

**ABSTRACT**

This paper presents an experimental study of physical and mechanical characterization of natural fiber reinforced polymer matrix. In this work, a thermoset polymer i.e. epoxy is chosen as a matrix material whereas short sisal fibre is taken as reinforcement. A set of composite with wide range of fibre content by varying weight percentage has been fabricated using simple hand lay-up technique. The effect of fibre content on various properties like density, tensile strength, cross breaking strength, impact energy and water absorption behaviour has been reported. The microstructure of the composites is also studied with the help of scanning electron microscopy. Later, based on the experimental investigation it has been suggested that the fabricated composites find its potential application in Indian railways like windows frames for non-air conditioned coaches, inner frames for sealed glass in air conditioned coaches, lavatory doors, roof formations and panelling work of side walls of Indian railways coaches.

**KEYWORDS:** Polymer matrix composites, Epoxy, Sisal fiber, Physical properties, Mechanical properties.

**I. INTRODUCTION**

The human potential and intelligence is noticeable by its knowledge on the nature. The nature involves availability and re-definability of materials and technology. In the recent trend of manufacturing, variety of jobs are handled at a time. All these manufacturing technologies are involves men, machines and materials. The human aspect deals with multi-skilled manpower as we need a person who can deals with different operation process as well as maintenance process of the machine. In general, the materials available to the engineer include timber, stone, cement, metals, textiles, ceramics and plastics. The requirement of varieties of properties is enforce researchers toward development of new product. Composite materials are having tailor made properties which is impossible to achieve in single materials. Composite materials is an advanced material and used in various sectors due to its outstanding properties [1]. The composite material is planned in such a way that the specific component holds their properties and so merged that the composite take advantage of their higher properties without compromising on the weakness of either [2]. The pure form of polymer is unable to satisfy the demands for various applications, hence to get supplementary strength reinforcements are added to the polymer. Natural fibers are eco-friendly and biodegradable substance. Government regulations and environment awareness pushed the world towards materials that are compatible with environment as well as does not produce any harmful effect on human. Now-a-days natural fibers based composites (green composites) are attracting the scientist as a new hope in lieu of synthetic fiber for safe guards of environment. Natural fiber-polymer composites (NFPCs) are becoming increasingly utilized in a wide variety of applications because they represent an ecological and inexpensive alternative to conventional petroleum-derived materials.

Natural plant fibers present themselves as a potentially more sustainable alternative to manmade fibers as composites fillers. The mechanical and physical properties of NFCs are described, including dimensional stability, reaction to fire and mechanical properties. NFCs present a high variability of properties depending upon fiber characteristics, coupling between fiber/matrix, type of matrix, production process and possible additives. Besides these factors, the performance of NFCs is also dependent on the influence of service conditions [3].

Natural fibers recently attracted the attention of scientists and technologists because of the advantages that these fibers provide over conventional reinforcement materials, and the development of natural fiber composites has

been a subject of interest for the past few years. These natural fibers are low-cost fibers with low density and high specific properties. These are biodegradable and non-abrasive, unlike other reinforcing fibers. Also, they are readily available and their specific properties are comparable to those of other fibers used [4].

Mankind has been solely depends upon plants and its fibers for their needs, resulting areas of natural fibers (oil, palm, sisal & jute) are increasing day by day in industrial and human applications. Composite are prepared either by synthetic fibers or by natural fibers. Now going with eco-friendly, biodegradable and economical scenario natural fibers are prominently used in place of synthetic fibers. Mohanty et al. [5] used jute fiber as reinforcement in polymer matrix. They modified the surface of jute fabrics by different methods, with a view to their use as reinforcing agents in composites based on a biodegradable polymeric matrix, Lundquist et al. [6] used pulp fiber as reinforcement in polymer. They reported that stiffness of the fabricated composite increased by a factor of 5.2 and their strength increased by a factor of 2.3 relative to the pure polymer. Mohammed et al. [7] presented a review article to provide a comprehensive review of widely used natural fiber reinforced polymer composites (NFPCs) and their applications. In a very recent work Kiruthika [8] presented a review on physico-mechanical properties of bast fiber reinforced polymer composites. Väisänen et al. [9] presented a review paper on composite material which they compiled the effects of waste materials, residues or by-products of multiple types on NFPCs are critically reviewed and their potential as NFPC constituents is evaluated.

