EXPERIMENTAL INVESTIGATION ON MECHANICAL PROPERTIES OF PLA REINFORCED WITH NATURAL FIBER COMPOSITES

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Abstract - *This project deals with the effect of matrix material (PLA) on mechanical properties of Phoenix Sp. fiber reinforced polymer matrix composites. The composite was prepared by varying the fiber length (300μm,10, 20 and 30 mm) and fiber volume fraction (10, 20, 30, 40 and 50%) with random fiber orientations using compression molding technique. The composite samples were tested by using the standard experimental conditions according to ASTM Standards. The results revealed that, the matrix material has a significant effect on the mechanical properties. The composites prepared with PLA matrix treated fiber showed good mechanical property than that of the composites prepared with untreated fiber.*

Key Words: Phoenix sp fiber, Poly Lactic Acid (PLA), composite, fiber volume fraction, compression moulding.

1. INTRODUCTION

Natural fiber reinforced composite materials possessing better properties such as, high strength, lightweight, low cost, corrosion resistance, availability and high fatigue resistance. Based on this uniqueness it found its application in the aerospace, automotive, construction, domestic and sporting goods etc. [1-5]. Rajeshkumar et al. [6] investigated the physical, chemical and vibration properties of raw Phoenix sp. fibers reinforced composites. The properties were determined by varying the fiber length (10, 20, 30, 40 and 50mm) keeping constant weight fraction of 10%. Plants belonging to the Phoenix species are traditionally used for decorative purpose or for the production of fruits. Considering that the maintenance of this plants produces considerable amount of agricultural wastes (especially petioles with leaves), an alternative use of these waste products is proposed in this work: i.e., to obtain fibers and particles to be used as reinforcement of polymer�based composites. However, to use natural fibers as reinforcement of composites materials, a complete knowledge of the fibers properties and their interaction with the polymer matrices is mandatory. Several less common natural fibers as snake grass [7–9]; Arundo Donax [10, 11]; artichoke [12, 13]; rice straw [14]; banana empty fruit bunch [15]; jowar, sisal, and bamboo [16]; alfa [17]; and rattan [18] were recently investigated in order to evaluate their use as reinforcement in polymer-based composites. From a literature review a Phoenix sp. fiber, PLA resin were chosen to create a bio-composite. It was decided from the literature review that Compression Molding will be done to produce the composite and various mechanical tests like Tensile test, Impact test and Flexural Test will be done find the characteristics of the produced composite.

2. MATERIALS AND METHODS

2.1 Phoenix sp. Fiber

Phoenix sp. fiber belongs to Aceraceae family and is widely found in India, China, Turkey, Canary Islands, Africa, etc. where the ground water level is high. This plant has high concentration of fibers in its petioles. The petioles are cut from the plant using a knife and are immersed in water. During this water retting process, the unwanted materials present in each petiole are removed. Then, single fibers were extracted by manual peeling process. Finally, the extracted fibers are washed in running water and dried at room temperature for 2-3 days. Then the fibers were cut to the required length *(300μm,10, 20 and 30 mm)* by using scissors. The properties of the Phoenix sp. fiber are shown in Table -1.

Table -1: Phoenix sp. Fiber properties

Property	Values
Diameter (mm)	0.5766
Density (g/cc)	1.2576
Cellulose (%)	76.13
Lignin (%)	4.29
Moisture (%)	10.41
Wax (%)	0.32
Ash (%)	19.69
Tensile Strength (MPa)	349
Young's Modulus (GPa)	7.62

2.2 Poly Lactic Acid (PLA)

Polylactic Acid (PLA) is different than most thermoplastic polymers in that it is derived from renewable resources like corn starch or sugar cane. Most plastics, by contrast, are derived from the distillation and polymerization of nonrenewable petroleum reserves. Plastics that are derived from biomass (e.g., PLA) are known as "bioplastics."

