

Design and Development of Natural Composite Material

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Abstract – The paper describes the design and development of natural composite material which is prepared using epoxy resin as matrix phase and century plant fiber as reinforcing phase which follows the category of Polymer matrix composite with fiber reinforced. The natural composite plates are prepared according to the ASTM standards (American society for testing and materials). Referring to the ASTM standards, the dimensions of the composite plates are decided. The percentage of fiber and their angle of orientation are varied. Finally, the composite plates are tested for tensile and flexural load and the results are plotted.

Key Words: ASTM, Tensile, Flexural, Epoxy & Fibre.

1. INTRODUCTION

Over the last thirty years composite materials, plastics and ceramics have been the dominant emerging materials. The volume and number of applications of composite materials have grown steadily, penetrating and conquering new markets relentlessly [2]. Modern composite materials constitute a significant proportion of the engineered materials market ranging from everyday products to sophisticated niche applications. While composites have already proven their worth as weight-saving materials, the current challenge is to make them cost effective. The efforts to produce economically attractive composite components have resulted in several innovative manufacturing techniques currently being used in the composites industry. It is obvious, especially for composites, that the improvement in manufacturing technology alone is not enough to overcome the cost hurdle. It is essential that there be an integrated effort in design, material, process, tooling, quality assurance, manufacturing, and even program management for composites to become competitive with metals.

The composites industry has begun to recognize that the commercial applications of composites promise to offer much larger business opportunities than the aerospace sector due to the sheer size of transportation industry. For certain applications, the use of composites rather than metals has in fact resulted in savings of both cost and weight. Some examples are cascades for engines, curved fairing and fillets, replacements for welded metallic parts, cylinders, tubes, ducts, blade containment bands etc. Further, the need of composite for lighter construction materials and more seismic resistant structures has placed high emphasis on the

use of new and advanced materials that not only decreases dead weight but also absorbs the shock & vibration through tailored microstructures.

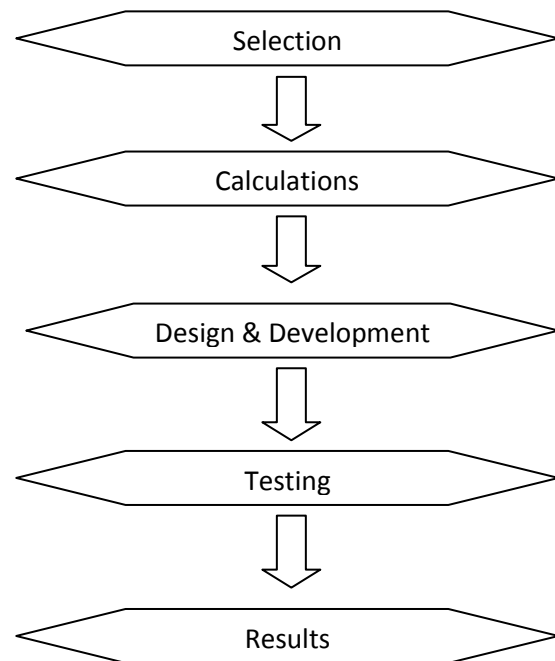


Fig-1: Methodology

1.1 OBJECTIVES

- To develop a new class of natural fiber-based composite to explore the potential of century plant fiber (Sisal fiber).
- To fabricate the different composite by varying the fiber fraction and matrix Fraction
- To study the effect of fiber percentage on mechanical behavior of natural fiber reinforced matrix-based composites.
- To Evaluate mechanical properties such as Tensile strength and Flexural strength
- To compare the test results of composite plates of different fiber percentage and their alignment angle.

1.2 DEFINITIONS

A composite material consists of two or more physically and/or chemically distinct, suitably arranged or distributed phases, with an interface separating them. It has characteristics that are not depicted by any of the components in isolation. Most commonly, composite materials have a bulk phase, which is continuous, called the matrix, and one dispersed, non-continuous, phase called the reinforcement, which is usually harder and stronger. The function of individual components has been described as:

Matrix phase: The primary phase, having a continuous character, is called matrix. Matrix is usually more ductile and less hard phase. It holds the dispersed phase and shares a load with it.

