Effect of Hygrothermal Environment on the Tensile Properties of Banana Fiber Epoxy Composites

Paresh V. Sawai, Abhijit R. Deshpande, and Kiran S. Wangikar

***Abstract*— However natural fibers are hydrophilic in nature and environmental degradation of their composites takes place during the service. In this present study, the hygrothermal behaviour of banana fiber epoxy composites and effect of the hygrothermal condition on the tensile properties of banana fiber epoxy composites are investigated. The banana fiber epoxy composites are fabricated by hand layup method with the various volume fraction of banana fiber epoxy such as 30:70, 40:60 and 50:50. The hygrothermal aging of specimens are carried out at the temperature 28°C and humidity 65% in the hygrothermal chamber. Usually, the composites are subjected to various loading conditions. Therefore, after hygrothermal aging an attempt has been made to study the tensile properties of the banana fiber epoxy composites. The variations in the tensile properties and rate of moisture absorption for different weight fractions of banana fiber epoxy in X-direction and Y-direction are investigated. The result from the hygrothermal studies shows that on prolonging exposure to the hygrothermal environment leads to decrease in the tensile strength values of banana fiber-epoxy composites.**

***Index Terms*— Natural fiber composites, Banana fiber composites.**

I. INTRODUCTION

It is a true fact that the technological development depends on advances in the field of materials. Today's modern world need more efficient material for the development of new product and the traditional materials failed to satisfy the requirements of the designers or manufacturers. Hence, to answer the needs of every engineering industry the advanced composite materials have the ability to meet the diverse design requirements with its noteworthy advantages [18]. But the non-recycling and non-biodegradability are the main demerits of the synthetic fiber composite materials [17]. Due to increased demand for green products, environmental awareness and to stop the effect of global warming there is the need to replace the synthetic fiber composite material with the natural fiber composite material. As natural fibers are easily available, remarkably cheap, eco-friendly, renewable, it is a desired option for the replacement of Synthetic fibers [1]. Among the available natural fibers, researchers had shown a significant interest in using the banana fibers for various engineering applications. They also focused on using banana fibers more effectively and economically. Banana fibers have many advantages over other natural fibers such as availability, the range of application, biodegradability and cost effectiveness [3] [10].

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II. LITERATURE REVIEW

S.V. Joshi et.al [1] reviewed and compared the life cycle of natural fiber and glass fiber composites, and found the motives of their relative environmental performance. Andressa Cecília Milanese et.al [2] studied the the tensile behaviour of four natural fiber composites: dry sisal/polyurethane, humid sisal/polyurethane, dry sisal/phenolic and humid sisal/phenolic resin and observed that dry sisal/phenolic composites had more the tensile strength than the humid sisal/ polyurethane. Rao et.al [4] accessed the the tensile, flexural and dielectric properties of vakka fiber and resin matrix polyester composites with different volume fractions of fibers are studied. The study reported that banana composites have the more ultimate the tensile strength and flexural strength than the sisal composites. R Yahaya et. al.[5] investigated the mechanical properties, water absorption and thickness swelling behavior of Kenaf/Kevlar hybrid composites at different volume fractions before and after water aging. by The reduction in the tensile strength of Kenaf/epoxy, (20/80) Kenaf/Kevlar epoxy and (50/50) Kenaf/Kevlar epoxy composites were observed by 5.6%, 16.8% and 22.4% respectively after water aging but impact strength of samples was not affected by water aging N. Venkateshwaran et.al [6] investigated the effect of fiber length and weight percentage of banana and sisal fiber composites on mechanical properties to determine the optimum fiber length and wt. percentage. Also observed that the effect of the addition of sisal fiber to banana fiber composites results in the improved mechanical and moisture absorption property. N. Venkateshwaran et.al. [7] Studied the effect of fiber surface treatment through various concentrations of sodium hydroxide (NaOH) as (0.5%, 1%, 2%, 5%, 10%, 15% and 20%) on the mechanical properties and visco-elastic behavior of banana/epoxy composites. Of the