Polylactic Acid is biodegradable and has characteristics similar to polypropylene (PP), polyethylene (PE) or polystyrene (PS). It can be produced from already existing manufacturing equipment (those designed and originally used for petrochemical industry plastics). This makes it relatively cost efficient to produce. Accordingly, PLA has the second largest production volume of any bioplastic (the most common typically cited as thermoplastic starch).

There is a vast array of applications for Polylactic Acid. Some of the most common uses include plastic films, bottles, and biodegradable medical devices (e.g., screws, pins, rods, and plates that are expected to biodegrade within 6-12 months). For more on medical device prototypes (both biodegradable and permanent) read here. PLA constricts under heat and is thereby suitable for use as a shrink wrap material. Additionally, the ease with which Polylactic Acid melts allows for some interesting applications in 3D printing (namely "lost PLA casting" - read more below). On the other hand, its low glass transition temperature makes many types of PLA (for example, plastic cups) unsuitable to hold hot liquid.

Table -2: PLA Properties

Property	Values
Technical Name	Poly Lactic Acid
Chemical Formula	$(C_3H_4O_2)n$
Melt Temperature	157 - 170 °C
Typical Injection Moulding Temperature	178 - 240 °C
Heat Deflection Temperature (HDT)	49 - 52 °C at 0.46 MPa
Tensile Strength (MPa)	61 - 66
Flexural Strength (MPa)	48 - 110
Specific Gravity	1.24
Shrink Rate	0.37 - 0.41% (0.0037 - 0.0041 in/in)

2.3 Manufacturing Process of the Composite

The composites will be prepared by using Phoenix sp. fiber as reinforcement in different forms such as 300 µm particles and chopped short fibers with length of 10 mm, 20 mm and 30 mm respectively. The dried fibers will be cut to above-mentioned lengths by using scissors whereas a powder was obtained by using a ball mill. Then, the so obtained powder will be sieved to obtain particles with maximum size equal to 300 µm. Both particles and randomly oriented short fibers composites will be made with fiber volume content equal to 0% (i.e., neat resin), 10%, 20%, 30%, 40%, and 50%, respectively. The volume fraction of fiber (Vf) is calculated by using the following relation:

$$Vf = \frac{(W_f/\rho_f)}{(W_f/\rho_f)+(W_m/\rho_m)}$$

where Wf and Wm are the weight of fiber and matrix (g), respectively, ρf and ρm are the densities of reinforcement and matrix (in g/cm^3), respectively. Composites will be manufactured through compression-moulding technique placing the reinforcement on a die and pouring the resin/hardener mix on to it. The mould will be kept under a pressure of 4.5 bar for 6 hours using a hydraulic press to obtain a uniform thickness in the whole plate, as suggested by the supplier. Composite panels with dimension 300x300x3 mm^3 will be subjected to a post curing process for 4 h at 60° C in an oven to promote the homogeneity of the curing process. Samples are obtained by cutting the panels with the aid of a diamond saw.

3. RESULTS AND DISCUSSION

3.1 Tensile Test

Tensile testing is a fundamental materials science test in which a sample is subjected to a controlled tension until failure. Uniaxial tensile testing is most commonly used for obtaining the mechanical characteristics of isotropic materials. For anisotropic materials, such as composite materials and textiles, biaxial tensile testing is required. The Universal Testing Machine (Deepak Poly Plastic Pvt. Ltd. India; Model DTRX – 30 kN) ASTM D638 standard is selected for the tensile testing. The length, width and thickness of the specimens are 165 mm, 13 mm and 3 mm respectively. The crosshead speed was maintained at 50 mm/min. The test was conducted at room temperature.

Fig -1: Universal Testing Machine

3.1.1 Tensile Strength

Tensile strength is the maximum load that a material can support without fracture when being stretched, divided by the area of the material.

