# MECHANICAL CHARACTERIZATION OF UNIDIRECTIONAL BANANA-GLASS FIBER REINFORCED EPOXY HYBRID COMPOSITES

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***Abstract:*** This study has been undertaken to mechanical characterization of Banana-Glass fiber reinforced epoxy hybrid composites. Natural fibers have higher economic impact and miniature in density when compared to glass fibers while making composites. Though the strength of the natural fibers is not as high as glass fibers, these specific properties are comparable. In this project a study has been carried to characterize the mechanical properties of hybrid composite made by intruding unidirectional banana and unidirectional glass fibers in to epoxy resin mixture. The hand Layup method of fabrication was employed in preparing the composites laminates of unidirectional Banana-Glass fiber. The objective of present work is to evaluate and compare the mechanical properties of laminates such as tensile strength, flexural strength, impact strength and hardness of different composition of unidirectional Banana and E-glass fabrics. Also to evaluate the density of each laminate and water absorption properties.

***Keywords:*** **Natural fibers, unidirectional banana fabric, unidirectional E-Glass fabric, composite laminates, properties of banana and E- glass fibers, mechanical properties.**

## I. INTRODUCTION

In the recent days there has been an increasing demand for natural fibers because of its environmental friendly nature, which has raised the interest to engineers, scientists, professionals and research scholars to focus on natural fibers. Natural fiber acts as an alternative reinforcement material for composites because of its advantages like low density, high specific weight and low cost, eco-friendly, and bio-degradable in nature to replace the synthetic fibers [1]. This ecological friendly feature makes the materials exceptionally mainstream in building markets, like automobile and construction development industry [2]. The fusion of natural fibers with the glass fiber increases its mechanical properties and these composites can be utilized for medium strength applications [3]. K. Palani kumar et al. [4] conducted experiment to investigate the tensile properties of unidirectional banana and glass fiber reinforced epoxy composites and compared the results with single reinforced composite in both experimental and numerical analysis tests. From the obtained test results it is found that unidirectional Glass fiber reinforced composite possess higher tensile strength of 567MPa when compared with the unidirectional banana–glass reinforced composites.
M.R. Sanjay et al. [5] presented the mechanical and physical characterization of Banana and E-Glass fabrics reinforced polyester hybrid composites. In this different composition of banana and E-glass fabric laminates are fabricated by using hand layup and vacuum bagging methods. The composite test specimens are prepared according to the ASTM standards. The test results shows that the higher tensile strength, flexural strength, impact strength and hardness values are found in glass fabric laminate and while it is low for banana fabric laminate. Sandhyarani Biswas et al. [6] presented the physical and mechanical behaviour of unidirectional Banana-Jute fiber reinforced epoxy based hybrid composites and compared it with the single natural fiber and hybrid reinforced composites. From the observed results it is found as the percentage of the fiber increases the void content of the composite also increases. C. Deepa et al. [7] Investigated the processing and mechanical evaluation of banana fiber reinforced with epoxy based composites. Three different volume fractions of banana based epoxy composite laminates are fabricated to characterize its mechanical properties. From the result it is noticed that equal proportion of fiber and resin can withstand the heavier loads when compared with the other combination of weight fractions.
Pongsathornkongkae [8] studied the mechanical properties of epoxy resin by using random orientation discontinuous banana fiber and coconut fiber as reinforcement. The both fibers are successively treated by