Reinforcing phase: The second phase (or phases) is embedded in the matrix in a discontinuous form. This secondary phase is called dispersed phase. Dispersed phase is usually stronger than the matrix, therefore it is sometimes called reinforcing phase.

1.3 Classification of composites

Composites can be grouped into categories based on the nature of the matrix each type possesses and the type of reinforcing material to be used [5]. Methods of fabrication also vary according to physical and chemical properties of the matrices and reinforcing fibers. Based on the reinforcing fibers they can be grouped into particulate composites, fibrous composites and laminate composites [13].

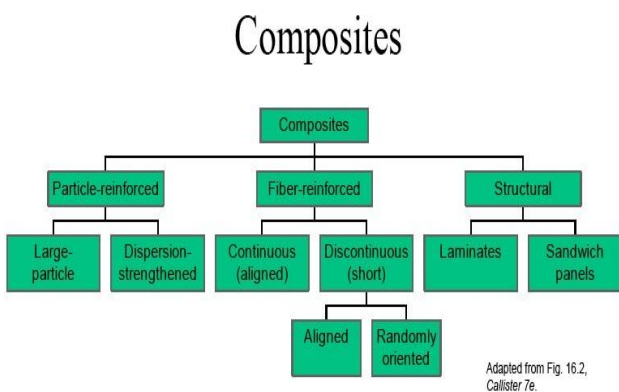


Fig 2: Reinforced based composites

a) Particulate Composites

Particulate Composites consist of a matrix reinforced by a dispersed phase in form of particles. These are the cheapest and most widely used. They fall in two categories depending on the size of the particles. Composites with random orientation of particles. Composites with preferred

orientation of particles. Dispersed phase of these materials consists of two-dimensional flat platelets (flakes), laid parallel to each other.

b) Fibrous Composites

The fibrous composites are again divided into two types. One is short fiber reinforced composites which consists of a matrix reinforced by a dispersed phase in form of discontinuous fibers (length < 100*diameter) and long-fiber reinforced composites which consists of a matrix reinforced by a dispersed phase in form of continuous fibers.

c) Laminate composite

When a fiber reinforced composite consists of several layers with different fiber orientations, it is called multilayer composite [8].

1.4 Classification of reinforcements

Reinforcements for the composites can be fibers, fabrics particles or whiskers.[17],[19] Fibers are essentially characterized by one very long axis with other two axes either often circular or near circular. Particles have no preferred orientation and so does their shape. Whiskers have a preferred shape but are small both in diameter and length as compared to fibers. Figure.3 shows types of reinforcements in composites

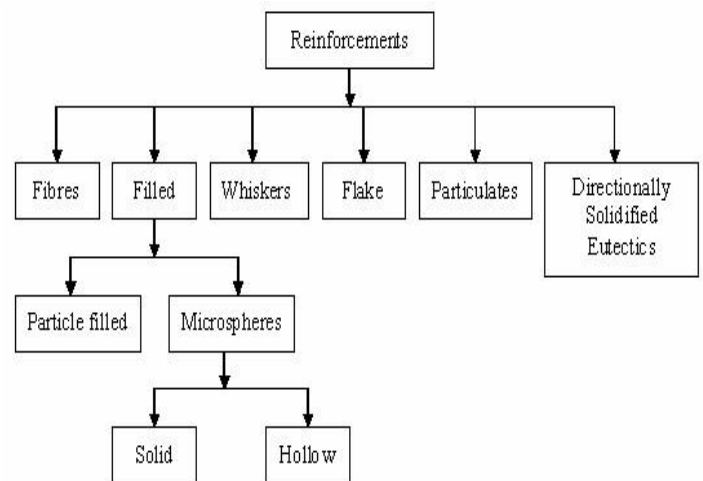


Fig 3: Types of reinforcement

Fiber-reinforced polymer composites have played a dominant role for long time in a variety of applications for their high specific strength and modulus. The fiber-reinforced polymer, usually made of glass, carbon or aramid fibers-reinforced thermoplastic and thermoset resins [5] are considered critical because of environmental problems [6]. Natural fiber composites means a composite material that is reinforced with fibers, particles or platelets from natural or renewable resources, in contrast to for example carbon or aramid fibers that have to be synthesized.