Against this background, the present research work is undertaken which explores the possible utilization of natural fiber in the form of short fiber in polymer composites. Attempt have been made to explore the possible use of natural fiber such as short sisal fiber derived from the leaves of sisal plant as functional filler materials in these composites.

## II. MATERIALS AND METHODS

### Materials used

The thermoset polymer epoxy is used as matrix material. The epoxy resin with its corresponding hardener is procured from M/s Atul Limited, Bhopal. It is a liquid, room temperature curing substance, unmodified epoxy resin of medium viscosity which can be used with particular hardener for making composites. Its density approx 1.2 g/cm<sup>3</sup>, tensile strength approximately 50 MPa, cross breaking strength 130 MPa, Impact energy is 17 KJ/m<sup>2</sup> and hardness is approximately 20 barcol hardness numbers. The sisal fiber used in present work was obtained from the local market. It is having a diameter varying between 170-300 micro-meters. In decortications, the extraction process, sisal leaves are crushed and beaten until the fibers remain. The sisal fibers then dried, classified and baled after the wax and other impurities are washed off with plenty of water. The chemical composition of sisal fibers includes 78.8 % cellulose, 8 % lignin, 10 % hemicellulose, 2 % waxes and about 1 % ash by weight and it has density approx 0.8 g/cm<sup>3</sup>, tensile strength is 450-600 MPa, Young modulus approximately 7-13 MPa [10].

### Composite Fabrication

In this experiment composite fabrication done with varies weight percentage of sisal fiber with epoxy resin as per sets shown in the Table 1. Dry sisal fibers are cut in the size of approximately 5 mm length. The mould 320×320×3 mm was used for fabrication of composites. The epoxy resin and the corresponding hardener were mixed in the ratio of 10:1 by weight as recommended. Short sisal fiber are then added to the epoxy-hardener combination and mixed thoroughly by hand stirring. A spray (waxpol) was used at the inner surface of the mould for smooth release of composite. The curing was done at room temperature for 24 hours. After 24 hours composites are removed and cut according to ASTM standard for evaluating various physical and mechanical properties.

*Table 1 Epoxy based composites reinforced with sisal fiber*

SET	Composition
Set 1	Neat Epoxy
Set 2	Epoxy + 3 % sisal fiber
Set 3	Epoxy + 6 % sisal fiber
Set 4	Epoxy + 9 % sisal fiber

Set 5	Epoxy + 12 % sisal fiber
Set 6	Epoxy + 15 % sisal fiber

### III. CHARACTERIZATIONS

Measurement and testing of composite was carried out in view of standard procedure and guidelines. Scanning electron microscope Carl Zeiss limited is used to study the surface morphology of the fiber reinforced composites. The experimental density ( $\rho_{ce}$ ) of composites is determined by the Archimedes principle using distilled water as a medium (ASTM D 792-91).

$$\rho_{ce} = \frac{\rho_w W_a}{W_a - W_w} \quad (1)$$

Here  $\rho_{ce}$  is the measured density of composite,  $\rho_w$  is the density of water,  $W_a$  is weight of sample in air and  $W_w$  is weight of sample in water. The theoretical density ( $\rho_{ct}$ ) of composite materials in terms of volume fractions of different constituents can easily be obtained using rule of mixture.

$$\rho_{ct} = \phi_f \rho_f + (1 - \phi_f) \rho_p \quad (2)$$

The volume fraction of voids in the composites is calculated by following equation:

$$V_v = (\rho_{ct} - \rho_{ce}) / \rho_{ct} \quad (3)$$

Here  $V_v$  gives the amount of voids present in the composite body.

