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# Physical Properties Tensile, Compressive and Water Absorption for Epoxy Composite Reinforced With Sisal Fiber

Vaishali Gupta

Ph. D. Scholar

PK University, Jhansi, (U.P.), India.

**Abstract-** *This work explores the possible utilization of sisal fiber i.e. a natural fiber, in the form of short fiber in polymer composites and assesses its reinforcing potential. This experimental investigation on short sisal fiber/epoxy composites has led to the following specific outcomes: sisal fiber possesses ample reinforcing potential to be used as a filler material in epoxy matrix composites. Successful fabrication of epoxy matrix composites reinforced with short sisal fiber is possible by simple hand-lay-up technique. These composites possess low amount of porosity with reduced density, low water absorption rate, improved compressive and flexural strength and reduced loss of material because of wear. The sisal fiber-epoxy composites fabricated and experimented in this investigation are found to have adequate potential for a wide variety of applications. Manufacturing of light weight sports goods such as: cricket bat, tennis racquets etc. are few such examples. However, the weight fraction of fiber in the composite is to be decided from the view point of required strength. If the place of use is hostile, then sisal fiber epoxy composites are to be preferred due to their fairly good mechanical and wear characteristics. Use of these composites may be suggested in automotive industries as most of the car companies in the world have done a lot of investigation in order to insert the NFPCs in their products. Its main use in automotive industries specially in car interior such as seat backs, parcel shelves, boot linens, front and rear door linens, truck linens, and door-trim panels.*

**Keywords:-** Epoxy, Sisal fiber, Properties, Density, Tensile strength, Compressive strength.

## I. Introduction

### 1.1 General Objects and Limits

It is difficult to draw a building material to assess the strengths and weaknesses of metals, plastics and clay because each of these terms covers all families of objects where the scope of buildings is usually as wide as the differences between the three classes. Comparison in general terms, however, may point to some of the obvious advantages and disadvantages of different types of assets. At the simplest level then:

Plastics have very low material content. They have good chemical resistance for a while but have no thermal stability and have only a moderate resistance to environmental degradation. They have bad mechanical properties, but they are easily made and assembled. Clay materials can be of low size (although some are very dense). They have high heat resistance and are resistant to many types of attacks (abrasion, wear, rust). Although they are extremely strong and durable due to their chemical composition, they are all shy and can only be built and molded with difficulty.

Metals are mostly medium to high in size. Many have good thermal stability and can be made to resist corrosion by bonding. They have useful properties and high hardness, and are moderately easy to join. It is largely due to their inefficiency and resistance to cracking that metals, as a class, became (and remained) popular materials.



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On the basis of the above comparisons it can be seen that each category has certain internal advantages and disadvantages, although the polymer presents fewer problems to the designer than steel or clay vessels.

### **1.2 Introduction to Consolidation Materials**

The scarcity of common materials has forced the scientific community to work on another matter of material and after intensive research they came out with a composite material. A compound is defined as any combination of two or more different elements. If you look at this definition, it will include bricks, concrete, wood, bone and modern man-made compositions such as plastic reinforced with long or short wire. The man-made combination took a huge market fifty years ago, when low-rise building combined with high strength and durability was a concern. Apart from the above definition of integration, in addition three other methods must be met before we can call an asset a combination. First of all, all the elements that make up a combination must be present in the right proportions. Second, all components used to make a composite must have different properties so that the composite structures differ significantly from the sand structures formed by the impact of any single component which must not first control the composite structures. Finally, synthetic compounds are usually produced by deliberate mixing and combining of elements in various ways [1].

