depend on the adhesion between the fibre and the matrix. To enhance fibre-matrix interfacial characteristics, chemical and physical modification techniques are applied. These methods have been used to process jute, coir, and flax fibres, improving their suitability as reinforcement in composite materials.[2]

The mechanical properties of composites under various loading conditions were examined. Under tensile load, the matrix has a minimal role, while the fibre can withstand higher tensile loads along its direction. In contrast, under compression loading, the matrix helps prevent the fibres from buckling. Unidirectional fibre-reinforced composites exhibit high tensile strength but lower compressivestrength[3]. The properties of natural fibre-reinforced composites were also studied. Natural fibre-reinforced composite materials with a thermoplastic matrix have emerged as alternatives to glass fibre-reinforced composites. Replacing glass fibre reinforcement with natural fibres such as kenaf, flax, or cotton enhances properties like sound absorption, impact strength, and crash behavior, while reducing the overall weight of the components[4]. Wood fibre reinforced composites, made from renewable resources for both the matrix and fibres, were assessed for their mechanical properties and fibre-matrix adhesion. Cyclic loading was used to measure the dynamic stress transfer from the matrix to the fibres, simplifying the development of wood fibre composites[5].

The use of natural fibre-reinforced composites has been extensively researched, particularly regarding their thermal and mechanical characteristics. Over the last decade, mechanical properties like elastic modulus and ductility significantly improved bio-composites compared to standard polymers. Increasing fibre content in the polymer matrix enhanced the mechanical properties of plant fibre-based composites. Test results showed that adding fibres increased storage modulus (stiffness) and lowered tan delta values. Bio-composites with a modest proportion of animal fibres exhibited superior thermal properties compared to virgin polymers[6].

The effect of the fiber's natural waxy surface coating on matrix/fiber bonding was evaluated by performing a single fibre pullout test and calculating the tensile properties of discontinuous fibre composites. Removing the waxy layer improved the matrix-fibre bond, but this improvement came at the cost of reduced tensile strength, fibre pullout stress, and modulus of the composites. The waxy

 

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surface layer of the fibre exhibited a stronger polymeric nature and better interfacial bonding compared to a layer grafted with C15 long-chain alkyl molecules. During extrusion, the morphological characteristics and matrix surface compatibility promoted the directed flow of exceptionally long fibres[7]. Fiber-reinforced composites exhibited strong load-bearing capabilities, leading to their use in industries such as maritime, rail transportation, and automotive. These composites are more suitable for constructing complex-shaped components, thanks to their superior compressive strength, fatigue resistance, specific tensile properties, and anti-corrosion qualities, all of which require fewer manufacturing steps than conventional metals[8].

Epoxy composites reinforced with woven banana fibre for household furniture were also evaluated. The design process was methodically presented, and the final product a golden-brown telephone stand was visually pleasing and functional. This banana fibre composite proved to be a cost-effective and suitable reinforcement for creating new materials for household furnishings [9]. The matrix serves to bind the fibers and transmit the applied loads to them. Common binders include thermoplastic and thermosetting matrices, such as epoxy, polyester, polyethylene, and polypropylene. Epoxy, known for its strong adhesive properties, efficiently bonds the fibers in Fiber Reinforced Composites (FRP), resulting in high productivity. It also offers excellent moisture resistance, and its hardness and strength can be enhanced by adding reinforcing materials. The addition of epoxy resin improves the binding between ordinary cement mortar particles, and natural fibers reinforced with resins achieve optimal results, allowing them to replace synthetic fibers in various applications.

## MATERIALS AND METHODS

### Extraction of Acalypha Indica Fiber

The plant roots were gathered and thoroughly rinsed with running water to remove impurities. The roots were then soaked for twelve days to facilitate easier manual fiber extraction, followed by drying in the sun. The fiber extraction was done entirely by hand, without the use of chemical treatments or biochemical additives. The extracted fibers are depicted in Figure 1.

### Epoxy Matrix

For this study, epoxy resin and hardener were sourced from Thirumal Nadar and Sons, located in Madurai, India.

### Preparation of Composites

The hand lay-up, compression moulding, injection moulding, and Resin Transfer Moulding (RTM) methods are the most commonly used techniques for fabricating composites. However, this study utilized the hand lay-up method.

