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A Study of Moisture Diffusion Phenomenon in Jute-Epoxy Composite

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***Abstract*— There is considerable increase in the use of natural fiber based composite materials in various fields of engineering. Natural fiber based composite laminate have advantages such as low density, available at low cost, acceptable mechanical properties and are environment friendly. Along with advantages there are some undesirable properties which limit the applications of natural fiber based composites. The associated disadvantages are being hydrophilic in nature due to its chemical constituent cellulose. Due to cellulose, readily moisture absorption takes place which results into decrease in mechanical properties. For the current study, Jute-Epoxy composite laminate is selected. The study focuses on reducing moisture gain. In order to reduce moisture gain, jute fibers are initially treated with 18% NaOH. Two types of coatings are used- epoxy coating and acrylic paint coating. The moisture gain after certain time interval is measured and it is compared with uncoated specimens. The results showed that there is considerable decrease in moisture gain with the application of coatings.**

***Index Terms*— alkaline treatment, coatings, Jute-epoxy, moisture study**

I. Introduction

THIS research paper contains study of moisture absorption in natural plant fibers and its effect on mechanical properties. There are number of applications of natural fiber based composites in many fields ranging from construction industries to automotive industries e.g. Automobile door panels, interior trim panels, seat backs, and in roof structures. The major problem with the natural fiber is that they are hydrophilic in nature due to its chemical constituent cellulose. It has tendency to absorb moisture and hence their mechanical properties gets degraded over a period of time. The degradation of mechanical properties limits the potential applications of these natural fiber based composites.
The original motivation for the study is natural fiber based composites to be used widely within the different areas of application; they must be protected from moisture.

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Considerable research has been conducted in recent years on natural fiber based composites, but limited attention has been given to moisture absorption and its affect on degradation of mechanical properties in the composite. So these composites can't be used as potential materials in the primary application. The results of this can be used to guide the optimal design of new natural fiber based composites for moisture resistant in service performance

A. Diffusion and Fick's Law

Generally the moisture absorption takes place according to Diffusion and Fick's Law:- Diffusion is the process in which matter is transported from one part of a system to another part of the system as a result of random molecular motions.[1]

B. Diffusion Coefficient

The average coefficient of diffusion, for each specimen was determined from the maximum percent of moisture uptake.

C. Experimental Procedure to Calculate Moisture Diffusion

The water absorption tests are performed following ASTM D570 standard. Specimens are immersed in distilled water. The specimens are taken out from the water weighed frequently to calculate the weight gain by the specimens[1].

II. Literature Survey

Wang et al. [1] carried out research to introduce percolation. Five sheets of different rice hull loadings were prepared. The obtained samples were immersed in distilled water at room temperature. After certain time intervals, samples were taken out from water, their surface moisture was removed and their weights and electrical conductivities were measured immediately by set-up of electrical current measurement. Moisture absorption was obtained. The observation suggests that moisture penetrates into composites only through rice hulls.

Hua et al. [2] studied behavior of short jute fiber composite material in hydrothermal environment. Aging is a multi-scale chemical as well as physical changing process. The aging process was carried out for uncoated specimens. It is observed that the moisture absorption followed Fick's law. The rate of moisture absorption coated sample was lesser than that of uncoated sample. In uncoated sample three distinct stages of moisture absorption were observed quick, slow and rapid respectively. The significant tensile strength decrease was observed in uncoated sample due to moisture gain.

Masoodi et al. [3] selected jute as natural fiber for studying moisture absorption phenomenon also epionoxy and bio-epoxy as resin. For experimentation work six different specimens using different percentage of jute fiber were made. Specimens were cut according to ASTM D 570 standard. The moisture absorption test was performed in distilled water for certain time durations. It is observed that water absorption and swelling measurement was higher for bio-epoxy composites as compared to epionoxy composites. The result shows that increasing percentage of jute fiber higher rate of swelling and water absorption was observed.

Rao et al. [4] Focused on to study influence of internal factors fiber volume fraction and orientation of fibers on the moisture absorption. The fibers used are permeable - Jute fiber and impermeable glass-epoxy. Permeable fibers are those that themselves absorb moisture to a greater extent as compared to resin. For experimentation work specimens of different fiber orientation were made. Moisture absorption measurements were carried out under water emersion at room temperature. Results obtained for equilibrium moisture level were opposite in nature for both the fibers. Comparatively higher moisture gain was observed in jute fiber for same volume fraction. Also it is observed that the overall diffusion coefficient increases with increase in volume fraction in jute-epoxy fiber and decreases in glass-epoxy. The moisture absorption curve remains almost practically unchanged for all fiber orientation angles in case of jute-epoxy although curves were different for glass-epoxy composites. Therefore it is concluded that jute-epoxy composites needs subsequent modification to reduce permeability and enhance scope for practical applications.