various concentrations of NaOH, 1 % NaOH treated composites have superior properties. The moisture absorption rate in treated fiber composites was 15% lesser than that of untreated fiber composites. M. Boopalan et. al. [8] studied and compared the mechanical and thermal properties of jute/banana fiber reinforced epoxy hybrid composites. The cross-plied jute and banana fibers hybridized in an epoxy matrix and prepared with various weight ratios (100/0, 75/25, 50/50, 25/75 and 0/100). The results indicate that the addition of banana fiber in the composites resulted in 17%, 4.3% and 35.5% increase in the tensile strength, flexural strength and impact strength respectively, also the 50/50 weight ratio hybrid composite possess the better thermal property and less water absorption capacity. J.Santhosh et. al. [9] analyzed and compared untreated and treated with 5% of NaOH banana fiber reinforced composites and the hybrid composite of coconut powder mixed with banana fiber for the behavior of mechanical properties and development of new hybrid composite material. V. Paul et. al [10] synthesized and tested the bio-composite of banana fibers infused with the resin made from banana sap. The two composites were analyzed as banana/banana sap bio resin composites and banana/control resin for their mechanical properties, thermal property, and bio-degradable characteristics. The result of the experiment showed that the significant difference was observed in the the tensile and flexural properties of banana-sap resin composites and control resin composites. Banana sap resin composites possessed 6% more flexural strength as compared to control resin composites. Also, a banana sap resin composite was more stable to thermal degradation and heat deflection temperature. Alavudeen et. al [11] evaluated the mechanical properties of banana, kenaf and banana/kenaf fiber- hybrid reinforced polyester composites with reference to various weaving patterns and random orientation of fiber in composites . The report shows that the irrespective of reinforced fiber used in polymer matrix due to uniform distribution of stress transfer, plain weaved hybrid composites exhibits the higher the tensile strength than twill weaved pattern composites. Rui-Hua Hu et al.[12] investigated aging behavior of short jute/polylactide (PLA) composite material in the hygrothermal environment which is probable to actual practice and the tensile properties of the composite. The result showed that the the tensile strength of uncoated samples was greatly reduced in the hygrothermal environment as compared to coated samples. Rajesh Ghosh et .al. [13] focused the effect of ultrasonic treatment on water absorption characteristics and mechanical properties of woven banana/vinyl ester fiber composites. From results, it was found that the tensile strength and flexural strength of sonicated composite materials increased by 4.25% and 6.21% respectively as compared to specimens prepared by the normal process. It was because the strong adherence of fibers with resin due to ultrasonic wave force. P Surya Nagendra et. al. [14] evaluated and analyzed the percentage the tensile strength, percentage elongation, flexural strength and modulus of the composite of nano banana fiber/epoxy composites on the experimental basis. In this report naturally the moderate improvement in the mechanical properties of the composites was observed due to the incorporation of nano-fibers with the Epoxy matrix. Raghavendra et. al. [16] studied the mechanical properties of short banana fiber reinforced natural rubber composites by varying a length of fiber and fiber content. The report reveals that as fiber concentration increases the tensile strength also increased.

The literature survey shows that most of the research is related to the effect of surface treatment of natural fibers, fiber length, fiber percentage, fiber orientation, hybrid natural composites on mechanical properties of banana fiber composites. It is also realized that the banana/epoxy composites have a lot of potential for development as an advanced material in various sectors such as structural, automotive, and textile applications. But very limited literatures and very little work are available on banana/epoxy composites, which figure out the effect of few parameters on the mechanical behavior of banana/epoxy composites.

The research on aging behaviours of banana fibers reinforced composites in the hygrothermal environment has not yet been found. Hence, in this study, the hygrothermal aging behaviours of banana fiber epoxy composites are investigated in a controlled temperature and humidity environment which is probably used in actual practice.

III. MATERIALS

For this study, the Banana Fibers, Epoxy resin and Hardener used as the constituent material for fabricating the banana fiber/epoxy composite plates are,

The banana fibers as reinforcement are purchased from the suppliers. To orientate the fiber in the composite material the plain weaved banana fiber bidirectional mat was prepared. The epoxy-520 and epoxy hardner K6 were purchased from local distributors, Pune.

IV. METHODOLOGY

For proper inter laminar shear strength, the bidirectional banana fiber mat was cut into standard size square sheets having dimensions 300mm × 300mm. The various layers of the banana fiber mat are bind together by using the mixture of epoxy resin and hardener. The optimum mixing ratio 10:1 was used for mixing of epoxy and hardener. The epoxy-520 mixed with hardener K6 is used to prepare the composite plate. The various volume fraction of banana fiber/epoxy such as 30:70, 40:60 and 50:50 is used to prepare the three different plates of banana fiber/epoxy composites. The fiber orientation and volume fraction are two important factors which affect the properties of composites so proper care has taken during composite preparation.

