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Sisal/Coconut Coir Natural Fibers – Epoxy Composites: Water Absorption and Mechanical Properties

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Abstract: Natural fibers (Sisal and Coconut coir) reinforced Epoxy composites were subjected to water immersion tests in order to study the effects of water absorption on the mechanical properties. Natural fibers like coconut coir (short fibers) and sisal fibers (long fibers) were used in hybrid combination and the fiber weight fraction of 20%, 30% and 40% were used for the fabrication of the composite. Water absorption tests were conducted by immersing specimens in a water bath at 25^0 C and 100^0 C for different time durations. The tensile and flexural properties of water immersed specimens subjected to both aging conditions were evaluated and compared with dry composite specimens. The percentage of moisture uptake increased as the fiber volume fraction increased because of the high cellulose content of the fiber. The tensile and flexural properties of Natural fiber reinforced Epoxy composite specimens were found to decrease with increase in percentage moisture uptake. Moisture induced degradation of composite samples was observed at elevated temperature. The water absorption pattern of these composites at room temperature was found to follow Fickian behavior, whereas the water absorption properties at higher temperature did not follow Fick's law.

Keywords: **Natural Fibers, Epoxy Composites, Water Absorption, Tensile and Flexural Properties.**

I. INTRODUCTION

The availability of natural fibers is abundance and also they are very inexpensive when compared to other advanced man-made fibers. These natural fibers are used as a suitable reinforcing material environmental concern and they are now emerging as a potential alternative for glass fibers in engineering composites [1]. The natural fibers are used as reinforcements for composite materials due to its various advantages compared to conventional man-made fibers [2, 3]. The primary advantages of natural fibers are low density, low cost, biodegradability, acceptable specific properties, less wear during processing and low energy consumption during extracting as well as manufacturing composites and wide varieties of natural fibers are locally available. Natural fibers have a few disadvantages when used as reinforcements, such as lower impact strength, higher moisture absorption which leads to dimensional changes thus leading to micro-cracking. All polymer composites absorb moisture in humid atmosphere and also when immersed in water. The effect of this moisture absorbed leads to the degradation of fiber-matrix interface region creating poor stress transfer between fiber and matrix and resulting in reduction of mechanical properties along with dimensional changes. One of the main concerns for the use of natural fiber reinforced composite materials is their susceptibility to moisture absorption and the effect on physical and mechanical properties. It is important therefore that this problem is discussed in order that these natural fibers may be considered as a favorable reinforcement in composite materials. Many researches have studied in detail the effect of moisture absorption on the mechanical properties of the natural fiber reinforced composites, to mention a few; The water sorption characteristics and the effect of hybridization with glass fiber and the chemical modification of the fiber on the water absorption properties of banana fiber reinforced polyester composites by immersion in distilled water at 28^0–90^0C were studied [4]. Pine Needles of different dimensions were used to prepare bio-composites with Phenol-Formaldehyde and the effects of different fiber dimension on the mechanical properties of the composites were determined. These polymer composites were further subjected to various standardized characterization tests such as moisture absorption and chemical resistance analysis [5].The moisture absorption of short hemp fiber and hemp-glass hybrid reinforced thermoplastic composites was investigated to study their suitability in outdoor applications [6].The mechanical properties of sisal fiber-reinforced epoxy composites aged in water and the moisture absorption behavior of sisal were investigated [7]. The relationship between the moisture absorption of pineapple-leaf fiber-reinforced low density polyethylene composites and the fiber loadings were studied [8] and found that the moisture absorption increased almost linearly with the fiber loading. The mechanical properties of unsaturated polyester composites reinforced with different natural fibers such as sisal, jute and flax and glass fiber were reported. Jute composites showed the best flexural and tensile strength values but the lowest impact values as a consequence of the higher interface adhesion. On the other hand, sisal fiber composites showed the lowest mechanical and water resistance properties [9]. The hydrophilic nature of natural fibers provides weak interfacial adhesion in polymer-matrix composites. An experimental study of water absorption in unsaturated polyester composites reinforced with macambira natural fiber was done by V.C.A.Cruz et al [10]. They studied the samples with weight composition of 30% macambira fiber and 70% unsaturated polyester. Tests for water absorption were performed by immersing the samples in a bath of distilled water at 25, 50 and 70°C, and water uptake was measured gravimetrically along the process. Results of the micrographs (SEM), moisture content and area / volume relationships of the composites were analyzed. There are three different governing mechanisms of moisture diffusion in polymeric composites. The first involves of diffusion of water molecules inside the micro gaps between polymer chains. The second involves capillary transport into the gaps and flaws at the interfaces between fiber and the matrix. This is a result of poor wetting and impregnation during the initial manufacturing stage. The third involves transport of micro-cracks in the matrix arising from the swelling of fibers as in the case of natural fiber composites. Generally, based on these mechanisms, diffusion behavior of polymeric composites can further be classified according to the relative mobility of the penetrant and of the polymer segments, which is related to either Fickian, non-Fickian or anomalous, and an intermediate behavior between Fickian and non-Fickian [11, 12]. In general moisture diffusion in a composite depends on factors such as volume fraction of fiber, voids, viscosity of matrix, humidity and temperature. The objectives of this work are (1) to study the water absorption behavior of the hybrid composites made by combining Sisal fibers and Coconut coir as reinforcements in the Epoxy matrix at Room Temperature and elevated temperature (100^0C). (2) Studying the influence of fiber reinforcement and water uptake behavior on mechanical properties of hybrid-composites.

