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Studies on Mechanical Properties of Banana/E-Glass Fabrics Reinforced Polyester Hybrid Composites

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Abstract
The purpose of this research work is to evaluate and compare the mechanical properties of laminates prepared of different composition of Banana and E-Glass fabrics. The mechanical properties evaluated are tensile strength, flexural strength, impact strength and hardness. The density of each of the laminates and water absorption properties are also evaluated. The six laminates of banana and E-glass fabrics of dimension 240*240*3 mm^3 is fabricated by hand layup and vacuum bagging method. The impregnation of laminates is done by using polyester resin as matrix material. Finally, curing is done in the autoclave for 4 hours at 70 ^{0}C. From the results of the testing process, it is found that the maximum tensile strength, maximum flexural strength, maximum impact strength and maximum hardness is observed in pure glass fabric laminate and minimum in pure banana fabric laminate. The pure E-glass fabric laminate absorbs more amount of water and pure banana fabric laminate absorbs minimum amount of water. From all these tests, it is found that as the glass layer in the laminate increases its mechanical properties enhances.

Keywords: Banana Fabrics, E-glass fabrics, Polyester, Mechanical properties

1. Introduction
In recent years the natural fibers as reinforcements in composite materials are used as substitute in many applications. Natural fibers have attracting the interest to engineers, researchers, professionals and scientists all over the world as an alternative reinforcement for fiber reinforced polymer composites, because of its superior properties such as high specific strength, low weight, low cost, fairly good mechanical properties, non-abrasive, eco-friendly and bio-degradable characteristics [1]. Natural fiber composites have become more popular especially with automobile industry. Several products like mobile phone cases, laptop cases, toys, snowboards, tennis rackets, building/construction materials, musical instrument parts, furniture and may more have already developed from natural fiber composites apart from automotive exterior & interior components [2]. In some instances, best results may be achieved through the use of natural fiber composites reinforced with synthetic materials [3]. Gomes et al. [4] worked on the development and effect of alkali treatment on tensile properties of curaua fiber green composites. This work describes development and improvement of mechanical properties of green composite that was fabricated by reinforcing a cornstarch-based biodegradable resin with natural fibers extracted from a plant named curaua. Tensile test results showed that alkali-treated fiber composites increased in fracture strain twice to three times more than untreated fiber composites, without a considerable decrease in strength. This result proves that appropriate alkali treatment can improve mechanical properties of cellulose-based fiber composites. Velmurugan et al, [5] investigated on mechanical properties of palmyra/glass fiber hybrid composites. Palmyra fiber is a natural

