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Fabrication and Mechanical Characterization of Pineapple Leaf Fiber Reinforced Polymer Composite

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Abstract—*The requirement of light weight material with good mechanical properties is the primary need of modern industries. Growing awareness for environment has pushed most of the industries to adopt material with low carbon footprint. The natural fiber reinforced composite of adequate strength can be a good substitute for traditional metal and other synthetic materials. Pineapple leaf fiber (PALF) contains high cellulose with low microfibrillar angle, therefore; it has good inherent fiber strength. In this work, PALF reinforced natural composite was fabricated using hand layup method to analyze the effect of fiber contents, length and its orientations on various mechanical properties of the composite. Samples were fabricated using different fiber length (short fiber and long fiber), fiber orientations (0°, $90^{\circ}$and 45°) and fiber contents (5, 10, 15, 25 wt.%). The result of mechanical characterization reveals that the tensile and flexural strength for short fiber composite is maximum at 25 % of fiber content. While long fiber composite with 5 % of fiber content exhibits maximum tensile and flexural strength. The orientation of fiber plays an important role in determining the strength of composite. The 0° orientation composite has maximum value of flexural strength. While 90° orientation composite exhibits lowest value of tensile and flexural strength. The composite with 25 % of fiber contents exhibits the maximum value of impact strength.*

Keywords: *Pineapple leaf fiber; polymer composites; fiber length; fiber content; fiber orientation; mechanical properties.*

1. INTRODUCTION

In past few years, composite made from natural fiber in polymer matrix have gain attention in aerospace, automobile and packaging industries because natural fiber used are of low density, high strength, biodegradability and easily available. We are aware that in order to limit the usage of synthetic materials and replace them with more environmentally friendly alternatives, the world needs to move away from these materials because pollution brought on by plastic trash is a serious issue for the ecosystem. Since manmade waste release various toxins to the environment and to encounter the effect of synthetic material, natural fiber is becoming more popular as a viable alternative to synthetic material. J. Jefferson Andrew, et al. [1] review article that provides various information about bio-based material and their composites. He classified natural fiber into three parts namely plant fiber, animal fiber and mineral fiber. The plant fiber are further classified on the basis of leaf, grass,blast etc. Many natural fiber such as bamboo, coir and pineapple leaf fiber have excellent advantages such as low density, low cost, good thermal properties and environment friendly etc.

Among these natural fiber, pineapple leaf fiber are chosen because of following reason:

Firstly, Pineapple Leaf is the waste product of pineapple after harvesting. Apart from this, crown of pineapple fruits is also the waste part when it comes in market. So without any input cost, Fibers from pineapple leaf can be used as a composite reinforcement. Secondly, Pineapple leaf fiber has high cellulose content with low microfibrillar angle thus exhibits high strength.

These natural fiber which reinforce into polymer matrix must have good interfacial bonding for effective load transfer. M Asim, et al.[2] conclude that 3% of NaOH treatment did not affect the fiber while 6% of NaOH treatment affect the fiber and make the surface rough. In polymer matrix, thermoset polymer have an advantage over thermoplast polymer such as low density, exhibits low shrinkage and there viscosity is controlled depending on the amount of hardener. Despite of this, Non-biodegradability and non-recycle of thermoset matrix is still challenging in present world. S. Sathees Kumar, et al. [3] conclude that tensile and flexural strength is increase and maximum when both PALF and sisal fiber share equal weight % (i.e. 50%). Pranshanth murthy, et al. [4] investigate the effect of nanoclay on mechanical property of pineapple fibers epoxy composite and conclude that tensile, flexural and impact strength increase with addition of nanoclay upto 4 wt%. B. Suresha, et al. [5] study the role of $CaCO_3$ on mechanical properties of pineapple leaf fiber/ polypropylene composite. Their result shows that tensile and flexural strength of $CaCO_3$ filled pineapple fiber/epoxy composite is maximum at 3 wt% of $CaCO_3$ while it decrease at 5 wt% of $CaCO_3$. K. Senthilkumar, et al. [6] reveals that mechanical properties increase with increase in PALF loading varies from 25% to 45%.They finds that flexural strength is maximum at 35% of fiber loading. Toho Dustin Sutomo, et al. [7] reported that increase in PALF loading from 0% to 40% results in increase in mechanical properties of PALF/PP composites. Ayu Natasya Kasim, et al. [8] study the effect of fiber loading on mechanical properties of pineapple leaf /polypropylene composite. They observed that tensile strength is increased with increase in fiber loading at 30 wt% while it decrease drastically at 70 % of fiber loading Rungsima Chollakup, et al. [9] observed that tensile strength of PALF/PP composites increased when the PALF contents increased from 0% to 25%. They also finds that composites containing long fiber were stronger than short fiber. Rapeta Sundara Raman, et al. [10] found that fiber orientation affects the mechanical properties of natural fiber/epoxy composites. Their result shows that 0° fiber orientations had greatest values for tensile and impact strength. From above review paper, it is clear that mechanical properties of composite material is mainly depends on fiber length, orientations and fiber contents. Since, so many research has been done by taking fiber contents of natural fiber but very few work is done on Pineapple fiber reinforced epoxy composite of different fiber length, orientations and fiber contents. In this study, I have study the effect of fiber contents, length and fiber orientations and on mechanical properties of pineapple leaf fiber reinforced epoxy composite.

