Physical and Mechanical Properties of Short Sisal Fiber Filled Epoxy Composites

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Abstract— The present work aims at developing a class of polymer composites consisting of thermoset polymer i.e. epoxy as a matrix material with natural fiber i.e. sisal fiber as a reinforcing material. The sisal fiber used in present work are in short form i.e. dimension of around 4 mm. A set of composite with varying fiber loading has been fabricated by simple hand lay-up technique. The effect of fiber content on physical and mechanical properties of such fabricated samples are investigated and presented in this work. The various property evaluated are density, void content, tensile strength, compressive strength and flexural strength of the fabricated samples. The values obtained under controlled laboratory conditions are analyzed to identify its behavior. From the experimental results, it is found that density of the composite decreases with increase in filler content. However, voids are increases when fiber content in epoxy matrix increases. Further, short inclusion in epoxy matrix increases the flexural and compressive strength of the composite. Against that, decreasing trend is obtained when tensile strength of the fabricated samples was analyzed.

Keywords: Polymer Matrix Composites, Epoxy, Sisal Fiber, Density, Mechanical Properties

I. INTRODUCTION

In the last few decades, natural fiber-reinforced polymer composites have received substantial attention in the field of research and innovation [1, 2]. Natural fibers in simple definition are fibers that are not synthetic or manmade. They can be sourced from plants or animals. Among the two natural fibers obtained, plants fibers find more potential application in polymer composites. Natural fibers obtained from plants are harvested from renewable resources and readily available at low prices. Their specific properties are comparable to synthetic fibers (e.g., glass fibers) that are traditionally used as reinforcing phases in polymer based composite materials [3, 4]. The plant, which produces cellulose fibers can be classified into bast fibers (jute, flax, ramie, hemp and kenaf), seed fibers (cotton, coir and kapok), leaf fiber (sisal, pineapple and banana), grass and reed fibers (rice, corn and wheat) and core fibers (hemp, kenaf and jute) as well as all other kinds (wood and roots) [5].

Fiber reinforced polymer composites are in great use because of the good properties and superior advantages of natural fiber over synthetic fibers in terms of its relatively low weigth, low cost, less damage to processing equipments, good relative mechanical properties, improved surface finish, renewable resources, being abundant, biodegrability and minimal health hazards [6]. On the other hand, natural fibers are not free from problems and they have notable deficits in properties. The natural fiber structure consists of cellulose, hemicellulose, lignin, pectin etc and permits moisture absorption from the surroundings which cause weak bindings between fiber and polymer.

Among the different types of natural fibers, sisal fibers is a promising reinforcement for use in composites on account of its low cost, low density, high specific strength and low modulus, no health risk, easy availability & renewability. In recent years there is increasing interest in finding new applications for sisal fiber composites that are traditionally used for making ropes, mats, carpets, fancy articles, etc. Suppakarn and Jarukumjorn [7] presented flame retardancy behavior sisal fiber reinforced polypropylene composites with and without using flame retardant material. In their study, they found that the addition of flame retardants into sisal/PP composites reduced burning rate and increased thermal stability of the composites. Martin et al. [8] studied thermal analysis of sisal fiber by thermogravimetric analysis and differential scanning calorimetry under air and nitrogen atmospheres. By both the above analysis they show that cellulose and hemicellulose degraded at lower temperatures than that of the raw sisal fiber, which can be attributed to the removal of lignin.

Zhou et al. [9] works on the development of polymeric composites reinforced with sisal fibers. The main aim of their work is to propose a composite material which will be stronger so that can used in place of timber structures. They present the mechanical characterization of composites under study. In a more recent work, Fiore et al. [10] proposed another method for improving the surface properties of sisal fiber. They utilized eco-friendly and cost effective surface treatment method based on the use of commercial sodium bicarbonate (i.e. baking soda) on properties of sisal fiber and its epoxy composites. Ramesh et al. [11] fabricated hybrid composites with a combination of synthetic and natural fiber. They used sisal and jute fiber as natural fiber and glass fiber as synthetic fiber in their study. They reinforced the combination of these fibers in polyester resin and fabricated a new class of composites.