Rao et al. [5] studied the influence of external factors such as relative humidity and ambient temperature on the moisture absorption behavior of both permeable jute-epoxy and impermeable glass-epoxy as well as graphite-epoxy. The temperature dependence of both the composite diffusion coefficient is represented by Arrhenius relationship. To study moisture absorption specimens are immersed in distilled water at different temperatures with specific volume fraction of 0.7. The observations were the jute composite has lower activation energy indicating a weaker diffusion barrier which results in high diffusion coefficient values. Moisture diffusion study was carried out for jute and glass composites by exposing specimens to various relative humidity conditions. The specimens were cut according to ASTM E-104. Higher moisture absorption was recorded in jute.

Rao et al. [6] performed study on the moisture absorption characteristics of jute composite with polyester and epoxy resin systems, under conditions of constant humidity and ambient temperature. Unidirectional untreated jute fiber composite laminates in polyester and epoxy resin matrices have been fabricated using a filament winding technique. The specimens cut have been coated along the edges. Specimens are immersed in distilled water maintained at room temperature. The specimens are periodically taken out of water. The weight measurements are made using a single pan balance. These similar measurements have also been carried out on pure resin specimens and on pure jute fiber specimens. Results obtained shows that equilibrium resin absorption value of a jute epoxy curing system is much higher than that for an unanalyzed system The diffusivities of resins such as polyester, and epoxy are far less than those of highly permeable natural fibers jute fiber, As a result the diffusivities as well as the moisture absorption levels of untreated pure jute fiber are brought down drastically, reason being their impregnation in resin systems.

Venkateshwaran et al. [7] studied the effect of layering sequence on the mechanical properties such as tensile, flexural and impact of woven jute/banana hybrid composites. The resin used in this work is LY556 with hardener HY951. Composites were fabricated in the combinations such as Jute fabric composite, Banana fabric composite, Jute/Banana/Jute [JBJ] and Banana/Jute/Banana [BJB].Various mechanical tests were carried out as per ASTM standards. Before testing the specimen were conditioned at a room temperature and relative humidity of 50% according to ASTM D 618 standard. Water absorption test was carried out in accordance with ASTM D570. Specimens were submerged in water at room temperature .The samples were taken out after certain time interval and weighted. The observations show that moisture diffusion in polymer composite follows Fickian as well as non-Fickian characteristic. The results showed that composite of BJB has better tensile strength and modulus also showed that composite of JBJ has lesser tensile properties than individual banana fiber. It can be concluded that addition of banana fiber as skin layer increases strength and stiffness. The process of hybridization improves the properties of the composites. The layering has more effect on flexural properties of the composite. The hybrid composite BJB is more suitable for applications encountering tensile and bending loads. Applications encounters impact loading hybrid composite of JBJ is more suitable. The results show that hybridization of jute fibers with banana fibers slightly decreases the moisture uptake.

Athijayamani et.al. [8] Performed experimentation on variation of mechanical properties of roselle and sisal fibers hybrid polyester composites at wet and dry conditions. For experimentation composite specimen were cut as per ASTM standard. For moisture absorption study edges of the specimen were coated with polyester resin. After regular time intervals, the specimens were removed from water and wiped with filter paper to remove surface water and weighed on precision balance. The test was carried out as per ASTM D570 standard. Similarly the tensile strength, flexural tests, was carried out in accordance with ASTM. The results found that increasing the fiber content and length at dry condition, the tensile and the flexural strength increased. At wet condition, the tensile and flexural strength have a high-level reduction. It is observed that the impact strength was reduced with the fiber content and length at dry and wet conditions. Exposure to moisture caused a significant drop in the mechanical properties due to the degradation of the fiber–matrix interface.