The Hand Lay Up method is used for the preparation of banana fiber epoxy composites laminates. The mould was prepared from rectangular plywood of size 600mm×500mm × 20mm in dimensions, both the upper and bottom plate coated with remover. The upper plate was used to compress the fiber mat after final layer of epoxy applied and also prevents the entry of dust and dirt during the curing. During the preparation

of banana fiber epoxy composite laminates the mould was cleaned well and dried. The mould is kept closed and pressed the composite material uniformly using C-clamps to get desired shape and uniform resin for 24 hours of curing.

The water jet machining was used for the cutting of test specimen from banana fiber epoxy composite plates. The bidirectional banana fiber mat used for composites, so it has different properties in X and Y- direction.

Fig.1. Preparation of Banana Fiber Epoxy Composite Plate

The X and Y direction was marked at the corner of the composite plate and accordingly the four test specimens in X-directions and four in Y-direction were cut from the each banana fiber epoxy composite laminates. The dimensions of specimens were kept as 210mm in length and width is 20mm.

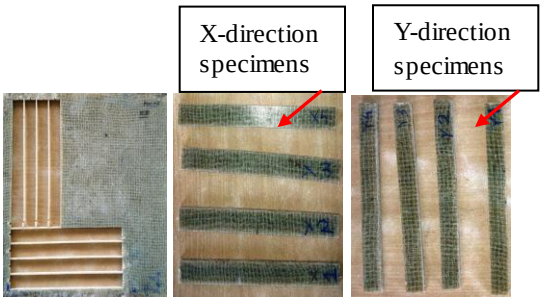

Fig.2. Cutting of test specimens in X and Y directions

TABLE I
PREPARATION OF TEST SPECIMENS

Plate No.	Volume Fraction of Fiber and Epoxy	Test Specimens X-Directions	Test Specimens Y-Directions
A	30:70	X1	Y1
		X2	Y2
		X3	Y3
		X4	Y4
B	40:60	X1	Y1
		X2	Y2
		X3	Y3
		X4	Y4
C	50:50	X1	Y1
		X2	Y2
		X3	Y3
		X4	Y4

The humidity chamber was designed and used for the hygrothermal treatment of specimens. For the measurements of temperature (Temp.) and relative humidity (RH) the hygrothermal cabinet had an inbuilt temperature sensor and humidity sensor (hygrometer) respectively. Proper insulation is provided inside the chamber to avoid temperature and humidity losses. To position the test specimens in hygrothermal chamber the perforated trays are placed.

V. TESTING OF COMPOSITES

A. *Hygrothermal Testing*

For hygrothermal study, the weather conditions in India were considered. The used temperature and humidity for the hygrothemal test was 28°C and 65% respectively. Once chamber attained the required temperature 28°C and RH is 65% then the test specimens placed in the chamber. The specimens of various weight fractions of banana fiber/ epoxy in X-direction and Y-direction was placed in the cabinet on the perforated tray. Before placing the specimen in chamber each specimen was weighed by an electronic balance (corrected up to 2 decimal places). The specimens were exposed to the hygrothermal conditioning for the different time span ranging from twenty-four hours to seventy-two hours.

After the hygrothermal treatment test specimen is removed from the chamber and wiped to remove excess of moisture on its surface and weighed again by an electronic balance (corrected up to 2 decimal places) to calculate the amount of moisture absorbed. Then Specimens were wrapped in aluminium foil to avoid moisture loss or moisture pickup. The % moisture uptake was given by the expression given below:

$$w_e\,(t) = 100\times(w_t - w_o) / w_o,$$

Where, w_e is water absorption percentage, w_t is weight after time t, and w_o is the initial weight of the sample at t=0.

