Physical Properties of Banana Fiber Filled Epoxy Composites

Mohd Shaver[1] Amit Kaimkuriya[2]
[1,2]Department of Mechanical Engineering
[1,2]Millennium Institute of Technology, Bhopal, India

Abstract— Banana fiber of around 4 mm length were incorporated in epoxy matrix in present work. Composite were fabricated in six different sets using simple hand lay-up technique. The fiber content varies in between 0 wt% i.e. neat epoxy and 15 wt % for fabricating the different sets of composites. The main emphasis of the present work is on the general trends observed in their physical properties i.e. density, void content and water absorption rate. Water absorption rate is analysed with respect to fiber content and immersion time both. Further, effect of treatment of fiber with NaOH in the various physical properties of the fabricated composite is studied in detail.

Key words: Polymer Matrix Composites, Epoxy, Banana Fiber, Density, Voids, Water Absorption Rate

I. INTRODUCTION

Human beings are exclusively depends upon plants and its fibers for their requirements. In this regards, use of natural fibers are increasing gradually in industrial and human applications. Composite are prepared either by synthetic fibers or by natural fibers. Now going with eco-friendly, decomposable and monetary scenario natural fibers are flagrantly used in place of synthetic fibers. The natural fiber possesses various unique characteristics. There is a long list of natural fibers available in nature which is being used by various researchers to develop new class of composite material.

The use of natural fiber as a filler material in composite was earlier reviewed by Saheb and Jog [1] in late 90's as natural fiber reinforced composites was emerging area at that time in the field of polymer science. Among the type of fiber, treatment of fibers and interface of fiber and matrix. Komuraiah et al. [2] presented the chemical composition of natural fibers and the effect of it in various mechanical properties. They reported that the main components of natural fibers are cellulose, hemicellulose, lignin, pectin and wax. They further studied that the composition of these natural fibers were primarily dependent on the geographical location where the plants are grown up. Mohammed et al. [3] reviewed widely used natural fiber reinforced polymer composites and their applications. They also discussed the effect of different chemical treatments applied to the natural fibers when they reinforced in various polymers. Impacts of surface modification on various properties like water absorption, tribology, viscoelastic behavior, relaxation behavior, flames retardancy, and biodegradability properties of NFPCs were also discussed in their article. Machado et al. [4] present an overview of physical and mechanical properties of natural fiber reinforced composites. They studied the effect of service condition on the properties of such composites. They studied the behavior of composites when it was used for short term application and for long term application. Fan and Fu [5] in their study first classified the type of natural fiber that can be used for construction purpose. Then on the basis of identification of various applications in construction site, they explore the hierarchical structure of such natural fibers.

Apart from various natural fibers, it has been seen that banana fiber has good specific strength properties comparable to the synthetic fiber i.e. glass fiber. This is the main reason banana fiber in its long form were used as reinforcement in polymers and were investigated by many researchers in past. In this series Liu et al. [6] used banana fiber in high density polyethylene in their study and evaluated the morphological, water absorption and thermal stability of the fabricated samples. Later Paul et al. [7] used banana fiber in the form of short length and incorporated it in polypropylene fiber. Prior to that, they modified the surface of banana fiber with various chemical treatment to provide good adhesion between fiber and matrix body. They used solvatochromic technique for investigating the polarity parameters of the chemically modified banana fiber. After that they observed that the polarity of the banana fiber was decreased after the chemical treatment. The adhesion between the matrix and fiber were increased drastically as observed by micrograph by them. The most effective treatment was alkali treatment as reported in their study. Raghvendra et al. [8] also used banana fiber in its short form but not with any plastic. They incorporated the fiber in rubber and established natural rubber based composites. They studied the mechanical properties of the fabricated composites. Venkateshwaran et al. [9] found that fiber length and its content were the most influential factor which determines the mechanical properties of the composites. In their study, they optimize the length of the fiber and produce a set of composites with varying content of fibers. The optimized results give best mechanical properties which include tensile strength and modulus, flexural strength and modulus and impact strength. Apart from that, they also study the water absorption behavior of the fabricated composite and found that length of the fiber is not a factor on which water absorption depend, rather it increases with increase in fiber content. Ramesh et al. [10] were also fabricated banana fiber reinforced polymer composites with thermoset polymer epoxy and experimentally determined its mechanical properties. Jorden et al. [11] improves the interfacial bonding between banana fiber and LDPE matrix with the help of chemical treatment. They used two different techniques for fiber treatment i.e. peroxide treatment and permanganate treatment. Muktha, and Gowda [12] focused their work on water absorption and fire resistance behavior of banana fiber reinforced polyester composites. They prepared specimen of two different thicknesses i.e. of 3 mm and 5 mm with same fiber volume fraction. In their analysis they found that water absorption and fire resistance capacity of 3 mm thick specimen is less than that of the 5 mm thick specimen. Against this background, an attempt has been made in this research work to develop short banana fiber (SBF) based epoxy composites using simple hand lay-up technique and to