Table-1: Mechanical Properties of Sisal Fiber and Coconut Coir

Fiber	***Species***	***Density (gm/cm^2)***	***Tensile Strength (MPa)***	***Young's Modulus (GPa)***
Sisal	Agave Sisilana	1.5	468	22
Coir	Cocos Nucifera	1.2	175	5

II. MATERIALS AND METHODS

A: Matrix

Epoxy is a thermosetting polymer that cures (polymerizes and cross links) when mixed with a hardener. Epoxy resin of the grade LM-556 with a density of 1.1–1.5 g/cm3 was used. The hardener used was HY-951. The matrix material was prepared with a mixture of epoxy and hardener HY-951 at a ratio of 10:1.

B: Fibers

The fibers used for the fabrication of the composites are Coconut coir (short fibers) and Sisal fibers (long fibers)

C: Coconut Coir:

Coconut Coir is a lingo-cellulosic natural fiber. It is a seed-hair fiber obtained from the outer shell, or husk, of the coconut, the fruit of Cocos-nucifera. The coarse, stiff, reddish brown fiber is made up of smaller threads, each about 0.03 to 0.1 cm long and 12 to 24 micrometer in diameter; coir is composed of lignin, a woody plant substance, and cellulose. The individual fiber cells are narrow and hollow, with thick walls made of cellulose. Mature brown coir fibers contain more lignin and less cellulose than fibers such as flax and cotton and are thus stronger but less flexible. The coir fiber is relatively waterproof and is the only natural fiber resistant to damage by salt water. The fibrous layer of the fruit is separated from the hard shell manually by driving the fruit down onto a spike to split it (de-husking).

Fig-1: Coir fibers

D: Sisal fibers

Sisal is a natural fiber (Scientific name is Agave sisalana) of Agavaceae (Agave) family yields a stiff fiber traditionally used in making twine and rope. Sisal is fully biodegradable and highly renewable resource of energy. Sisal fiber is exceptionally durable and a low maintenance with minimal wear and tear. Sisal fiber is extracted by a process known as decortication, where leaves are crushed and beaten by a rotating wheel set with blunt knives, so that only fibers will remain.

Fig -2: Sisal fibers

E: Fiber Surface Treatment

Washed and dried sisal fibers and coir were taken in separate trays, to these trays 10% NaOH solution was added, and the fibers were soaked in the solution for 10 hours. The fibers were then washed thoroughly with water to remove the excess of NaOH sticking to the fibers. The coir fibers were chopped into short fiber length of 3 cm for molding the composites. For Sisal fibers the length was maintained as long fibers.

