RESEARCH ARTICLE OPEN ACCESS

Synthesis, characterization of Banana / Glass Fiber Reinforced Epoxy Based Hybrid Composites

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ABSTRACT

Natural fiber composites are nowadays being used in various engineering applications to increase the strength and optimize the weight and the cost of the product. Hybridization is a process of incorporating synthetic fiber with natural fiber to get the better material properties. In this connection an investigation has been carried out to make better utilization of banana fiber for making value added products. The objective of the present research work is to study the mechanical and water absorption behaviour of banana/glass fiber reinforced epoxy based hybrid composites. Experiments are carried out as per ASTM standards to find the mechanical properties and water absorption capacity. The effect of fiber loading and length on mechanical properties like tensile strength, flexural strength, Impact strength and hardness of composites is studied. In addition to mechanical properties, water absorption capacity of the composite is also studied.

Keywords: Natural Banana fibers, glass fiber, epoxy, Different fiber loading and lengths of reinforcement, Mechanical properties, water absorption

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Date of Submission: 11-09-2017 Date of acceptance: 22-09-2017

I. 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].

Kelly [2] defined that the composites should not be regarded simply as a combination of two materials. It clearly states that; the combination has its own unique properties. In terms of strength to resistance to heat or some other desirable quality, it is better to attain properties that the individual components by themselves cannot attain. The composite materials have advantages over other conventional materials due to their higher specific properties such as tensile, flexural and impact strengths, stiffness and fatigue properties, which enable the structural design to be more versatile. Due to their many advantages they are widely used in aerospace industry, mechanical engineering applications (internal combustion engines, thermal control, machine components), electronic packaging, automobile, and aircraft structures and mechanical components (brakes, drive shafts, tanks, flywheels, and pressure vessels), process industries equipment requiring resistance to high-temperature corrosion, dimensionally stable components, oxidation, and wear, offshore and onshore oil exploration and production, marine structures, sports, leisure equipment and biomedical devices [3, 4].

The main idea of composites reinforced with natural fibers is to increase the mechanical properties of the polymer, such as tensile strength, impact strength and bending strength [5, 6].

From the research of many researchers found that the mechanical properties of composites reinforced with natural fibers have high value depend on the adhesion between fibers and the matrix [7, 10-12].Natural fiber is composed of cellulose, hemicellulose and lignin and rich in pectin. This resulted in the important problem of compatibility between fiber and matrix due to weakness in the adhesion between the surface fibers and the polymer matrix, so changing the fiber surface by treatment. It is the best method that researchers use to improve the strength and the compatibility between the interfacial bond strength [8, 9].

The surface treated bio fibers showed better efficiency than the untreated [13, 14].Alkaline treatment (mercerization process) is illustrious. Chemical treatment of surface modification of natural fibers reinforced composites. This alkaline treatment removes wax, hemicellulose and lignin hiding the surface of the fiber. It is accepted that the alkaline treatment result from increases surface roughness which create better mechanical interlocking between hydrophilic fibers and hydrophobic matrices [15].

Short banana fiber content has a greatly effect on mechanical properties of the fiber reinforced polyster composites. [16].Venkateshwaran et al. [17, 18] studied the mechanical properties of tensile, flexural, impact and water absorption tests were carried out using banana/epoxy composite material.

Many researchers have studied the effect of various parameters on the mechanical behaviour of synthetic fibre based polymer composites. Huang et al. [19] studied the effect of water absorption on the mechanical behaviour of glass/polyester composites. It was concluded that the breaking strength and tensile stress of the composites decreased gradually with increased water immersion time because the weakening of bonding between fibre and matrix.

The hybridization of banana fiber and glass fiber not only improve the mechanical properties of composite but also reduce its cost and make it ecofriendly composite [20]. Hybridization of natural fibre with high corrosion and stronger resistance synthetic fibres like glass, carbon, aramid etc. can improve the various properties such as strength, stiffness etc. It helps us to achieve a better combination of properties than fibre reinforced composites.Thus banana fiber in combination with glass has proved to be excellent for making cost effective composite materials.Uses of hybrid composites are aeronautical applications (pilot's cabin door), marine applications (ship hulls), wind power generation (blades), telecom applications (hybrid aerial, underground cable) [21].