Natural fibers include those made from plant, animal and mineral sources. Natural fibers can be classified according to their origin. Fig 4 shows the classification natural fibers according to their respective types

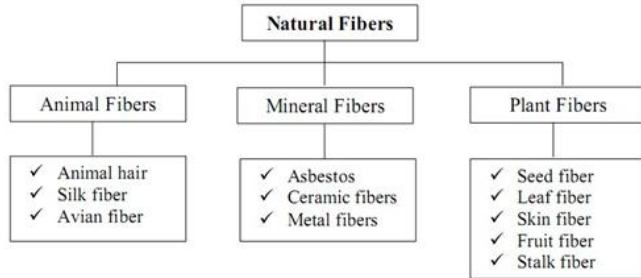


Fig 4: Classification of natural fibers

1.5 MANUFACTURING PROCESSES OF COMPOSITE MATERIAL

Manufacturing of a composite material is to combine the polymeric resin system with the fiber reinforcement [3]. Since the orientation of the fibers is critical to the end properties of the composite, manufacturing process is utmost important to align the fibers in desired direction [9]. A good manufacturing process will produce a higher, uniform fiber volume fraction along with a higher production of a large volume of parts economically and have repeatable dimensional tolerances. In this work, Hand lay-up process is used for manufacturing the composite material. The composite manufacturing techniques can be classified into two categories:

A. Open mould process

1. Hand lay-up process
2. Spray up process
3. Vacuum-bag auto clave process
4. Filament winding process

B. Closed mould process

1. Compression molding
2. Injection molding
3. Sheet molding compound (SMC) process
4. Continuous pultrusion process

2. MATERIAL

The following materials used in this work are as follows:

a) Epoxy resin (LY-556)

Epoxy LY-556 resin belonging to the epoxide family is chosen as the matrix due to its light weight, easy to fabricate, resists most alkalis and acids and resists stress cracking.

b) Hardener (HY-951)

Hardener is a curing agent for epoxy or fiberglass. Epoxy resin requires a hardener to initiate curing; it is also called as catalyst, the substance that hardens the adhesive when mixed with resin. It is the specific selection and combination of the epoxy and hardener components that determines the final characteristics and suitability of the epoxy coating for given environment needed for special purposes.

c) Century Plant fibre (Sisal)

Century plant's fibre was taken to fill as reinforcement in the polymer composite.

Century Plant is Commercially available and it is fully biodegradable and highly renewable resource. Sisal is a natural fiber (Scientific name is *Agave sisalana*) of Agavaceae (Agave) family yields a stiff fiber traditionally used in making twine and rope. Century Plant fiber is exceptionally durable and a low maintenance with minimal wear and tear.



Fig 5: Sisal Fiber

3. CALCULATIONS

The samples are cut to the following dimensions as per ASTM standards [10], [16],[18] for testing shown in Table 1.

Table -1: ASTM Standards for sample dimensions

S.N	ASTM Code	Mechanical Test	Sample Dimensions (mm)
1.	ASTM-D638	Tensile	200 × 25 × 4
2.	ASTM-D790	Flexural	100 × 15 × 4

1. Tensile:

- Volume = $4 \times 25 \times 200 \text{ mm}^3$
= $20,000 \text{ mm}^3 = 20,000 \times 10^{-9} \text{ m}^3$
- Density of epoxy = $1.15 \text{ gm/ml} = 1.15 \times 10^3 \text{ kg/m}^3$
- Density of hardener = $1 \text{ gm/ml} = 1 \times 10^3 \text{ kg/m}^3$
- Total density (Epoxy + Hardener) = 2.15 gm/ml
= $2.15 \times 10^3 \text{ kg/m}^3$
- Mass = Density × Volume
= $2.15 \times 10^3 \times 20,000 \times 10^{-9} \text{ kg}$
= 43 gm OR 0.043 kg