alkaline treatment in sodium hydroxide solution (NAOH) at room temperature. The composites were prepared with various fiber content (3, 5, 10, 15, 20and 30% by weight) of banana and coconut fibers in epoxy polymer matrix. The results from the tensile tests of banana and coconut fiber reinforced epoxy composites are that the 15 wt% banana fiber showed the highest value is 73.23 MPa for maximum tensile strength. Mathew John et al. [9] Presented the mechanical properties of woven banana and glass fiber reinforced epoxy composites. In which composite laminates are prepared by using hand layup method. The fabricated laminates were made with woven roving glass fiber mat with epoxy as a matrix material. Three different types of laminates are prepared with the stacking order B/B/B, G/B/B/G, G/B/G/B/G of thickness 1.2 mm of each layer of the fiber. The effect of layering arrangement of banana and glass fiber effects on the mechanical properties like ultimate tensile strength, ultimate flexural strength and impact energy. From the results revealed it is observed that the properties of all the three laminates the hybrid laminate with glass layers gives the higher mechanical properties with a good balance between the properties and cost. Abdullah-Al-Kafi et al. [10] studied the mechanical properties of Jute/glass fiber reinforced with the unsaturated polyester hybrid composite prepared by hand layup technique. The results present that the hybridization of jute with the glass in the ratio of 1:3 has increased its mechanical properties.

## II. METHODS AND MATERIALS

### 2.1. Materials

The materials which are used in fabrication process is unidirectional banana fabric, unidirectional E-glass fabric, Epoxy resin LY556, Hardener HY951, acetone, wax, and transparent sheet. The unidirectional banana fabric is purchased in the form of Mats from Go Green Products private Ltd from Chennai, India. The unidirectional E-Glass fabric, epoxy resin, Hardener and acetone are bought from a local retailer in Hyderabad. The physical, chemical and mechanical properties of the banana fiber are presented in Table 1.

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Table 1: Physical, chemical and mechanical properties of banana fiber [11]

| Properties | Banana Fiber |
|---|---|
| Cellulose (%) | 62-64 |
| Hemi cellulose (%) | 19 |
| Lignin (%) | 5 |
| Moisture content (%) | 10-11.5 |
| Lumen size | 5 |
| Density (g/cm$^3$) | 1.35 |
| Flexural modulus (GPa) | 2-5 |
| Tensile strength (MPa) | 540 |
| Young's modulus (GPa) | 3.48 |
| Microfibrillar angle | 11 |

### 2.2. Preparation of composite laminates

In this preparation process the hand layup method is adopted for the fabrication of composite laminates. Before to start the process the mould of dimensions 365 mm X 365 mm has to be cleaned with acetone in order to remove impurities present on the mould surface. Then the transparent sheet is placed over the mould surface and wax is applied to it for an easy removal of laminates from the mould. The unidirectional banana and unidirectional E- glass fibers are cut according to the mould dimensions. The Epoxy resin LY556 and hardener HY951 are mixed in the proportion of 10:1 and mix thoroughly with the help of mechanical stirrer. For each laminate five layers of different combination of unidirectional Banana and unidirectional E-glass fabrics are placed over the transparent sheet layer by layer in longitudinal direction as shown in the Figure 1. The epoxy mixture is applied evenly over the surface of the fabric by using a brush and allow the resin mixture to cure for 7-9 hours in order to impregnate in to the fabric. The laminates are then permitted to cool at room temperature. For every laminate the different combinations of banana and

E-glass fabric laminates are prepared to obtain the required thickness of the laminates and named as L-1, L-2, L-3, L-4, L-5 and L-6 and their detailed composition and designations are shown in the below Table 2.

Fig.1 Preparation of composite laminate

Table 2: Stacking sequence of laminates

| Laminates | Composition of Fiber (%) | | Stacking sequence |
|---|---|---|---|
| | Banana (B) | Glass (G) | |
| L-1 | 0 | 100 | G+G+G+G+G |
| L-2 | 20 | 80 | G+G+B+G+G |
| L-3 | 40 | 60 | G+B+G+B+G |
| L-4 | 60 | 40 | B+G+B+G+B |
| L-5 | 80 | 20 | B+B+G+B+B |
| L-6 | 100 | 0 | B+B+B+B+B |

## III. MECHANICAL TESTING

### 3.1. Tensile strength

In present work the tensile test is performed on flat specimens. The standard for tensile properties of fiber reinforced composites is ASTM D 3039 [12]. The dimensions of the composite specimen as per ASTM standard is 250 mm X 25 mm X 3 mm for longitudinal direction. The tensile test is conducted on computerized UTM of model Instron 1195 at a speed of 10 mm/min and load of 25 kN. For all the six laminates, three test specimens were tested and the average value is obtained. The tensile test specimen of unidirectional banana-glass fiber reinforced epoxy hybrid composite is shown in Figure 2.