fiber obtained from Palmyra tree. This work deals with the properties of palmyra fiber, glass fiber hybrid composites. Two types of specimens are prepared, one by mixing the palmyra and glass fiber and the other by sandwiching palmyrafiber between the glass fiber mats. Rooflite resin is used as matrix. Moisture absorption studies are conducted and the results are presented as a function of square root of time. Addition of glass fiber with palmyra fiber in the matrix decreases the moisture absorption of the composites. Davoodi et al, [6] worked on mechanical properties of hybrid kenaf/glass reinforced epoxy composite for passenger car bumper beam. This research is focused on a hybrid of kenaf/glass fiber to enhance the desired mechanical properties .Tests are conducted to know some of the mechanical properties such as tensile strength, Young's modulus, flexural strength, flexural modulus, impact strength of natural fiber. Results show that hybrid natural fibers can be used in some car structural components such as bumper beams. Ramanaiah et al, [7] introduced a new natural borassus seed shoot fiber as reinforcement in polymers for making partially green polymer composites. The fiber content in the composites was varied from 0.116 to 0.305 by volume and the variation of mechanical properties such as tensile, flexural and impact properties in each case were studied. Further, the density of the composites was found to decrease with increase in fiber content. Mwaikambo et al, [8] investigated on the performance of cotton–kapok fabric–polyester composites. Cotton–kapok fabric has been incorporated with unsaturated polyester resin. A simple manual lay-up technique was used in fabricating the composites. A hand operated hydraulic electrically heated press was used and the composites were cured. Mechanical properties such as tensile strength, tensile modulus, impact strength, and flexural properties of composites have been evaluated. Results showed that composites with untreated fibers had higher fiber volume fractions than composites prepared using treated fibers. The tensile strength of composites with untreated fibers was higher than that of composites prepared using treated fibers. Sreekala et al, [9] investigated on the mechanical performance of hybrid phenol-formaldehyde-based composites reinforced with glass and oil palm fibers. Oil palm fiber was hybridised with glass fiber in order to achieve superior mechanical performance. Tensile strength, tensile modulus and flexural strength increase with an increase in fiber loading. Hardness of the composites was decreased by glass fiber reinforcement. The effect of the tensile, flexural and impact response of the composites was investigated. The overall performance of the composites was improved by the glass fiber addition. Impact strength shows great enhancement by the introduction of a slight amount of glass fiber. Mishra et al, [10] investigated on mechanical performance of bio-fiber/glass reinforced polyester hybrid composites. The degree of mechanical reinforcement that could be obtained by the introduction of glass fibers in natural fiber (pineapple leaf fiber/sisal fiber) reinforced polyester composites has been assessed experimentally. Addition of relatively small amount of glass fiber to the pineapple leaf fiber and sisal fiber-reinforced polyester matrix enhanced the mechanical properties of the resulting hybrid composites. Different chemically modified sisal fibers have been used in addition to glass fibers as reinforcements in polyester matrix to enhance the mechanical properties of the resulting hybrid composites. The surface modification of sisal fibers such as alkali treatment produced optimum tensile and impact strengths, while cyanoethylation resulted in the maximum increase in flexural strength of the hybrid composites. Scanning electron microscopic studies have been carried out to study the fibre-matrix adhesion. Wambua et al, [11] worked on the replacement of glass fibers with natural fibers .The mechanical properties of the different natural fibre composites were tested and compared. Kenaf, hemp and sisal composites showed comparable tensile strength and modulus results. The tensile modulus, impact strength and the ultimate tensile stress of kenaf reinforced polypropylene composites were found to increase with increasing fiber weight fraction. Coir fiber composites displayed the lowest mechanical properties, but their impact strength was higher than that of jute and kenaf composites. In most cases the specific properties of the natural fiber composites were found to compare favourably with those of glass. Zhang et al, [12] investigated the tensile and interfacial properties of unidirectional flax/glass fiber reinforced hybrid composites. The tensile properties of the hybrid composites were improved with the increasing of glass fiber content. A modified model for calculating the tensile strength was given based on the hybrid effect of tensile failure strain. The fracture toughness and inter laminar shear strength of the hybrid composites were even higher than those of glass fiber reinforced composites Boopalan et al, [13] investigated on the mechanical properties and thermal properties of jute and banana fiber reinforced epoxy hybrid composites. The aim of the present study is to investigate and compare the mechanical and thermal properties of raw jute and banana fiber reinforced epoxy hybrid composites. To improve the mechanical properties, jute fiber was hybridized with banana fiber. The tensile, flexural, impact, thermal and water absorption tests were carried out using hybrid composite samples. This study shows that addition of banana fiber in jute/epoxy composites of up to 50% by weight results in increasing the mechanical and thermal properties and decreasing the moisture absorption property. Singh et al, [14]developed a banana fiber and silica powder reinforced composite material. Scanning electron microscopy shows that banana fibers are well dispersed in the resin matrix. Addition of fiber increases the modulus of elasticity and decreases the ultimate tensile strength of the epoxy. And further addition of silica also increases the modulus of elasticity reduces the ultimate tensile strength. Addition of banana highly reduces yield strength and addition of silica gives better results than banana reinforced composites but still having yield strength highly reduced. Banana reinforced improve the impact strength of epoxy materials. Addition of fibers increases the capacity of water absorption. This test is necessary where the composites are used in moisture affected areas. Gowda et al, [15] investigated on some of the mechanical properties of untreated jute fabric-reinforced polyester composites. This research work is concerned with the evaluation of the mechanical properties modulus, Poisson's ratio and strength of woven jute fabric-reinforced composites. The aim of this research work is fabrication of polyester hybrid composites reinforced with banana/glass fibers and enhance the properties by using hybridization.

2. **Experimental**

The materials used and their quantities are mentioned in the Table 1.

Table 1: Quantity and materials used in the preparation of laminates

Materials	**Suppliers**
Banana fabric (250 gsm)	Sri Lakshmi groups, Guntur, Andhra Pradesh
Glass fabric (250 gsm)	Sun-tech fibers, Bengaluru, Karnataka
Poly ester resin Catalyst Accelerator Wax	Chemi-coat engineers, Bengaluru, Karnataka
Resin absorber sheet Vacuum bag sheet Perforated sheet	Insulation House, Bengaluru, Karnataka

Banana fiber (Musaceae Family) a type of bast fiber, is extracted from the bark of banana tree. The laminates are prepared (Total nine plies) from banana and glass fabric of particular dimension (240*240*3 mm^3). The laminates were named L1, L2, L3, L4, L5 and L6 according to the combinations mentioned in the Table 2. Fabrics were used for composite fabrication with polyester resin in a close mould. Hybrid laminates of banana and glass fabrics were prepared by vacuum bagging method.