Orue et al. [12] studied the effect of different chemical treatments on sisal fiber as well as on tensile properties of their composites with poly lactic acid (PLA) as a matrix material. Among the various treatment agent, alkali treated fibers showed the highest tensile strength values. More recently, Dwivedi et al. [13] fabricated and studied the behavior of hybrid composite with carbon nanotubes and sisal fiber as reinforcement in epoxy resin. They investigated the electrical properties of the fabricated composites. In a very recent work, Prasad et al. [14] studied the impact strength of sisal fiber polyester composites. For this study, they used treated and untreated sisal fiber as reinforcement. Against this background, an attempt has been made in this research work to develop short sisal fiber (SSF) based epoxy composites using simple hand lay-up technique and to study their physical properties i.e. density and void content and mechanical properties i.e. tensile strength, flexural strength and compressive strength with varying fiber content.

II. MATERIAL CONSIDERED

Thermoset resin Lapox L12 is a liquid, unmodified epoxy resin of medium viscosity is used as the matrix material in present investigation. It is used with its corresponding hardener which is a low viscosity room temperature curing liquid. Hardener K6 is commonly employed with Lapox L12. Epoxy used in present investigation possesses density of 1.1 g/cc, tensile strength of 48 MPa, compressive strength of 91 MPa and flexural strength of 118MPa.The sisal fiber used in present work was extracted from the leaf of the plant Agave-Sisalana which is available in plenty in the Southern part of India. It is an herbaceous monocotyledonous plant from the Agavaceae family that consists of a rosette of sword-shaped leaves about 100–150 cm tall and 13–15 cm wide. A sisal plant has a 7–10 year life-span and produces about 200–250 leaves. When the plant completed two year of its growth, the fiber can be extracted from sisal leaf. By this this they reach a length of 80-100 cm. Among the various natural fibers, sisal fiber is chosen in present work because it is easily and cheaply available. Also it possesses reasonably good physical and mechanical properties.Sisal fiber possesses density of 0.75 g/cc and tensile strength of 511 MPa.

III. SAMPLE PREPARATION

In the present investigation, short fiber reinforced polymer composite is fabricated using simple hand lay-up technique. The fabrication of composite using hand lay-up method involves following steps:

1) The room temperature curing epoxy resin epoxy resin (L-12) and corresponding hardener (K-6) are mixed in a ratio 10:1 by weight as recommended.
2) Sisal fiber in its short form with approximate size of 3 mm will then added to the epoxy-hardener combination and mixed thoroughly by hand stirring.
3) Before pouring the epoxy/filler mixture in the mould, a silicon spray is done over the mold so that it will easy to remove the composite after curing. The uniformly mixed dough is then slowly poured into the mould so as to get the specimens as per ASTM standard for the entire characterization test.
4) The cast is than cured for 8 hours before it was removed from the mould. In this process exothermic reaction between the matrix and hardener occur which hardened the composite body in this specified duration.

Composites were fabricated with different weight fraction of filler ranging from 0 to 10 wt. %. The list of fabricated composite in present work is presented in table 1.

IV. EXPERIMENTAL DETAILS

The experimental density (ρ_{ce}) of composites under study is determined by using Archimedes principle using distilled water as a medium (ASTM D 792-91).The theoretical density (ρ_{ct}) of composite materials in terms of weight fractions of different constituents can easily be obtained using rule of mixture model. Comparison of experimental and theoretical density gives voids generated during fabrication of composites. The tensile strength of the composites is measured with a computerized Instron 1195 universal testing machine in accordance with ASTM D638 procedure by applying uni-axial load through both the ends at a cross head speed of 2 mm/min. The specimens used in present investigation to perform all the tensile tests are of dog-bone shape (length 115 mm, end width 19 mm, mid width 6 mm and thickness 3.2 mm) having both the surface flat. Static uniaxial compression tests on specimens are carried out using the same computerized universal testing machine. For performing the test, two 50 mm diameter hardened-steel compression platens are mounted on this testing machine with compression fixture. The method by which the compression test is conducted is in accordance with ASTM D695. The typical cylinder blocks used for these tests are 12.7 mm in diameter and 25.4 mm in length. The standard requires that the specimen is compressively loaded at a rate of 2 mm/min until fracture. The flexural test measures the force required to bend a beam under three point loading conditions. The three point bend test was carried out in Universal Testing Machine (UTM) in accordance with ASTM D790 to measure the flexural strength of the composites. Most commonly the specimen lies on a support span and the load is applied to the center by the loading nose producing three points bending at a specified rate. The parameters for this test are the support span, the speed of the loading, and the maximum deflection for the test.The test is stopped when the specimen reaches 5% deflection or the specimen breaks before 5%.