2. EXPERIMENTAL DETAILS

2.1. Material and Methods:

Pineapple fiber which is used as reinforcement in composite material was obtained from Fiber Region, Chennai (India) as seen in figure 1(a).The physical properties of Pineapple fiber are density: 1.2 g/cm^3; diameter: 0.3 mm. This fiber was used in two forms, namely short and long fiber. Short and long fiber was cut in length of 30 mm and 200 mm depending upon fiber l/d ratio. The epoxy LY 556 and hardener HY 951 which used as matrix material was procured from Funique composites, Delhi (India).The main properties of epoxy polymer are density: 1.16 g/cm^3; tensile strength: 11.14 MPa; flexural strength: 25.29 MPa. Other materials used are: Borosil Beaker, Measuring Flask, Brush (1 inch), Plastic sheet, Acrylic sheet and Hand roller.

In order to improve bonding with matrix, pineapple fiber is treated with alkali solution. 5% of NaOH solution is prepared by taking 100 g of NaOH pellets and 2 litre of distilled water. Pineapple fiber is then soaked in solution for 8 hours as shown in figure 1(b). After alkali treatment, fiber was washed about 4-5 times by distilled water until the washed water become clean (i.e. neutral).

Figure 1:(a) Pineapple leaf fiber,(b)Fiber dipped in NaOH sol.

The Hand-layup technique is used to fabricate the pineapple fiber reinforced epoxy composite. The mold made up from wood of dimensions $(200 \times 100 \times 6)\, mm^3$ was used for filling a mixture of fiber and matrix as shown in figure 2(a). The epoxy resin and hardener was mixed in the ratio of 10:1 (pbw) by glass rod to form a solution. To prepare a composite with short fiber, fiber of length 30 mm shown in figure 2(b), was mixed randomly mixed with the prepared solution. For long fiber upto length of 200 mm shown in figure 2(c), fiber was divided into 4 layer which placed separately one after other and thin layer epoxy is coat by brush in between each layer. Hand roller was used after that in order to prevent air bubbles in composites. After that, load is applied on the mold and fabricated composite is left to cure for 24 hours. The specimen is also post cured at room temperature. Specimen is finally cut into specific dimension depending upon ASTM standard after removing mold as seen in figure 2(d).

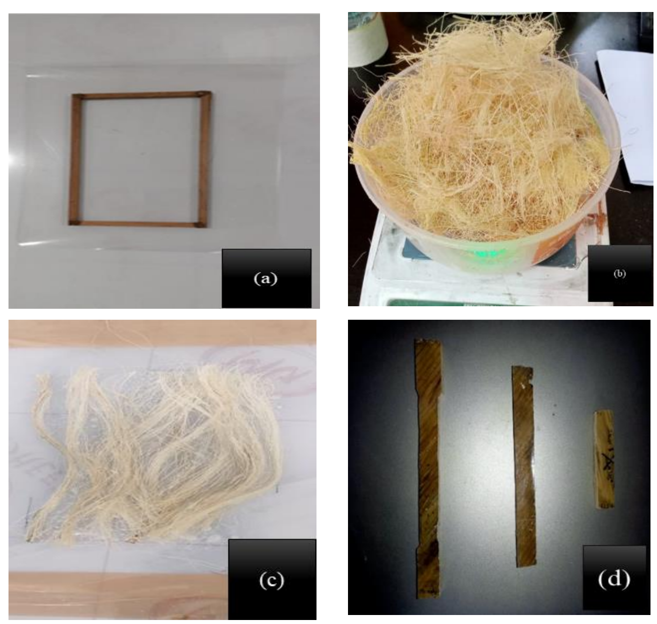


Figure 2: (a)Wood mold with plastic sheet, (b)short fiber (l = 30mm),(c) long fiber (l= 200 mm), (d) all specimen