Weight fraction method is used for calculations.
Sample 1: 0°

- Specimen with 5% fiber
- Total weight of the specimen = 43 gm
- Weight of the fiber = 5% of $43 \text{ gm} = 2.15 \text{ gm}$
- Weight of the polymer = $43 - 2.15 = 40.85 \text{ gm}$
- $40.85/3 = 13.61 \text{ gm}$
- Therefore, weight of the epoxy = 27.23 gm
- Weight of the hardener = 13.61 gm

Hardener used in the epoxy-hardener mixture is 1:2.

Similar calculations were carried out for different fiber percentages and their orientations. The results of tensile test specimens after calculations are shown in the table 2

Table -2: Tensile test sample calculations

Angle of fiber orientation	0°, 30° & 45°			
	5%	10%	15%	18%
Percentages of fibers	5%	10%	15%	18%
Total weight of the specimen (gm)	43	43	43	43

Weight of the fiber (gm)	2.15	4.3	6.45	7.74
Weight of the polymer (gm)	40.85	38.7	36.55	35.26
Weight of the epoxy (gm)	27.23	25.8	24.36	23.53
Weight of the hardener (gm)	13.61	12.9	12.18	11.76

2. Flexural:

- Volume = $4 \times 15 \times 100 \text{ mm}^3$
= $6000 \text{ mm}^3 = 6000 \times 10^{-9} \text{ m}^3$
- Density of epoxy = $1.15 \text{ gm/ml} = 1.15 \times 10^3 \text{ kg/m}^3$
- Density of hardener = $1 \text{ gm/ml} = 1 \times 10^3 \text{ kg/m}^3$
- Total density (Epoxy + Hardener) = 2.15 gm/ml
= $2.15 \times 10^3 \text{ kg/m}^3$
- Mass = Density × Volume
= $2.15 \times 10^3 \times 6000 \times 10^{-9} \text{ kg}$
= 12.9 gm OR 0.0129 kg

Sample 1: 0°

- Specimen with 5% fiber
- Total mass of the specimen = 12.9 gm
- Weight of the fiber = 5% of $12.9 \text{ gm} = 0.64 \text{ gm}$
- Weight of the polymer = $12.9 - 0.64 = 12.26 \text{ gm}$
- $12.26/3 = 4.08 \text{ gm}$
- Therefore, weight of the epoxy = 8.17 gm
- Weight of the hardener = 4.08 gm

Similar calculations were carried out for different fiber percentages and their orientations. The results of flexural test specimens after calculations are shown in the following tables

Table -3: Flexural test sample calculations

Angle of fiber orientation	0°, 30° & 45°			
	5%	10%	15%	18%
Percentages of fibers	5%	10%	15%	18%
Total weight of the specimen (gm)	12.9	12.9	12.9	12.9

Weight of the fiber (gm)	0.64	1.29	1.93	2.32
Weight of the polymer (gm)	12.26	11.61	10.97	10.58
Weight of the epoxy (gm)	8.17	7.74	7.31	7.05
Weight of the hardener (gm)	4.08	3.87	3.65	3.52

4. PLACING FIBERS INTO THE MOULD

It is the one of the simplest methods of composite processing. The processing steps are quite simple. Glass moulding is used to prepare the specimen. A thick flat glass sheet was chosen as the base on which specimen were prepared. To avoid sticking of the epoxy on the glass plate, aluminium foil paper is used to cover the glass plate as, epoxy resin contains OH group which means epoxy resin is very sticky. Glass plates were used to hold the specimen by providing supportive structure and also used to make the specimen in dimensions. Percentage of epoxy hardener in the specimen were calculated by weight fraction. Hardener used in the epoxy-hardener mixture is 1:2. After calculations of varying fibre % and their alignment angle, hardener and epoxy resin were mixed thoroughly in suitable proportion and poured between the space surrounded by the glass plates or glass mould. The mixture is uniformly spread with the help of brushes. Needle was used to remove any air trapped on bubble as well as excess polymer present. This process was separated for each fiber percentage and fiber alignment in the specimen. After done with this, aluminium foil sheet was wrapped around the glass mould to avoid entry of foreign particle and to avoid formation of air bubbles which creates irregularity on surface which will lead to poor quality finish and less strength.