F: Preparation of Hybrid Composite

A GI Sheet mould with required dimensions was used for making the sample as per ASTM standards. The mould was coated with a mould releasing agent for the easy removal of the sample. The resin and hardener were taken in the ratio of 10: 1 parts by weight, respectively. Then, a pre-calculated amount of hardener was mixed with the epoxy resin and stirred for 20 minutes before pouring into the mold. The hand lay-up technique was used to impregnate the composite structures. The weight fractions of coir and sisal fibers were maintained at 50:50. Calculated weight of short coir fiber was mixed in to the epoxy matrix and stirred well for 15 minutes. Mould releasing agent is sprayed to the mould, after which a small amount of coconut coir mixed epoxy matrix is poured to the mould until it forms a thin layer. A stack of sisal fibers were carefully arranged in a unidirectional manner and once again some amount of coconut coir mixed epoxy matrix is poured into the mold. This process is continued till the required thickness is obtained. Brush and roller is used to impregnate fiber. The closed mold is kept under pressure for 24 h at room temperature. Test specimens of required size were cut out composite manufactured after curing. The percentages of fibers used are 20%, 30% and 40% by weight.

III. WATER ABSORPTION TEST

The effect of water absorption on coconut coir-sisal fibers reinforced hybrid composites were investigated in accordance with BS EN ISO 62: 1999. The specimens were dried in an oven at 50^0C and then they were allowed to cool till they reached room temperature. The specimens were weighed to an accuracy of 0.1mg. Water absorption tests were conducted by immersing the composite specimens in distilled water in plastic tub at room temperature for different time durations. Once in 24 hours, the specimens were taken out from the water and all surface water was removed with a clean dry cloth and the specimens were reweighed to the nearest 0.1 mg. The specimens were weighed regularly from 24hours to 672 hours exposure, at an interval of 24 hours. The moisture absorption was calculated by the weight difference. The percentage weight gain of the samples was measured at different time intervals. Similarly, the specimens were immersed in water at 100°C to determine water absorption at a higher temperature. For this test, the specimens were placed in a container of boiling water. After 30 min of immersion, the specimens were removed from the boiling water, cooled in water for 15 min at room temperature then removed and weighed to the nearest 0.1 mg. The weight of the samples was measured at different time intervals up to 40 h of exposure until the water content reached saturation. The moisture absorption was calculated by the weight difference. The percentage weight gain of the samples was measured at different time intervals and the moisture content versus time was plotted.

IV. MECHANICAL TESTING

After moisture absorption tests, The tensile strength of the composites was measured with a universal testing machine in accordance with the ASTM D-638 procedure at a crosshead speed of 5 mm/min. The flexural tests were performed on the same machine, using the 3-point bending fixture according to ASTM D-790 with the cross-head speed of 5 mm/min. For the evaluation of mechanical properties dry samples and wet samples (immersed in water at room temperature) were considered.

V. RESULTS AND DISCUSSION

A: Effect of Fiber Percentage (Weight Fraction)

The percentage of water absorption in the composites was calculated by weight difference between the samples immersed in water and the dry samples using the following equation.

$M_t = ([W_t - W_o]/ W_o) \times 100$

Where, M_t is the moisture content in the specimen, W_t is the weight of the specimen at the immersion time and W_o is the weight of the specimen before the water absorption test. Equilibrium moisture absorption of samples was assumed to be reached when the daily weight gain of samples was less than 0.01%. The variation of moisture content with the fiber loading for at room temperature is shown in the figure-3.

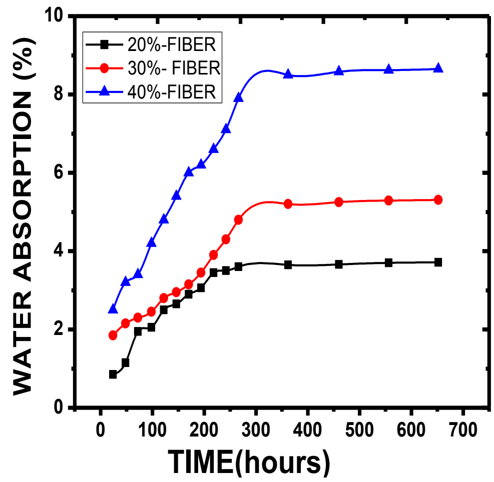

Fig-3: Water Absorption Curve at Room Temperature for Varying Fiber Loading (Weight Fraction)

