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Analysis of Mechanical Properties of Natural Fibre Reinforced Composites with the Effect of Water Absorption

Chandra Kumar[1], Vishwanath Kumar[2], Prashant Mishra[3]
[1]*M.Tech. Scholar, Dept. of Mechanical Engg., Shri Ram College of Engineering & Management, Palwal, India*
[2]*Assistant Professor, Dept. of Mechanical Engg., DPG Institute of Technology & Management, Gurugram, India*
[3]*Lecturer, Dept. of Mechanical Engineering, DPG Institute of Technology & Management, Gurugram, India*

***Abstract*: In the context of sustainable development, considerable interest is being shown in the use of natural fibres like as reinforcement polymer matrix composite using Luffa Cylindrica fibre. The accessibility to natural fibers and simplicity in manufacturing have persuaded researchers to aim for locally existing low cost fibers and to investigate their possibility of reinforcement intensions and up to what extent they can satisfy the essential detailing of superior reinforced polymer composite intended for different application program. Natural fibre represents a superior biodegradable and renewable alternative to the most popular synthetic reinforcement, i.e. glass fibre possessing high mechanical properties and low cost. This paper focuses on eco-friendly and sustainable green composites manufacturing using Luffa Cylindrica fibre. Luffa Cylindrica fibre reinforced epoxy composites of different number of layer were prepared in order to study the effect of water absorption on their mechanical properties. And also studied the mechanical performance testing such as tensile and flexural on the different number of layer of composites of both treated and untreated Luffa Cylindrica fibre in distilled water and saline water environment. It is also found that swelling of both treated and untreated Luffa Cylindrica epoxy composites material as a result of water absorption have positive effect on mechanical properties.**

***Keywords*: Epoxy resin, Luffa cylindrical fibre, Reinforced, Composite material**

1. Introduction

Growing environmental awareness has activated the researchers worldwide to enhance and utilize materials that are companionable with the environment. In the procedure natural fibers have become suitable options to traditional synthetic or manmade fibers and have the prospective to be used in cheaper, more sustainable and more environment friendly composite materials. Natural organic fibers can be obtained from either animal or plant sources. The merits of epoxy resins are low polymerisation shrinkages unlike polyesters during cure, excellent resistance to chemicals and solvents, good mechanical strength, and excellent adhesion to fibres. The epoxy molecule consists of two ring groups at its centre, that have the capability to absorb both thermal and mechanical stresses better than the linear groups, giving epoxy resin very good strength, toughness, stiffness and heat resistance.

The main demerits of the epoxy resins are that they need long curing times and, for the most part, their mould discharge qualities are poor. The epoxy resins are categorized by high adhesive strengths. After reviewing the stimulating literature accessible on the natural fiber composite hard work are put to recognize the basic needs of the emerging composite industry. The decisions drawn from this is that, the achievement of merging vegetable natural fibers with polymer matrices results in the improvement of mechanical properties of the composite associated with the matrix material. These fillers are cheap and non-toxic and can be acquire from renewable source and are effortlessly recyclable. Furthermore, in spite of their low strength, they may results into composite possessing high specific strength due to their low density.

Luffa cylindrica, locally called as 'Sponge-gourds' is that natural resource whose capability as fiber reinforcement in polymer composite has not been explored to date. The fibrous cords are liable in a multidirectional array resulting in a natural mat in ligneous netting system possess by 'Sponge gourds'. It comprises 62% cellulose, 20% hemicellulose and 11.2% lignin [14]. The sponge-gourd (Luffa Cylindrica) plant with fruit which belongs to the curcubitacea family is shown in Fig. 1(a) and 1(b).

(a) (b)
Fig. 1. Curcubitacea family

Joseph et al. [1] investigated the environmental effects on sisal fibre reinforced PP composites. Absorption of water was found to be increased with the fibre content and then settled off at longer period of time. In order to overcome this problem the fibres were treated chemically and the chemically treated fibres showed a decrease in water absorption because of the enhanced interfacial bonding. As the temperature stimulates the diffusion procedure, it was found that the water absorption of the composite increases with the temperature. Plasticization effect of water was the reason to decrease the tensile properties of the composites.