### Hand Lay-Up Method

This is the simplest and most traditional method of specimen preparation. The process involves using "prepreg" reinforcement, consisting of discrete layers known as piles. Multiple fibers are impregnated with resin before further processing, then bundled into tows and arranged as a unidirectional ply or knitted for reinforcement. In this study, composites were fabricated using Acalypha Indica fibers at various weight percentages, ranging from 20 to 40%, in 10% intervals in epoxy resin, following the hand lay-up method with fibers arranged in a random pattern. The chopped fibers were placed in a wax-layered mold measuring 200mm x 200mm x 3mm. Epoxy resin and hardener were mixed in a 10:1 ratio. The hardener was added to the epoxy resin in a glass beaker at room temperature, stirred for 10 minutes to ensure a consistent mixture, and then poured over the fibers in the wooden mold. The mixture and fibers were pressed with a wooden roller to ensure uniform distribution of the matrix material and to remove any trapped air. The composite was left to cure for 24 hours at room temperature, then removed from the mold and cut according to the testing specifications.According with needed specifications, the created specimen was sectioned into appropriate dimensions for various tests and characterization. Prior evaluation, every specimen was maintained for 24 hours at 55 percent

 

**Figure 1.** Acalypha indica plant, root fiber and fabricated composite.

**Tensile Test**

A universal testing machine was utilized to conduct the tensile test. For each composite, five measurements were recorded, and the average value was taken as the tensile strength in accordance with the ASTM 3039 standard. The sample dimensions were 250 × 25× 3 $mm^3$, as illustrated in Figure 2. The test was carried out using a 5 kN load cell, with a crosshead speed of 3 mm per minute and a gauge length of 80 mm.

**Flexural Test**

A DTRX-30 KN universal testing machine was used to conduct the flexural test following the ASTM 790 standard. The specimen had dimensions of 127 × 12 × 3 $mm^3$, with a span-to-depth ratio of 32:1, as illustrated in Figure 3. The test was carried out using a 5 kN load cell at a crosshead speed of 3 mm per minute. Five measurements were recorded for each composite, and the average value was considered to determine the flexural strength.

**Impact Test**

The impact test was conducted using a computerized Izod impact tester, following the ASTM D256-10 standard. Specimens with dimensions of 60 × 12 × 3 mm were used, as illustrated in Figure.4

**Morphological Study**

The fracture surface of the epoxy composites was examined using a ZEISS SIGMA Field Emission Scanning Electron Microscope (FESEM). The samples were analyzed at a 5 kV accelerating voltage, and prior to examination, they were gold-sputtered.

## RESULT AND DISCUSSION

This study discusses the mechanical properties, including tensile strength, tensile modulus, percentage of elongation, flexural strength and modulus, and impact strength, of Acalypha Indica root fiber reinforced epoxy resin composites. Composites with varying weight percentages of Acalypha Indica root fiber were fabricated. The specimens were cut from composite plates according to ASTM standards and tested for property evaluation. The study primarily focuses on identifying the optimal amount of Acalypha Indica root fiber in the epoxy matrix to achieve the best mechanical properties. The mechanical properties of randomly oriented raw Acalypha Indica root fiber reinforced epoxy resin composites at different weight percentages are detailed below.

**Tensile properties of Acalypha Indica Fiber Reinforced Composites**

The tensile test was carried out to assess parameters like tensile strength, tensile modulus, and percentage of elongation. The results of the test are presented in Table1.

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**Figure 2.** Tensile test sample.

**Figure 3.** Flexural test sample.

**Figure 4.** Impact test sample

**Table 1.** Tensile properties of Acalypha Indica epoxy composites.

| **Tensile properties** | **10 % wt** | **20% wt** | **30% wt** | **40% wt** |
|---|---|---|---|---|
| Tensile strength (Mpa) | 9.55 | 11.25 | 12.50 | 10.50 |
| Tensile modulus (Mpa) | 755 | 805 | 869 | 812 |
| Elongation (%) | 1.253 | 1.357 | 1.648 | 1.36 |