[32] Most of the studies made on natural fibre composites reveal that their mechanical properties are strongly influenced by a number of parameters such as volume fraction of the fibres, fibre length, fibre aspect ratio, fibre-matrix adhesion, fibre orientation and stress transfer at the interface. Therefore, both the matrix and fibre properties are important in improving mechanical properties of the composites. A number of investigations have been made on various types of natural fibres to study the effect of these fibre parameters on the mechanical properties of composite materials. Attempt has been made in the current research work to study the effect of fibre loading and length on the performance of composites.

All polymers and polymer based composites absorb moisture in humid atmosphere when immersed in water. In general, moisture diffusion in composites depends on factors, such as the volume fraction of fibre, void volume, additives, humidity, and temperature [22- 23]. Moisture diffusion in polymer composites has been shown to be governed by three different mechanisms. The first involves the diffusion of water molecules inside the micro gaps between the polymer chains. The second involves capillary transportation into the gaps and flaws at the interfaces between the fibre and the matrix. The third involves transportation of micro cracks in the matrix, arising from the swelling of fibres, particularly in the case of natural fibre composites [24- 25].

Hybridization of natural fibre, with stronger and more corrosion-resistance synthetic fibre (e.g., glass fibre), can improve the stiffness, strength, as well as the moisture resistance of the composites, and therefore, a balance between environmental impact and performance may be achieved. Importantly, hybridization between natural fibres and glass fibres is expected to improve the properties of the materials and decrease their water uptake, and subsequently reducing the water absorption problem.

Zamri et al. [29] studied the effect of water absorption on pultruded jute/glass fibre reinforced unsaturated polyester hybrid composites. They concluded that hybridization of natural fibres with synthetic fibres decreases the maximum moisture absorption and increases the mechanical properties of the composites.

II. ANALYTICAL STUDY

As the composites industry has grown there has become a bit of a divide between the language of the composite design engineer and the composite fabricator. In particular how each group describes the ratio of fiber to resin in the composite structure. The design engineer refers to the fiber/resin ratio in terms of volume of fibers to volume of resin. On the other hand, the composite fabricator will talk of the fiber/resin ratio in terms of fiber-to-resin weight ratios in the composite structure. Are they not the same thing? Well no they are not, but they are related. Each term has a very important relationship to the engineer or fabricator and they are essential in their development of the final composite component [31].

The discussion herein relates to wet resin lay-up techniques. Here the fabrication process will wet out the fibers with a wet resin system, i.e. wet lay-up, resin infusion processes and resin injection processes. The basic engineering properties of a composite material can be determined by either experimental stress analysis (testing) or theoretical mechanics (micromechanics). The micromechanics approach utilises knowledge of the individual fibre and resin properties, and the proportionality of fibers to the resin in the lamina. A rule of mixtures approach can best be used to derive the majority of the composite lamina properties. For example the lamina axial modulus is derived from:

$$Ex = Ef\,Vf + Em\,Vm \qquad (2.1)$$

Where,

Ef is the fiber modulus of elasticity, N/mm2

Em is the matrix (resin) modulus of elasticity, N/mm2

Vf is the fiber volume ratio

Vm is the matrix volume ratio

Vf + Vm = 1 with zero voids

2.1 FIBRE VOLUME AND WEIGHT RATIO RELATIONSHIP:

The determination of fiber weight ratio can be derived from the fiber/resin volume ratio. The approach is as follows:

We have,

$$V_f = 1 - V_r - V_{voids} \quad \text{(Assume Zero Voids)} \quad (2.2)$$

$$V_f = 1 - V_r$$

Where,

V_f = fiber volume

V_r = matrix or resin volume

Determine the Fiber matrix volume ratio:

And we have,

$$V_r = \frac{1}{1+\left(\frac{V_f}{V_r}\right)} \qquad (2.3)$$

From above expression we can find $\frac{V_f}{V_r}$

Determine the fiber/resin weight ratio:

We have,

$$\frac{V_f}{V_r} = \left(\frac{W_f}{W_r}\right)\left(\frac{\rho_r}{\rho_f}\right) \qquad (2.4)$$

From the above expression we can get $\frac{W_f}{W_r}$

The resin weight is the difference between the composite and fiber weights

$$W_{matrix} = W_{composite} - Wf_{iber} \qquad (2.5)$$

Substitute determined values in above equation, we can find W_{matrix} and Wf_{iber}

