Characterization of mechanical behavior of pineapple leaf fiber composite

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Abstract: In the current era, the need for an alternate material from the alloy has shown an abundant growth. For various reasons, the alloys are being replaced with composites. On this hand, natural fibers have discovered a speedy growth in the industry due to eco-friendly nature and availability. The current growth in natural composite are fibers obtained from the fruit. In this study, the pineapple fruit is considered, and the fibers are obtained from the leaf. It is commonly called as PineApple Leaf Fiber (PALF). As the length of the leaf varies, length of the fiber obtained are not uniform and scope of the fiber is observed to be short. The fibers are extracted from the leaf and is chemically treated. The obtained fibers are reinforced with epoxy resin and composites are prepared by hand lay-up method. The fiber content is varied from 10% to 30% by weight. The study is carried out to understand the basic properties of pineapple leaf fiber. As natural fibers are hydrophilic, it is highly sensitivity to moisture and heat, this behavior is understood with the moisture test. Furthermore, this study reviews about the extraction, fabrication and mechanical properties of the reinforced natural composite with its potential applications.

1. INTRODUCTION

Industries are demanding for alternate materials as the source for petroleum-based products that are uncertain. As the population increases, demand also increases for newer and advanced materials in various applications. The lightweight materials with high strength to weight ratio has replaced the conventional materials like metals and wood. The developing countries have found to be having lots of agro waste in spite of their own agricultural applications. The availability of these fibers is abundant in nature specially in the tropical countries as agricultural and forest waste are contributing to 30-40% waste and this can be used in value added processing. These days natural fibers have found eminent growth in several industries as these were considered as an agro-waste due to lack of knowledge about the properties of the natural fiber [1]. Also, extraction of these fibers for the desired application was challenging and expensive. The natural fibers are available from plants and animals, to name a few cotton, jute, wool, silk, coir, abaca and also fibers from seeds. To this addition, availability, ecofriendly, absence of health hazards also plays a key role identifying the desired composite for the respective application. In this regard, natural fibers have thrown light to serve the purpose [2].

Pineapple leaf fiber being one of such composites, led the researchers to understand the behavior of the composite in different conditions. It has low density, high cellulose, lignin and its non-abrasive in nature. Fibers from this fruit can be obtained from leaf or the skin. In this study, the fibers are obtained from the leaf. The fibers are extracted from the leaf with the help of tools like scratching roller, feed roller and serrated roller [3]. Different length of the fiber is obtained which is one of limitations in the fibers. These fibers are thread like structures, that can be used in making ropes and it forms major components of bio composite materials like boards and many structures. [4].

While extracting the fibers, the age of the plant, length of the leaf, soil, humidity and frost affect the properties of the fiber. To enhance the adhesive property the fibers needs to undergo surface modification. The extracted fibers are chemically treated to adhere with the resins [16]. It is very simple to manufacture the composite with the help of the epoxy resin, where it has wide range of applications in composite parts, concrete repairs and structures [5]. The fibers are mixed with suitable resin and hardener to take up the desired structure for its application. The percentage of fiber, type of fiber, percentage of hardener and resin play key role in determining the strength of the composite. In this study short or chopped fiber is considered, Epoxy resin used is LY556 grade and hardener used is HY951. Epoxy and hardener combination specified for the study exhibits better
adhesive properties. The epoxy chosen exhibits strong mechanical properties, resistance to corrosion, good adhesion, low shrinkage and better performance at elevated temperatures. The extracted fiber is chopped to desired length, mixed with the epoxy and allowed to cure. The manufactured composite is studied for its fiber loading on the mechanical properties of composite [6].

2. METHODOLOGY

Pineapple leaf fibers are observed to be waxy, strap shaped leaves which are generally having length of 2ft to 6ft. These fibers are almost 3% of strong white silky fibers. Fibers are mechanically sound since it has the highest cellulose present in them. These fibers also contain lignin, pentosan that improves the length of the fibers. Compared to other natural fibers, pineapple fibers are more delicate in texture and are fibrous in nature.

2.1. Extraction of Fiber

The leaf of the pineapple is washed to remove the dirt and impurities present on them. As the length of the leaf is not the same in the fruit, utmost care has taken while extraction of fibers from the leaf. Since the leaf is hard and thorny, while extracting the fibers suitable pressure and methodology is used. Rapic two roll machine is used to extract fibers from the leaf. The setup is as shown in the figure 1. The setup has two rollers, in which the leaves are pressed, and fibers are extracted. The extracted fibers are washed in solution which contains 2% detergent at 70°C and then it is washed with tap water to remove the impurities present in the fiber. This process is carried out to remove the hydrogen bonding in the fiber thereby increasing the surface roughness.