2.2. Testing of composites:

Mechanical Test: The tensile and flexural test was conducted as per ASTM D638 and ASTM D790 with a rate of 5 mm/min and 2 mm/min respectively. A 100 KN Instron-1195 universal testing machine was used to carried out these test as shown in figure 3(a) and 3(b). While the impact test was carried on Zwick/Roell impact tester using ASTM D256 standard. The charpy impact with V-notch of dimension 2 mm and 45° in the middle of composite sample was used for the measurement of impact strength.

Figure 3: (a) specimen in tensile test, (b) specimen in flexural test.

3. RESULTS AND DISCUSSION

Tensile properties: The tensile properties of composites at different fiber length, contents and fiber orientations are shown in Table 1, 2 and 3. Table 1 indicates tensile properties of short fiber composites (i.e. composite with fiber length= 30 mm) while table 2 and 3 indicates tensile property of long fiber composites with fiber length of 200 mm. From Table 1, 2 and 3, it is clear that the mechanical properties of composites are significantly influenced by the fiber length and orientation. In case of short fiber composites, fibers are randomly orientated in a composites and their end effect is taken into consideration. At low fiber contents composites (i.e. fiber wt. %= 5), stress is highly concentrated on the end because of more fiber orientations. However if the fiber contents increased in composites (i.e. fiber wt. % = 25), the composites become more compact with decrease in fiber orientations which thus results into less stress concentration at the end. This is the reason that yield stress occurs at later stage in stress-strain curve and greater tensile strength for high fiber contents composites.

Table 1: Tensile properties of short fiber composites with different fiber contents

Sample Composition (fiber wt. %)	Tensile Strength (MPa)	Tensile Modulus (GPa)	Max. Strain (%)
5	5.37	2.56	0.38
15	8.94	3.30	0.47
25	20.85	3.54	0.65

Table 2: Tensile properties of long fiber composites with different fiber contents

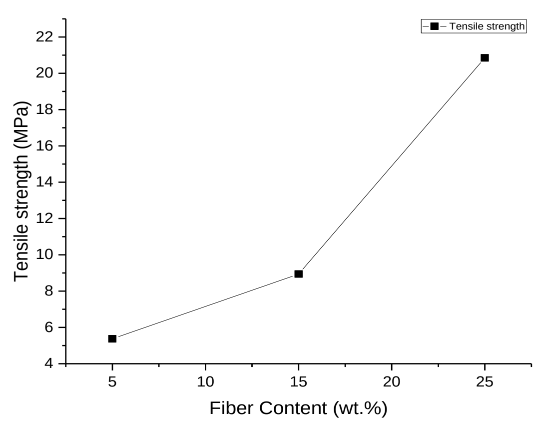
Sample Composition (fiber wt. %)	Tensile Strength (MPa)	Tensile Modulus (GPa)	Max. strain (%)
5	35.72	3.60	1.12
10	19.01	3.68	0.52
15	20.70	3.47	0.64

Table. 3: Tensile properties of composites with different fiber orientations at Fiber wt. %= 15

Sample orientations (degree)	Tensile strength (MPa)	Tensile Modulus (GPa)	Max. strain (%)
0°	20.70	3.47	0.64
90°	13.89	3.40	0.24
45°	21.42	3.70	0.58

For long fiber composites, the unidirectional fiber carries major load along the length of fiber and thus composite is more strong. From table 2 and figure 4, tensile strength is maximum at 5 % while it decrease at 10 % and then increase at 15 % of fiber weight. This is because at 5 % of fiber weight, single layer fibers is orientated in same direction and fiber arrangement gives good bonding with matrix. Four layer fiber at 15 % of fiber weight cause a matrix fails in load transfer. This result was comparable with the study of A E Hadi, et al. [11] who stated that tensile and flexural strength of composite decrease when the fiber exceed the critical limit of 3L (where, L= Layer).

The tensile property of composites with different fibers orientations at 15 % of fiber weight is shown in table 3. From table 3, it is obvious that fibers at 90° restrict the tensile strength of the composite to low value because load is partly divided into both direction. In case of 0° fiber orientation composite, load is fully distributed along the length of fiber, which stacked in the same direction of load applied and thus, tensile strength is more than 90°fiber orientation-composite.