First of all, wax is applied on the mat which acts as a releasing agent used to facilitate easy removal of the composite from the mould after curing. Then the six laminates were impregnated with matrix material consisting of isophthalic polyester resin, catalyst and accelerator. Resin was impregnated by hand into fibers which are in the form of woven or bonded fabrics. Then the laminates are covered by perforated sheet followed by resin absorber sheet to absorb excessive resin. Later the laminates are sealed with vacuum bag sheet over the wet laid-up laminate on to the tool. The air under the bag is extracted by a vacuum pump under atmospheric pressure in order for the compacting and hardening process to take place. The outer atmospheric pressure caused through the vacuum within the closed system will compress the laminate and excess resin is sucked out of the wet laminate. The curing process is allowed for 4 hrs in the vacuum bag at a pressure of 60-70 bar and post curing is done for 4 hours in the autoclave at 70 ^{0}C. The various combinations of the composites and their weights before and after fabrication are mentioned in the Table 2.

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Table 2: Designation of laminates

Laminates	Designations	Layers		Laminates Weights	
		Banana	**Glass**	**Before in g**	**After in g**
L1	G+G+G+G+G+G+G+G+G	00	09	198	403
L2	B+B+B+B+B+B+B+B+B	09	00	54	247
L3	B+G+B+G+B+G+B+G+B	05	04	118	291
L4	G+B+G+B+G+B+G+B+G	04	05	134	377
L5	B+B+G+B+G+B+G+B+B	06	03	102	285
L6	G+G+B+G+B+G+B+G+G	03	06	150	321

2.1**.** *Methods used*

Vacuum Bagging (Figure 1 & 2): This is basically an extension of the wet lay-up process where pressure is applied to the laminate once laid-up in order to improve its consolidation. This is achieved by sealing a plastic film over the wet laid-up laminate and on to the tool. The air under the bag is extracted by a vacuum pump and thus up to one atmosphere of pressure can be applied to the laminate to consolidate it.

Figure 1: Vacuum bagging technique

Figure 2: Laminates laid-up on the mat

Auto-clave Method: Auto-clave (Figure 3 & 4) curing achieves the desired fiber content and elimination of voids by placing the layup within a closed mold and applying vacuum, pressure, and heat by means other than an autoclave. Autoclaves are utilized where the highest of material performance standards are required such as a void content of less than 2% and high glass transition temperatures. Aerospace autoclaves normally operate from 120 to 230 degrees Celsius within a nitrogen environment at 7 bars of pressure. Liquid nitrogen is injected into the heated autoclave to create the internal pressure. Most common materials cured in an autoclave are advanced composites such as carbon fiber and epoxy resins. Curing cycles range from 90 minutes to 12 hours.

Figure 3: Auto-clave

Figure 4: Laminates Placed Inside Autoclave Machine

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2.2. *Preparation of laminates for testing*

The six laminates prepared are subjected to tensile, flexural, impact, water absorption and hardness test. The shape of the specimens required for these tests along with the dimensions and ASTM standards are shown below in the figures 5-9. (All dimensions in mm).

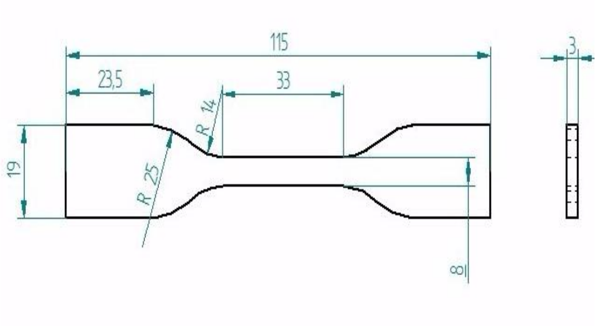

Figure 5: Tensile Test specimen (ASTM D – 638)

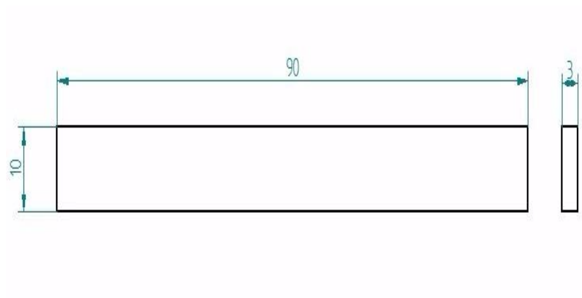

Figure 6: Flexural Test specimen (ASTM D – 790)

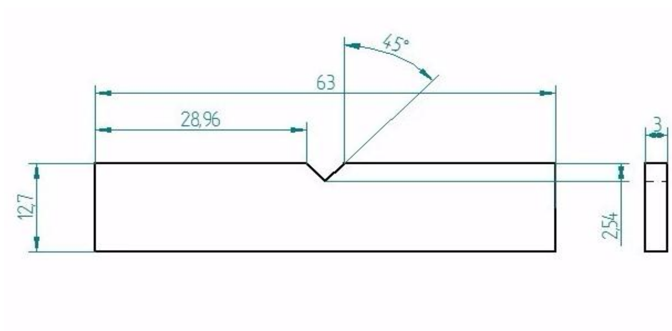

Figure 7: Impact Test specimen (ASTM D – 256)