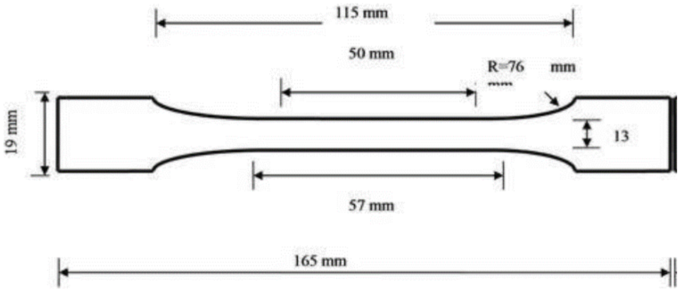

Fig -2: Dimensions of the sample used for testing

Tests were conducted according to ASTM D638 standard and the following results were obtained.

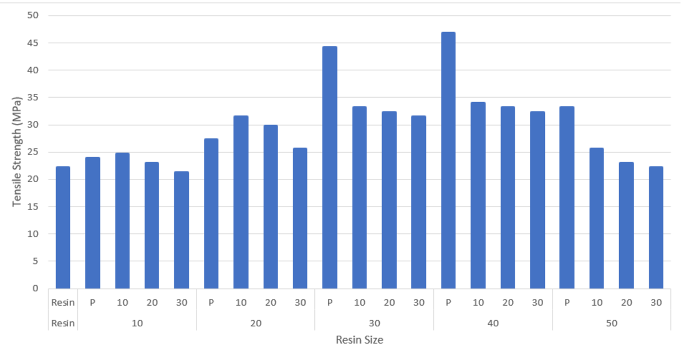

Chart -1: Tensile Strength Results

Table -3: Tensile Strength of various compositions

Volume Fraction (%)	Fibre Length (mm)	MPa
-	Pure Resin	22.1
10	P(300 μm)	23.8
	10	24.65
	20	22.95
	30	21.25
20	P(300 μm)	27.2
	10	31.45
	20	29.75
	30	25.5
30	P(300 μm)	44.2
	10	33.15
	20	32.3
	30	31.45
40	P(300 μm)	46.75
	10	34
	20	33.15
	30	32.3
50	P(300 μm)	33.15
	10	25.5
	20	22.95
	30	22.1

The composite sample with 40% volume fraction with P(300 μm) fiber length the highest Tensile strength of 510 MPa.

3.1.2 Tensile Modulus

The tensile modulus of a solid material is a mechanical property that measures its stiffness. It is defined as the ratio of its tensile stress (force per unit area) to its strain (relative deformation) when undergoing elastic deformation. Tests were carried according to ASTM D638 standards and the following results were obtained. The composite sample with 30% volume fraction with 20mm fiber length the highest Tensile Modulus of 510 MPa.

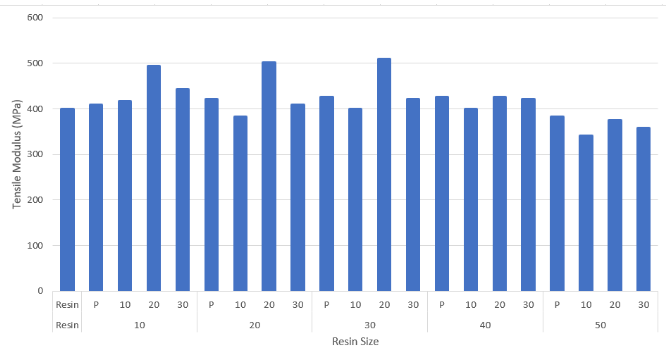

Chart -2: Tensile Modulus Results

The results obtained for each composition is given in the table below:

Table -4: Tensile Modulus of various compositions.

Volume Fraction (%)	Fibre Length (mm)	MPa
-	Pure Resin	400
10	P(300 μm)	408
	10	416.5
	20	493
	30	442
20	P(300 μm)	420.75
	10	382.5
	20	501.5
	30	408
30	P(300 μm)	425
	10	399.5
	20	510
	30	420.75
40	P(300 μm)	425
	10	399.5
	20	425
	30	420.75
50	P(300 μm)	382.5
	10	340
	20	374
	30	357

3.2 Flexural Test

The flexural test (three-point bending) was conducted according to ASTM D790-10 standards, using the same Universal Testing Machine. Test samples of size 64X 12.7X3 mm^3 with a span length of 48 mm were tested in each case and the average value was noted as the flexural property of the respective composites.