Water absorption test were carried out according to ASTM D 570, to analyze the behaviour of composite in the presence of water affected environments and to assess the amount of water absorbed by the composite. In order to determine apparent gain in weight or amount of water absorbed by the specimen is calculated by the following equation.

$$\text{Percentage of water absorption} = 100 \times \frac{(W_2 - W_1)}{W_1} \quad (4)$$

Here  $W_1$  is the weight of the specimen in dried conditions and  $W_2$  is weight of specimen in wet condition (after 24 hours immersion in water).

The tensile test has been performed in universal testing machine (UTM) INSTRON H10KS. The standard test method as per ASTM D3039-76 has been used. The tests were performed with a cross head speed of 0.5mm/min. The three point bend test was carried out in Universal Testing Machine INSTRON 3382 in accordance with ASTM D2344-84 to measure the cross breaking strength of the composites. The cross breaking strength in a three point bending test is found out by using equation 5.

$$\sigma = 3FL/2bt^2 \quad (5)$$

where “ $\sigma$ ” is the cross breaking strength, F is the load, L is the gauge length, b is the width and t is the thickness of the test specimen.

Barcol hardness is measured by an instrument, called the Barcol impresser, gives a direct reading on a 0 to 100 scale. The hardness value is often used as a measure of the degree of cure of a plastic. ASTM D2583-67 barcol Hardness test method is used to determine the hardness of both reinforced and non-reinforced rigid plastics. Izod impact tests were performed to understand the toughness of material. The size of the specimen for the impact test was  $64 \times 12.7 \times 3.2 \text{ mm}^3$ .

### IV. RESULTS AND DISCUSSIONS

#### Density measurement

The densities of fabricated composites along with void content are shown in table 2. It can be seen that the density of composite decreases with increase in fiber content which is obvious because fibers are having very low density as compared to matrix material. This decrease in density value is desirable because with reduced

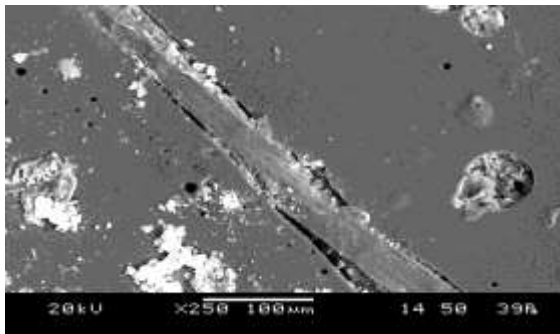
density the weight of the component reduces and is required for present application. The minimum density value achieved is  $0.95 \text{ g/cm}^3$  with 15 wt % of fiber content. It can also be noted from all the tables that the theoretically calculated density values are higher as compared to the measured values. The reason for this is, while calculating the density; it has been assumed that the composites are free from voids, but actually, fabrication of composites gives rise to a certain amount of voids within the composite body. The void fraction presented in the present investigation is calculated with the help of measured density and theoretical density.

**Table 2** Variation of theoretical and measured density with different fiber content

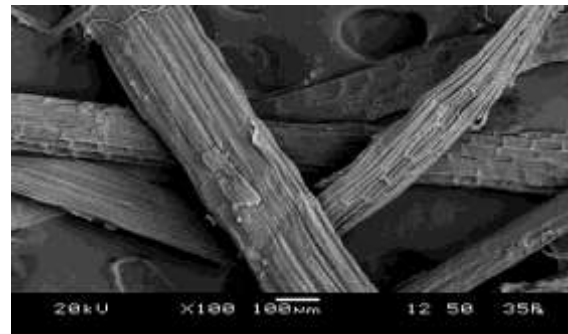
SET	Measured density ( $\text{gm/cm}^3$ )	Theoretical density ( $\text{gm/cm}^3$ )	Volume fraction of voids (%)
Set 1	1.2	1.2	-
Set 2	1.16	1.188	2.00
Set 3	1.11	1.176	5.00
Set 4	1.05	1.164	9.00
Set 5	1.01	1.152	12.00
Set 6	0.95	1.14	16.00