Combined materials increase the range of designers across all engineering branches. Compounds are grouped in a way that will help us make the most of their beauty while minimizing the effects of their failures. This process of excellence can free the designer from the problems associated with the selection and production of standard materials. They can use solid and lightweight materials, with structures designed to fit specific design requirements. And because it is so easy to make complex designs, a complete rethinking of a composite design can lead to both cheaper and better solutions [2]. Compound materials create expertise that can be acquired by the materials scientist and his clients, a design engineer. Also, according to the same definition, two or more different categories mean that they must have a chemically intermediate phase and it is also important that the specification of these components is possible in any way. Between the two distinct elements there should be a continuous phase that usually occurs in large quantities in the compound, though not always. This continuous phase is called the matrix. A common theory is that it is the matrix characteristics that are developed when another component is produced to integrate. Some elements are known as the reinforcement phase. In many cases reinforcement is harder, stronger and stronger than the matrix, although there are some exceptions. The geometry of the reinforcement phase is one of the major constraints in determining the performance of reinforcement; in other words, composite machine structures are a function of the shape and size of the reinforcement. The separation of composites can be done in two different phases, first on the basis of the matrix material as shown in below figure, where there may be metal composites, ceramic matrix composites and polymer matrix composites. It is evident that the polymer matrix has also been divided into thermo-set compounds and thermoplastics compounds properties of composites are a function of the shape and dimensions of the reinforcement. Classification of composites can be made in two different categories, first on the basis of matrix materials as shown in below figure, in which it can be metal matrix composites, ceramic matrix composites and polymer matrix composites. It is observed that polymer matrix is further categorized as thermo-set composites and thermoplastics composites.

## **II. Materials**

### **2.1 Epoxy**

The most popular epoxy monomers are those found in the reaction of bis (4 -hydroxy phenylene) - 2,2 propane (called bisphenol A) and 1 - chloroprene 2 - oxide (called epichlorohydrin), in the presence of sodium hydroxide. The composition of the main product, bisphenol Adiglycidyl ether (DGEBA or BADGE) and its



derivatives depends on the stoichiometry of the reactants. Conventional monomers (“resins”) are sold at n prices ranging from 0.03-10 in diameter.

At room temperature these monomers are crystalline solid for n values close to zero, liquids for n values up to n = 0.5, and amorphous solid (glass changing glass,  $T_g \sim 40 - 90^\circ \text{C}$ ) at high values n . Another large group of epichlorohydrin-derived epoxy monomers is that they contain monomers composed of amine-containing odors, such as methylene dianiline (TGMDA). Oxirane groups can be formed by carbon peroxidation - carbon double bond. Types of such oligomers are poxidized oils or cycloaliphatic oxides.

Epoxy monomers containing vinyl groups, such as glycidyl (meth) acrylate or glycidylstyrene, can be used for the synthesis of active oligomers. Direct or detached epoxy polymers are obtained by the reaction of co-monomers with co - monomers (“hardeners”) and / or initiators. Epoxy polymers can be produced step by step or by hundreds of planks or, finally, by a combination of both methods. Step-by-step polymerization growth continues in a step-by-step sequence of basic responses between active sites. Each independent step results in the disappearance of two co-operative sites and creates a new bond of cooperation between the working groups.

The number of active sites per monomer (performance) and the molar ratio between the interactive sites are the main parameters that govern the polymer structure. To get straight polymers, reactants must work well; Mono-functional responses disrupt polymer growth. The condition for finding cross-linked polymers is that at least one of the monomers has a higher performance than 2.

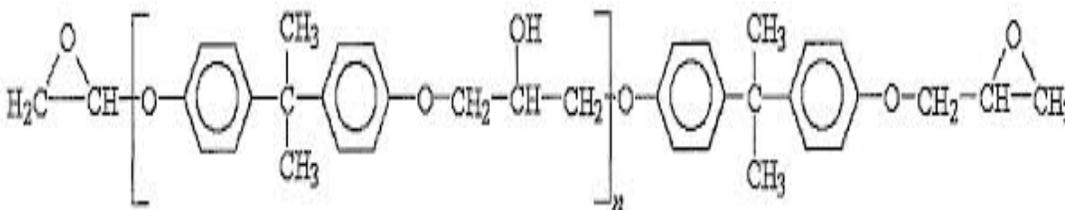


Figure 2.1: Epoxy resin chain.