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study their density, void content and water absorption rate with varying fiber content.

II. MATERIALS & METHODS

A. *Material Considered*

The epoxy resin Lapox-12 is used in the present work which belongs to the epoxide family. Bisphenol-A-Diglycidyl-Ether (commonly abbreviated to DGEBA or BADGE) is the common name of the presently used epoxy. It provides a solvent free room temperature curing system when it is combined with the hardener tri-ethylene-tetramine (TETA) which is an aliphatic primary amine with commercial designation HY 951. The various physical and mechanical properties of epoxy resin are presented in Table I.

Characteristic Property	Values	Units
Density	1.2	g/cm^3
Tensile strength	55	MPa
Cross breaking strength	140	Mpa
Impact strength/Energy	17	kJ/m^2
Micro-hardness	0.087	GPa

Table 1: Important Properties of Epoxy Resin

Banana fiber, a natural fiber is used in present investigation as reinforcement. Banana fiber is obtained from pseudo-stem of banana plant. Banana fiber has good mechanical strength and an appreciable specific property. Apart from good specific properties, smaller elongation, fire resistance quality, great potentialities and biodegradability are the major advantages of this fiber. The main setback of using this fiber was reported that it has strong moisture absorption quality. This can be sorted by proper surface treatment of fibers which is discussed in next section. Table II shows the physical and mechanical properties of the banana fiber used in present investigation.

Characteristic Property	Values	Units
Density	0.85	g/cm^3
Tensile strength	720	MPa
Average diameter	80-250	Micron
Average length	1000-5000	mm
Failure strain	1-3	%

Table 2: Important Properties of Banana Fiber

B. *Composite Fabrication*

Fabrication of composites is accomplished by fabricating two different sets of composites. In Set I composite, epoxy is reinforced with untreated short banana fiber in different weight fraction ranging from 3 to 15 wt %. For Set II composites, prior to the incorporation of fiber in matrix, it is treated with alkali solution i.e. NaOH. This process is also known as mercerization of fiber and is well established method for producing high quality fibers. From the past researchers experience it was found that, mercerization reduces the diameter of fiber by removing unwanted waxes and minerals from its surface thus develops a rough surface over the fiber. The rough surface created results in improvement of adhesion between fiber and matrix. With this improvement in interaction, mechanical properties of the composite increases significantly. Sisal fiber was cut into an approximate length of 4 mm. The fiber was immersed in 2 wt. % NaOH solution for 2 h. than it is properly washed with water. Later the treated fiber is dried in a heating oven at 80 ^oC overnight for the removal of any moisture present. After this, the treated fiber is ready to be used for composite fabrication. In Set II composite, epoxy is reinforced with NaOH treated short banana fiber in different weight fraction ranging from 3 to 15 wt %. In present work composite is fabricated using simple hand lay-up technique which involves following steps:

1) The epoxy resin (LY556) and the corresponding hardener (HY 951) are mixed in a ratio 10:1 by weight as recommended.
2) Short banana fiber will then added to the epoxy-hardener combination.
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 respective mould.
4) The cast is than cured for 24 hours before it was removed from the mould.
5) The specimens of different sizes according to the ASTM standards for different tests were then cut from the fabricated rectangular sheet.