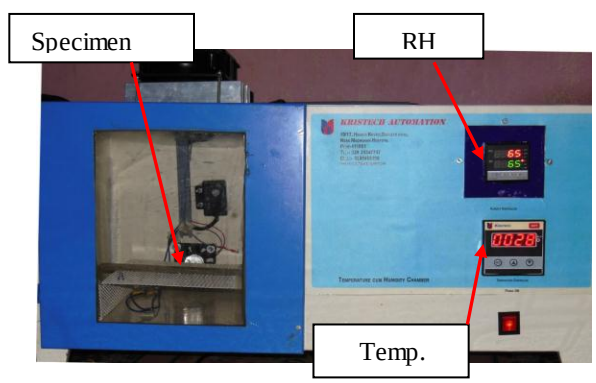

Fig.3. Testing of Specimen in Hygrothermal Chamber

B. *The tensile Testing*

The tensile test was carried out on the hygrothermal conditioned specimens for characterizing the tensile behaviors. The tensile test was carried on specimens as per ASTM standards. The computer monitories universal testing machine is used for the tensile testing. The length of the test specimens was 210 mm in loading direction and width was 20 mm. The specimen is held in the upper and bottom jaw of machine and the uni-axial load is applied through the ends. The load is applied until the breaking of the specimen. The the tensile stress and strain are recorded and graphs are generated.

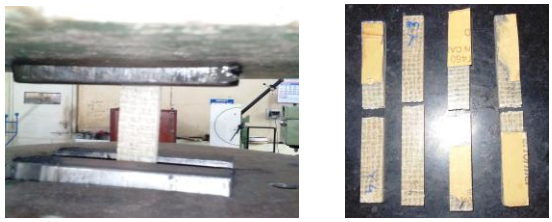

Fig.4. Tensile Testing of Specimens

VI. RESULTS AND DISCUSSION

A. The hygrothermal Behavior of Plain Woven Banana Fiber Epoxy Composites

The temperature and humidity maintained for the hygrothermal test were 28°C and 65% respectively and time duration was (0 Hrs, 24 Hrs, 48 Hrs, and 72Hrs.). The varying volume fraction of banana fiber epoxy specimens, their initial weight and weight after moisture absorption of specimens is shown in graph. Which details the % of moisture uptake with the hygrothermal aging time.

The experimental data details that diffusion process of water in banana fiber epoxy composites followed the Fickians second law of diffusion as Fickian curve is obtained. Initially, the rate of moisture absorption is high because of the moisture is absorbed in the voids or pores present in the matrix. The rate of moisture absorption is decreased gradually after a particular time. This is because of the saturation of the absorbed moisture which is enough to fill the spaces. The rate of absorption gets reduced but % of moisture absorption is increased with the increase of time of the hygrothermal treatment.

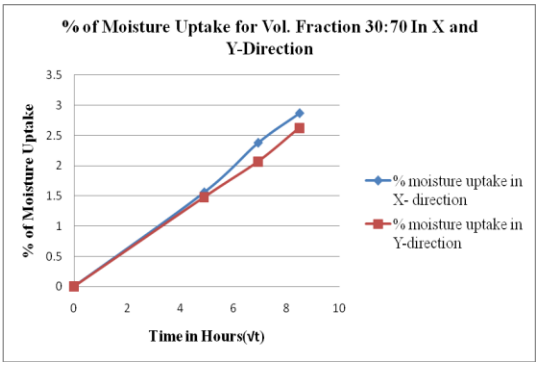

Fig. 5. % of Moisture Uptake for Vol. Fraction 30:70 Specimens in X and Y – Direction

This cycle of absorption and diffusion of moisture continues so that the most of the matrix is saturated with the moisture and the moisture interacts with the fiber-matrix interface. The Fig. 6. reveals that, moisture uptake percentage in the X-direction specimen is more as compare to Y-direction Specimen. The moisture uptake % is high in 50:50 volume fraction specimens this is because as the fiber volume fraction of the composites increased the rate of weight gain and equilibrium moisture content increased.

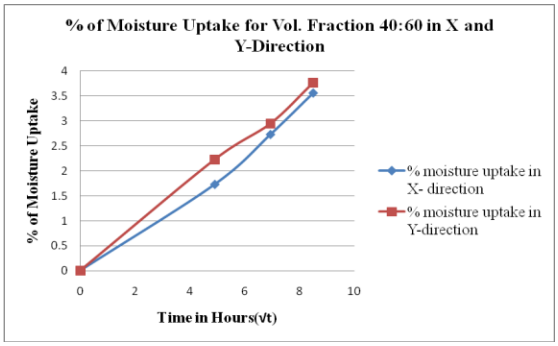

Fig. 6. % of Moisture Uptake for Vol. Fraction 40:60 Specimens in X and Y – Direction