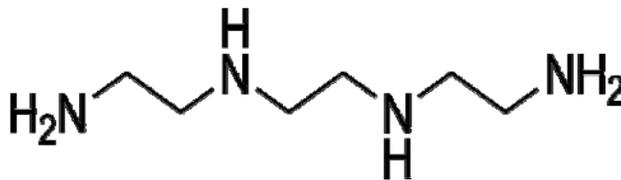


Figure 2.2: Tri-ethylene-tetramine chain.

Chain - polymerization growth is characterized by initiation, distribution, chain transfer and termination steps. In the case of epoxies, the initiation step produces an ion (either an anion or a cation) called an active polymerization center. Ion can be produced by chemical reactions or by a sufficient source of radiation. As soon as the functional centers produce the main chains by sequencing the monomers with a diffusion response step. Since functional centers are always present at the end of key chains, the distribution response continues until interrupted by a chain transfer step or a termination step.

The main parameters that control the formation of polymer are monomers, the molar ratio between the starter and the monomers, the interaction of the species involved in the chain transfer steps, and the temperature (hot



cycle) affecting the corresponding levels of various steps. The structure of the currently used chains of epoxy resin is shown in Figure 3.1.

**Table 2.1:** Characteristic Property Epoxy.

Characteristic Property	Values	Units
Density	1.1	g/cm <sup>3</sup>
Tensile strength	50	MPa
Tensile modulus	3.4	GPa
Compressive Strength	91	MPa
Impact Energy	17	kJ/m <sup>2</sup>
Micro-hardness	0.087	GPa

## 2.2 Reinforcement Material

The sisal fiber used in the current work is derived from the leaf of the Agave-Sisalana plant which is abundant in the southern part of India. It is a herbaceous mono cotyledonous plant from the Agavaceae family with a rosette of sword-shaped leaves about 100-150 cm long and 13-15 cm wide. The sisal plant has a life span of 7-10 years and produces about 200-250 leaves. When the plant has been growing for two years, the fiber can be extracted from the sisal shell. With this they reach a height of 80-100 cm.



**Figure 2.3:** Sisal plant, long and short sisal fiber.

At this time, while attaining the respective length, they give high extraction rate and also provide superior mechanical properties. During the process of extraction, which is known as decortication, sisal leaves are crushed and beaten until only the fibers remains. Later the fibers are dried, classified and baled after the pectin and impurities are washed off. The extracted fibres are generally ivory or cyan in colour with a length of no less than 80 cm. It is having a diameter varying between 170-300 micro-meters. A pictorial view of sisal fiber plant and extracted fiber from that plants are shown in figure 3.4. The impurities and water contents of the fibers should be less than 3% and 10% respectively. The main chemical constituents of sisal fiber are given in Table 3.2.

**Table 2.2:** Chemical constituents of sisal fiber [21].

Chemical constituent	Weight (%)
Cellulose	67-78
Hemi cellulose	11-15
Pectin	10-11
Lignin	8-11
Wax	2-2.5

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. The various physical and mechanical properties of sisal fiber used in present investigation are presented in Table 3.3.

**Table 2.3:** Important properties of sisal fiber [22].

Characteristic Property	Values	Units
Density	0.75	g/cm <sup>3</sup>
Elongation at break	2-2.5	%
Tensile strength	556	MPa
Young 's modulus	9.4-22	GPa
Water absorption	11	%

Traditionally, sisal fiber is used for the manufacture of ropes, twines, and general cordages due to its strength and durability. The fibers are mainly divided into three categories, first the low-grade fiber with high cellulose and hemi cellulose content is utilized in the paper industry. Second is the medium-grade fiber is used in the cordage industry for making ropes, baler and binder twine, which are widely employed for marine, agricultural and general industrial uses. Third is the high-grade fiber after treatment is converted into yarns and used by the carpet industry. In recent years sisal fiber has been utilized as an environmentally friendly reinforcement to replace asbestos and fiber glass in making composite structures in various applications, such as the automobile industry. In our work we used first category of fiber i.e. raw fiber.