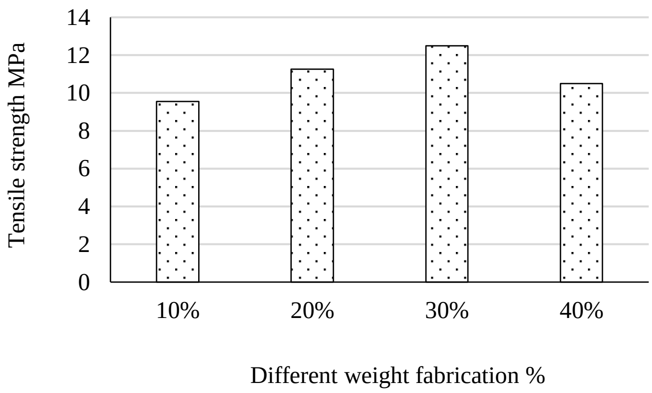


**Figure 5.** Tensile strength Vs different weight fraction of Acalypha Indica.

Figures: 5, 6 and 7 display the tensile strength, tensile modulus, and percentage of elongation of Acalypha Indica root fiber reinforced epoxy composites at different weight fractions. As the fiber content increases in the matrix, the tensile strength improves. Specifically, composites with 10% and 20% fiber content demonstrated tensile strengths of 9.55 MPa and 11.25 MPa, respectively. The maximum tensile strength of 12.50 MPa was observed with 30 wt% fiber reinforcement, due to stronger intermolecular bonding between the fiber and epoxy matrix. The tensile strength of the 30 wt% fiber composite exceeded that of the pure epoxy composite. However, when the fiber content exceeded 30%, issues such as fiber pull-out and fiber debonding occurred, likely due to the interaction between the fiber and matrix, as shown in the SEM image in Figure: 11. As a result, the tensile strength decreased from 12.50 MPa to 10.50 MPa for the composite with 40% fiber content. Therefore, 30 wt% fiber content in the epoxy matrix is considered the optimal fiber reinforcement level.

The tensile moduli for Acalypha Indica fiber reinforced composites at various fiber loadings-10 wt%, 20 wt%, 30 wt%, and 40 wt% were 755 MPa, 805 MPa, 869 MPa, and 812 MPa, respectively, as shown in Figure:6

The inclusion of Acalypha Indica fibre content up to 30% in pure matrix increased the tensile modulus from this value. This showed that the loaded fibres operate as an efficient stress transmission medium to the epoxy matrix, reaching a maximum loading of 30wt.% Acalypha Indica fibre in matrix. The matrix proved unable to distribute the fibre when the Acalypha Indica fibre concentration in the matrix increased. As a result, stress transmission between fibre and matrix is inefficient. As a result, with 40wt. percent of Acalypha Indica root fibre loading composite, a decrease in tensile modulus is detected.

 

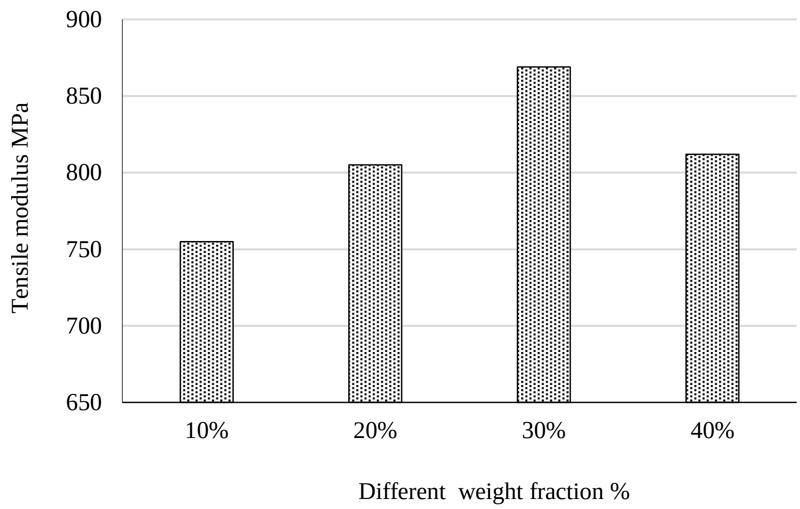


**Figure 6.** Tensile Modulus Vs different weight fraction of acalypha indica.

**Elongation study of Acalypha Indica Fiber Reinforced Composites**

The percentage of elongation of the pure epoxy composite is percent in Figure:7 While increasing the raw AH leaf fibre loading in the epoxy matrix, this elongation % is raised. This is due to the addition of Acalypha Indica fibre to the matrix, which changes the matrix's brittle character to ductile. At 30wt. percent Acalypha Indica fibre loading composites with fracture, this ductile behaviour has attained a maximum value of percent, as shown in SEM Figure 11.