Table 1: Short banana and glass fiber and Epoxy resin of composite materials for different volume fraction of fiber and resin

Sample composite	Volume fraction of matrix ($\forall_f$)	Volume fraction of banana & glass fiber ($\forall_f$)	Equivalent Weight fraction of resin (W_m)	Equivalent Weight fraction of banana & glass fiber (W_f)
S1	0.85	0.15	0.75	0.25
S2	0.85	0.15	0.75	0.25
S3	0.85	0.15	0.75	0.25
S4	0.85	0.15	0.75	0.25
S5	0.8	0.2	0.7	0.3
S6	0.8	0.2	0.7	0.3
S7	0.8	0.2	0.7	0.3
S8	0.8	0.2	0.7	0.3

2.2. Model calculation of weight of the fiber and resin for tensile test:

Then the weight required of tensile specimens as per ASTM D-638 for different volume fraction of different types of fiber and resin can be evaluated from,

$$weight\ of\ fiber = \rho_f \times \forall_t \times \forall_f$$

$$weight\ of\ resin = \rho_m \times \forall_t \times \forall_m$$

Where, $\forall_t$ total volume of tensile sample, depended on as ASTM standard, selected the shape and dimensions of tensile test sample, as shown in Figure.3

Density of different materials:

Epoxy Resin Materials ρ_r =1.56 g/cm3

Glass Fiber ρ_g = 2.62 g/cm3

Banana Fiber ρ_b = 1.35 g/cm3

Weight of resin (W_m) = (1.56) × (16.5×1.9×0.7) × (0.85) = 29.1 gm

Weight of fiber (W_f) = (3.97) × (16.5×1.9×0.7) × (0.15) = 13.1 gm

III.PREPARATION & EXPERIMENTAL METHOD

The experimental study of composite materials included study of mechanical properties of different types of composite materials with various volume fractions and fiber lengths of reinforcement fiber as short banana and glass fiber as shown in Figures 1&2.

Fig: 1 Short banana fibre

Fig: 2 Short glass fibre

The short banana fibre is collected from local sources and E-glass fibres procured from Ram composites, Hyderabad are taken as reinforcement. Epoxy resin (LY 556) is supplied by sree Industrial composite products, Hyderabad is taken as matrix material. The low temperature curing epoxy resin and corresponding hardener (HX 951) are mixed in a ratio of 10:1 by weight as recommended. Moulds are used for casting the composite slabs for mechanical specimens as per ASTM standards. Banana fibre treated with NaoH and this alkaline treatment removes wax, hemicellulose and lignin hiding the surface of the fiber. The short banana/glass fibres are mixed with epoxy resin by the simple mechanical stirring. The composites are prepared with three different fibre loading and four different fibre lengths keeping glass fibre content constant (20 wt.%) using simple hand lay-up technique. The mixture is poured into various moulds conforming to the requirements of various testing conditions and characterization standards. The detailed composition and designation of the composites are presented in Table 2.The cast of each composite is preserved under a load of about 20 kg for 24 hours before it removed from the mould cavity. Then this cast is post cured in the air for another 24 hours after removing out of the mould. Specimens of appropriate dimension are cut for physical and mechanical tests. Figures 1&2 shows short banana fibre and short glass fibre. Figure 3 shows short banana/glass fibre reinforced epoxy hybrid composite.

Table 2: Preparation of Composites

Composites	Compositions
S1	Epoxy (75wt %) +Glass Fibre (20wt. %) +banana Fibre (Fibre length 5 mm) (5wt %)
S2	Epoxy (75wt %) +Glass Fibre (20wt. %) + banana Fibre (Fibre length 10 mm) (5wt %)
S3	Epoxy (75wt %) +Glass Fibre (20wt. %) + banana Fibre (Fibre length 15mm) (5wt %)
S4	Epoxy (75wt %) +Glass Fibre (20wt. %) + banana Fibre (Fibre length 20 mm) (5wt%)
S5	Epoxy (70wt %) +Glass Fibre (20wt %) + banana Fibre (Fibre length 5 mm) (10wt %)
S6	Epoxy (70wt %) +Glass Fibre (20wt %) + banana Fibre (Fibre length 10 mm) (10wt %)
S7	Epoxy (70wt %) +Glass Fibre (20wt %) + banana Fibre (Fibre length 15 mm) (10wt %)
S8	Epoxy (70wt %) +Glass Fibre (20wt %) + banana Fibre (Fibre length 20 mm) (10wt %)

