Experimental Evaluation of Effect of Humidity and Temperature on the Tensile Strength of Adhesively Bonded Banana-Epoxy Composite Joint.

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Abstract
Fiber reinforced composites are being used in a wide range of applications such as aerospace, automotive, packaging, agriculture and construction industries in today's society. The man-made fibers such as glass, rubber, carbon, aramid, nylon etc. make good reinforcements for composites since they give improved mechanical properties with good moisture resistance but are expensive and not environment- friendly. Also their production requires high energy consumption. A wide research is being carried out by many researchers on natural fiber composites such as sisal, hemp, jute, coir, kenaf, flax, bamboo etc. so that they can be used as replacements for man-made fiber composites. Recently, banana fiber has caught the interest of many researchers since it is an abundantly available, biodegradable, agricultural waste having low density and cost. Factors like fiber content, fiber length, fiber orientation, humidity etc. affect the mechanical properties of the composite. In this study the effect of volume fraction on the tensile strength of the banana composite is investigated. From that, the most suited volume fraction for the composite is determined and the effect of humidity and temperature on its strength is studied. There are different types of joining processes for composite joints out of which adhesive bonding is the most suitable because unlike the joints made by the stitching process or use of mechanical fasteners like screws, rivets and clamps, in adhesively bonded joints the load is uniformly distributed and there is neither any alteration of the basic design of assembly nor any fiber damage.

***Keywords*: Adhesive Bond, Banana Composite, Humidity, Single Lap Joint, Temperature Effect.**

I. INTRODUCTION

Engineering metals and alloys have been a major part of our society since centuries before. Be it screws, brackets, cooking cutlery, accessories, work tools, machinery or construction components, automobile or computers and laptops, metals have brought great improvement to the quality of our daily life. But metals when used in bulk are heavy and expensive. Also they are non – renewable and are being consumed a lot with high rate and are on the verge of extinction. These demerits gave rise to the replacement of metals by composites. A composite or composition material is an anisotropic combination of two or more materials that results in better properties than the parent material. The composite has basically two constituents- reinforcement and matrix. The reinforcements are responsible for imparting durability, strength and stiffness whereas the surrounding matrix keeps the reinforcements in the desired position and orientation while acting as a load transfer medium between them , also protecting them from environmental damages such as elevated temperatures and humidity [1]. Depending on the type of fiber reinforcement used the composites are mainly classified as man-made fiber reinforced composites and natural fiber reinforced composites. The man-made fiber composites such as glass fiber, rubber, carbon, aramid, nylon etc. impart high strength and high stiffness to the polymer, making the fiber reinforced composites suitable for a large number of diverse applications ranging from aerospace to sports equipment. However they being non-biodegradable and non-environment-friendly possessed a threat which drove the researchers to find alternatives and investigate use of natural fibers in composite material for lower mechanical strength applications [2]. Natural fibers as the name suggests are sourced from nature i.e. plants or animals, which are abundantly available around the world. They are biodegradable as they are extracted from renewable natural sources and are light in weight owing to their low density [3]. They possess high specific strength and are low in cost as compared to artificial fibers. Investigations have been carried out on many natural fibers such as: jute, hemp, kenaf, cotton, coir, bamboo, ramie, sisal etc.

The banana is not a tree but a perennial plant that replaces itself i.e. after each pseudo stem bears fruit it dies and is replaced by another pseudo stem. Each pseudo stem bears fruit only once. After the harvestation of the plantain, the stem of

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banana plant being a banana cultivation waste is usually thrown away. Fiber can be extracted from these agricultural waste pseudo stems and can be put to various uses such as fiber lining for car interiors, domestic furnishings, floor mats, bags, cardboard, currency notes, baskets, paper etc [4]. Banana is an abundantly cultivated fruit. India is the leading producer of banana wherein the banana is cultivated throughout the year [5].

Hence the fiber can be uninterruptedly supplied to the industries. The banana fiber has very low density as compared to glass fiber and good mechanical strength. Hence it can be successfully used for applications where weight reduction plays a major role and medium strength is required. Table1 shows some of the physical properties of banana fiber.