### 3.2. Flexural strength

The flexural test performed in this is three point bend test. The standard for flexural properties of fiber reinforced composites is ASTM D 790 [13]. The dimensions of the composite specimen as per ASTM standard are 125 mm X 13 mm X 3 mm for longitudinal direction. The flexural test is conducted on computerized UTM of model Instron 1195 at a speed of 10 mm/min and at a load of 25 kN. For all the six laminates, three test specimens were tested and the average value is obtained. The flexural test specimen unidirectional banana-glass fiber reinforced epoxy hybrid composite is shown in Figure 4.

### 3.3. Impact test

The Impact test was carried out on rectangular flat specimens. The standard for impact properties of fiber reinforced composites is ASTM D 256 [14]. The dimensions of the specimen as per ASTM standard are 100 mm X 10 mm X 3 mm for longitudinal direction. The impact test conducted was charpy impact test the specimen with a pendulum hammer, measuring the spent energy and relating it to the cross section of the specimen. The impact energy of all the specimens are directly recorded on the dial indicator. The impact test specimen of unidirectional banana-glass fiber reinforced epoxy hybrid composite is shown in Figure 6.

**3.4 Hardness test**

Hardness is resistance to indentation. Hardness method used here is the Barcol hardness. This method is often used for the composites materials to determine how much amount of resin is cured and to check the softness, hardness of the material. The test is performed according to ASTM D 2583 [15]. The dimensions of the specimen as per ASTM standard are 50 mm X 50 mm X 3 mm for longitudinal direction. Barcol impresser gives the consistent reading of 0-100 scale on the dial gauge. The Hardness test specimens of unidirectional banana-glass fiber reinforced composite is shown in Figure 8.

**3.5 Water Absorption test**

Water absorption test performs to know the amount of absorbed by the composites. For water absorption the test specimens are prepared as per the ASTM D 570 standard [16]. The dimension of the specimen is 30 mm X 30 mm X 3 mm. The test specimens of six different laminates are to be tested in water. First the specimens are uniformly dried before the test and to be weighed. Then the specimens are to be immersed in the plastic tub of water at room temperature for a period of 8 days. For every 24 hour's the specimens are taken from the plastic tub carefully to remove excess water on the surface of the specimen and weighed immediately. Water absorption for all the six of the specimens is noticed. Then the moisture absorption is calculated by the weight difference of dry specimens and wet specimens. The water absorption percentage of the composite specimens was determined using the relationship below and the water absorption test specimen is shown in Figure 9.

$$\text{Water absorption} = [(W_1 - W_2)/W_2] \times 100$$

Where, $W_1$ = Weight of the dry specimen

$W_2$ = Weight of the wet specimen

**3.6 Density and void Fractions**

Density of the composites can be calculated by using the formula

$$\rho_c = \frac{1}{\left[\frac{W_f}{\rho_f} + \frac{W_m}{\rho_m}\right]}$$

Where,

$W_f$, $W_m$ are the weight fractions of the fiber and the composite.

$\rho_f$, $\rho_m$, $\rho_c$ are the densities of the fibre, matrix and composite.

Density of glass fiber = 2.54 g/cm$^3$, Density of Banana fiber =1.35 g/cm$^3$,

Density of matrix =1.16 g/cm$^3$.

Void fractions are calculated in order to know the number of voids present in the composites. It is given by

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

**RESULTS AND DISCUSSION**

The unidirectional Banana-Glass fiber reinforced epoxy Hybrid composite test specimens are tested in their relating testing machines. The various test specimens of laminates it's before and after failure modes are shown in the below figures. Then the ultimate tensile strength, ultimate tensile load, flexural strength, flexural modulus, impact energy, hardness, water absorption properties and density of the composites are determined. For each laminate of different composition three test specimens are tested and the average values are obtained.