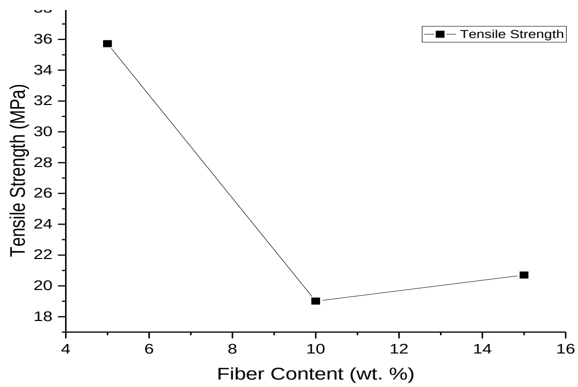


Figure 4: Tensile strength of short fiber, long fiber composite versus fiber contents

Flexural properties: The flexural properties of composite at various fiber length, orientations and contents is shown in table 1, 2 and 3. From table 1 and figure 5, the flexural strength is maximum at 25 % of fiber content. This is due to fibers agglomeration in same area which leads to carries more load. While for long fiber composite as present in table 2 and figure 5, the flexural strength is maximum at 5 % of fiber content because of unidirectional distribution of fiber. The unidirectional fiber evenly holds the same transverse load thus resist the bending.

In case of fiber orientations, The flexural strength and maximum strain for 0˚ fiber orientations composites is 52.98 MPa and 2.32 % respectively, while for 90˚ orientations composites is 27.57 MPa and 3.53 % as depict from table 3.The flexural strength for 0˚ fiber orientation is greater than 90˚ fiber orientation. The result obtained was similar with the study of A.S. afkari et al. [12] who in their work obtained that the flexural strength of 0˚ fiber orientation has higher value than 90˚ fiber orientations. However, 90˚ fiber composite has greater strain value than 0˚ fiber composite because both fiber carries same load and thus stretch equally along longitudional and transverse direction.

Table. 1: Flexural properties of short fiber composite with different fiber contents

Sample Composition (fiber wt. %)	Flexural Strength (MPa)	Max. Strain (%)	Yield Stress (MPa)
5	33.90	1.60	0.068
15	27.64	0.96	0.058
25	42.70	2.28	0.102

Table 2: Flexural properties of long fiber composite withdifferent fiber contents

Sample Composition (fiber wt. %)	Flexural Strength (MPa)	Max. Strain (%)	Yield Stress (MPa)
5	56.19	1.91	0.08
10	45.75	1.92	0.09
15	52.98	2.32	0.10

Table 3: Flexural properties of composites with different fiber orientations at fiber wt. % =15

Sample Orientations (degree)	Flexural Strength (MPa)	Max. Strain (%)	Yield Stress (MPa)
0˚	52.98	2.3	2.32
90˚	27.57	3.5	3.53
45˚	39.24	2.1	2.16

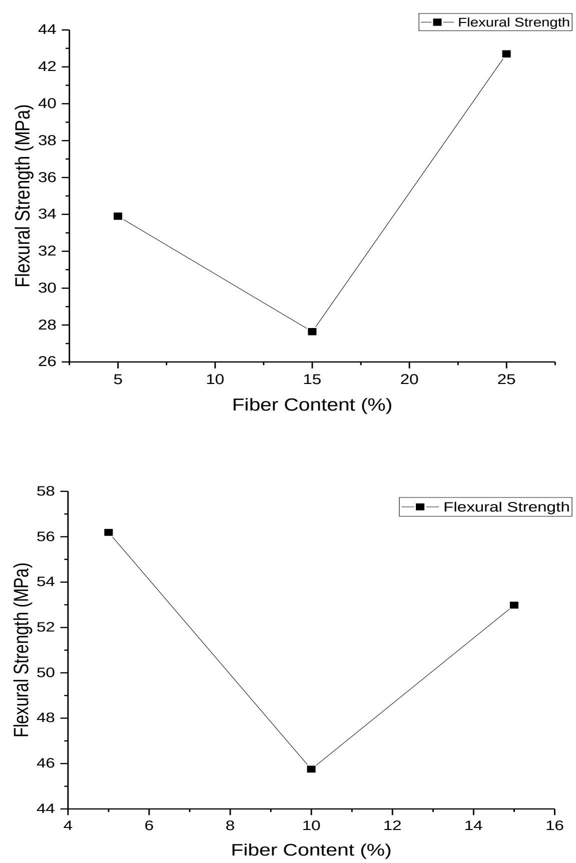
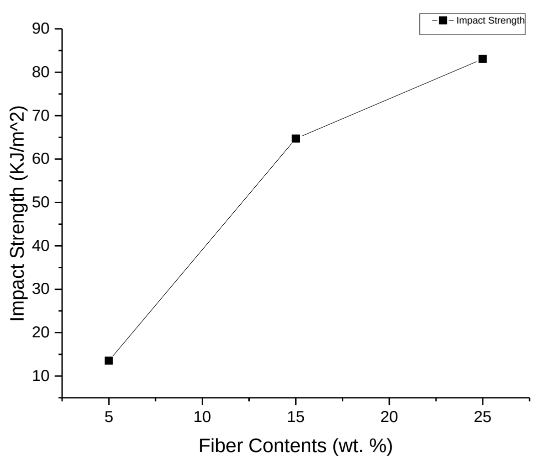