S.No.	Set	Composition
1	Set 1	Neat Epoxy
2	Set 2	Epoxy + 2 % by weight SSF
3	Set 3	Epoxy + 4 % by weight SSF
4	Set 4	Epoxy + 6 % by weight SSF
5	Set 5	Epoxy + 8 % by weight SSF
6	Set 6	Epoxy + 10 % by weight SSF

Table 1: List of fabricated composites

V. RESULTS AND DISCUSSION

A. Density

With the help of Archimedes method, density of neat epoxy is predicted as 1.2 g/cm^3 which match with the value of density provided by the supplier. The densities of the reinforced composites were also evaluated theoretically. For this a well-known rule of mixture model is used. From the measured and the theoretical values, the amount of air got trapped while fabricating the composites can be evaluated. All the three values, i.e. theoretical values, measured values and the corresponding void content were presented in table 2. From the table it was observed that density of the composite decreases when sisal fiber was added in epoxy matrix. Also, this value of density continuously decreases with the further increase in fiber content. From the table it can be observed that for maximum content of filler, the density of the composite reduces to 0.97 g/cm^3 when sisal fiber were used as reinforcement. This is a decrement of 11.8 % in density as compared to neat epoxy. The decrease in density with fiber content is gainful finding as it reduces the overall weight of the component made from the developed material compared to when it is made from pure matrix.

Set No.	Theoretical density (g/cm^3)	Measured density (g/cm^3)	Void content (%)
Set 1	-	1.1	-
Set 2	1.089	1.06	2.73
Set 3	1.079	1.04	3.68
Set 4	1.070	1.01	5.61
Set 5	1.060	0.99	6.64
Set 6	1.050	0.97	7.70

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

Further, it can also be noted from the tables that the calculated values are higher as compared to the values obtained from experimentation. Also it is observed that void content slightly increases with filler content. The maximum void content is of 7.70 % when 10 wt. % of fiber is used in epoxy matrix. Although maximum possible measures were taken to minimize the percentage of void fraction, but composites were fabricated by hand lay-up method, hence generation of voids in the composite cannot be avoided.

B. Tensile Strength

The tensile strength of all the fabricated samples are measured by universal testing machine. The results obtained after the experimentation are plotted and shown in figure 1. From the figure it can be seen that the ultimate tensile strength of the fabricated composite decreases with increase in fiber content. The minimum tensile strength among the various fabricated samples was of sample with 10 wt. % of short sisal fiber. Its values were reported to be of 40.5 MPa which is an decrement of around 15.6 %. The presence of hydroxyl and other polar group in sisal fiber makes them exhibit highly hydrophilic properties which leads to incompatibility and poor wettability in a hydrophobic polymer matrix, thus weak interfacial properties consequently lower the tensile strength.

C. Compressive Strength

The dependence of compressive strength of epoxy composites reinforced with short sisal fibers with different fiber content shown in figure 2. It can be seen from the seen that with increase in fiber content, compressive strength of the composites increases. The compressive strength of neat epoxy is 91 MPa which increases to 112.3 MPa at a loading of 10 wt% of short sisal fiber. This is an appreciable increment of 23.4 %. The improvement in compressive strength with fiber addition is mainly because of the high compressive strength of fiber material. Also, the increase in compressive strength with increased fiber content is due to the favorable deformation processes facilitated by the presence of fiber in the matrix. Under a compressive loading situation, the fiber apparently aid the load bearing capability of a composite, rather than acting as stress raiser as is the case in tensile loading. Further, the fact that in a compression test, any crack or flaw introduced by dispersion of the fiber will, if at all, get healed (closed) and made ineffective, contrary to the crack opening mechanism occurring in a tensile loading situation.