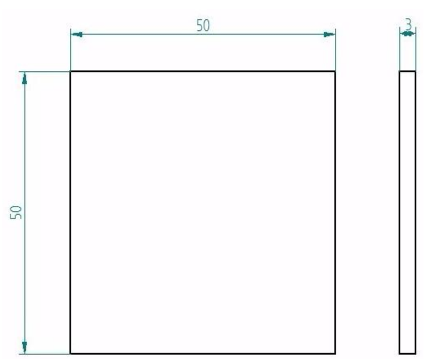

Figure 8: Hardness Test specimen (ASTM E - 384)

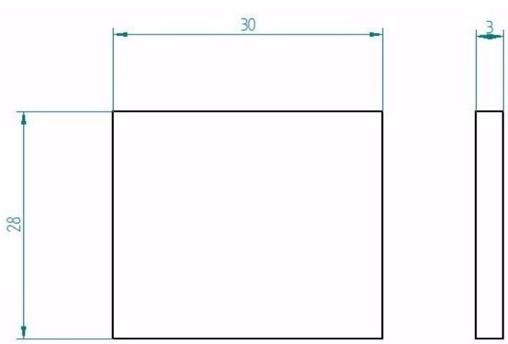

Figure 9: Water absorption test specimen (ASTM D - 570)

2.3. *Testing of composites*

The mechanical properties are carried out by different instruments for the fabricated composites. Laminates layer sequence of each laminate are as shown in the Table 2. The thickness of each layer of banana fabric is 0.3 mm and each layer of glass is 0.29 mm. As per ASTM standard, the thickness of each laminates is 3 mm, So as to maintain the ASTM standard, considering nine layers of glass for L1 (Pure glass and resin mixture), for L2 it takes nine layers of banana (pure banana and resin mixture), for L3 it takes four layers of glass and five layers of banana, for

L4 it takes five layers of glass and four layers of banana, for L5 it takes three layers of glass and six layers of banana and for L6 it takes six layers of glass and three layers of banana (mixture of glass/banana and resin mixture).

2.3.1. *Density and Void Friction*

Density can be generally defined as the mass by volume. Density of the composites can be obtained by the formula

Density = $1 / [W_f / P_f + Wm / P_m]$

Where,

W_f is weight fraction of fiber and is given by

W_f = Wt. of fiber / Wt. of composite, $P_{f\,=}$is density of fiber, $W_{m\,=}$ is weight fraction of matrix, P_m= is density of matrix , Density of glass = 2.0 gm/cc, Density of matrix = 1.2 gm/cc.

Void fraction is calculated to know the number of voids present in composite. It is given by

Void fraction = $(\rho_{theo} - \rho_{exp}) / \rho_{theo}$

Experimental density is calculated using Archimedes principle.

2.3.2. *Tensile Test*

The tensile test is done by cutting the composite specimen as per ASTM: D638 standard. A universal testing machine (UTM) as shown in Figure 10 is used for testing with a maximum load rating of 10 KN (Model: Instron 3366). The tensile test is generally performed on flat specimens. The commonly used specimens for tensile test are the dog-bone type. Composite specimens with different fiber combinations are tested, which are shown in Figure 11. The specimen is held in the grip and load is applied and the corresponding deflections are noted. The load is applied until the specimen breaks and break load, ultimate tensile strengths are noted. Tensile stress and strain are recorded and load v/s displacement graphs are generated.

Formulae:

Tensile strength = peak load / maximum displacement

Tensile modulus = slope (By graph)

Figure 10: Computerized Universal Testing Machine

Figure 11: Tensile test Specimen before for testing

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2.3.3. *Flexural Test*

The flexural test is done in a three point flexural setup (Figure 12) as per ASTM: D790 standard. When a load is applied at the middle of the specimen, it bends and fractures as shown in Figure 13. It is a 3-point bend test, which generally promotes failure by inter-laminar shear.

Formulae:

$$\text{Flexural strength} = 3PL / 2WT^2$$

Where, P = Peak load
L = Gauge Length
W = Width
T = thickness

Figure 12: Computerized UTM

Figure 13: Flexural Test Specimen for testing

2.3.4. *Impact Test*

The impact test is done in a charpy impact setup (Figure 14) as per ASTM: D256 standard. The specimens are shown in Figure 15. The specimen must be loaded in the testing machine and allows the pendulum until it fractures or breaks. Using the impact test, the energy needed to break the material is noted.