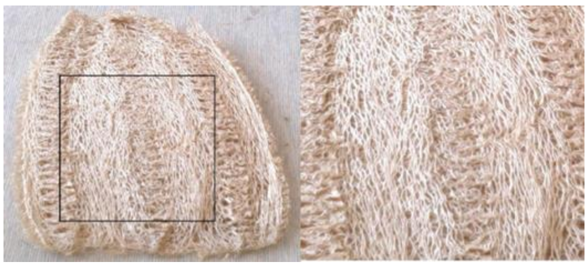
Fig. 2. Fibres

Yuan et al. [2] investigated experimentally that cleaned and chemically customized fiber surface improves the interfacial adhesion among the fibre and matrix and the rate of moisture absorption in bio-composite was also reduced by the strong intermolecular bonding among fiber and matrix. Stamboulis et al. [3] reported that the swelling and moisture absorption of the treated flax fibre polypropylene composites is lower than the untreated flax fibers composites. The result shows that the absorption for the treated fibre is approximately 30% lower than the untreated fibre composites. Thomas et al. [4], found experimentally that the water absorption characteristics of sisal fiber polyester composites established that the diffusion coefficient decreases with chemical treatment of fiber and also the capacity of water absorption of the composite reduces.

Verma et al. [5] has been studied the benefits provided by renewable resources for the development of composite materials based on bagasse fibers and they determined that the natural fibre composites can be more suitable for technical applications such as automotive interior parts when they are hybrid with certain quantity of synthetic fibre. Yoldas et. al. [6] carried out report of Luffa cylindrica-reinforced polyester composite to water aging in a steam of seawater containing 5% NaCl for 170 hrs at 500C and they also found that flexural strength, tensile strength, tensile elongation and interlaminar shear strength at break values was decreased by 28%, 24%, 45%, and 31%, respectively, after the process of aging. Msahli et al. [7] have reported the influence of fiber weight ratio reinforcement structure and chemical modification on the flexural proprieties of Luffa-polyester composites. It resorts that acetylating and cyanoethylating improve the flexural strength and the flexural modulus. They also observed a maximum value of strength and strain is over a 10% fiber weight ratio. Muthumani et al. [12]investigated the mechanical properties of the ASTM standards sample and they found that the 35% of Kenaf and 35% of Abaca fiber reinforcement showed the highest tensile strength and impact strength respectively among the other fiber volume fraction. Only a few studies [8] have been focused on the processing of natural fiber composites by LCM processes. The paper will focus on to prepare a PMC using luffa fiber as reinforcement and epoxy as matrix material and to study its moisture absorption characteristics under different environmental conditions and then to find its mechanical properties i.e.; tensile and flexural strength. Out of the available manufacturing techniques, we have chosen hand-lay-up method to construct the composite. Then the composites were manufactured by varying the no. of layers of fiber i.e.; single, double and triple layers.

2. Materials and Methodology

A. Materials

Dried Luffa Cylindrica was collected locally. These fibres were then treated with water for 24 hrs in order to remove wax, lignin and oil from the external surface of luffa fibre and then dried at room temperature. After these the fibres were cut with appropriate dimensions (150×140 mm) and then these fibres were kept between two wooden boards followed by pressing it into the bench vice to straighten the fibres.

In this study a wooden moulds with dimensions of 140 x 120 × 10 mm^3 were prepared for the fabrication. For different number a layer of fibre, epoxy resin and hardener (ratio of 10:1 by weight) with a calculated amount was mixed thoroughly in a glass jar. The mould used to construct the composite shown in Fig. 3(a). Mould release sheet was put over the glass plate and a mould release spray was sprayed over the inner surface of the mould for quick and easy removal of composite. After keeping the mould on a ply board a thin layer of the mixture was poured. Then the fiber lamina was distributed on the mixture. Then again resin was applied over the fiber laminate and the procedure was repeated to get the desired thickness. The remaining mixture was then poured into the mould. Precaution was taken to prevent the air bubbles formation. Then from the top pressure was applied and the mould was kept at room temperature for 72 hrs. During application of pressure some amount of mixture of epoxy and hardener squeezes out. Care has been taken to consider this loss during manufacturing of composite sheets. After 72 hrs the samples were taken out of the mould. Figure 4 (a, b) shows the photograph of the composite specimen cut for further experimentation.


Fig. 3. Mould used for fabrication of the composite

B. Chemical Modification of Fiber

For a well-developed composite using natural fibre as reinforcement the understanding of surface adhesive bonding of fibre and the chemical composition is essential. Interfacial bonding between fibers and the resin needs to be good as it plays a significant role in enhancing the mechanical properties of the composites. Chemical treatment comprising alkali, silane, acetylation, benzoylation, acrylation, isocynates, maleated coupling agents; permanganate treatment is discussed in detail.