In many practical applications, it is impossible to manufacture an entire structure in a single piece mostly due to geometrical limitations and the high costs involved. Hence small parts are manufactured and assembled together with the help of joints. The process of joining two similar or dissimilar materials by the use of adhesives is known as adhesive bonding**.** The classical mechanical fastening techniques like usage of screws, nuts, rivets, clamps and through thickness stitching damage the fiber and also alter the basic design of the assembly creating stress concentrators. In addition to overcoming the demerits of the traditional joining techniques, adhesive bonding has other advantages like uniformly distributed load, high strength to weight ratio, high fatigue resistance and distribution of load is over a larger area [6].

Table 1: Physical properties of banana fiber [7]

Parameter	**Values**
Density (kg/m^3)	1350
Flexural Modulus (GPa)	4
Tensile Strength (MPa)	56
Young's Modulus (MPa)	3.5
Moisture Content (%)	11

This project includes two parts. In the first part the basic properties of banana-epoxy composite are studied. The effect of varying volume fraction on the tensile strength of banana composite is studied for x and y- directions. The best suitable fiber volume fraction for the woven banana-epoxy is determined and the effect of temperature and humidity is carried out on the tensile strength of the same. Comparison of dry and wet banana composites is also done. In the next part single lap adhesively bonded joint having the initially determined best suited volume fraction is manufactured and subjected to varying humidity and temperature conditions and its effect on the tensile strength of the bonded joint is investigated and compared.

II. Literature review

KristiinaOksman, studied the properties of sisal, jute, flax, banana based polypropylene (PP) composites with varying fiber content from 20- 45wt % and compared them. It was observed that the banana /PP composite showed best mechanical properties at 40% wt. (fiber content) having 45 MPa flexural strength, 3.3 GPa flexural modulus and 17 KJ/m^2impact strength which were favorably comparable with 20-30 wt.% flax/PP, sisal/PP and Jute/PP composites [8].

Alavudeen, N. Rajini presented a study on the effect of two different weaving patterns (plain weave(0°/90°) and twill weave) and random orientation on the mechanical strength of kenaf, banana and banana-kenaf fiber reinforced hybrid polyester composites. It was concluded that the plain weave pattern gave higher strength than twill weave and randomly oriented banana composites. Irrespective of the orientation patterns, the hybrid composite had the highest strength in each orientation pattern respectively. However the tensile strength of the randomly oriented hybrid-polyester composite was still lower than the tensile strength of plain weaved banana-polyester composite [9]

Antonio F. Avila and Plinio de O. Bueno carried out an experimental and numerical study on adhesively bonded wavy-lap and single-lap composite joints. A 16 layer plain weave E-glass-epoxy (XR1553 and HY 1246) composite laminate was used as adherend and adhesive AW106 along with its hardener HV953U was used as the bonding agent. The mean value of maximum force was observed to be 7.18 KN and 10.71 KN for single-lap joint and wavy-lap joint respectively. Light fiber tear failure mode was observed in all specimens with wavy-lap joints showing a secondary failure mode of adherent delamination as well. It was indicative that the strength of wavy lap joint was more than single lap joint but it was quite difficult to manufacture [10].

R.D.S.G. Campilho compared tensile fracture toughness of adhesive and co-cured joints in woven jute-epoxy composites using ductile polyurethane adhesive. For the co-cured specimen, double cantilever beam specimens were developed for analyzing the strength and conventional methods were used to obtain tensile fracture toughness, where as *J*-integral was used for the adhesively-bonded joints. It was observed that fracture toughness increases from initiation in co-cured specimens due to fiber bridging between the adherends while the crack grows. It was also observed that bonded joint was tougher than co-cured joint [11].

Gonzalez Murillo investigated the influence of joint geometry on the strength of single lap shear joints made of henequen and sisal fiber composite. It was found that for SLJs the ultimate load and displacement increases when the overlap length is increased. The experimental results and Finite element method results were found to be in good agreement with each other [12].

Abdelaziz Taib studied the influence of various factors like joint configuration, adhesive layer thickness, humidity and adherend by tensile testing of glass fiber-vinylester composite laminates (DERAKINE MOMENTUM 411-350 matrix resin reinforced with E-glass woven fabric) manufactured by resin infusion and bonded with an epoxy adhesive

(Hysol EA 9359.3). Joggle lap joint (JLJ), L-section joint (LSJ), single lap joint (SLJ) and the double strap joint (DSJ) configurations with adherend thickness 1.62 mm and 0.127 mm adhesive thickness were considered for the study. The ultimate load was found higher in DSJ and SLJ. The average failure load and its corresponding displacement decreased as the adhesive thickness increased. When subjected to moisture, it was observed that the SLJ specimens degraded (not aged SLJ failure load – 9892 N, aged SLJ failure load- 8657 N) [6].