The ductility of Acalypha Indica fiber-reinforced composites with a certain percentage of fiber loading is significantly higher than that of the composite without fiber reinforcement. However, when the fiber content in the epoxy matrix exceeds a certain percentage, the elongation percentage decreases, dropping from a higher value to a lower one. The addition of Acalypha Indica fiber beyond the optimal fiber content causes a decline in mechanical properties, making them lower than those of composite without fiber reinforcement, as indicated by the tensile test results. Table :1 compares the maximum tensile strength of a specific wt% Acalypha Indica fiber-reinforced composite with the highest tensile strength of other natural root fiber-reinforced composites.

As shown in Table:2, the tensile strength of Acalypha Indica fiber-reinforced composites is lower than that of other natural root fiber-reinforced composites. In many technical applications, materials with high specific strength are preferred to minimize dead load. Specific strength is defined as the ratio of a material's strength to its density.

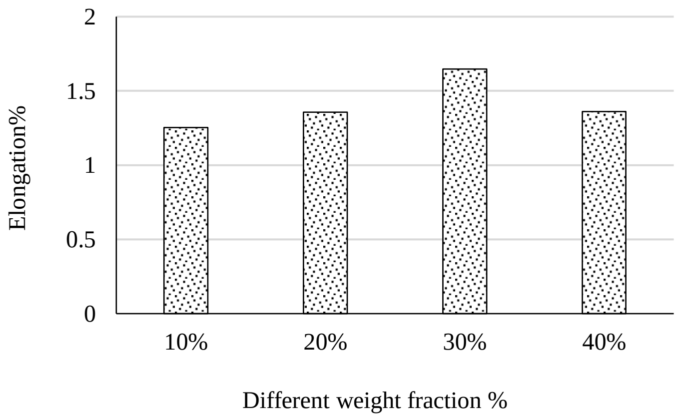


**Figure 7.** Elongation % Vs different weight fraction of acalypha indica.

 

**Table 2.** Tensile properties of some plant fiber epoxy composites.

| **Fiber** | **Tensile strength (MPa)** | **Tensile modulus (MPa)** | **Reference** |
|---|---|---|---|
| Acalypha Indica | 12.50 | 8.69 | Present Study |
| Phonixsp | 39.22 | 4.98 | [10]Rajeshkumar*et al.* (2017) |
| Kenaf | 31.30 | 3.75 | [11]Fiore*et al.* ( 2015) |
| Sisal | 8.37 | 1.0002 | [12]Owen*et al.* (2015) |
| Oil palm | 29.9 | 1.43 | [13]Yusoff*et al.* (2010) |
| Banana | 16 | 0.54 | [14]Venkateshwaran*et al.* (2011) |
| Sansevieria trifasciata | 75.22 | 1.05 | [15]Ashokkumar*et al.* (2011) |

**Table 3.** Flexural properties of Acalypha Indica epoxy composites.

| **Flexural properties** | **10wt.%** | **20wt.%** | **30wt.%** | **40wt.%** |
|---|---|---|---|---|
| Flexural strength (MPa) | 24.35 | 26.74 | 27.87 | 26.80 |
| Flexural modulus (MPa) | 1254.76 | 1289.54 | 1320.56 | 1294.97 |

**Flexural Properties of Acalypha Indica Root Fiber Reinforced Composites**

As illustrated in Table:3, the flexural properties of matrix composites improve as the loading of raw Acalypha Indica root fiber increases. At 30 wt% Acalypha Indica root fiber loading in the epoxy matrix, the peak flexural strength and modulus values are 27.87 MPa and 1289.54 MPa, respectively. However, at 40 wt% fiber loading, a decrease in flexural properties is observed. This reduction occurs because increasing the fiber content beyond 30% leads to greater fiber-to-fiber contact and poor bonding at the interface between the fiber and the epoxy matrix.

The results of the flexural strength as shown in figure:8 and figure:9 illustrated the flexural modulus with respect to different Weight%.