The main reason for performing chemical alterations on natural fibres is to improve the adhesion between fibre surface and the polymer matrix by altering the fibre surface and the fibre strength. It also helps in enhancing the mechanical properties by decreasing the water absorption capability of the fibre. Out of the available treatments, for the present case to have a decent bonding between the fibre and the matrix Luffa Cylindrica fibre have been treated with alkali. The subsequent section will elaborate separately the treatment of the fibre surface by alkali methods, study of mechanical properties of both treated and untreated fibre reinforced polymer composite followed by studying environmental effects on mechanical performance of the composite along with moisture absorption characteristics.

C. Method of Chemical Modification

1) Alkaline Treatment

When it comes to reinforce thermoplastics and thermosets, alkaline treatment is one of the mostly used treatments. In the modification done by the alkaline treatment the disruption of hydrogen bonding in the network structure takes place resulting in increased surface roughness. By using this treatment, certain amount of lignin, wax and oils covering the outer surface wall of the fibre was removed, depolymerizes cellulose and depicts the short length crystallites [9]. Addition of aqueous sodium hydroxide (NaOH) to natural fibre stimulates the ionization of the -OH group to the alkoxide.

Fiber –OH + NaOH → Fiber – O – Na +H2O

Alkaline treatment has two effects on the fibre:

- It increases surface roughness by the disruption of hydrogen bonding resulting in better mechanical linking.
- It increases the number of possible reactions sites by increasing the amount of cellulose exposed on the fibre surface.

Subsequently, this treatment has a lasting effect on the mechanical behaviour of flax fibre, especially on the strength and stiffness of the fibre. For performing this treatment, Firstly the Luffa Cylindrica fibre were kept in a solution containing 5%NaOH at room temperature maintaining a liquor ration of 15:1 for 4hrs. Secondly, the fibers were washed many times with water in order to remove the NaOH sticking to the fibre surface followed by neutralizing with dilute acetic acid and washed with distilled water, so that pH of 7 was maintained. Lastly, the fibers were dried at room temperature for 48hrs followed by oven drying for 6hrs at 100ºC. The alkali reaction between Luffa Cylindrica fibre and NaOH is as follows:

(Luffa Cylindrica) – OH + NaOH ↔ (Luffa Cylindrica) – O-Na+ + H2O

D. Study of Environmental Effect

To study the effect of environmental conditions on performance of Luffa Cylindrica fiber epoxy composite, the composite sample with both untreated and chemically treated fibers were subjected to various environments such as:

(a) Saline treatment (b) Distil treatment

1) Moisture absorption test

Moisture absorption and thickness swelling tests were conducted in accordance with ASTM D570-98. Four specimens for different layers (Single, Double and Triple layers) were cut with dimensions of 140 x 15mm (length x width) and the experiment was performed using test samples. The specimens prior to testing were dried in an oven at 800 C and then were allowed to cool to room temperature and kept in a desiccator. The weight of the samples were taken before subjected to steam, saline water and distil water environments. After expose for 12 hr, the specimens were taken out from the moist environment and all surface moisture was removed with a clean dry cloth or tissue paper. The specimens were reweighed to the nearest 0.001 mg within 1 min. of removing them from the environment chamber. The specimens were weighed regularly from 12-156 hrs with a gap of 12hrs of exposure. The percentage weight gain of the samples was measured at different time intervals by using the following equation:

$$\%M_t = \frac{(W_t - W_o)\times 100}{W_0} \tag{1}$$

Where ‘W_O’ and ‘W_t’ denote the oven-dry weight and weight after time’s’, respectively. Equilibrium Moisture Content (EMC) of the sample is the moisture content when the periodic weight change of the sample was less than 0.1% and thus the equilibrium state was assumed to be reached.

The thickness swelling (TS) was determined by using the following equation.

$$TS(t) = \frac{H_t - H_o}{H_o}\times 100 \tag{2}$$

Where, ‘H_t’and ‘H_O’are the composite thickness after and before the water immersion respectively.

2) Mechanical testing of sample

(a) Tensile test

The tensile test is generally performed on flat specimens. The most commonly used specimen geometries are dog-bone and the straight side type with end tabs. The specimen used in present case is shown in fig. 4. The tensile tests were conducted according to ASTM D 3039-76 standard on a computerized Universal Testing Machine INSTRON H10KS. The span length of the specimen was 42 mm. the tests were performed with constant strain rate of 2 mm/min.

Fig. 4. Tensile test samples

Fig. 5. Flexural test samples

(b) Flexural test

Three-point bend test was carried out in an UTM machine in accordance with ASTM D790-03 to measure the flexural strength of the composites. All the specimens (composites) were of rectangular shape having length varied from 100-125 mm, breadth of 100-110 mm and thickness of 4-8 mm as shown in fig. 5. A span of 70 mm was employed maintaining a cross head speed of 0.5mm/min.