Composites were fabricated with different weight fraction of filler ranging from 0 to 15 wt. %. The list of fabricated composite is presented in table 3.

S.No.	Set	Composition
1	Set 1	Neat Epoxy
2	Set 2	Epoxy + 3 % by weight SBF
3	Set 3	Epoxy + 6 % by weight SBF
4	Set 4	Epoxy + 9 % by weight SBF
5	Set 5	Epoxy + 12 % by weight SBF
6	Set 6	Epoxy + 15 % by weight SBF

Table 3: Epoxy Composites Filled With Short Banana Fiber

C. *Physical Characterization*

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).

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

Here ρ_{ce} is the measured density, ρ_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 of composite materials can easily be obtained using rule of mixture model

$$\rho_{ct} = 1 \Big/ \left[\left(\frac{w_f}{\rho_f} \right) + \left(\frac{w_m}{\rho_m} \right) \right] \quad (2)$$

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 to analyze the behaviour of composite in the presence of water affected environments. Mainly the test was conducted in normal water to assess the amount of water absorbed by the composite according to ASTM D 570-98 standard. The samples were taken out from the water at regular interval of time. In present case time is fixed to 1 hour. The water present on the surface were wiped out with a dry cloth and then weighed in precision balance. The apparent gain in weight or amount of water absorbed by the specimen is calculated by the following equation. Percentage of water absorption

$$\frac{(W_2 - W_1)}{W_1} \times 100 \qquad (4)$$

Here W_1 is the weight of the specimen in dried conditions and W_2 is weight of specimen in wet condition for specific immersion time.

III. RESULTS AND DISCUSSION

A. *Density*

With the help of Archimedes method, density of neat epoxy is evaluated as 1.2 g/cm^3. Hence, for evaluating the density of presently fabricated composites, the same method is used. The densities of the reinforced composites were also evaluated theoretically using rule of mixture model. From the measured and the theoretical values, the void content can be evaluated All the three values, i.e. theoretical values, measured values and the corresponding void content were presented in table 4. From the table it was observed that density of the composite decreases when banana 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 1.03 g/cm^3 when untreated fiber were used as reinforcement, whereas for same content of fiber, the density of composite reduces to 1.08 g/cm^3. This is a decrement of 14.1 % and 10 % for untreated and treated fiber. 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	-	1.2	-
Set 2	1.185	1.17	1.29
Set 3	1.171	1.14	2.65
Set 4	1.157	1.12	3.20
Set 5	1.143	1.08	5.55
Set 6	1.130	1.03	8.86
Set 7	1.185	1.18	0.45
Set 8	1.171	1.15	1.80
Set 9	1.157	1.13	2.34
Set 10	1.143	1.11	2.92
Set 11	1.130	1.08	4.44

Table 4: 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. 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.

It is the reason that when treated fiber is used as reinforcement, the reduction in density is restricted to only 10 % which less than 14.1 % when untreated fiber is used. From this observation it may be concluded that usage of untreated fiber is good as it reduces the density of composite largely. But this is not true, as usage of untreated fiber as reinforcement significantly increases the void content with the composite body. Also it is observed that void content slightly increases with filler content. The maximum void content is of 8.86 % when untreated fiber is used and it reduces significantly to 4.44 % when treated fiber is used.

B. *Water Absorption Behavior*

Table 5 and 6 shows the water absorption behavior of all sets of composites. The samples are immersed in water for duration of 4 hours. Prior to that, each sample was made to a rectangular shape specimen having 10 gm of weight for simplifying the problem. At the end of each hour, samples are taken out of the water and their weight is noted. Table 5 shows the data related to the weight of the sample at the end of each hour and table 6 shows 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. Also it is noted that the weight of sample increase with the time of immersion. This increase in weight with time attained a saturation value after duration of approximately 3 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.