III. . Material and Method

The plain weave banana fiber was purchased from Shrutisilk industries, Tamil Nadu, India. Epoxy resin 520 and its hardener PAM (Tri Ethylene Tetra Amine (TETA)) purchased from Electrocoating and institution technology Pvt. Ltd. Hinjewadi, Pune, India was used as the matrix for the composite. 10:1 weight ratio was taken for mixing the resin and the hardener. The properties of the epoxy and hardener are mentioned in table 2. Three laminates having fiber volume fraction 30%, 40% and 50% were fabricated by hand lay-up method followed by compression in a compression molding machine for 24 hrs. at room temperature. Water jet cutting method was used to cut the specimens (210 mm*20mm*6mm) from the laminates in x-direction and y-direction on which tensile test was later performed. ASTM D 3039 was referred for this.

The fiber volume fraction is determined by equation 1

$$\boldsymbol{Vf} = \frac{\frac{Wf}{\rho f}}{\frac{Wm}{\rho m}+\frac{Wf}{\rho f}} \times \mathbf{100} \qquad \mathbf{(1)}$$

Where,

Vf : Fiber volume fraction

W_f: Total mass of fibers

ρ_f: Density of Fibres

W_m: Mass of matrix

ρ_m: Density of matrix

Table 2: Specification of epoxy and hardener [12]

Property	Unit	Value
Epoxy eq. wt.	g/eq	180-190
Epoxy viscosity at 27°C	mPa.s	10,000-15,000
Epoxy density	g/cm^3	1.1
TETA density at 27°C	g/cm^3	0.900-0.950
TETA AMINE value	mg KOH/g	1200-1400
Mix viscosity at 27°C	mPa.s	8000
Pot life of 500 g mix	Min	10-15
HDT	°C	100

IV. Test Results

A. Volume fraction effect-

The tensile testing of x and y direction composites of 30% V_f, 40% V_f and 50% V_f banana composites was carried out. For all the volume fractions, it was observed that the y-direction composites had lower strengths as compared to x-direction composites. The x-direction composite was higher by 5.91%, 1.58%, and 2.57% than its y-direction composites for 30% V_f, 40% V_f and 50% V_f banana composites respectively as shown in chart 1. The tensile strength was highest for 40% V_f composites. The y- direction 40% V_f strength was higher than both the 30% V_f and 40% V_f x and y-direction composites. It was observed that there was not much of a difference in the tensile properties of the 40% V_f x and y-direction composite though the tensile modulus of x-direction composite was 9.75 % higher than y-direction composite which can be seen clearly seen from table 3. Figure 2 represents the stress strain plot of x-direction and y direction composite in dry condition.

Table 3: Tensile properties of 40% V_fx and y direction composite.

Sample Description	**Tensile strength (MPa)**	**Elongation at break %**	**Tensile Modulus (E) (MPa)**
X-direction	36.52	3.011	2003
Y-direction	35.95	3.011	1825