Dhakal et.al. [9] performed experimentation work on Hemp fiber reinforced unsaturated polyester composites (HFRUPE) which was subjected to water immersion tests to study the effects of water absorption on the mechanical properties. The matrix material used in this work was ‘‘NORPOL 444-M888’’ mixed with curing catalyst, methyl ethyl ketone peroxide (MEKP). The samples for tensile and flexural tests containing different fiber volume fraction were machined to perform moisture absorption. The percentage weight gain of samples was measured at different time intervals. The tensile strength and modulus of the hemp fiber reinforced composites before and after water immersion were measured similarly flexural strength also measured. It shows that with increase in voids and cellulose content moisture uptake increase. It is observed that at room temperature it follows Fickian behavior, and at elevated temperature the absorption behavior is non-Fickian. Water uptake behavior is radically altered. Significant drops in tensile and flexural properties due to the degradation of the fiber–matrix interface.

Chow et al. [10] studied the effects of the moisture immersion treatment on the tensile and impact fracture characteristics on sisal fiber reinforced polypropylene (SF/PP) composites. Polypropylene homopolymer and maleic anhydride grafted polypropylene wax were used as the matrix and compatibilizer. First the specimens were dried and weighted then the specimens were were immersed into a hot water bath at 90^{o}C for different durations before removal from the water bath. The water absorption characteristics of the composites were evaluated by two parameters: the percentage of apparent weight gain (WG), and the percentage of weight loss (WL) respectively. It is observed that the rate and the maximum value of moisture absorption increases with increasing sisal fiber content. Also WL increased sharply with increasing the immersion time. If there is higher the SF content, the higher the WL value was found at any given immersion time. The weight loss was mainly concerned with the dissolution of the loganiaceous material and waxy substances on the sisal fiber surface. Thus due to this weight loss characteristics observed in the SF/PP composites, the moisture absorption phenomenon is non-Fickian. Whereas the tensile modulus and tensile strength decreased continuously with increasing immersion time, the impact strength was improved initially with increasing immersion time until reaching the maximum.

Sreekala et.al. [11] studied water sorption characteristics of oil palm fibers. The specimens were immersed in distilled water having different temperatures in a thermostatically controlled air oven. Moisture gain of the samples was noted at specific time intervals. Work is performed until equilibrium is reached. The diffusion mechanism for all the systems was to be non-Fickian. The treatment used reduces the water uptake at all temperatures. The decrease observed is due to its physical and chemical changes occurred to the fibers on modifications. The diffusion coefficient, sorption coefficient as well as permeability coefficient decreased upon treatments. The mechanical performance of the fibers decreases on water sorption and it regains on desorption. The treatment used reduces the mechanical strength of the fibers. Young’s modulus also shows enhancement on mercerized and silane treatment. It is observed that in the swollen stage the stiffness of the fiber was considerably reduced.

Tamrakar et al [12] performed study on water absorption of wood polypropylene composite sheet piles and its influence on mechanical properties. The specimens used for water absorption tests were cut from the Z-section of sheet piles in the longitudinal direction and were identified as C-lock and T-lock flange section and web section. Specimens for absorption tests were coated on the cut edges using an epoxy adhesive. Water absorption tests were carried out on specimens cut from flanges and webs of the Z-section by immersion in tap water. It is observed that the absorption behavior followed the kinetics of a Fickian diffusion process. Also the modeling results showed the accurate prediction of the absorption process at both the temperatures (21^o C and 70^o C). Also, the change in diffusion coefficient with respect to temperature was found to conform to Arrhenius-type relation.

Ferreira et al [13] studied experimental work on mechanical properties of natural fiber reinforced composites. Hemp short fibers and pine sawdust were randomly distributed in polypropylene matrices. Injection molding technique used to produce composite plates with 5 mm thickness. Stiffness modulus and ultimate stresses were obtained for different weight fraction content of reinforcement and discussed taking in account the failure modes. The four series of pine sawdust reinforced specimens were immersed in water for periods up to 20 days. Periodically, the specimens were taken out from the water recipient and tested immediately. The hemp reinforced composites shows that increasing the stiffness modulus fiber with fiber volume fraction. Ultimate strength tends to increase slightly with fiber content for bending loads, but for tension and particularly for low fiber content.

III. EXPERIMENTATION WORK

A. Materials

For study of moisture absorption in natural fiber based composites jute fiber mat with 0-90^o orientation is selected as reinforcement in polymer composite along with epoxy resin-520 and Epoxy hardener-PAM. To increase adhesion between jute fiber and polymer matrix (to enhance the mechanical properties of the fiber) the jute mat is treated with 18% NaOH. [7].