3.2.1 Flexural Strength

The flexural strength of a material is defined as the maximum bending stress that can be applied to that material before it yields. The most common way of obtaining the flexural strength of a material is by employing a transverse bending test using a three-point flexural test technique. Flexural strength is also known as bending strength, modulus of rupture or transverse rupture strength.

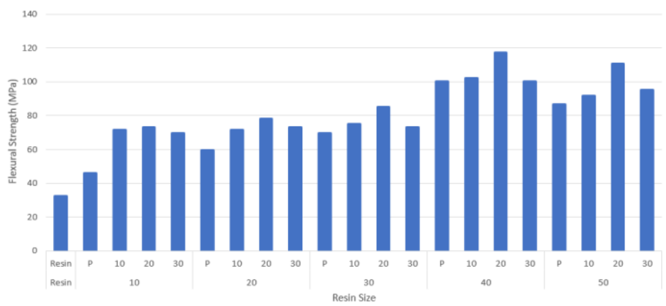

Chart -3: Flexural Strength Results

Test were carried out according to ASTM D790-10 standards and the following results were obtained for various compositions of the composite. The composite with 40% volume fraction and 20mm fibre length showed the highest flexural strength of 117.3 MPa.

3.2.2 Flexural Modulus

The flexural modulus of a material is a physical property denoting the ability for that material to bend. In mechanical terms, it is the ratio of stress to strain during a flexural deformation, or bending. Tests were carried out according to ASTM D790-10 standard.

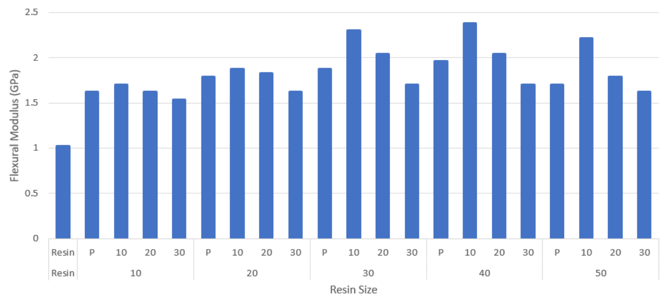

Chart -4: Flexural Modulus Results

The composite with 40% volume fraction and 10mm fibre length showed the highest Flexural Modulus of 2.38 GPa. The Flexural Modulus of various compositions of the composite is given in Table -6.

Table -5: Flexural Strength of various compositions

Volume Fraction (%)	Fibre Length (mm)	MPa
-	Pure Resin	32.3
10	P(300 μm)	45.9
	10	71.4
	20	73.1
	30	69.7
20	P(300 μm)	59.5
	10	71.4
	20	78.2
	30	73.1
30	P(300 μm)	69.7
	10	74.8
	20	85
	30	73.1
40	P(300 μm)	100.3
	10	102
	20	117.3
	30	100.3
50	P	86.7
	10	91.8
	20	110.5
	30	95.2

Table -6: Flexural Modulus of various compositions

Volume Fraction (%)	Fibre Length (mm)	GPa
-	Pure Resin	1.02
10	P(300 μm)	1.615
	10	1.7
	20	1.615
	30	1.53
20	P(300 μm)	1.785
	10	1.87
	20	1.8275
	30	1.615
30	P(300 μm)	1.87
	10	2.295
	20	2.04
	30	1.7
40	P(300 μm)	1.955
	10	2.38
	20	2.04
	30	1.7
50	P(300 μm)	1.7
	10	2.21
	20	1.785
	30	1.615