The flexural strength of composites was found out using the following equation:

$$\tau = \frac{3fl}{2bt^2} \quad (3)$$

3) Measurement of Diffusivity

The water absorption kinetics in LCF reinforced epoxy composite has been studied through the diffusion constants k and n. The behaviour of moisture sorption in the composite was studied by the shape of the curve represented by the equation (2.4) [10, 4]:

$$\frac{M_t}{M_m} = kt^n \quad (4)$$

Where, M_t is the moisture content at specific time't', M_m is the equilibrium moisture content (EMC), and *k* and *n* are constants.

The value of k and n were found out from the slope and the intercept of M_t /M_m versus time't' in the log plot which was drawn from the data obtained from experiment of moisture absorption with time. It was observed that the value of n is close to 0.9 for all of the composites. This confirms that the Fickian diffusion can be used to adequately describe moisture absorption in the composites. A higher value of n and k indicates that the composite needs shorter time to attain equilibrium water absorption. The value of k was found to increases with increasing fibre content for LCF reinforced epoxy composite in all environments resulting higher moisture absorption initially. The value of k for untreated fiber composite was higher than that of treated fiber composite, except saline water environment. It might have happened due to the gathering of NaCl ions in the fiber's surface which delays subsequent moisture diffusion.

The diffusion coefficient or diffusivity (D_x) of moisture absorption was calculated using the following equation:

$$D_x = \pi\left[\frac{h}{4M_m}\right]^2\left(\frac{M_2 - M_1}{\sqrt{t_2} - \sqrt{t_1}}\right) \quad (5)$$

where *'M_m'* is the maximum percentage of moisture content, *'h'* is the sample thickness, *'t_1'* and *'t_2'* are the selected points in the initial linear portion of the plot of moisture absorption.

3. Results and discussion

A. Moisture absorption behaviour

It is quite observed that as the fibre content increases, the initial rate of moisture absorption and the maximum moisture absorption for both the environment increases. Moisture absorption is maximum for three layered composites. It is known that, the factors like adhesion between fibre and matrix, porosity content and the lumen are responsible for the moisture absorption behaviour of the natural fibre composites. But in this case the hydrophilicity of Luffa Cylindrical fiber, in addition to poor adhesion between fiber–matrix and voids content might have affect the moisture uptake characteristics of the composite.

It has also be found that, the moisture absorption increases as the immersion time increases, and got saturated after certain time period. Time required to reach the saturation point is not same for both the environments. The saturation time is approximately 120 hrs for distil, and 108 hrs for saline water. Environmental conditions also play a significant role in moisture absorption process. Figure 6 to 9 shows the maximum moisture absorption of composite in all three environments. In Distil Water environment moisture absorption is maximum as compare to saline water environment. The rate of absorption in case of saline water is low as compared to steam. This happens because of the gathering of NaCl ions in the fibre's surface immersed in saline water, which increases with time and delays moisture diffusion.

It has been observed D_x value increases with the LCF content for the composites examined. These results are consistent with previous findings on wood and natural fibers composites. The increase was more pronounced for the specimens subjected to steam than those subjected to saline water and sub-zero environments. The surface modification of fiber decreases the diffusion coefficient (D_x).

B. Effect of moisture absorption on mechanical properties

The mechanical properties of the natural fibre polymer composite were greatly influenced by the moisture absorption. Figure-3.6 to3.13 shows the result of mechanical properties of the composite with both treated and untreated fibre reinforced composite after expose to different environment for a period of 156 hrs. It has been observed that, both strength and stiffness of all composite decrease after moisture absorption. This reduction in the stiffness and strength is accredited to the changes occurring in the fibre, and the interface between fibre and matrix. When fibre/matrix interface is exposed to moisture from the environment, the cellulosic fibers tend to swell, thereby developing shear stresses at the interface, which favours ultimate debonding of the fibers, which in turn causes strength reduction. It is also observed that the reduction in properties was greatly influenced by the fibre loading and nature of environment. The maximum reduction in strength and stiffness occured in case of three layered composite in both the environments. Further it is also noticed that the amount of decrease in mechanical properties is reduced with chemical modification of fibre. The alkali treated fibre composite exhibits the best result in both the environments in.