Figure 14: Impact Testing Machine

Figure 15: Flexural Test Specimen for testing

2.3.5. *Water Absorption Test*

The water absorption specimens are shown in Figure 16. The water absorption of the composite was determined using the relationship below:

Water absorption = $W_1 – W_0 / W_0$ * 100%

Where, W_0 = Weight of laminate before immersion and W_1 = Weight of laminate 6 days after immersion.

Figure 16: Water Absorption Testing Specimen

2.3.6. *Hardness Test*

Micro-hardness measurement is done using a Leitz micro-hardness tester. A diamond indenter, in the form of a right pyramid with a square base and an angle 136^0between opposite faces, is forced into the material under a load F. The two diagonals X and Y of the indentation left on the surface of the material after removal of the load are measured and their arithmetic mean L is calculated. In the present study, the load considered F = 24.54N. The specimens are shown in Figure 17.

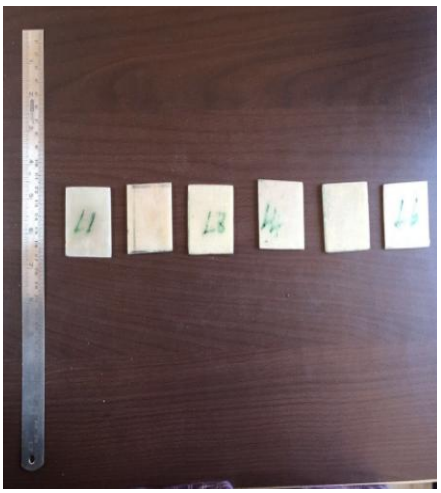

Figure 17: Hardness Testing Specimen

3. **Results and discussion**

3.1.*Density and Void fraction*

The comparison between the theoretical density and experimental density is shown in the graph (Figure.18) and Table 3. The experimental is slightly reduced compared to the theoretical density in all the six laminates, while both theoretical and experimental density is maximum for laminate L1 which is of pure glass and minimum for laminate L2 which is of pure banana. Since the laminates are cured using vacuum bagging method, void fractions in the laminates are very less.

Table 3: Theoretical and Experimental Density of Laminates

Laminates	Theoretical density in g/cc	Experimental density in g/cc	Void fraction in %
L1	1.492	1.4453	2.61
L2	1.187	1.10358	7.027
L3	1.358	1.3216	2.68
L4	1.3609	1.34	1.53
L5	1.3269	1.2096	8.8
L6	1.4361	1.3541	5.7

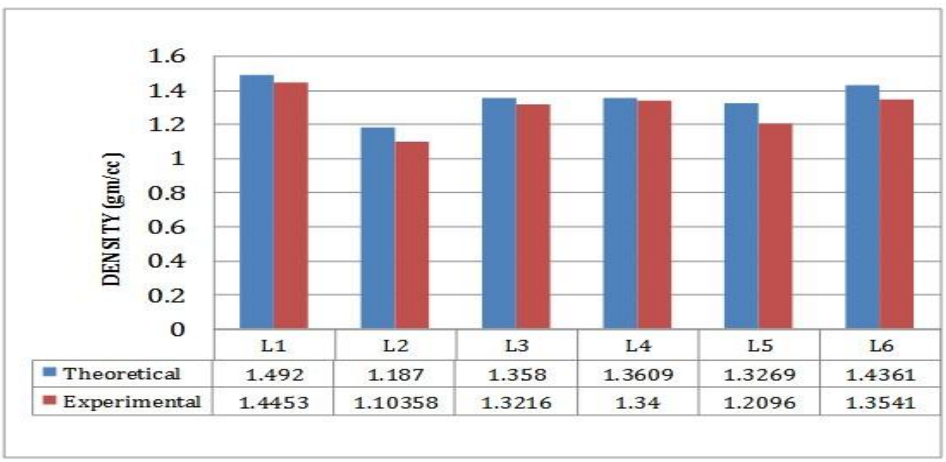

Figure 18: Theoretical and Experimental Density of Laminates

3.2. *Tensile test results*

The composites specimens L1, L2, L3, L4, L5 and L6 are tested for tensile properties in UTM and obtained tensile properties are shown in Table 4. The mechanical properties like break load, tensile modulus and ultimate tensile strength (UTS) are shown in Table 4. The Laminate L1 which consists of 9 pure glass layers shows a high tensile strength of 250 MPa and L2 which consists of pure banana layers shows a lower tensile strength of 6.45 MPa.