B. Fabrication of Composite Laminate

The fabrication of jute-epoxy composite laminate is carried out by hand lay-up technique using compression molding machine. For fabrication purpose Epoxy resin-520 and Epoxy hardener-PAM is used in the proportion 10:1. From the fabricated laminate composite specimens are cut as per ASTM D570 standard for moisture absorption study and ASTM D3039 standard for tensile strength study respectively. The moisture absorption study has been carried out on jute-epoxy composite specimens coated with acrylic paint as well as epoxy resin. The comparison of the percentage weight is done with the uncoated jute-epoxy composite specimens.

C. Moisture study

Moisture absorption study is performed on NaOH treated uncoated and coated specimen in distilled water and in the solutions of pH 4, 7 and 8. The same pH range is selected considering jute-epoxy composite as a proposed material for biogas plant which experiences pH variation in-between 5 to 9 due to provided feed. [14].

After certain time intervals, the specimens are taken out from distilled water and as well as from pH solutions. The specimen are wiped with the absorbent paper and then weighed with the help of digital balance having accuracy 0.01 mg. The weighing is done within 30 seconds so that the error due to evaporation can be avoided. Specimens are reimmersed in respective pH solutions and distilled water to continue moisture study. The moisture study is carried out upto saturation. The weight increase in specimen due to moisture absorption can be calculated from following formulae:

$$W(\%) = \frac{M_t - M_o}{M_o} \times 100$$

Where, $W(\%)$ = Weight gain by specimen in percentage, M_o = Dry specimen weight and M_t = Weight of specimen after time (t).

Fig. 1. Experimental set up of moisture study in jute-epoxy coated and uncoated specimen exposed to different solution media

D. Tensile strength study

The test is carried out on the universal testing machine which has Model No as -STS248 and an accuracy ± 1%. The cross head speed is maintained as 10 mm/min. The tensile strength of the specimen is about 35 MPa for NaOH treated jute fiber before exposing to the moisture absorption.

Tensile strength is carried out after saturation for coated as well as uncoated specimen having same volume fraction of jute fiber in distilled water solution. It is observed that reduction in tensile strength was more in case of uncoated specimen as compared to coated specimen. Thus it can be said that with the application of coating reduction in tensile strength can be minimized as compared to uncoated specimen.

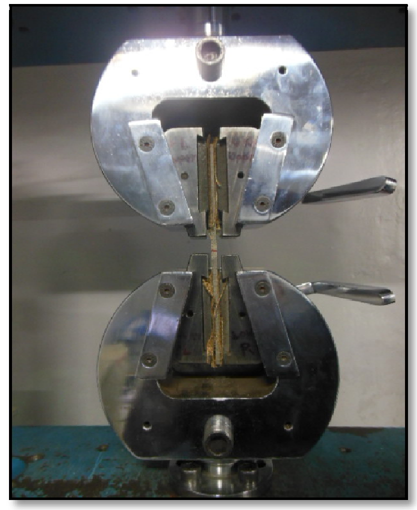

Fig.. 2. Tensile test of coupon specimen of jute-epoxy composite laminate

TABLE I

COMPARISON OF TENSILE STRENGTH AFTER SATURATION STAGE

Sr. No.	Type of the specimen	Tensile Strength (MPa)
1	Uncoated specimen	21.96
2	Epoxy coated specimen	24.685
3	Acrylic coated specimen	31.765

IV. RESULTS AND DISCUSSION

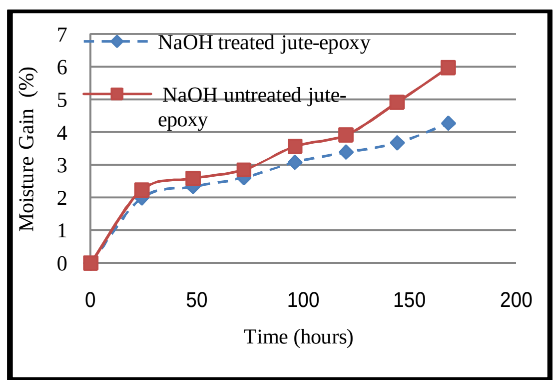

Fig. 3. Comparison of moisture gain of jute-epoxy in distilled water

Fig. 3 shows comparison of percentage moisture gain for NaOH treated and untreated jute fiber reinforced epoxy composite laminate. It is observed that NaOH treated specimen registered lower percentage moisture gain as compared to untreated jute-epoxy laminate in distilled water [15]. Thus it can be concluded that with NaOH chemical treatment there is reduction in moisture gain. This comparison is done for 200 hrs.