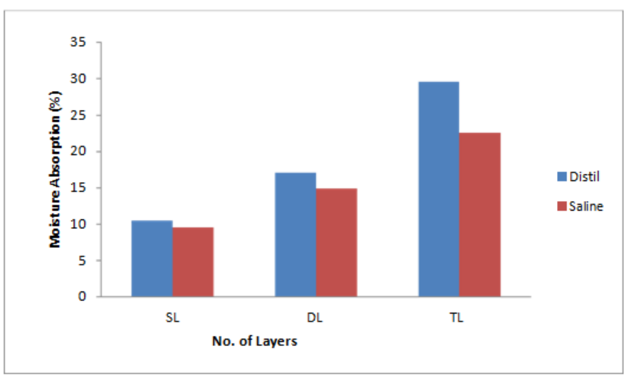

Fig. 6. Maximum moisture absorption of untreated Luff Cylindrica fibre epoxy composite (Tensile Sample) versus loading on the both environments

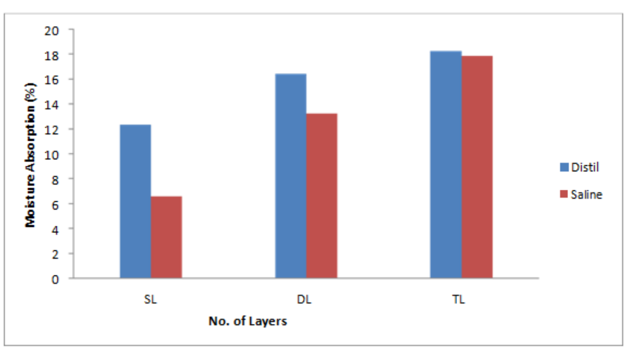

Fig. 7. Maximum moisture absorption of untreated Luff Cylindrica fibre epoxy composite (Flexural Sample) versus loading on the both environments

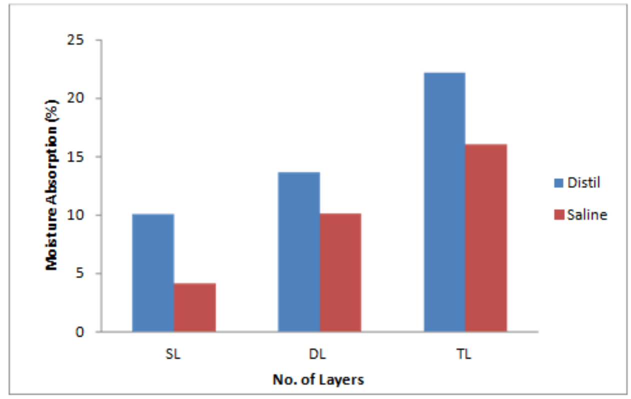

Fig. 8. Maximum moisture absorption of treated Luff Cylindrica fibre epoxy composite (Tensile Sample) versus loading on the both environments

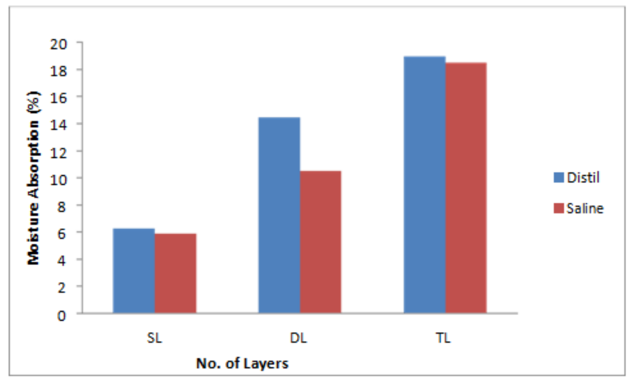

Fig. 9. Maximum moisture absorption of treated Luff Cylindrica fibre epoxy composite (Flexural Sample) versus loading on the both environments

4. Conclusions

Based on experimental results, this study has led to the following conclusions:

The Luffa Cylindrica fibre can successfully be used as reinforcing agent to fabricate composite by suitably bonding with epoxy resin. On increasing the fibre content the strength, modulus and work of fracture increases and the best combination is found with Double Layered composite. The fibre surface modification by chemical treatments significantly improves the fibre matrix adhesion, which in turn improves the mechanical properties of composite. The moisture absorption and thickness swelling values increases with increase in fiber loading. Both values are found to be higher in saline environment than in distil water environments. However, these values are considerably reduced with chemical treatments of the fibre. Under all environment conditions, the moisture diffusion process of both treated and untreated Luffa Cylindrical fibre composites are found to follow the Fick's law. It can be concluded that the results suggest that swelling of Luff Cylindica fibers in the composite material as a result of water absorption can have positive effects on mechanical properties. This luff cylindrical fibre composites show their potential use in outdoor applications due to the exposure to water absorption not affecting negatively their mechanical properties.

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