### Scanning Electron Microscopy

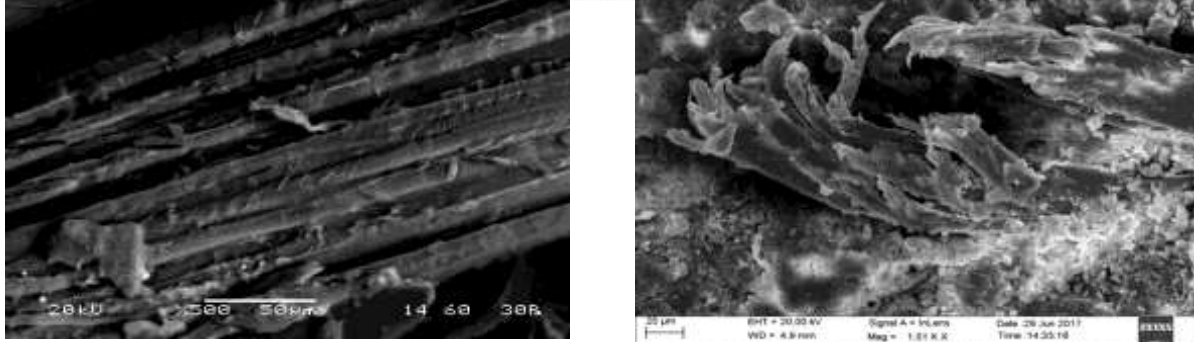
The properties of the composites are strongly affected by the compatibility between the matrix and filler phase. Figure 1 shows the morphologies of cross-section of composites reinforced with short sisal fiber. From the figures it is clear that the distributions of sisal fiber in epoxy resin for the fabricated samples are more or less uniform. Figure 1 a shows the adhesion between the fiber and matrix body. As the gap between the matrix and fiber is very less, this shows good adhesion between them. Figure 1 b shows the distribution of fiber within matrix body. Figure 1 c shows the magnified view of fiber and shows roughness on fiber surface which results in good adhesion between matrix and fiber. Figure 1 d shows the SEM image of composite after tensile test. This shows the cross section of break surface. From the figure the breakage of fiber and its pull out can be seen.



(a)



(b)



(c) (d)  
 Figure 1 Typical SEM images of sisal/epoxy composite

### Water absorption behaviour analysis

Weight of all sets of specimen is measured in dried condition, then specimens are dipped into normal water for 24 hour. After 24 hour, again weights were taken in wet condition. The various data obtained under both the conditions are shown in the table 3.

Table 3 Water absorption percentage in normal water of fabricated composites

SET	Weight of sample in dry condition $W_1$ (gm)	Weight of sample in wet condition $W_2$ (gm)	Percentage of water absorption (%)
Set 1	15.0	15.045	0.30
Set 2	15.0	15.051	0.34
Set 3	15.0	15.055	0.37
Set 4	15.0	15.058	0.39
Set 5	15.0	15.063	0.42
Set 6	15.0	15.069	0.46

The percentage of water absorption in normal water by composite specimen is recorded and from these values it is observed that as the fiber loading increases, water absorption increases. The maximum water absorption percentage is recorded for composite with maximum fiber loading i.e. set 6 and its values recorded to 0.46 % only. The results show that with higher fiber content has a greater diffusion coefficient, due to the fact that absorption of water is higher, as a result of a higher content of cellulose.

### Hardness

Surface hardness of the composites is one of the most important factors that directly concerned with the wear resistance of the composites. From figure 2 it is clear that, with the increase of fiber loading, hardness of the sisal-epoxy composites increases and reaches its maximum value of 51.3 at 15% fiber loading for composites for set 6. This increment is attributed to 150 %. This is attributed to the fact that hardness is a function of the relative fiber content and this may be due to the reason that increase in the weight percentage of the fiber within matrix body increases the ductility of the material which offers resistance for indentation.