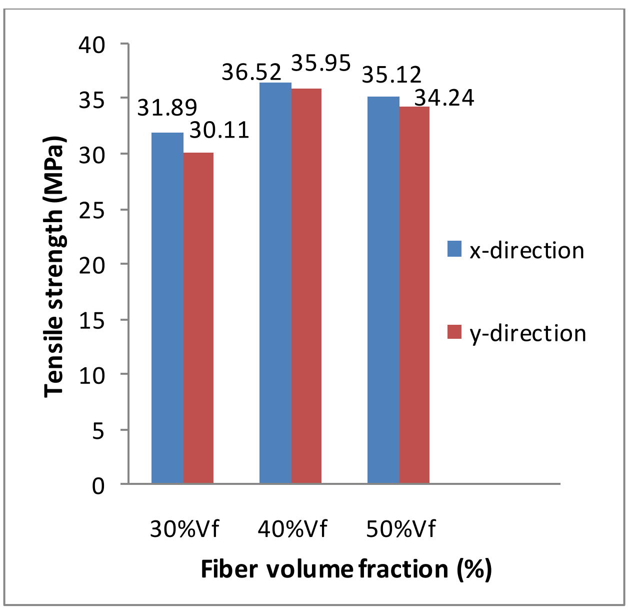

Chart 1: Effect of fiber loading on tensile strength

Fig. 1. Tensile testing of specimen

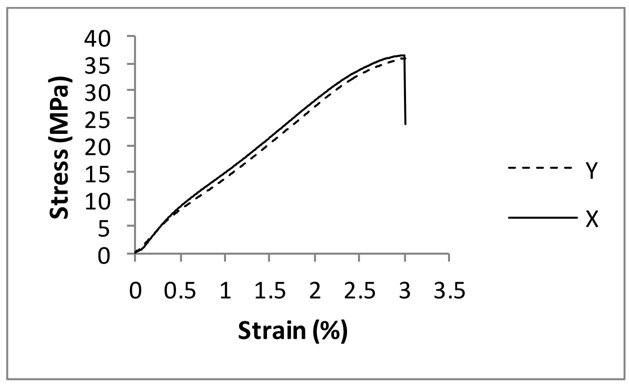

Fig. 2. Stress-strain plot of 40% V_f dry composite

B. Humidity and temperature effect-

Natural fibers have more moisture absorption capacity than the artificial fibers and hence it is their one of the most undesirable factors because moisture degrades the interfacial adhesion between fiber and matrix. A study on the effect of humidity on the 40% V_f banana composite is carried out. Four specimens each in x-direction and y-direction were cut from the same laminate and were put in a temperature cum humidity chamber at an average 30°C temperature and 65 % humidity.

The specimens were subjected to humidity in the chamber for 24 hrs, 48 hrs, 72 hrs and 120 hrs which were tensile tested within 24 hrs of removal from the chamber. Table 4 represents the tensile properties of all the wet specimens. The stress-strain plots of x-direction wet composites and y-direction wet composites of 40% V_f banana composite are represented in figure 4 and figure 5 respectively. Figure 6 shows comparison of the effect of humidity on the tensile strength of x- direction and y-direction composites.

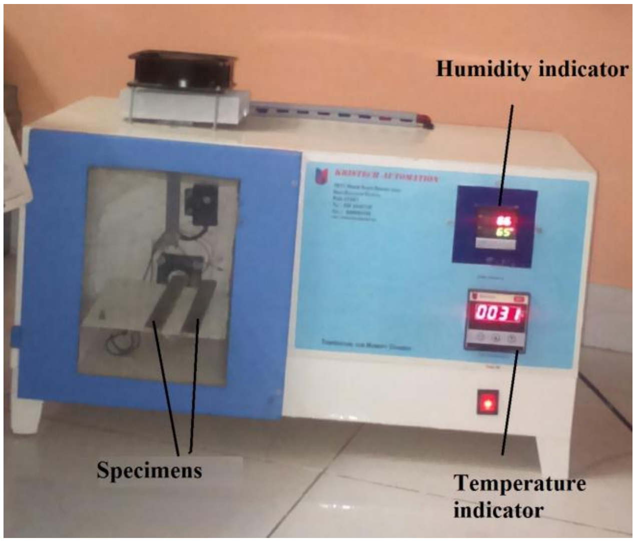

Fig. 3. Humidity cum temperature chamber

In wet conditions, the natural fiber composite tend to follow Fick's law. When a composite is subjected to wet environment, the natural fiber swells up due to absorption of moisture which may lead to temporary increase in the strength of the composite. However with time, the water molecules penetrate the cellulose network of the natural fibers and move into the capillaries and spaces between the fibrils forcing the cellulose molecules apart, reducing the forces that hold them together resulting in softening of mass of the cellulose which ultimately causes fiber-matrix debonding. As a result the strength reduces significantly which can be clearly seen in figure 6 and tables 3 and 4.

Table 4: Comparison of the tensile properties of wet specimens.