Fig.2: Tensile test specimen


Fig.3: Tensile test specimen failure mode

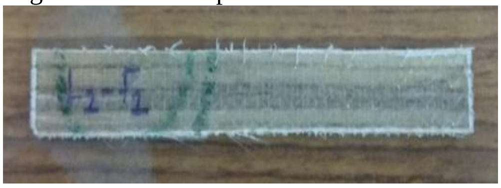
Fig.4: Flexural test specimen


Fig.5: Flexural test specimen failure mode

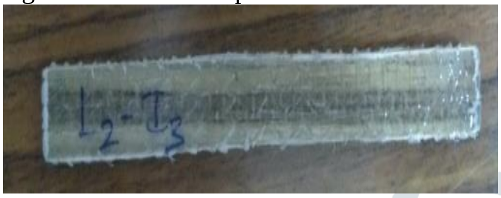
Fig.6: Impact test specimen


Fig.7: Impact test specimen failure mode

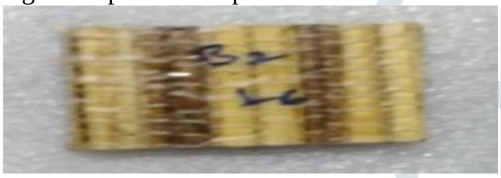
Fig.8: Hardness test specimen


Fig.9: Water absorption test specimen

### 4.1. Tensile strength analysis

The ultimate tensile strength and ultimate tensile load of unidirectional Banana-Glass fiber reinforced with varying wt. % combination of hybrid composite was studied here, and its failure mode is shown in Figure 3. Tensile properties of different weight combinations of Banana–Glass fiber reinforced hybrid composites is summarized in the Table 3. The comparative bar graph charts for ultimate tensile strength, ultimate tensile load of laminates are presented in Figure 10, 11. Among the all six laminates the average ultimate tensile strength is high for laminate L-1 is noted as 510 MPa with ultimate tensile load of 61 kN and average ultimate tensile strength is low for laminate L-6 is noted as 55 MPa with ultimate tensile load of 6 kN.

Table 3: Tensile properties of different laminates

| Laminates | Ultimate Tensile Load (kN) | Ultimate Tensile Strength (MPa) |
|---|---|---|
| L-1 | 61 | 510 |
| L-2 | 39 | 370 |
| L-3 | 28 | 252 |
| L-4 | 21 | 145 |
| L-5 | 13 | 80 |
| L-6 | 6 | 55 |