As a result, the flexural properties of Acalypha Indica root fiber reinforced composites decreased at 40 wt% fiber loading. Therefore, the weight percent of Acalypha Indica root fiber in the epoxy matrix should be considered the optimal level of reinforcement. Table:4 compares the maximum flexural parameters of Acalypha Indica root fiber reinforced composites with those of other natural root fiber composites.

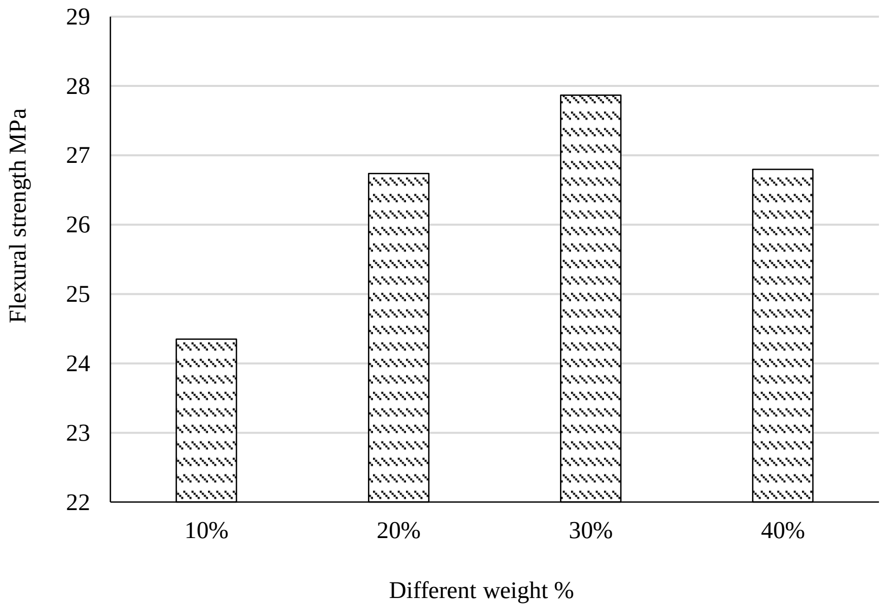


**Figure 8.** Flexural strength Vs different Wt%

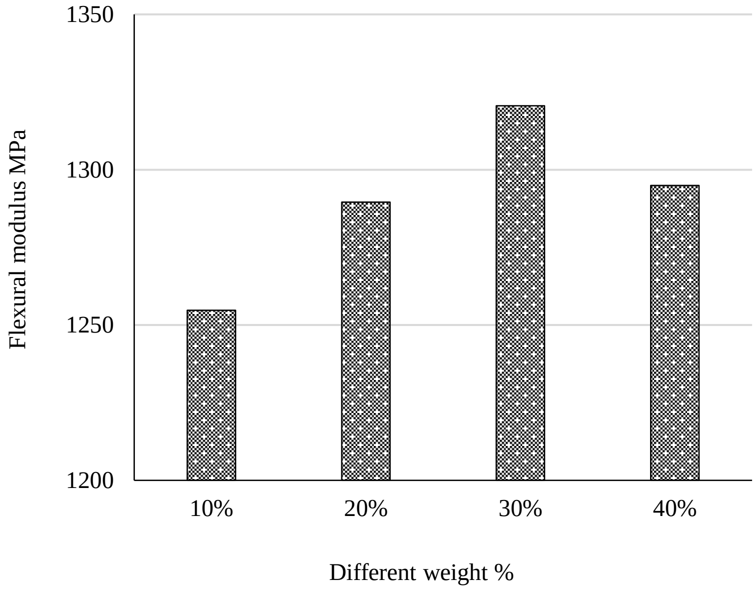


**Figure 9.** Flexural modulus Vs different Wt%.

**Table 4.** Flexural properties of some natural fiber epoxy composites.

| Fiber | Flexural strength (MPa) | Flexural modulus (MPa) | Reference |
|---|---|---|---|
| Acalypha Indica | 27.87 | 1289.54 | Present study |
| Phonixsp | 137.05 | 2.38 | [10] Rajesh kumar*et al.* (2017) |
| Kenaf | 56.40 | 7.82 | [11]Fiore*et al.* (2015) |
| Sisal | 40.48 | 0.39 | [12]Owen*et al.* (2015) |
| Oil palm | 51 | 3.30 | [13]Yusoff*et al.* (2010) |
| Banana | 57.53 | 8.92 | [14]Venkateshwaran*et al.* (2011) |
| Sansevieria trifasciata | 82.33 | 0.003 | [15]Ashokkumar*et al.* (2011) |

**Impact Strength of Acalypha Indica Fiber Reinforced Composites**

Impact resistance refers to a material's ability to withstand rupture under impact load. Figure: 10 illustrates the impact strength of Acalypha Indica root fiber reinforced composites at different weight percentages.