![Rapic Two Roll Mill Machine](image1.png)

**Figure 1.** Rapic Two Roll Mill Machine

The fibers obtained are dried in a furnace at suitable temperature. The processed fibers obtained are of different length, hence long fibers cannot be used for the study. The fibers are chopped to a length of 5mm. Figure 2 and figure 3 refers to the fibers obtained by processing and chopped fibers.

![Fibers extracted from the leaf](image2.png)

**Figure 2.** Fibers extracted from the leaf

![Chopped Fibers](image3.png)

**Figure 3.** Chopped Fibers

2.2. Composite Properties

In order to understand the basic properties of the chemically treated composite fiber, the fibers where tested from the reputed organization – Central Silk Board Bangalore. Since the pineapple fibers are very delicate, to choose a certain application for this fiber, mechanical properties were studied. To name a few, tensile strength,
young’s modulus and elongation. Table 1 shows the tabulated values of the properties of the pineapple leaf fiber and table 2 indicates the physical properties.

Table.1. Mechanical Properties of Pineapple fiber

| Properties                  | Values  |
|-----------------------------|--------|
| Tensile Strength (MPa)      | 170    |
| Elongation at failure (%)   | 3      |
| Specific Modulus (MPa)      | 4070   |
| Young’s Modulus (MPa)       | 6260   |
| Density (g/cm3)             | 1.526  |
| Moisture Absorption (%)     | 12     |

Table.2. Physical Properties of Pineapple fiber

| Parameters                   | Values  |
|------------------------------|--------|
| Linear Density (Tex)         | 14.4   |
| Moisture Content (%)         | 10.1   |
| Tensile Strength             |        |
| Breaking Load (N)            | 5.1    |
| Elongation (%)               | 0.7    |

2.3. Manufacturing of Composite

As the chopped fibers are obtained from the extraction process, these fibers are used for the manufacturing of the composite. For mold preparation epoxy resin is used. Epoxy resins are extensively used as thermo plastic. When cured, they have very less shrinkage and also exhibits good adhesion property. Epoxy resin also shows better resistance to environmental conditions, chemical reactions and insulating properties [11]. Epoxy resins are widely used in aircraft components due to their enhanced adhesive property and moisture resistant. As suitable resin is chosen, the short fibers are mixed with it and hand lay-up method is used for the manufacturing of composite. The composites are manufactured by varying the weight fraction of the fiber by 10%, 20% and 30%. In the hand layup method, initially a freezing solution is spread all over the mold to easily separate the composite from the mold. Thin plastic sheets are used on the upper and lower surfaces to obtain good surface finish. The chopped fibers are spread evenly on the sheet for the size of (220*220*5) mm³ to obtain the composite. In a jar, suitable quantity of hardener, resin and the fibers are mixed to obtain the desired specimen.

Figure 4. Mold for the manufacturing of the composite

Considering 10% of the fiber weight, the mass of the composite required is 298.14g, mass of the resin mixture is 268.33g and mass of fiber is 29.81g. Based on these values, the composites with varying volume fraction has been manufactured. As the composite specimens are fabricated, its cured with the help of hydraulic press which adds suitable weight on the composite for uniform distribution of resin and hardener. Three such samples of the composites are manufactured to study the behavior of the composites. The fabrication process is as shown in the figure 4, figure 5 and figure 6.
3. EXPERIMENTAL ANALYSIS

As the samples are manufactured by varying the percentage of fibers, certain tests are conducted to analyze the behavior of the composite for varying loading conditions [7]. To name a few, hardness test, tensile test and flexural test. Moisture absorption test is conducted to understand its performance when exposed to water.

Vickers hardness test is carried out to understand the behaviors of resistance to penetration as it is called as micro hardness test. ASTM D2240 is the standard specimen i.e. 125mm length, 10mm width and 5mm thickness. The indentation (figure 7) is observed in the 500X microscope. Three trials are conducted for each sample and the results obtained are tabulated.

| Sl No | Weight Ratio | VHN (kgf/mm²) |
|-------|--------------|---------------|
| 1     | 10%          | 6.32          |
| 2     | 20%          | 6.94          |
| 3     | 30%          | 8.32          |

Moisture absorption test depends on the conditions like amount of fibers used, temperature, duration of exposure to moisture [8]. This test helps in understanding the composite reactions to humid conditions. The standard specimen is manufactured based on ASTM D 570, whose dimensions are 50mm in length, 15mm in width and
5mm thick. Initially these samples are weighed and immersed in distilled water for a total period of three to four days. Once in 24hrs the samples were weighed and determined the weight of the specimen. The percentage of absorption of water is calculated using the below formula. The test setup is as shown in the below figure 8.

\[ M(\%) = \frac{m_f - m_o}{m_o} \times 100 \]  

(1)

Where, \( m_f \) = Weight of the sample after time \( t \)  
\( m_o \) = Weight of the sample before immersion.