Fig: 3 Short banana/glass fibre reinforced epoxy based hybrid composites

IV.MECHANICAL PROPERTY TESTS

4.1 Tensile test: The tensile test was conducted in Universal testing machine MCS 60 UTE -60.The test specimen was cut according to the ASTM D-638 standard. The test specimen of dimension 165x19x7mm is prepared as in figure. The test specimen is enclosed between the grippers of the Universal testing machine. The load is applied gradually until the deformation of the specimen is observed. The corresponding value of the load is noted down for the deformation of the specimen. The stress for the corresponding load is calculated. Figure 6 shows the experimental set up for tensile test. Figure 5 shows the specimen of short banana/glass fiber reinforced epoxy hybrid composites for tensile test.

Fig: 4 Tensile Test Specimen (ASTM D – 638)

Fig: 5 Specimen of short banana/glass fibre reinforced epoxy hybrid composites

Fig: 6 Experimental set up for tensile test

4.2 Flexural test: Flexural test was conducted in the three point bending test arrangement in a MCS 60

UTE -60.specimen is cut according to ASTM D-790 standard. The test specimen of the dimension 90x10x3 mm is prepared as shown in Figure 7. The test specimen is placed on the roller support at both the ends. The load is gradually applied from the top roller until the deformation is observed. The load value at the maximum deformation is noted down. Figure 9 shows the experimental set up for flexural test.Figure 8 shows the specimen of short banana/glass fiber reinforced epoxy hybrid composites for flexural test.

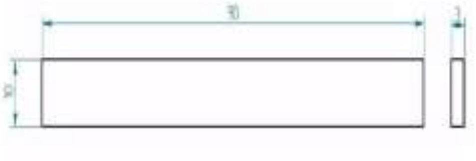

Fig: 7 Flexural Test Specimen (ASTM D – 790)

Fig: 8 Specimen of short banana/glass fibre reinforced epoxy hybrid composites

Fig: 9 Experimental set up for Flexural test

4.3 Impact test: The impact test was conducted in the Izod Krystal Elmec,KI 300,168J for izod impact test machine. The test specimen was cut according to the ASTM D-256 standards. The test specimens of the dimension 63x12.7x3mm are prepared as in the Figure 10. The specimen was fixed on the slot. Then the impact load is applied by releasing the swinging pendulum. The pendulum hits the specimen placed in the slot. The load absorbed for the breakage of the specimen is noted down. Figure 12 shows the experimental set up for impact test. Figure 11 shows the specimen of short banana/glass fiber reinforced epoxy hybrid composites for impact test.

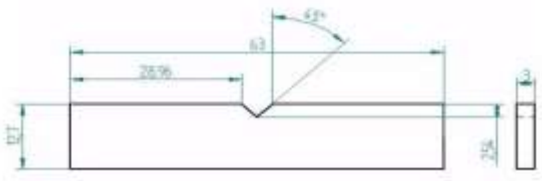

Fig: 10 Impact Test specimen (ASTM D – 256)

Fig: 11 Specimen of short banana/glass fibre reinforced epoxy hybrid composites

Fig: 12 Experimental set up for Impact test

4.4 Water Absorption Test: The test is conducted according to ASTM D570 standard. The water absorption test specimen of the dimension 25x25x3 is prepared as shown in Figure 13.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 specimen before immersion and W_1 = weight of specimen after 72hrs after immersion.

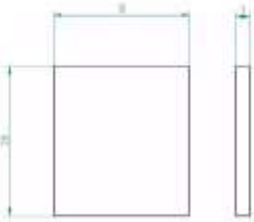

Fig: 13 Water Absorption specimen
(ASTM D - 570)

Fig: 14 Water Absorption Testing Specimen

4.5 Hardness Test: The test is conducted according to ASTM D785 standard. The test specimen of the dimension 30x30x3 is prepared as shown in Figure 15.As known hardness implies a resistance to indentation, permanent or plastic deformation of material. In a hybrid composite material, fiber weight fraction significantly affects the hardness value of the hybrid composite material. The hardness testing of plastics is most commonly measured by the Rockwell hardness test or Shore (Durometer) hardness test. Both methods measure the resistance of the plastic toward indentation. Hardness values measured on the Rockwell M-scale showing the effect of weight percentage of banana and glass fibers on the hardness values of hybrid composites are presented in Table 3.