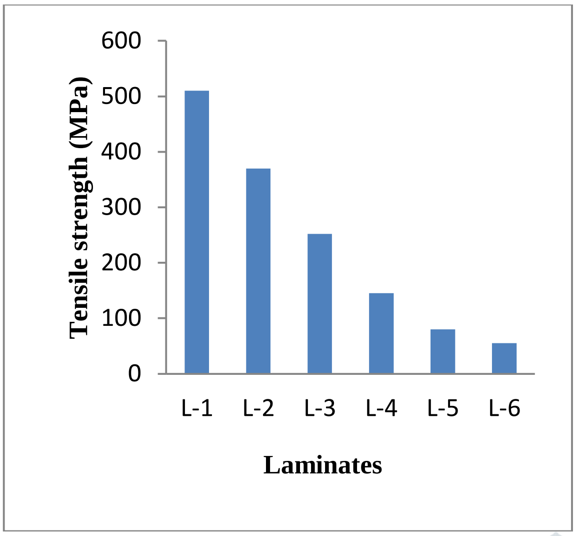


Fig.10: Tensile strength comparison chart

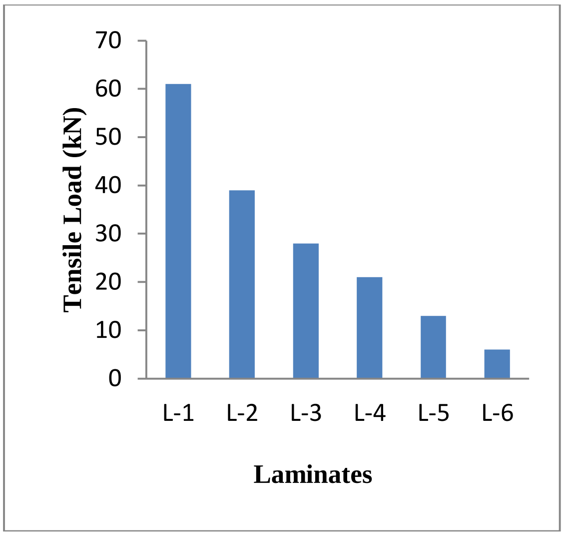


Fig.11: Tensile Load comparison chart

## 4.2. Flexural strength analysis

Flexural strength of unidirectional Banana-Glass fiber reinforced epoxy Hybrid composites was studied and its failure mode is shown in Figure 5. Flexural properties of different combinations of hybrid composites with Banana-Glass fibre is summarized in the Table 4. The comparative charts for flexural strength and flexural modulus of different laminates are presented in figure 12, 13. Among all the six laminates the average flexural strength and flexural modulus is high for the laminate L-1and it is noted as 168 MPa, 18850 MPa and average flexural strength and flexural modulus is low for the laminate L-6 and is noted as 31 MPa, 1209 MPa.

Table 4: Flexural properties of different laminates

| Laminates | Flexural strength (MPa) | Flexural modulus (MPa) |
|---|---|---|
| L-1 | 168 | 18850 |
| L-2 | 125 | 12471 |
| L-3 | 82 | 7758 |
| L-4 | 64 | 2294 |
| L-5 | 45 | 1797 |
| L-6 | 31 | 1209 |

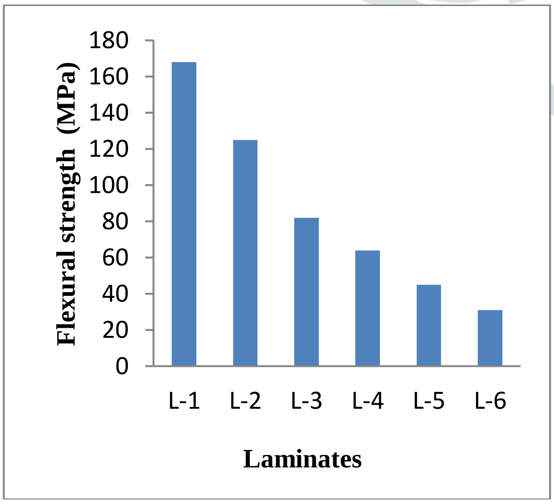


Fig.12: Flexural strength comparison chart

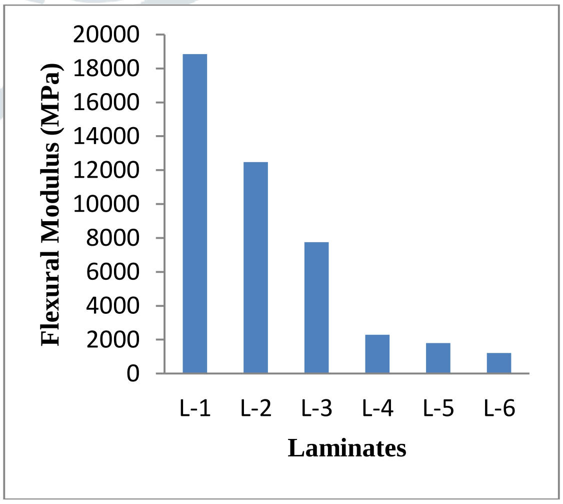


Fig.13: Flexural modulus comparison chart

### 4.3. Impact strength analysis

The energy absorbed of Banana-Glass fiber reinforced epoxy hybrid composite was studied and its failure mode is shown in Figure 6. Impact properties of different laminates combinations of Banana-Glass fiber reinforced hybrid composites is summarized in the Table 5. The comparative chart for Energy absorbed of all the laminates are presented in Figure 14. Among the all six laminates the Impact Energy is high for the laminate L-1 of 7 J and Impact energy is low for the laminate L-6 of 2.5 J.