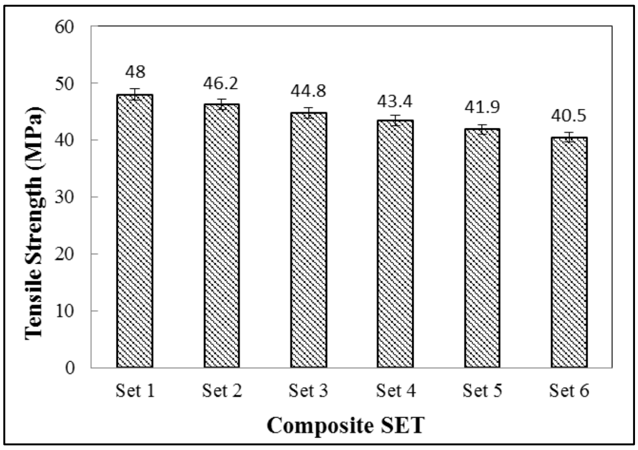

Fig. 1: Tensile strength of epoxy/short sisal fiber composites

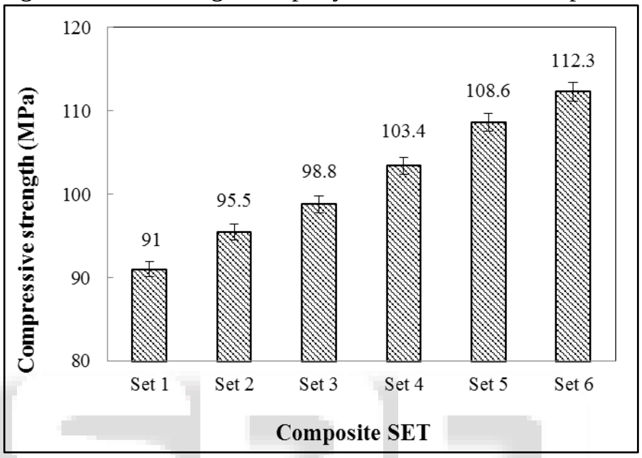

Fig. 2: Compressive strength of epoxy/short sisal fiber composites

D. Flexural Strength

Composite materials used in structures are prone to fail in bending and therefore development of new composites with improved flexural characteristics is essential. In the present work, the variation of flexural strength of epoxy based composites reinforced with short sisal fiber with respect to the content of sisal fiber is shown in figure 3. It is observed from the figure that there is a gradual increase in the value of flexural strength with increase in short sisal fiber content in epoxy resin.

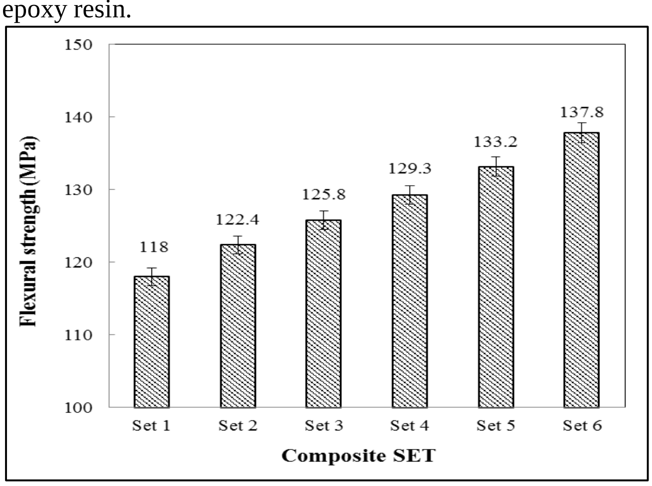

Fig. 3: Flexural strength of epoxy/short sisal fiber composites

The maximum value of flexural strength for epoxy composite with sisal fiber is reported to be 137.8 MPa for 10 wt % of fiber. This is an increment of 16.6 % over neat epoxy resin. It can be seen that the flexural properties of the samples can be explained on the basis of the changes in chemical interaction at the fiber-matrix interaction. This results in the improvement of flexural properties of the composites and increases the value of the developed material.

VI. CONCLUSIONS

This experimental investigation on short sisal fiber reinforced epoxy composites has led to the following specific conclusions:

1) The density of the fabricated composites decreases with increase in weight fraction of the fiber content. The reduction in density is mainly because of low density of fiber. With increase in fiber content, void content of the composite also increases. The maximum void content is 7.70 % maximum fiber content of 10 wt. %.
2) The water absorption rate increases with increase in fiber content and duration of immersion of composite body inside the water. With fiber maximum absorption rate is 10.5 % with 10 wt % fiber for duration of 96 hours.
3) On increasing the fiber content the tensile strength of the epoxy based composites decreases marginally. For maximum fiber reinforcement of 10 wt % gives the least value of tensile strength. The minimum tensile strength reported is 40.5 MPa for maximum fiber content.
4) The compressive strength of the fabricated composite increase with increase in fiber content. The maximum value of compressive strength for epoxy composite with 10 wt. % sisal fiber is reported to be 112.3 MPa. This is an increment of 23.4 % over neat epoxy resin.
5) The flexural strength of the fabricated composite increase with increase in fiber content. The maximum value of flexural strength for epoxy composite with 10 wt. % sisal fiber is reported to be 137.8 MPa. This is an increment of 16.6 % over neat epoxy resin.

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