Table 4: Tensile properties of the laminates

Laminates	Break load (N)	Tensile modulus (MPa)	UTS (MPa)
L1	221.28	5700	250
L2	534.52	901.4	6.45
L3	397.63	3812.1	9.25
L4	345.4	3021.5	18.1
L5	389.76	2845.8	6.9
L6	380.9	3713.3	22.1

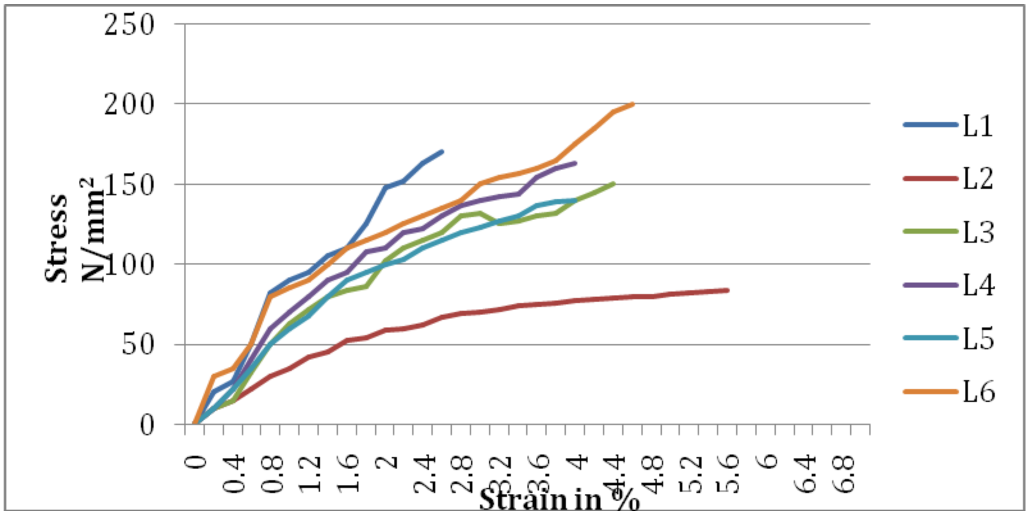

Figure 19: Stress vs Strain graph for tensile test

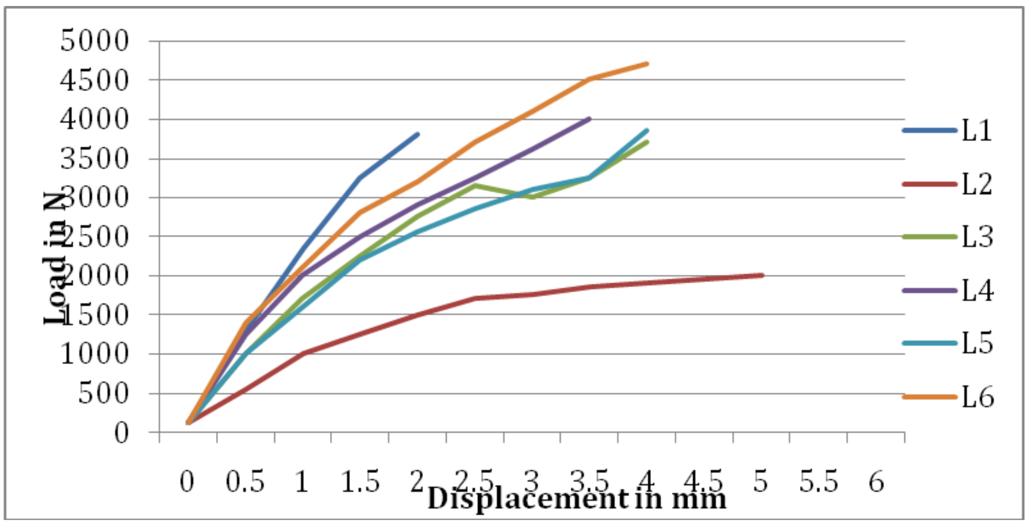

Figure 20: Load vs Displacement graph for tensile test

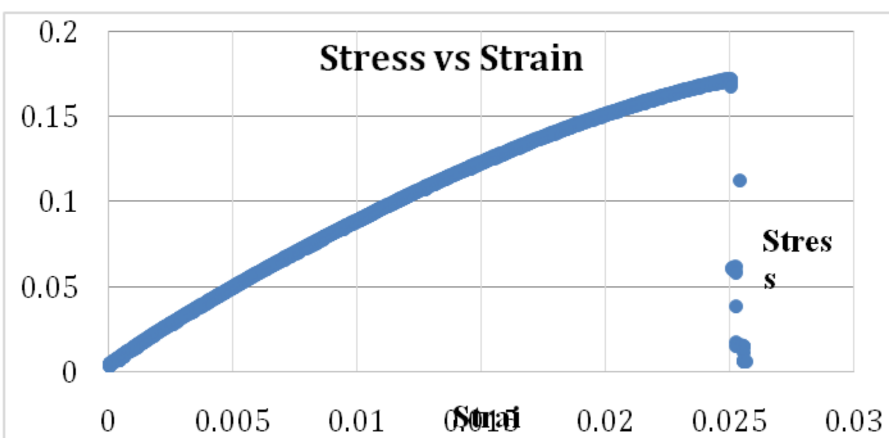

Figure 21: Sample Stress v/s Strain graph obtained in UTM

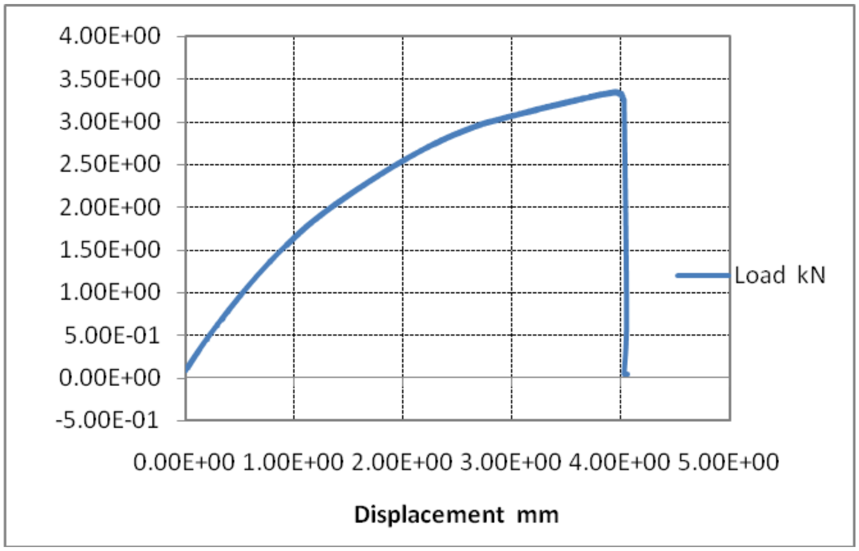

Figure 22: Sample Load v/s Displacement graph obtained in UTM

3.3. *Flexural test results*

The ultimate flexural strength of the laminates are tabulated in the Table 5. From the test conducted, the maximum flexural strength is found in laminate L1 and minimum in laminate L2. The maximum and minimum values are 193.75 MPa and 81.2 Mpa respectively.

Table 5: Ultimate flexural strength of Laminates

Laminates	UFS (MPa)
L1	193.75
L2	81.2
L3	100
L4	125
L5	93.75
L6	168.7

3.4. *Impact test results*

The loss of energy during impact is the energy absorbed by the specimen during impact. The values of the energy absorbed by various laminates are tabulated in the Table 6. The maximum impact strength is found in the pure glass laminate (L1) and minimum in pure banana laminate (L2). The maximum and minimum impact strength is 6 J and 1 J respectively.