Table 5: Impact properties of different laminates

| Laminates | Laminate thickness (mm) | Width of the specimen (mm) | Energy absorbed K (J) |
|---|---|---|---|
| L-1 | 3.15 | 10 | 7 |
| L-2 | 4.21 | 10 | 6 |
| L-3 | 4.6 | 10 | 4.4 |
| L-4 | 5.39 | 10 | 3.2 |
| L-5 | 5.71 | 10 | 2.7 |
| L-6 | 6.2 | 10 | 2.5 |

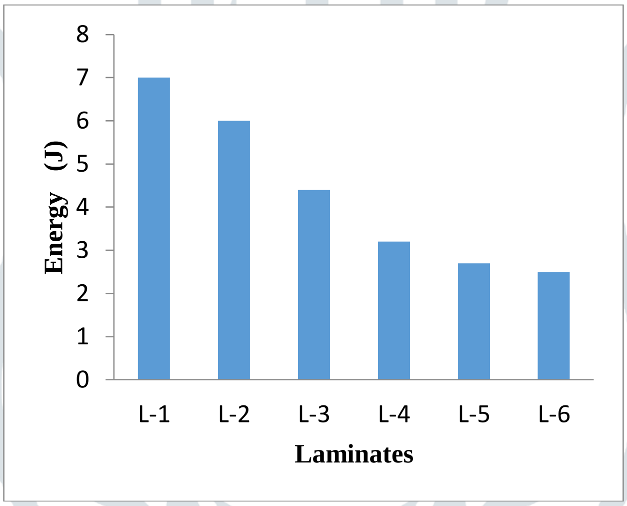


Fig.14: Impact Energy comparison chart

### 4.4 Hardness Test Analysis

Hardness test values of different hybrid combinations of Banana-Glass fiber reinforced composites laminates are summarized in the Table 6. The comparative chart for Hardness values of all the laminates are presented in Figure 15. Among all the six laminates the higher hardness values is observed in laminate L-1 and it is noted as 68 HV and lowest Hardness is observed in laminate L-6 and it is noted as 32 HV.

Table 6: Hardness values of different laminates

| Laminates | Laminate thickness (mm) | Hardness Values (HV) |
|---|---|---|
| L-1 | 3.15 | 68 |
| L-2 | 4.21 | 61 |
| L-3 | 4.6 | 52 |
| L-4 | 5.39 | 39 |
| L-5 | 5.71 | 34 |
| L-6 | 6.2 | 32 |

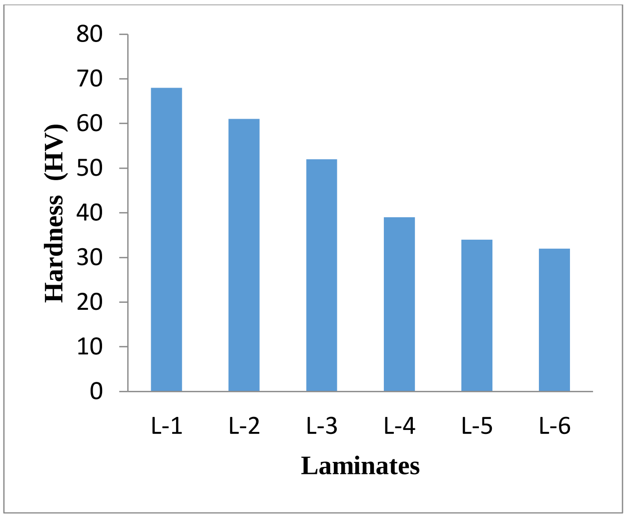


Fig.15: Hardness test values of different laminates

### 4.5 Water Absorption Test Analysis

The water absorption test was conducted in order to know the amount of water absorbed by the composite specimen. Six different composition of hybrid composite laminates are tested for a period of 8 days in the water. The increase of weight percentage of composite laminate specimens is noted at specified intervals of time i.e, 24hr's, 48hr's, 72hr's, 96hr's, 120hr's, 144hr's, 168hr's, 192hr's as shown in Table 7. From the test among all the different combinations of composite laminate specimens the maximum water intake is observed in laminate L-6 which is of unidirectional banana fabric laminate while the minimum water intake is found in laminate L-1 which is of unidirectional E-Glass fabric laminate. The water absorption comparison chart for different laminates as shown in Figure 16.