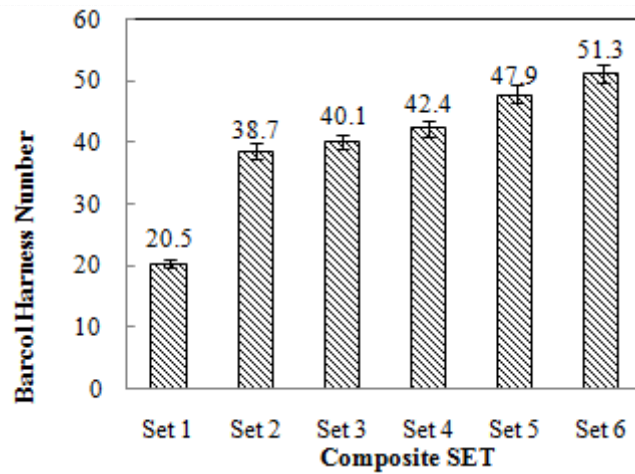


Figure 2 Barcol hardness numbers of composites

### Tensile strength

The tensile strength of different composites measured by universal testing machine with are shown in figure 3. From the figure it is observed that the tensile strength of composite decreases with increase in fiber content. Although the reported decrement in tensile strength is marginal. The minimum tensile strength reported is 42.6 MPa. The reduction in tensile strength with increase in fiber reinforcement may be due to the weak chemical bond between fiber and the matrix body which is unable to transfer the tensile load. This leads to increase in stress concentration and ultimately results in matrix cracking. Shorter fiber length will create more fiber ends, which eventually act as stress concentration points where failure often occurs at these sites.

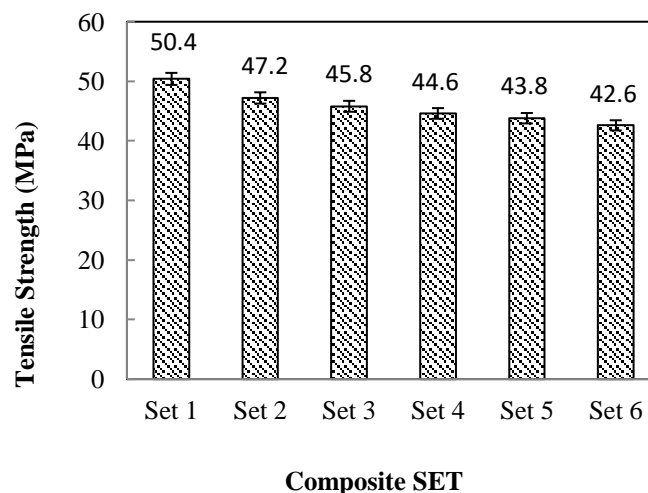


Figure 3 Tensile strength of the composites

### Cross breaking strength

The cross breaking strength of different composites measured by universal testing machine with ASTM D2344-84 are shown in figure 4. From the figure, it is clear that there is an increasing trend in cross breaking strength as the fiber contents in the composite increases. The maximum value for is 152.6 MPa for set 6. This is an increment of around 17 %. Increasing the fiber content in the composite increased the cross breaking strength of the composites and the strong interface between fiber and matrix results in composite with high cross breaking strength.