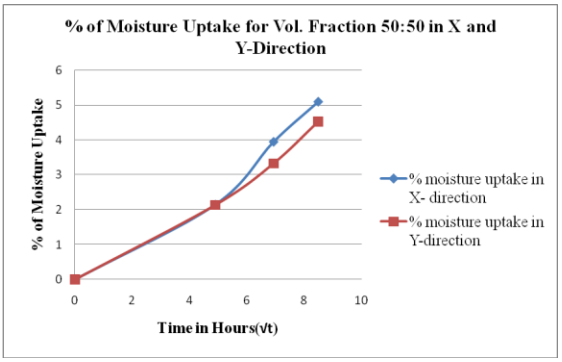

Fig. 7. % of Moisture Uptake for Vol. Fraction 50:50 Specimens in X and Y – Direction

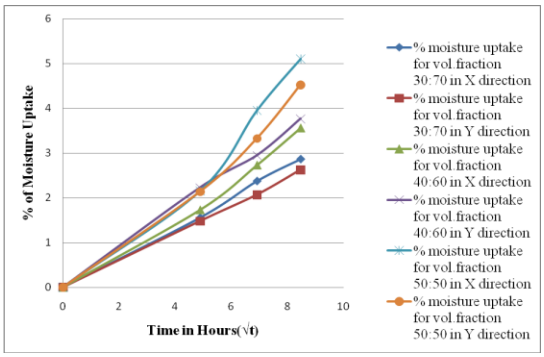

Fig. 8. % of Moisture Uptake for All Vol. Fraction Specimens in X and Y –Direction

The average percentage of moisture uptake in 30:70 test specimens in X-direction is 1.7025 % and in Y-direction is 1.5450%. Whereas, the average percentage of moisture uptake in 40:60 test specimens in X and in Y-direction specimens is 2.005% and 2.2375% respectively. Similarly the average percentage of moisture uptake in 50:50 test specimens in X-direction is 2.8% and in Y-direction is 2.5%. The % of moisture uptake is observed less in 30:70 volume fraction banana fiber epoxy composites. At the end of aging test after 72 hours the observed average % of moisture uptake in all specimens is 5.08%.

B. The tensile Behavior of Plain Woven Banana Fiber Epoxy Composites

The tensile tests were conducted on the banana fiber epoxy

composites for different weight fraction in X and Y-direction after the hygrothermal conditioning for 24 hours, 48 hours and 72 hours to obtain mechanical strength values. These values are acts as a benchmark for comparison of the strength of the hygrothermal treated samples. The absorption of water changes volume, changes microstructure and development of the hygrothermal stresses in banana fiber epoxy composites.

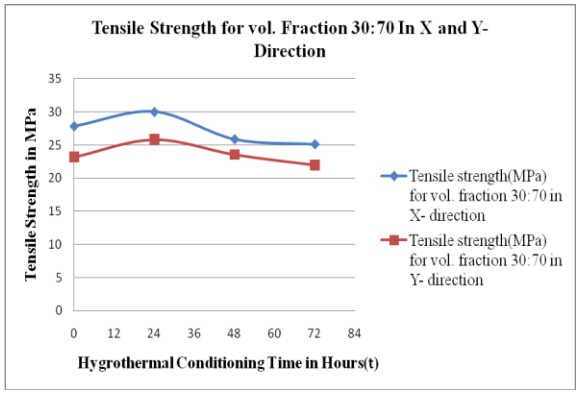

Fig. 9. Tensile Strength for Vol. Fraction 30:70 Specimens in X and Y – Direction

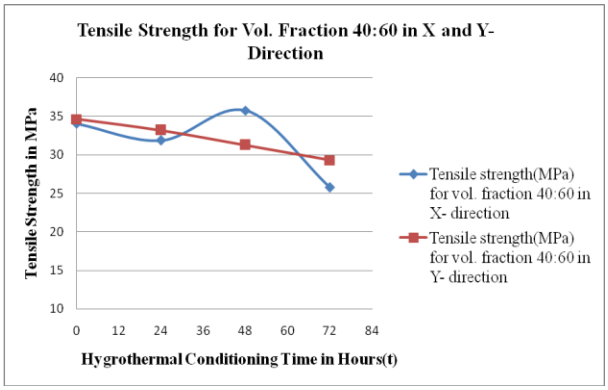

Fig. 10. Tensile Strength for Vol. Fraction 40:60 Specimens in X and Y – Direction