Table 7: Percentage increase in weights of the different laminates

| Laminates | Initial weight of the specimen in grams ( *g* ) | 24 Hr's | 48 Hr's | 72 Hr's | 96 Hr's | 120 Hr's | 144 Hr's | 168 Hr's | 192 Hr's |
|---|---|---|---|---|---|---|---|---|---|
| L-1 | 4.7 | - | - | - | - | - | - | - | - |
| L-2 | 5.8 | 1.6 | 3.3 | 3.3 | 6.4 | 6.4 | 7.9 | 9.3 | 9.37 |
| L-3 | 6.6 | 2.9 | 2.9 | 8.3 | 10.8 | 10.8 | 13.1 | 13.1 | 15.3 |
| L-4 | 6.8 | 10.5 | 10.5 | 12.8 | 15 | 15 | 17.0 | 19.0 | 19.0 |
| L-5 | 7.2 | 12.1 | 12.1 | 14.2 | 16.2 | 16.2 | 18.8 | 18.8 | 20 |
| L-6 | 7.5 | 12.7 | 12.7 | 15.3 | 16.6 | 16.6 | 19.3 | 19.3 | 22.6 |

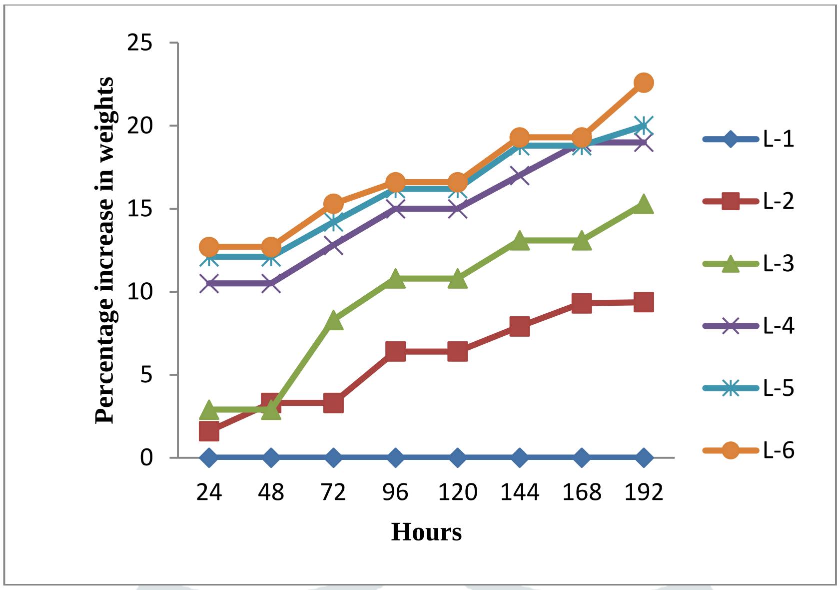


Fig. 16: Water absorption comparison chart for different laminates

### 4.6 Density and void fraction

The theoretical and experimental densities of six different composite laminate specimens are calculated and its values summarized in the Table 8. The experimental density is less when compared to the theoretical density in all the six composite specimens. The unidirectional Glass fiber reinforced epoxy composite of laminate L-1 has high density and the unidirectional Banana fiber reinforced epoxy composite of laminate L-6 has less density. The void fractions are high in banana fiber reinforced composites as the fiber percentage of the natural fiber increases the void fractions also increases.