To study the behavior of the composite to resist the application of load and its response to rupture, tensile test was conducted. The test samples are prepared as per the standards ASTM D 3039, with length 100mm, width 10mm to conduct the test. The test samples of different weight ratio are shown in the figure 9. The samples prepared are tested in the universal testing machine shown in figure 10, with the gauge length of 60mm. The test results obtained are as tabulated with respect to ultimate tensile strength and young’s modulus as shown in table 3. From the results obtained it can be observed that as the fiber weight ratio is increased, the strength of binding also increases.
Table 4. Tensile Test results

| Sl No | Weight Ratio | Ultimate Tensile Strength (MPa) | Young’s Modulus (MPa) |
|-------|--------------|---------------------------------|-----------------------|
| 1     | 10%          | 10.5                            | 825                   |
| 2     | 20%          | 10.91                           | 973                   |
| 3     | 30%          | 11.41                           | 1038                  |

4. RESULTS AND DISCUSSION

The sustainability of the products for the growth in the demand, natural resources must be exploited to understand their fundamental importance for the improvement and possible solution for social-economic problems [14]. Hence pineapple leaf fiber can be the new source of raw material that can replace the nonrenewable synthetic fiber. Physical and mechanical properties of the composites highly depend on the fiber length, matrix ratio and fiber arrangement [12]. To understand the response of the fabricated composites, mechanical test was carried on. Primarily, Hardness test, to analyses its behavior for the application of load with the help of indentation. It was observed that the samples showed increase in hardness of the composite, for 10% volume fraction of specimen the hardness value was found to be 6.32 Kg/mm². It was observed that for 20% volume fraction specimen hardness value increased only by 9% whereas for 30% volume fraction specimen hardness value increased by 19%. This clearly indicates the uniform distribution of resin in the samples and the fibers are bonded effectively.

Natural fibers are known to have moisture within it. This property is not suitable for major applications. This character of the fiber must be analyzed to fit itself in the desired area [13]. The samples were tested for the water uptake test, the samples showed increment of moisture absorption for 10% and 20% volume fraction upto 48 hours. After 48 hrs the moisture absorption was found to be increasing for 20% compared to 10% specimen. But for 30% volume fraction, the moisture absorption was more compared to 10% and 20% specimens for the entire length of the experiment. This clearly indicates that as the percentage of fiber increased, the amount of water absorption also increases. Hence, Moisture test shows a downward trend with respect to the fiber weight ratio. This might be due to the presence of voids in the samples, due to removal of interfibrillar matrix material like lignin and pectin [15]. Moisture was absorbed comparatively through the restrained lumens in the fiber in addition to the diffusing flaws and holes in the matrix. The specimens were observed to be swollen which increased its weight gradually. The effects of moisture test are shown graphically in figure 11.

![Figure 11. Moisture absorption](image_url)

The pineapple leaf fiber has high cellulose content, which is the indication of having better tensile and ultimate strength. By analyzing the tensile strength results and the response of composites for varying load, compared to 10% volume fraction 20% showed an increment of 17.94% in Young’s modulus value. Whereas 30% specimen showed an increment of 6.68% in Young’s modulus compared to 20% specimen. The ultimate tensile strength was found to be 10.5MPa, 10.91MPa and 11.41MPa respectively for the volume fractions 10%, 20% and 30%. Compared to 10% composite, 20% composite showed 3.9% increase in its ultimate tensile strength. Whereas compared to 20%, 30% composite showed 4.6% increase in ultimate tensile strength. The results obtained for the strength performance of the composite determines that as the volume fraction increased the composite showed better performance. This concludes that the mechanical property of the fiber is related to high cellulose content and low microfibrillar angle.
5. CONCLUSION

Natural fibers and their importance have shown considerable growth in the present, where researches are also gaining interest in identifying new sources to explore an alternate for metals and synthetic fibers. From the review, it is observed that limited work has been carried out on the pineapple leaf fiber composite [10]. Based on the results obtained from the mechanical properties of the composite, it can be used in construction materials, furniture’s, sound absorbers and thermal insulators.

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