Table 6: Impact test results of various laminates

Laminates	Impact strength (J)
L1	6
L2	1
L3	4
L4	4
L5	2
L6	5

3.5. *Water absorption results*

The laminates gain weight by absorption of water. The percentage increase of these weights for the interval of six days for distilled water and normal water is tabulated in the Tables 7 & 8 respectively. The test was done for a period of 24 days. The comparison of the laminates for its water absorption property for distilled water and normal water is shown in the Figures 23 & 24 using the line chart. From the test, it is found that the maximum water absorption is observed in laminate L2 which are of pure banana layers while it is minimum in laminate L1 which is of pure glass.

Table 7: Water Absorption test results for distilled water

Laminates	Initial weight in grams	Percentage increase in weights			
		Day 6	Day 12	Day 18	Day 24
L1	3.502	2.12	4.26	7.85	10.32
L2	4.489	6.75	8.48	14.28	15.12
L3	4.148	5.1	8.20	10.12	14.56
L4	4.734	4.46	7.20	9.25	13.25
L5	4.225	5.4	8.62	12.6	14.3
L6	3.703	3.52	6.30	8.78	11.28

Table 8: Water Absorption test results for normal water

Laminates	Initial weight in grams	Percentage increase in weights			
		Day 6	Day 12	Day 18	Day 24
L1	4.002	2.10	4.3	8.02	10.6
L2	4.030	6.3	8.25	11.4	15.8
L3	3.966	4.6	7.54	10.3	14.6
L4	4.605	5.2	8.5	11.3	13.4
L5	3.967	4.8	7.6	9.2	12.8
L6	3.352	3.2	6.2	8.9	12.4