Table 8: Theoretical and Experimental density of different laminates

| Laminates | Theoretical density in (g/cm$^3$) | Experimental density in (g/cm$^3$) | Void fractions in (%) |
|---|---|---|---|
| L-1 | 1.75 | 1.68 | 4 |
| L-2 | 1.66 | 1.58 | 4.81 |
| L-3 | 1.58 | 1.57 | 6.32 |
| L-4 | 1.47 | 1.36 | 7.48 |
| L-5 | 1.4 | 1.25 | 8.57 |
| L-6 | 1.28 | 1.13 | 11.71 |

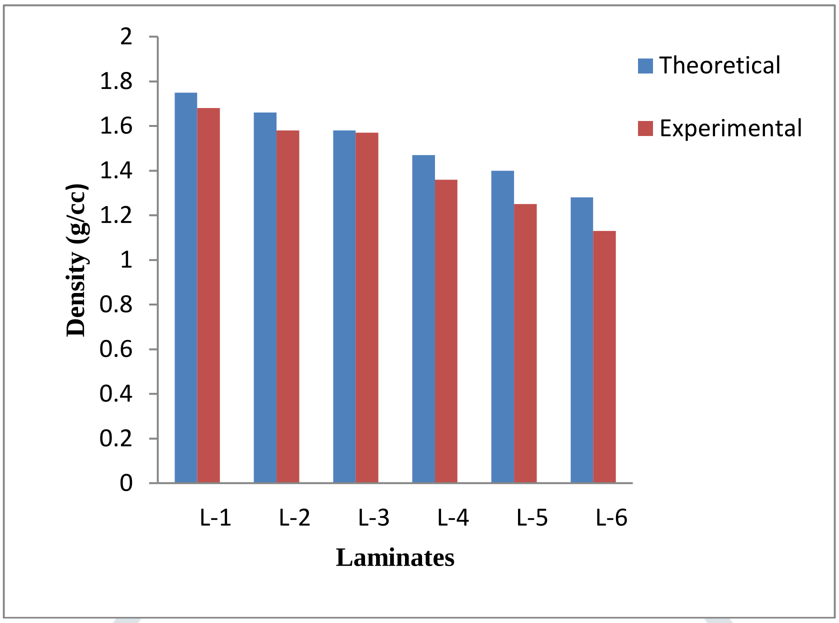


Fig.17: Theoretical and Experimental densities of different laminates

## 5. Conclusions

The unidirectional Banana-Glass fiber reinforced epoxy based hybrid composites were fabricated by simple hand layup technique. In the present work an experimental investigation was carried to characterize the physical and mechanical properties of unidirectional banana-Glass fiber reinforced epoxy hybrid composites. From the results of testing of the composites it has been noticed that various properties of the composites are-

- The unidirectional glass fiber reinforced epoxy composite has high ultimate tensile strength among all the laminates and can withstand at ultimate tensile strength of 510 MPa at load 61 kN while the unidirectional banana composite possesses lower ultimate tensile strength of 55 MPa at load of 6 kN.
- The flexural test results shows that laminate L-1 has the higher flexural strength 168 MPa and laminate L-6 has the lowest flexural strength 31 MPa.
- From the charpy impact test results it is noticed that the impact energy is high for the laminate L-1 of 7 J and while it is low for the laminate L-6 of 2.5 J.
- From the Hardness test values of all the laminates the unidirectional Glass fiber reinforced hybrid composite of laminate L-1 has higher hardness value of 68 HV and it is more harder and can withstand high resistance of indentation compared to other laminates while and laminate L-6 has the lowest hardness value of 31 HV.
- From the water absorption test it is found that unidirectional banana fiber reinforced epoxy hybrid composite laminate of L-6 absorbs high amount of water while unidirectional Glass fiber reinforced composite laminate of L-1 absorbs low amount of water.
- From the theoretical and experimental densities of all the six laminates the experimental density is reduced in all the laminates compared to theoretical density. The void percentage is high in the unidirectional banana fiber reinforced composites.

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