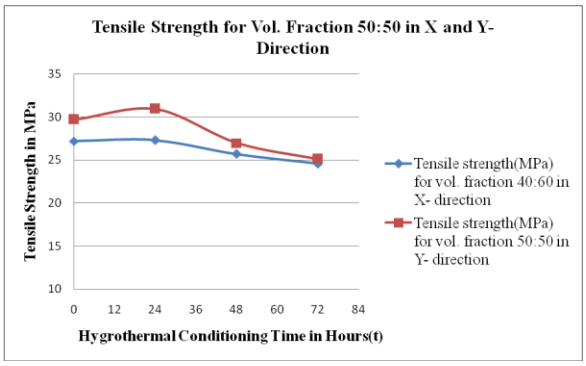

Fig. 11. Tensile Strength for Vol. Fraction 50:50 Specimens in X and Y – Direction

After 24 hours of the hygrothermal exposure, the graphical data of the tensile test of all specimens shows that the the tensile strength of specimens is increased. This because of relief of the stresses induced during curing. The induced the hygrothermal swelling stresses principal which details that the moisture absorption is opposite in nature to the curing stresses. Hence, the tensile strength increases for the short duration of the hygrothermal exposure. The % of moisture uptake is increased with increase in exposure time from 24 hours to 72 hours. With the prolonged time of the hygrothermal exposure the moisture absorption kinetics changes from fickian to non-fickian. The absorbed moisture by specimens is directly interacting with fiber and matrix. This causes poor adhesion between the resin matrix and fibers, at last causing the de-bonding. The fracture during the tensile testing depends on the strength of the fiber-matrix interface. Also, it depends on the toughness and strength of the matrix. The increased the hygrothermal stresses cause plasticization of matrix and crack. The propagation of fracture gives the decreased values the tensile strength in the specimens subjected to the hygrothermal aging for 48 hours and 72 hours.

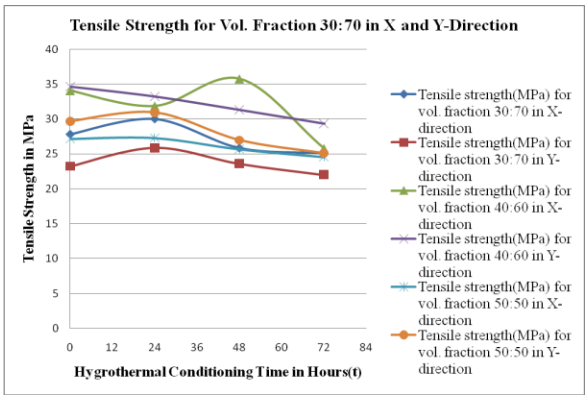

Fig. 12. Tensile Strength for All Vol. Fraction Specimens in X and Y – Direction

In the comparison of the tensile strength of specimens of different weight fractions, it is observed that the the tensile strength of 30:70 and 50:50 weight fraction specimens are greatly influenced by moisture uptake during the hygrothermal aging. The % decrease in the tensile test of 30:70 weight fraction specimens exposed to the hygrothermal conditions in X-direction and Y-direction are 9.84549% and 5.297158% respectively. Whereas the % decrease in the tensile test of 40:60 volume fraction specimens exposed to the hygrothermal conditions in X-direction and Y-direction are 24.35446% and 15.3624% respectively. Similarly the observed % decrease in the tensile test of 40:60 volume fraction specimens exposed to the hygrothermal conditions in X-direction and Y-direction are 9.639441% and 15.43127% respectively. From the results, it is also observed that the tensile strength of 40:60 volume fractions in X-direction is higher than the other volume fraction specimens.

VII. CONCLUSION

In the investigation of mechanical properties of banana fiber epoxy composites in X and Y direction, more % of moisture uptake is observed in 50:50 volume fraction banana fiber

epoxy composites as compared to 30:70 and 40:60 volume fraction composites. The % moisture uptake is high in X-direction specimens as compared to Y-direction specimens. From the tensile test data, it is observed that in the hygrothermally treated specimens the tensile strength is get decreased with increasing the hygrothermal exposure time. The maximum value of the tensile strength is observed in 40:60 volume fraction banana fiber epoxy composites. In the comparison of the tensile strength of specimens of different volume fractions, it is observed that the tensile strength of 30:70 and 50:50 volume fraction specimens is greatly influenced by moisture uptake during the hygrothermal aging. During hygrothermal aging the tensile strength of banana fiber epoxy composites subjected to reduced by average 13.3217%. This change of the mechanical behaviour depends on how the environment changes the state of the fiber/matrix interface and causes de-bonding.

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