The moisture absorption increased with increasing fiber content in all the cases. This behavior has been explained on the basis of enhancement of micro void formation in the matrix resin. The percentage of gain in moisture absorption for first and 28th day at 20 wt. % of fiber composites is 3.71%, for 30 wt. % of fiber composites is 5.31% and for 40 wt. % fiber composites is 8.65%. It is evident from the graph that the initial rate of water uptake increases with increase in fiber content. The increasing water absorption is due to the hydrophilic nature of sisal and coir fiber and the greater interfacial area between the fiber and the matrix. The amount of water uptake by epoxy resin is almost negligible as it is hydrophobic in nature. The maximum percentage weight gain is 8.65% for 40% (weight fraction) of sisal and coir fiber reinforced specimens at room temperature. The initial rate of water absorption and the maximum water uptake increased for all composite specimens as fiber content increased in the composites. The water absorption for all specimens is linear in the beginning and then slows till it approaches saturation point. The process is very similar to a Fickian diffusion process. The initial rate of water absorption increases for all natural fiber composites samples as the fiber loading (weight fraction) increases. The reason for this can be justified by considering the water uptake characteristics of both sisal and coir fibers. The natural fiber reinforced composite is exposed to moisture, due to the hydrophilic nature of sisal and coir fiber, these fibers swells. The brittle epoxy resin (matrix) undergoes micro cracking due to fibers swelling. The high cellulose content in sisal and coir fibers further contributes to more water penetrating into the interface through the micro cracks which was induced by swelling of fibers creating swelling stresses. As the composite cracks and gets damaged, capillarity and transport via micro cracks become active. The capillarity mechanism involves the flow of water molecules along fiber–matrix interfaces and a process of diffusion through the bulk matrix. The water molecules are actively attack the interface, resulting in de-bonding of the fiber and the matrix.

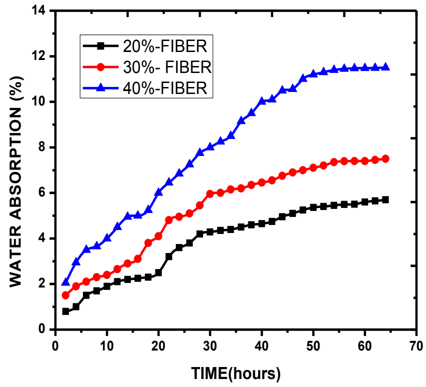

Fig-4: Water Absorption Curve at Boiling Temperature for Varying Fiber Loading (Weight Fraction)

The variation of moisture content with the fiber loading for at 100^0C is shown in the figure-4.For 20%, 30% and 40% Sisal-Coconut coir reinforced specimens the percentage of moisture absorption is 5.7%, 7.5% and 11.5% respectively. The effect of fibre volume fraction and temperature on water absorption can be clearly seen. The rate at which the equilibrium is reached much more rapid for the 100^0C specimens than the samples immersed at Room Temperature. Higher temperatures seem to accelerate the moisture uptake behavior. When the temperature of immersion of the composite material is increased, the moisture saturation time is greatly reduced. The weight gain percentage at moisture saturation point at boiling temperature is approximately 33% higher than at room temperature for 40% fiber reinforced hybrid composite. It is evident that there is different absorption behavior for immersion at room temperature than for elevated temperature. The higher and faster weight gain upon exposure to boiling water may be attributed to the different diffusivity of water into the material leading to moisture induced interfacial cracks at an accelerated rate as a result of degradation in the fiber–matrix interface region as well as the state of water molecules existing in the Sisal-Coconut coir composites. Liao K et.al [13] also has reported a similar trend for ageing of polymer composites at higher temperatures.

*B: **Effect of Moisture Absorption on Tensile Strength***

Mechanical properties of fiber-reinforced composites depend on the nature of the polymer matrix, distribution and orientation of the reinforcing fibers, the nature of the fiber–matrix interfaces and of the interphase region.Fig:5 represent the tensile strength of the hybrid composites at dry and wet conditions. By testing the dry samples, it was found that for 20 wt %, 30 wt % and 40 wt % the tensile strength were 39MPa, 52MPa and 56MPa respectively. The tensile strength for the wet samples with 20 wt %, 30 wt % and 40 wt % fibers reinforcement were 38MPa, 42MPa and 48MPa respectively. There was a considerable decrease in tensile strength of the wet samples when compared to dry samples. The reason for this is that in the wet samples the absorbed water molecules reduces the intermolecular hydrogen bonding between cellulose molecules in the fibre and establishes intermolecular hydrogen bonding between cellulose molecules in the fibre and water molecules, thereby reducing the interfacial adhesion between the fibre and the matrix and resulting in decreased strength.