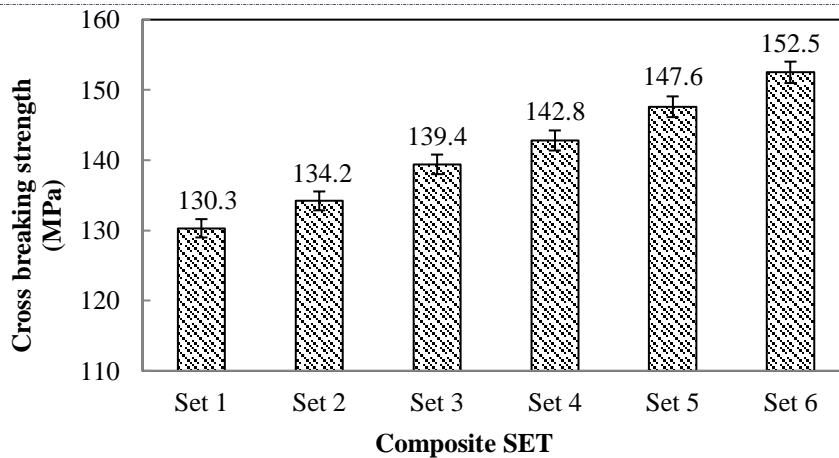


Figure 4 Cross breaking strength of composites

### Impact Energy

The effect of fiber content on the impact energy of the fabricated composite is shown in figure 5. It is observed from the figure that addition of fiber in the matrix leads to improved impact strength of the composites. The impact strength increases with the increase in the fiber loading of the composites. The maximum stored energy reported is 28.5kJ/m<sup>2</sup>. This increment is around 60 %. The gradually increasing trend in impact strength is due to the increase of fiber contents and also due to compression pressure which eliminates voids contents. The fiber play an important role in the impact strength, they resist the crack propagation and act as a load transfer medium. Improvement in impact strength of the composites is due to increments in fiber contents. The applied stress is transferred effectively due to effective interfacial bonding strength. The energy dissipation in fiber pull-out is much greater than the fiber fracture.

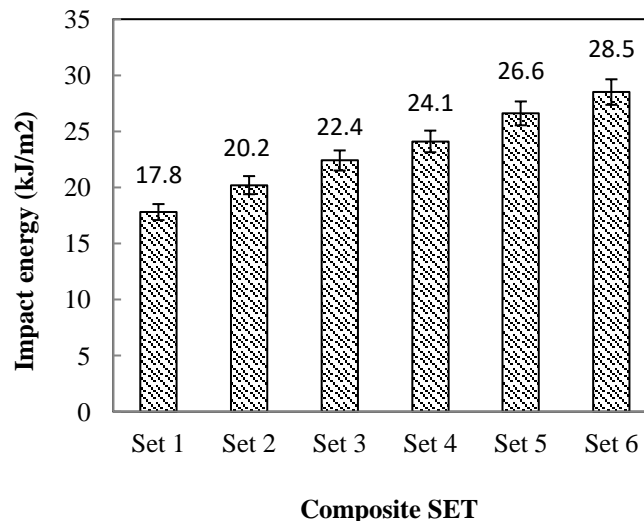


Figure 5 Impact energy of the composites

## V. CONCLUSIONS

From the present study the following conclusions can be drawn:

1. Micrographs of the fabricated composites confirmed the uniform distribution of fiber in matrix and good adhesion between them.
2. The fabricated composites were reported to possess low density compared to pure epoxy, so it can be considered as a useful light weight material. The density of the composite decreases with the increase in fiber content.
3. Percentage of normal water absorption falls within the limit of 0.5% for all sets of composites.
4. Hardness of the composite show increasing trend with the increase of fiber loading. Maximum Barcol hardness number observed 51.3 at 15% fiber loading. This is an increment of about 150 %.

5. On increasing the fiber content the tensile strength of the epoxy based composites decreases marginally. For maximum fiber reinforcement of 15 wt % gives the least value of tensile strength. The minimum tensile strength reported is 42.6 MPa
6. Cross breaking strength shows improvement with the increase in fiber content for all set of composites. At 15 wt% fiber reinforcement, with fire retardants cross breaking strength is 158.8 MPa which is 22 % higher than the pure epoxy respectively.
4. The impact energy of all sets of composite shows increasing trends with increase in fiber content. The maximum impact energy values reported is 28.5 kJ/m<sup>2</sup> at 15 wt % of fibre loading. This has an improvement of 60%.
5. The presently fabricated composites found its potential application in Indian railways i.e. for railways window assembly in non-air conditioned coaches sealed window glass holding arrangement in air conditioned coaches, internal furnishing components in Railway coaches, lavatory fittings in railway coaches and snack table, water holders, magazine bags, ladders etc

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