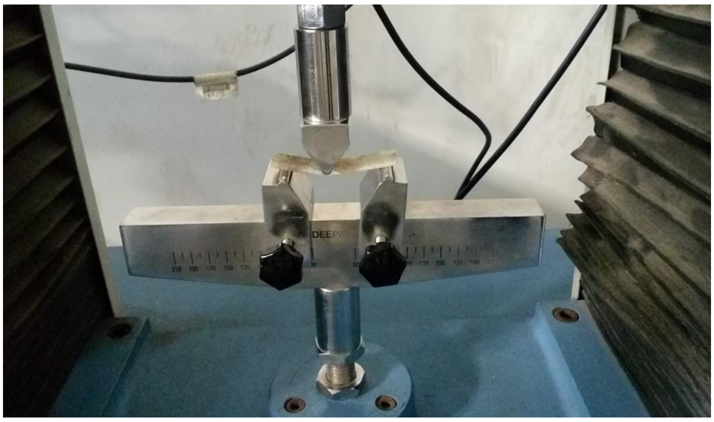

Fig -4: Sample Used for flexural Test

3.3 Izod Impact Test

Izod impact test is a standard test that measures the impact energy needed to fracture a material. This test helps engineers and scientists assess the fracture properties of a given part or component. The information obtained from the Izod impact test is used to determine how various materials will perform when subjected to impact loading. Izod impact test was conducted according to ASTM D256-10 standards using the IM245 impact testing machine (Deepak Poly Plastic Pvt. Ltd. India) of capacity 0 to 15 J. test samples of size 64x12.7x3 mm3 were tested in each case and the average value was noted as the impact property of the respective composites.

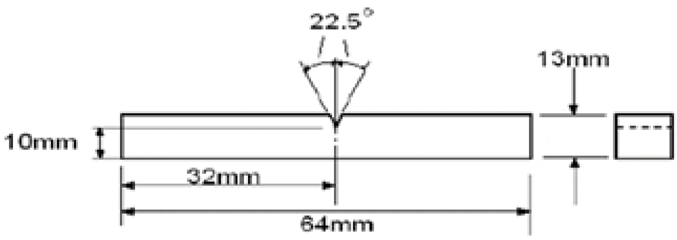

Fig -3: Dimensions of sample used for Izod Impact testing

Izod impact tests were carried out and Impact Energy for various compositions were obtained.

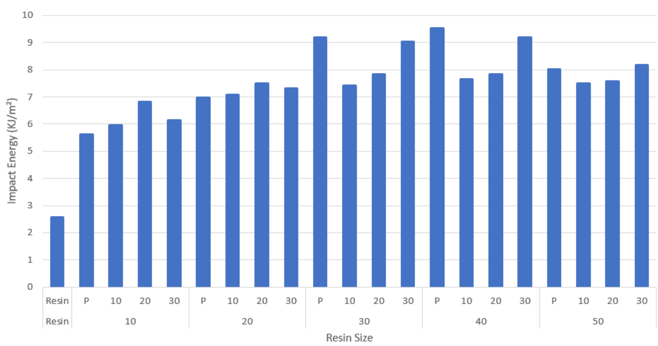

Chart -5: Impact Energy Results

Impact Energy results for various compositions are given in Table -7.
The composite with 40% volume fraction and P(300 µm) fibre length showed the highest Impact test of 9.52 KJ/m².

Table -7: Impact Energy for various compositions

Volume Fraction (%)	Fibre Length (mm)	KJ/m²
-	Pure Resin	2.55
10	P(300 µm)	5.61
	10	5.95
	20	6.8
	30	6.12
20	P(300 µm)	6.97
	10	7.055
	20	7.48
	30	7.31
30	P(300 µm)	9.18
	10	7.395
	20	7.82
	30	9.01
40	P(300 µm)	9.52
	10	7.65
	20	7.82
	30	9.18
50	P(300 µm)	7.99
	10	7.48
	20	7.565
	30	8.16

Fig -5: Izod Impact Test

4. CONCLUSIONS

Test results indicate that the composites with 40% volume fraction showed overall better tensile strength, flexural and impact properties compare to pure resin and other volume fractions. The composites with 30% volume fraction with 20mm fiber length showed 21.56% higher tensile modulus compared to pure PLA resin.

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