Fig 6: Glass moulding

All the specimen are then kept at room temperature for 15-20 hours and then mould is opened and the developed composite part is taken out and further processed. The time of curing depends on type of polymer used for composite processing for e.g. for epoxy-based system, normal curing time at room temperature is 20-24 hours. This method is mainly suitable for small scale application, and infrastructural requirements were less as compared to other methods. Production rate is less and high-weight fraction of reinforcement is difficult to achieve in the processed composition. Composite plates after placing the fibers are shown in Fig 7.

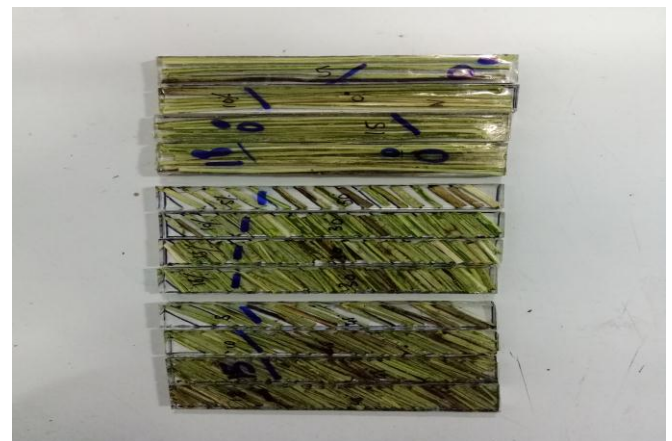


Fig 7: Natural composite plates after placing of the fibers

5. TESTING

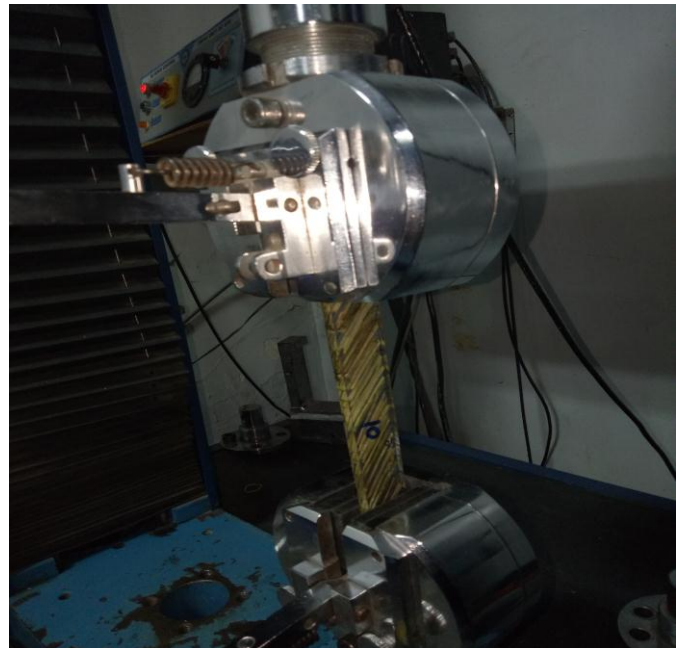
Mechanical properties such as Tensile strength, Flexural strength are computed from the test conducted using universal testing machine (UTM) shown in the (Fig 8) in accordance to ASTM standards for specimen preparation. The 10-ton capacity UTM machine used for testing was supplied by PRAJ Metallurgical Laboratory, Pune, India. UTM Specifications are shown in Table 4.