Set No.	Weight of sample in wet condition W_2 (gm) after 1 hour	Weight of sample in wet condition W_2 (gm) after 2 hour	Weight of sample in wet condition W_2 (gm) after 3 hour	Weight of sample in wet condition W_2 (gm) after 4 hour
Set 1	10.04	10.09	10.12	10.12
Set 2	10.08	10.20	10.31	10.32
Set 3	10.11	10.36	10.52	10.53
Set 4	10.16	10.47	10.61	10.62
Set 5	10.19	10.58	10.76	10.78

Set 6	10.22	10.64	10.98	11.01
Set 7	10.06	10.11	10.18	10.19
Set 8	10.07	10.15	10.23	10.25
Set 9	10.09	10.22	10.36	10.37
Set 10	10.12	10.32	10.48	10.50
Set 11	10.14	10.38	10.56	10.58

Table 5: Weight of Wet Samples at Different Time of Water Immersion

It is further observed that treatment of fiber with specified concentration of NaOH solution reduces the water absorption behavior of composites to a great extent. For present analysis, banana fiber in its short form was treated by 2 wt. % NaOH aqueous solution. The reduction in water absorption by fiber treatment is because fiber and resin are hydrophilic and hydrophobic in nature respectively. NaOH treatment of fibers removes the organic material from the fiber surface. This increases the surface roughness of the fiber and hence surface area. Both the above factor results in increase in contact area between the matrix and fiber and increases the bonding strength between fiber and matrix.

Set No.	Percentage increase in weight after 1 hour	Percentage increase in weight after 2 hour	Percentage increase in weight after 3 hour	Percentage increase in weight after 4 hour
Set 1	0.4 %	0.9 %	1.2 %	1.2 %
Set 2	0.8 %	2 %	3.1 %	3.2 %
Set 3	1.1 %	3.6 %	5.2 %	5.3 %
Set 4	1.6 %	4.7 %	6.1 %	6.2 %
Set 5	1.9 %	5.8 %	7.6 %	7.8 %
Set 6	2.2 %	6.4 %	9.8 %	10.1 %
Set 7	0.6 %	1.1 %	1.8 %	1.9 %
Set 8	0.7 %	1.5 %	2.3 %	2.5 %
Set 9	0.9 %	2.2 %	3.6 %	3.7 %
Set 10	1.2 %	3.2 %	4.8 %	5.0 %
Set 11	1.4 %	3.8 %	5.6 %	5.8 %

Table 6: Water Absorption Percentage of Wet Samples at Different Time of Water Immersion

This results in the reduction of water absorption rate. The maximum absorption of water for untreated fiber sample occur at 15 wt % fiber and is of 10.1 % whereas maximum absorption of water for treated fiber samples also occur at 15 wt % and is of 5.8 % only. The other reason of low water absorption rate for treated fiber is that the treated fiber has higher lignin content than the untreated fibers and lignin is hydrophobic compound that acts against hydrothermal degradation of fiber.

IV. Conclusions

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

1) Successful fabrication of epoxy matrix composites reinforced with short banana fiber is possible by simple hand-lay-up technique.
2) Successful modification of surface of banana fiber is possible with NaOH aqueous solution as can be observed by the improved properties obtained.
3) The density of the fabricated composites decreases with increase in weight fraction of the fiber content. The reduction in density is compromised when modified fiber is used. The reduction in density is mainly because of low density of fiber. The density increases with modified fiber because of reduction in the value of void contents. The maximum void content is 8.86 % with untreated fiber and 4.44 % with treated fiber.
4) The water absorption rate increases with increase in fiber content and duration of immersion of composite body inside the water. The rate of increment decreases when surface of fiber is treated with NaOH prior to the fabrication. With untreated fiber maximum absorption rate is 10.1 with 15 wt % fiber for duration of 4 hours. Under the similar situation, when treated fiber is used, the absorption rate is 5.8 %. In both cases, increase of absorption rate ceases after 4 hours of immersion.

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