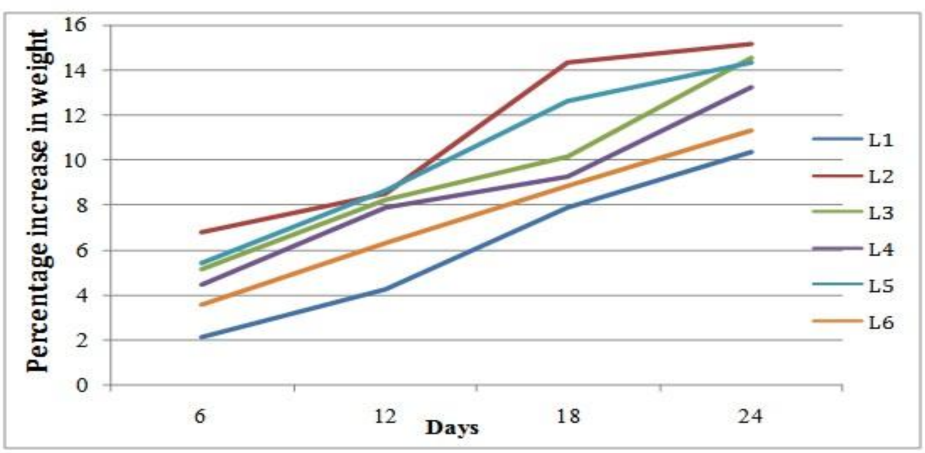

Figure 23: Water Absorption Test Results for distilled water

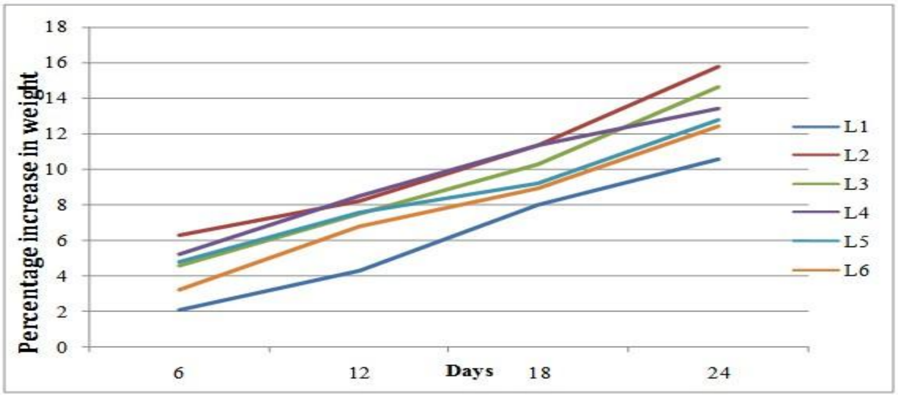

Figure 24: Water Absorption Test Results for normal water

3.6 *Hardness test results*

The measured hardness values of all the six laminates are presented in the Figure. 25 using bar graph. From the test it is found the hardness decreases with increasing banana fabric layers. The maximum hardness is observed in pure glass laminate while it is minimum in pure banana laminate. The hardness values are 26.72 HV and 12.23 HV respectively.

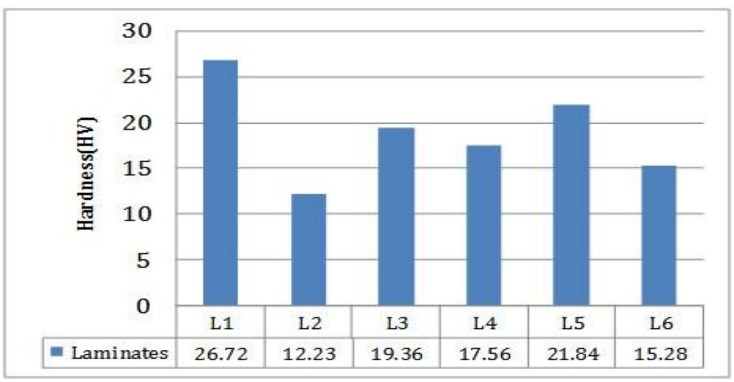

Figure 25: Hardness Test results of Laminates

4. **Conclusion**

This paper presents the fabrication of hybrid composite using Banana/ E-glass fiber reinforced polyester composite by vacuum bagging method. From the tests, the following conclusions are drawn:

- Since the laminates are cured using vacuum bagging method, void fractions in the laminates are very less.
- From the tensile test it is found that, the maximum tensile strength was pure glass layer laminate (250 MPa) and minimum was for pure banana (6.45 MPa).
- Flexural test result shows that, laminate L1 has the highest flexural strength (193.75MPa) and laminate L2 has the lowest flexural strength (81.25 MPa).
- It is found from the impact test that, impact strength of laminate L1 is the highest (6 J) and impact strength of laminate L2 is the lowest (1 J).
- From the Hardness test it is found that laminate L1 is Harder (26.72 HV) and laminate L2 is least harder (12.36 HV).
- From the water absorption test it is found that L2 absorbs more amount of water and L1 absorbs minimum amount of water.
- It is found that as the glass layer in the laminate increases its mechanical properties enhances.
- These composites can be used for medium load applications.

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