Fig 8: Universal testing machine (UTM)

Table -4: Specifications of Universal Testing Machine

Parameter	Specifications
Capacity	10 tones
Load frame	Mild steel C channel with double ball screw mechanism pre-loaded ball screw with zero backlash covered with bellow
Mounting	Free standing
Load range	1 kg-1000 kg using 1-ton load cell 1 kg-10000 kg using 10-ton load cell
Length measurements	Rotary encoder mounted on to the screw rod
Length resolution	0.01 mm
Cross head speed	0.1 to 100 mm/min
Controls	Emergency off, up and down key
Input power	220V±10% VAC,50 HZ,1500 VA
Net weight	225 kg
Grippers	Tensile, Compression, Three-point Bending
Length accuracy	±0.1 mm


Fig 9: Tensile Testing on UTM machine

5.1 Tensile Testing of Composites

One of the most common testing methods, tensile testing, is used to determine the behavior of a sample while an axial stretching load is applied. These types of tests may be performed under ambient or controlled (heating or cooling) conditions to determine the tensile properties of a material. Tensile testing is performed on a variety of materials including metals, plastics, elastomers, paper, composites, rubbers, fabrics, adhesives, films, etc. Tensile testing is commonly used to determine the maximum load (tensile strength) that a material or a product can withstand. Tensile testing may be based on a load value or elongation value. Here in tensile test ASTM D-638 is used to prepare specimens however, in ASTM D-638 dumbbell shaped specimens are given in type 1- type 5. However rectangular specimens were used in this testing, because if we make dumbbell shaped specimen, fiber will break. Hence, the purpose of putting the fiber material will defeat. Hence, rectangular samples are prepared. Tensile test sample placed in the UTM is shown in the Fig 9.

5.2 Flexural Testing of Composites

Flexural testing is used to determine the flex or bending properties of a material [15]. Sometimes referred to as a transverse beam test, it involves placing a sample between two points or supports and initiating a load using a third point or with two points which are respectively call 3-Point Bend testing [13]. Maximum stress and strain are calculated on the incremental load applied. Typical materials tested are plastics, composites, metals and woods. Flexural test sample placed in the UTM is shown in the Fig 10.


Fig 10: Flexural Testing on UTM machine

Load vs Displacement graphs are generated from the UTM for both tensile and flexural tests samples and the readings are recorded. Figure 11 shows one of the (Load vs Displacement) of tensile test of 0° orientation with 10% of the reinforced fiber.

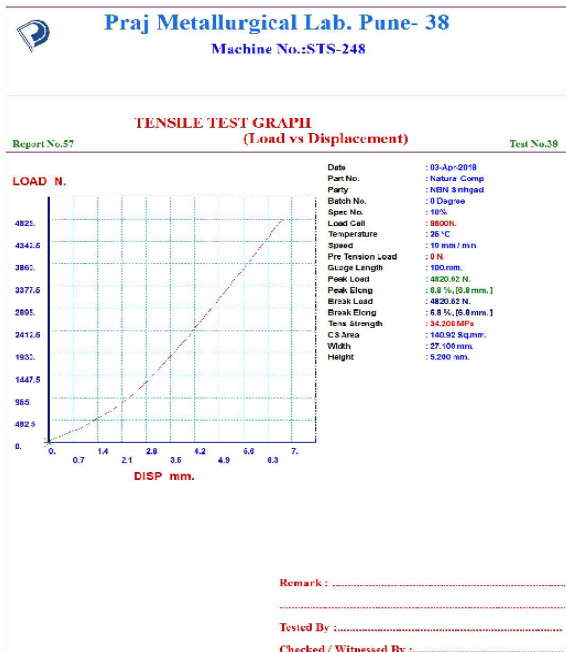


Fig 11: Load vs Displacement - 0°, 10%

Similar graphs are generated for all the remaining samples of both tensile and flexural tests samples and the readings are recorded.