Figure 5: Flexural Strength of short fiber, long fiber composite versus fiber contents

Impact properties: The impact strength or toughness is the amount of energy a material can withstand before fracture. The material must be strong enough to bear a sudden load. So, it is required to measure the impact strength of composite material. When sudden load is applied, fibers adhesion with matrix absorbed energy. Strong adhesion with matrix results in maximum energy absorbed by the composite material. The impact strength of composites is shown in Table 1 and Figure 6. From table 1, it is observed the impact strength increase with increase in fiber content in both short and long fiber composite. For short fiber composite, the impact strength is maximum at 25 % of fiber content. This was because of fiber coupling with each other absorb more impact energy as suggested by Jagadish et al. [13]who finds the maximum value of impact strength at 20 % of fiber weight. While in case of long fiber composites, the impact strength is maximum at 15 % fiber content.

Table 1: Impact strength of composite with short fiber and long fiber at different fiber contents

Sample Composition (fiber wt. %)	Impact Strength (KJ/m^2)
Short fiber = 5	13.53
15	64.72
25	83.05
Long Fiber = 5	8.07
10	14.41
15 (0°)	25.30
15 (90°)	15.17
15 (45°)	21.00



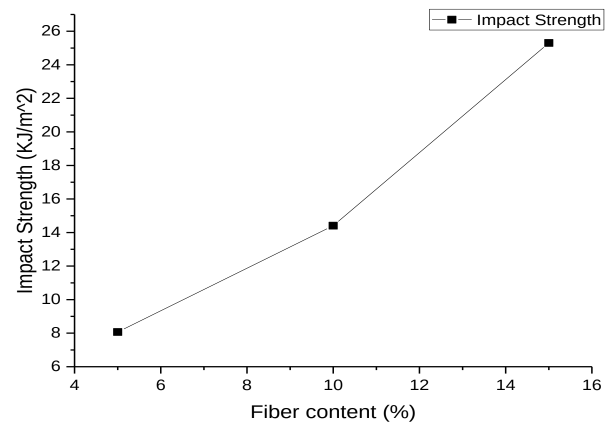


Figure 6: Impact Strength of short fiber and long fiber composite versus fiber content

Morphological analysis: In order to investigate the fracture surface of composite, optical microscopy was used. Figure 7 and figure 8 shows the fracture surface of composite with 25 % and 15 % fiber content. From figure, it can be seen that pineapple fiber was randomly orientated in short fiber composite as shown in figure 7(a) while it was properly arranged in 90° orientation composite shown in figure 8(a). It is clear that the failure modes occurs due to fiber fracture and stretching in short fiber composite as seen in figure 7(b). Some voids was also seen in both composite which in turn cause the fiber debonding.

4. CONCLUSION

Based on outcomes, following conclusion are found:

1. Fiber contents, length and fiber orientation play an important role on mechanical properties of pineapple fiber-epoxy composite. In long fiber composite, fiber layer also affects the mechanical properties of composite.
2. For short fiber composite, The tensile and flexural strength is maximum at 25 % of fiber weight. While for long fiber composite, 5% of fiber weight exhibits maximum strength.
3. In case of composite with fiber orientation, 0° fiber orientation composite exhibits greater tensile and flexural strength than 90° fiber orientations composite.
4. The composite with 25 % of fiber contents exhibits the maximum value of impact strength.
5. From fracture surface image, it is clear that composite fails due to fiber fracture, stretching and voids.

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