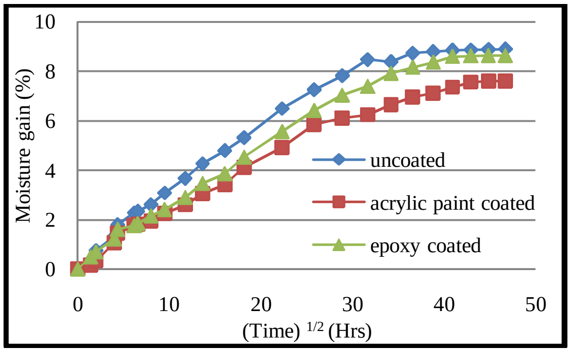

Fig. 4. NaOH treated specimen with different coatings subjected to moisture absorption in distilled water

From Fig. 4, it is observed that there is considerable reduction in percentage moisture gain in acrylic coated as well as epoxy coated specimen as compared to uncoated specimen. It shows that with coatings percentage moisture gain can be reduced.

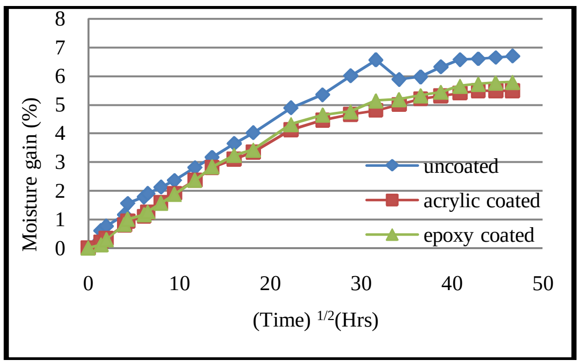

Fig. 5 NaOH treated Jute-epoxy Specimen immersed in pH 4 solution

From Fig. 5 it is observed that when the coated and uncoated specimen are immersed in the pH 4 solution the reduction in percentage moisture gain is observed in coated specimen as compared to uncoated specimen. The similar kind of results were observed in the pH 7 and pH 8 solutions as well. The results are obtained until the saturation stage is observed.

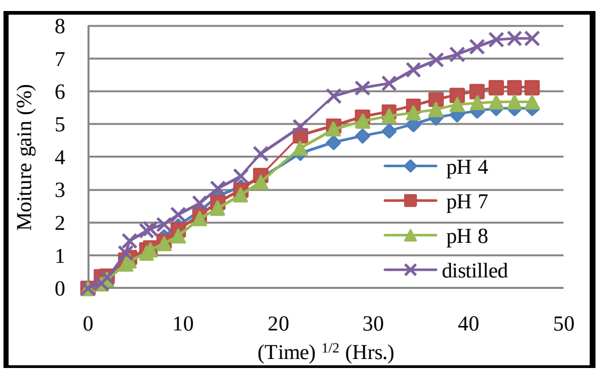

Fig. 6. NaOH treated and acrylic coated Jute-Epoxyspecimen in solutions of different media

From above Fig.6, it is observed that when coated specimen are immersed in the solutions of different pH media there is reduction in percentage moisture gain as compared to specimen in distilled water. Therefore it is said that even if there is change in pH value the percentage moisture gain does not vary to a considerable extent. Therefore whenever there is change in pH value in the solution acrylic coating can be used for natural jute fiber.

The similar kind of results were observed in epoxy coated specimen also. Therefore both coatings acrylic as well as epoxy are found to give good results.

V. Conclusion

Research is carried out to study moisture absorption phenomenon in natural jute fiber based composite. Jute mat is treated with 18% NaOH. Two different kinds of coatings namely acrylic paint and epoxy resin are used. The experimentation work is carried out till saturation stage is reached.

It is observed that there is considerable reduction in moisture gain when the specimens are coated as compared to uncoated specimen. The similar kind of results is observed in solutions of different pH media as well as in distilled water solution.

Also it is observed that even though there is change in the pH value there is not much variation in the percentage moisture gain both in case of coated and uncoated specimens. Therefore it can be concluded that pH variation does not affect moisture gain. Therefore both used coatings can be used whenever the natural fiber based composite is subjected to variation in pH value.

The considerable reduction in moisture gain observed when the jute mat is initially treated with NaOH. Whenever the natural fiber based jute-epoxy composite is exposed to moisture it results in significant decrease in tensile properties due to degradation of fiber matrix properties.

For natural fiber based composites exposed to moisture it is necessary to provide coatings so that moisture absorption can be reduced. Coatings used for the experimental work gave satisfactory results therefore these coatings can be used in future for further applications.

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