6. RESULT

The following tests results of both tensile and flexural tests recorded are as follows:

6.1 Tensile Test Results:

The readings obtained for tensile tests specimens are shown in table 5.

Table -5: Tensile Test Results

Sr.No.	Sample Identification	Tensile strength (MPa)			
		5%	10%	15%	18%
1.	0°	38.87	34.20	34.03	34.70
2.	30°	13.60	7.59	7.28	5.44
3.	45°	10.92	9.15	10.54	8.44

The graph of Tensile strength vs Fiber Percentage is shown in Chart 1

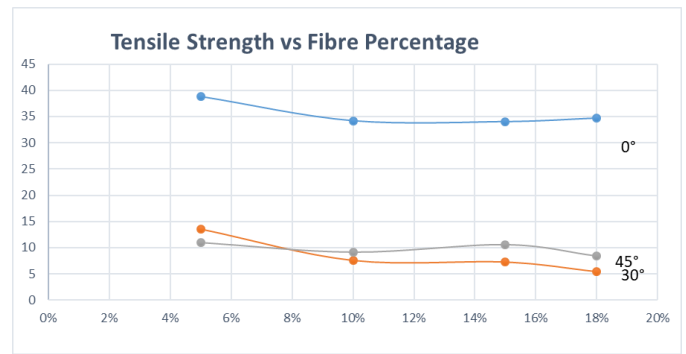


Chart -1: Tensile strength vs Fiber Percentage

6.2 Flexural Test Results:

The readings obtained for flexural tests specimens are shown in table 6.

Table -6: Flexural Test Results

Sr.No.	Sample Identification	Flexural strength (MPa)			
		5%	10%	15%	18%
1.	0°	81.29	68.55	67.51	59.38
2.	30°	29.22	31.05	20.18	23.38
3.	45°	34.05	30.75	27.56	19.31

The graph of Flexural strength vs Fiber Percentage is shown in Chart 2

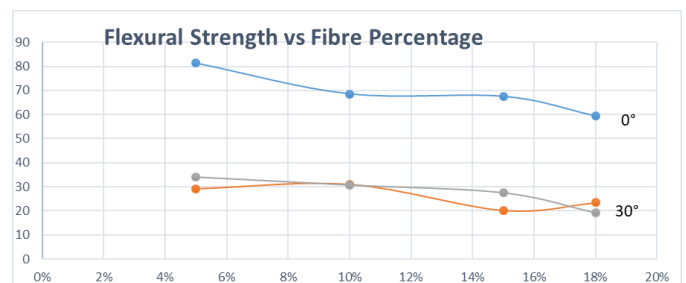


Chart -2: Flexural strength vs Fiber Percentage

7. CONCLUSIONS

From the observations and results of specimens under tensile and flexural testing, the various conclusions are taken out which are as follows

- The maximum properties (both tensile strength and flexural strength) are at 5% fiber reinforcement.
- After 5% reinforcement i.e. 10%, 15%, 18% the properties gradually reduce. This maybe because of increase in reinforcement.
- In flexural strength at 30°, the strength marginally increases for 10% as compared to 5%.

- d) From the above results, we got to know as we increase the fiber percentage the brittleness of the specimen also increases with it.
- e) Hence, to conclude the 5% reinforcement is better as compared to 10%, 15% and 18%.

8. FUTURE SCOPE

Presently, the main markets for bio composites are in the construction and automotive sectors. With further developments and improvements in performance, however, new opportunities [19] and applications will likely arise. In addition to this, improvements in the mechanical performance of existing bio composites through, for example, the introduction of new fiber types, processing and additives may well result in an expansion in their use into more diverse, and technically demanding, application areas. There are also good prospects for using reclaimed fiber from products such as MDF (medium density fiberboard) or other waste streams from the pulp and paper industry to manufacture a range of cost-effective and environmentally effective materials and products [9]. While there is ample opportunity for these products to enter new markets and find new application, it is essential that benefit in terms of cost saving be highlighted and a stronger commercial case for these materials be made.

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