### III. Experimental Work

#### 3.1 Composite Fabrication

In the present investigation, short fiber reinforced polymer composite is fabricated using simple hand lay-up technique. Hand lay-up is generally an open molding technique of composite fabrication. Though production volume will be low in this method but it is feasible to produce substantial production quantities using multiple molds. This method is considered as the simplest technique for composite fabrication. 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 3.1.

**Table 3.1:** List of epoxy based composites filled with short sisal fiber.

Sr. 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



**Figure 3.1:** Pictorial views of some fabricated samp.

This chapter presents the measured values of various physical, mechanical and tribological properties of the short sisal fiber reinforced epoxy composites. The effects of short sisal fiber content on composite properties have been discussed in detail.



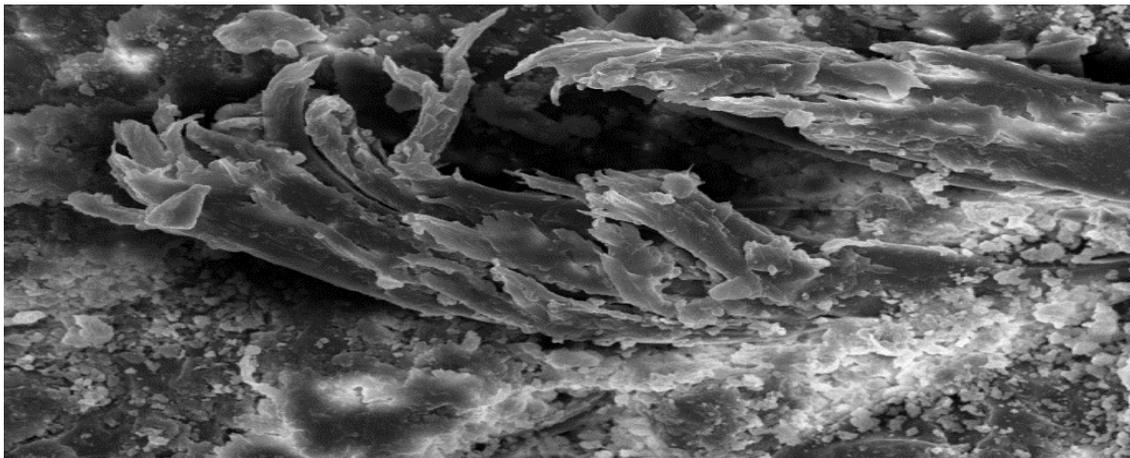
### 3.2 Physical Characteristics

Assessment of the physical behavior of developed composite body is necessary for applied applications. In the present work, a property data has been generated by conducting various tests under controlled laboratory conditions to evaluate properties of composites under study.

#### 3.2.1 Scanning Electron Microscopy

The properties of the composites are strongly affected by the compatibility between the matrix and filler phase. In order to assess this fiber-matrix interaction, the dispersion of fiber in the matrix body and bonding between the fiber and the matrix are observed under scanning electron microscope (SEM). Figure 3.1 shows typical SEM images of composites used in the present work.

Figure 3.1 shows the morphologies of cross-section of epoxy 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. It can also be observed from SEM images that further increase of fiber content in matrix material beyond 10 wt.% is quite difficult task, as increase in filler content reduces its flow ability and results in various fabrication defect. This shows the cross section of break surface. From the figure the breakage of fiber and its pull out can be seen. From the figure it is clear that during breaking also, resin does not leave the fiber and pull out is very marginal. This is a clear evidence of compatibility between fiber and matrix which results in good composite.



**Figure 3.2:** Typical SEM images of sisal/epoxy composite.

With the help of Archimedes method, density of neat epoxy is predicted as  $1.2 \text{ g/cm}^3$  which match with the value of density provided by the supplier. Hence, for evaluating the density of presently fabricated composites, All the three values, i.e. theoretical values, measured values and the corresponding void content were presented in table 3.1. 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. This decreasing trend in the value of density is obvious as the intrinsic density of fiber is less as compared to the intrinsic density of the epoxy. From the table it can be observed that for maximum content of filler, the density of the composite reduces to  $0.97 \text{ g/cm}^3$  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.