Sample Description	**Tensile Strength MPa**	**Elongation (%)**	**Tensile Modulus (E) MPa**
24 hr. x-direction	34.95	2.626	1380
24 hr. y-direction	34.09	2.65	1315
48 hr. x-direction	38.01	3.193	1317
48 hr. y-direction	37.88	2.939	1520
72 hr. x-direction	35.33	2.539	1544
72 hr. y-direction	35.09	2.547	1642
120 hr. x-direction	32.38	2.372	1580
120 hr. y-direction	32.18	2.261	1888

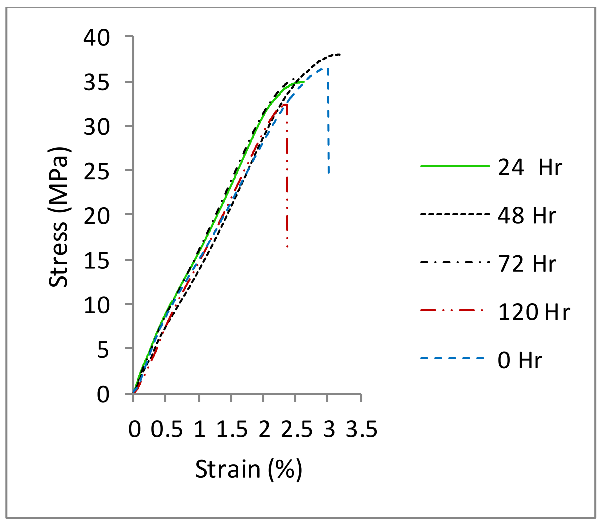

Fig. 4.Stress-strain plot of x-direction wet composite specimens.

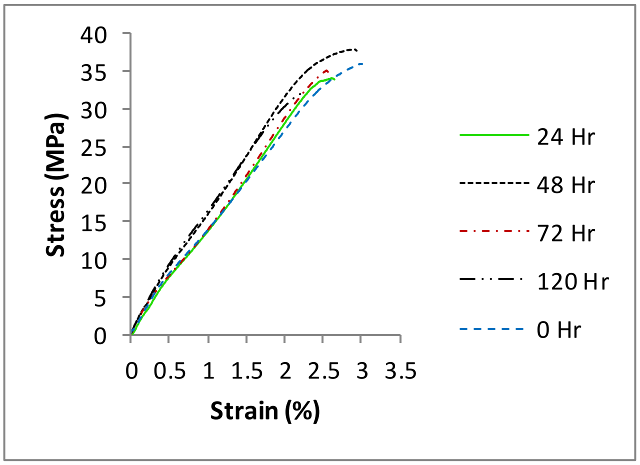

Fig. 5.Stress-strain plot of y-direction wet composite specimens.

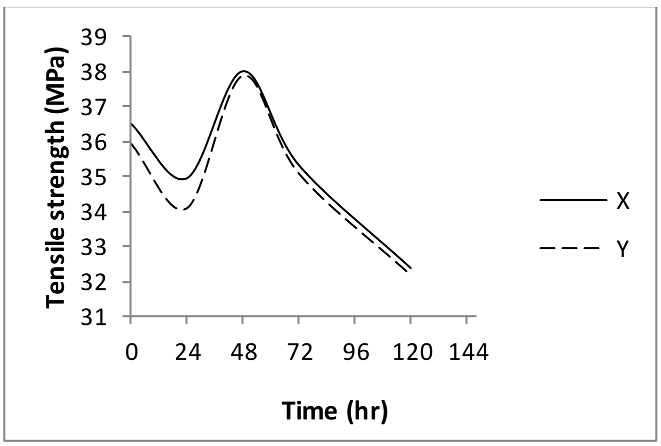

Fig. 6. Moisture effect on x and y-direction composites.

V. CONCLUSIONS

The effect of fiber loading on banana epoxy composite has been studied. Composites having three different fiber volume fractions were considered for this study: 30%, 40% and 50%. It was observed that as the fiber content increased the tensile strength also increased. However 40% V_f had the highest tensile strength among all the volume fractions considered. Also, the tensile strength of x-direction banana composites and y-direction composite does not much differ for 40% V_f. Hence 40% V_f is found to be the best suitable banana fiber volume fraction for plain weave banana-epoxy composite.

The effect of humidity on 40% V_f composite is also studied. Banana fiber composites have good moisture absorption capacity which reduces its mechanical strength considerably in wet conditions. When subjected to humidity, the strength of the banana-epoxy composite initially increased by 5.5 % for some time duration and then dropped considerably. This is in accordance with the Fick's law. Due to humidity fiber-matrix debonding of the composite occurs which results in decrease in its tensile strength. To overcome this demerit one can use hybridization effect or can give chemical treatment on the banana fibers [7, 6, 20, 24].

NOTE: The tensile testing of adhesively bonded single lap joints of banana epoxy composite is in progress.

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