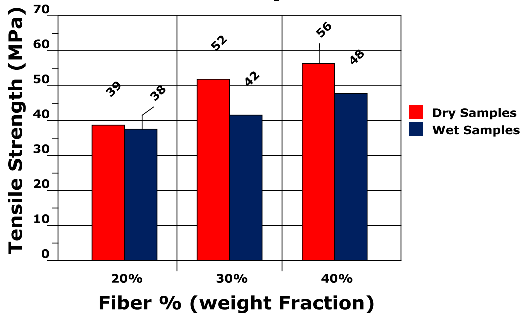

Fig: 5 Tensile strength of Dry and Wet samples.

*C: **Effect of Moisture Absorption on Flexural Strength***

Fig. 6 shows the effect of fiber content on Flexural strength of coconut coir-sisal fibers hybrid epoxy composites under dry and wet conditions. The flexural strength of the composites having 20 wt%, 30 wt% and 40 wt% were 47MPa, 58MPa and 66MPa, respectively, in dry condition. The percentage of improvement from 10 wt% to 30 wt% is 71%. It is found that the flexural strength of the composites increased with the fiber content. The flexural strength of the composites having 20 wt%, 30 wt% and 40 wt% were 43MPa, 50MPa and 57MPa, respectively, at wet condition. The percentages of reductions ranged from 9% to 14% when compared with dry samples. It is also observed that the flexural strength of the composites increased with the fiber content at wet conditions. But the ranges of increase in strength values in all fiber length at various fiber wt% were low in the case of moisture absorbed samples. This could be due to the fact that the immersion of composites samples at water affected the interfacial adhesion between the fiber and matrix and create the de-bonding leading to a decrease in the mechanical properties of the composites. Generally, for higher fiber wt% composites samples immersed in water, it was expected that the relative extent of decrease in flexural properties was greater compared to dry samples. It is interesting to note that for 20 wt% composites samples, the flexural strength of wet samples was nearer (47MPa and 43MPa). When the fiber/matrix interface was accessible to moisture from the environment, the cellulose fibers swelled. This resulted in the development of shear stress at the interface, which led to the ultimate de-bonding of the fibers, delamination and loss of structural integrity, thus the strength of composites was affected by immersion in water.

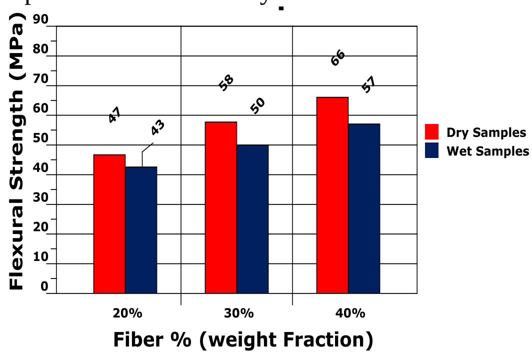

Fig: 6 Flexural Strength of Dry and Wet Samples.

VI. CONCLUSION

In the present investigation, the effect of moisture absorption of the sisal-coir composites at room temperature and elevated temperatures has been found. It is found that higher fiber content samples have a greater diffusivity because of higher cellulose content. The moisture uptake at elevated temperatures does not show Fickian behavior as compared to room temperature moisture up take behavior. At elevated temperature there is 33% higher moisture absorption for 40% sisal-coir fiber reinforced composites. The moisture absorption results in this investigation show Fickian behavior at room temperature and non-Fickian at boiling temperature. This is because of the moist, high temperature environment and micro-cracks developed on the surface and inside the materials. As the cracks develop, the material is lost in the form of resin particles. Due to the occurrence of damage in the composites water transport mechanisms become more active. Further in this investigation, the effect of moisture absorption on mechanical properties of coconut coir and sisal fiber-reinforced hybrid Epoxy composite were investigated and compared with the composites containing the dried fibers. Increasing the fiber content at dry condition, the tensile and the flexural strength increased. At wet condition, the tensile and flexural strength have a high-level reduction. Exposure to moisture caused a significant drop in the mechanical properties due to the degradation of the fiber–matrix interface, thus there is a need to understand of the moisture absorption characteristics of natural fibers reinforced hybrid composite materials to obtain the positive hybrid effect and to develop optimized composite material.

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