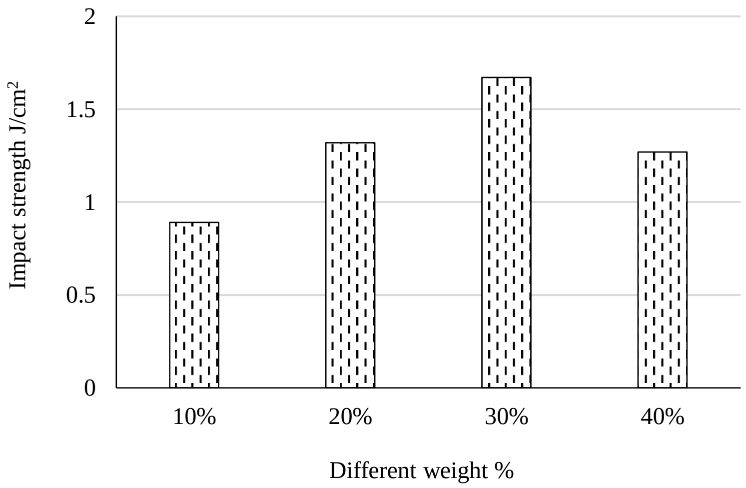


**Figure 10.** Impact Strength Vs different Wt%.

 

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**Table 5.** Impact energy of Acalypha Indica epoxy composites.

| Impact properties | 10wt.% | 20wt.% | 30wt.% | 40wt.% |
|---|---|---|---|---|
| Impact strength (J/cm$^2$) | 0.89 | 1.32 | 1.67 | 1.27 |

**Table 6.** Impact properties of some natural fiber epoxy composite.

| Fiber | Impact strength(kJ/m$^2$) | Reference |
|---|---|---|
| Acalypha Indica | 16.7 | Present study |
| Phonixsp | 9.44 | [10]Rajeshkumar*et al.* (2017) |
| Sisal | 5.8 | [12]Owen*et al.* (2015) |
| Sansevieria trifasciata | 89.7 | [15]Ashokkumar*et al.* (2011) |

Table:5 presents the impact strength values obtained from the impact test. Figure:10 demonstrates that as the percentage of Acalypha Indica root fiber in the pure matrix increases up to 30%, the impact strength improves, but then decreases. Therefore, reinforcing the epoxy matrix with 30 wt% Acalypha Indica root fiber is considered the optimal fiber content.

The decline in impact strength is attributed to the fact that when the fiber content in the resin composites exceeds 30%, the matrix becomes inadequate in properly wetting the fiber surfaces.

The Acalypha Indica root fiber reinforced composites with 10 wt% and 30 wt% fiber content exhibit the lowest and highest impact strengths of 0.89 J/cm² and 1.67 J/cm², respectively, as shown in Table 6. Table 6 compares the maximum impact strength of Acalypha Indica root fiber reinforced composites with that of other natural root fiber composites.

The impact strength of Acalypha Indica root fiber reinforced composites with wt% fiber content is higher than that of other natural root fiber and synthetic fiber reinforced composites, as shown in Table: 6