**Table 3.2:** Variation of theoretical and measured density with different fiber content.

Set No.	Theoretical density (g/cm <sup>3</sup> )	Measured density (g/cm <sup>3</sup> )	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

Further, it can also be noted from the tables that the calculated values are higher as compared to the values obtained from experimentation. The main reason behind this is when we are working on theoretical calculation; we are not concern about the amount of voids generated, as theoretical formula not considered its content, whereas we have seen that fabrication of composite will always give rise to certain voids. We know that density of voids will always be less than the density of composites. While doing experimentation the effects of voids were also come into play and we get reduced density of composite than theoretical. 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.

### 3.2.3 Water absorption behavior

The samples are immersed in water for duration of 96 hours. Prior to that, each sample was made to a square shape of (10 x 10 x 3) mm specimen having 10 gm of weight for simplifying the problem. Mainly the test was conducted in normal water. At the end of each 24 hours, samples are taken out of the water and their weight is noted.

**Table 3.3:** Weight of wet samples at different time of water immersion.

Set No.	Weight of sample in dry condition W <sub>1</sub> (gm)	Weight of sample in wet condition W <sub>2</sub> (gm) after 24 hour	Weight of sample in wet condition W <sub>2</sub> (gm) after 50 hour	Weight of sample in wet condition W <sub>2</sub> (gm) after 72 hour	Weight of sample in wet condition W <sub>2</sub> (gm) after 96 hour
Set 1	10 gm	10.06	10.11	10.14	10.14
Set 2	10 gm	10.10	10.22	10.33	10.34
Set 3	10 gm	10.13	10.38	10.54	10.55
Set 4	10 gm	10.18	10.49	10.63	10.64
Set 5	10 gm	10.22	10.61	10.79	10.81
Set 6	10 gm	10.27	10.68	11.04	11.05

**Table 3.4:** Water absorption percentage of wet samples at different time of water immersion.

Set No.	Percentage increase in weight after 24 hour	Percentage increase in weight after 50 hour	Percentage increase in weight after 72 hour	Percentage increase in weight after 96 hour
Set 1	0.6 %	1.1 %	1.4 %	1.4 %
Set 2	1.0 %	2.2 %	3.3 %	3.4 %
Set 3	1.3 %	3.8 %	5.4 %	5.5 %
Set 4	1.8 %	4.9 %	6.3 %	6.4 %
Set 5	2.2 %	6.1 %	7.9 %	8.1 %
Set 6	2.7 %	6.8 %	10.4 %	10.5 %

the data related to the weight of the sample at the end of each 24 hour and the corresponding increase in water absorption percentage with filler content and with immersion time. It can be seen from the table that the weight of the sample increases when immersed in water as the fiber content in the composite increases. This increase in weight with time attained a saturation value after duration of approximately 50 hour and later no noticeable increase in weight is registered with immersion time. The time taken to reach a saturation point was almost same for all sets of composites. The reason for increasing the water absorption rate with fiber content is because it made more amount of fiber to come in contact with water and also increase in fiber content result in incomplete encapsulation of fiber by the resin. Also, the formation of micro-cracks at the interface region, induced by fiber swelling, can increase the diffusion transport of water via them. Furthermore a capillarity mechanism becomes active, water molecules flow through the interface of fiber and matrix, leading to greater water absorption. The maximum absorption of water for 10 wt. % fiber sample occurs at 10wt % fiber and is of 10.1 %.

#### IV. Conclusion

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

1. Successful fabrication of epoxy matrix composites reinforced with short sisal fiber is possible by simple hand-lay-up technique.
2. 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. %.
3. 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.
4. 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 40.2 MPa for maximum fiber content.



5. 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 111.5 MPa. This is an increment of 23.4 % over neat epoxy resin.

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