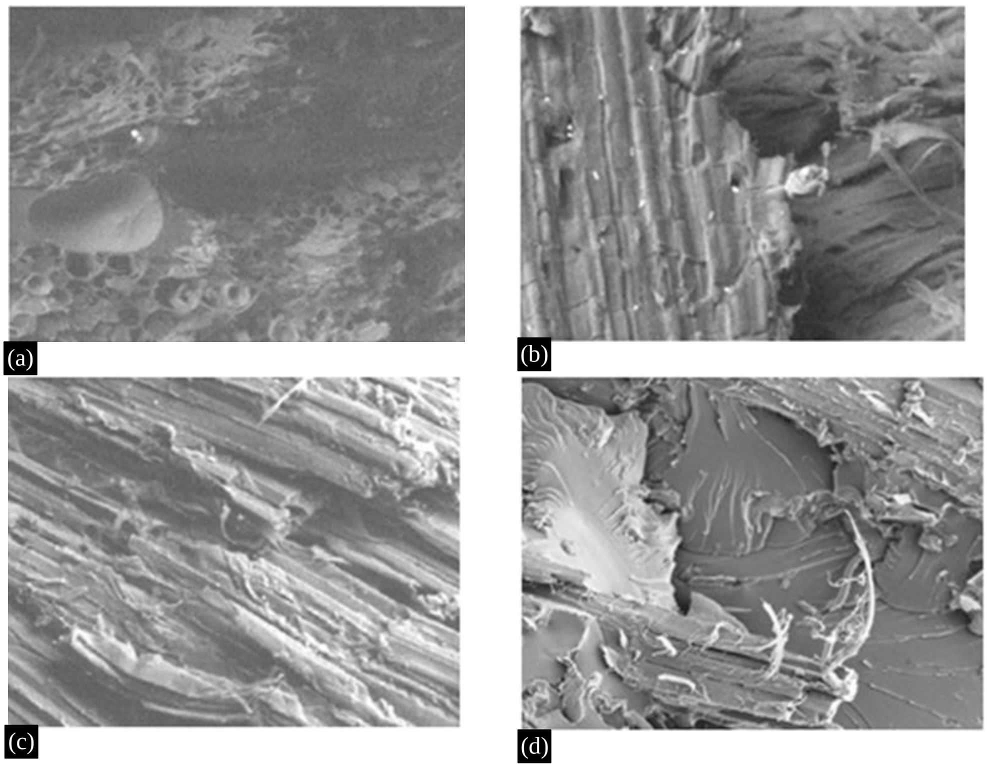


**Figure 11.** (a), (b), (c) and (d):Morphological analysis of fractured samples of 10, 20, 30 and 40wt.% acalypha indica fiber reinforced composites.

**Scanning Electron Microscopy (SEM) Analysis**

Scanning Electron Microscope analysis was carried on to examine interfacial adhesion for cracked samples of Acalypha Indica root fibre reinforced epoxy composites in a tensile test. Figure:11 depicted the SEM images (a-d). The voids in 10% wt. percent and 20% wt. percent of Acalypha Indica root fibre reinforced composites are due to fibre pull out and fibre debonding, as shown in Figure:11 a and b. In tensile loading, this is due to inadequate stress transmission between fibre and matrix.

Figure:11 (d) illustrates a large amount of acalypha indica root fiber loading in the matrix, leading to the formation of bundles due to fiber agglomeration, which results in a weaker fiber-matrix interface. in the epoxy composites with 30 wt% acalypha indica root fiber loading (figure:11 (c), fiber breakage was observed. this fiber breakage under tensile loading suggests strong fiber-matrix adhesion and efficient stress transmission between the resin and the reinforced fiber.

## CONCLUSIONS

According to ASTM standards, epoxy composites reinforced with Acalypha Indica root fibers were fabricated and analyzed. This paper discusses the use of root fiber as an effective reinforcement in an epoxy matrix, with no prior studies focusing on Acalypha Indica root fiber as a reinforcement in this context.

- The tensile, flexural, and impact properties of randomly oriented raw Acalypha Indica root fiber-reinforced composites were found to depend on the fiber content, with the optimal fiber reinforcement observed at 30% by weight.
- The tensile strength and modulus of the Acalypha Indica root fiber-reinforced composites (at 30% by weight) were determined to be 12.50 MPa and 869 MPa, respectively, with an elongation at break of 1.648%.
- The flexural strength and modulus of the composites with 30% by weight Acalypha Indica root fiberwere measured at 27.87 MPa and 1320.56 MPa, respectively. The impact strength of these composites was 1.67 J/cm$^2$.
- Scanning electron microscopy (SEM) analysis indicated that when the Acalypha Indica root fiber content exceeded 30% in the epoxy matrix, the bond between the fiber and the matrix weakened.
- Compared to pure epoxy composites, the strength of the Acalypha Indica fiber-reinforced composites increased by 10%, 20%, and 30%, respectively. Due to their enhanced mechanical properties, these composites are highly suitable for applications in the automotive, aerospace, and biomedical industries.

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