Fig15: Hardness Test specimen (ASTM D785)

Fig: 16 Hardness Test Specimen

Fig: 17 Experimental set up for Hardness test

V.RESULTS AND DISCUSSION

This chapter presents the results of mechanical and water absorption behaviour of Short banana/glass fibre reinforced epoxy based hybrid composites.

Tensile strength of composites:
The tensile strength calculated from the below relations,

Where,
Max. Tensile strength = W / A
W – Maximum tensile load in N
A – Cross section Area in mm^2

Flexural strength of composites:
Flexural strength calculated from the below relations,

Max Flexural strength = 3WL/2bh2
Where,
W - Maximum load in N
L - Span of the specimen in mm
b - Width of specimen in mm
h – Height of the specimen in mm

Impact strength of composites: Impact strength calculated from the below relations,

Max impact strength = E / t
Where,
E - Impact energy in J
t - Thickness of the specimen in mm

Table3: Properties of Hybrid composite observations

Composites	*Tensile strength (MPa)*	*Flexural strength (MPa)*	*Impact strength (MPa)*	*Hardness*	*Water Absorption (%)*
S1	***23.40***	***95.68***	***43.95***	***46***	***2.646***
S2	***25.76***	***101.71***	***67.91***	***51***	***2.924***
S3	***28.84***	***114.86***	***96.84***	***54***	***3.122***
S4	***26.92***	***108.3***	***87.15***	***57***	***3.312***
S5	***23.84***	***98.56***	***51.3***	***43***	***3.651***
S6	***26.54***	***104.24***	***72.56***	***47***	***3.741***
S7	***29.61***	***118.32***	***101.84***	***51***	***3.906***
S8	***27.70***	***112.47***	***92.1***	***53***	***4.310***

Influence of fibre loading and length on tensile strength composites:

The influence of fibre loading and length on the tensile strength is shown in Figure 18. A gradually increase in tensile strength can be perceived with the increase in the fibre length up to 15 mm of banana/glass epoxy based hybrid composites. It is because of the proper adhesion between the both types of fibre and the matrix. But, further increase in fibre length i.e. 20 mm there is a decrease in the tensile strength. The reason may be due to the curling effect of the long banana fibre [26]. The curly nature of fibres prevents the proper alignment of fibres in the (longitudinal direction) composites. The maximum tensile strength is observed for the composite with 10wt% fibre loading at 15mm length. Previous reports reveal that normally the fibres in the composite restrain the deformation of the polymer matrix, reducing the tensile strain [27-28].

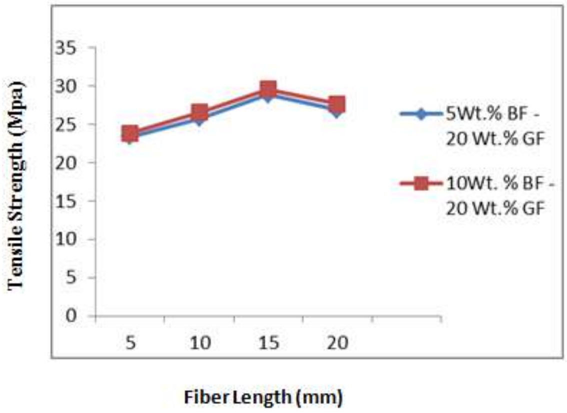

Fig: 18 Influence of fibre loading and length on tensile strength of composites

Influence of fibre loading and length on flexural strength of composites:

The influence of fibre loading and length on flexural strength of composites is shown in Figure 19. It is marked from the figure that the flexural strength of composite increases with increase in fibre length up to 15mm. Conversely, further increase in fibre length (up to 20mm) the value decreases. As far as the influence of fibre loading is concerned, composites with 10wt% fibre loading shows better flexural strength value as compared to 5wt% fibre loading. The maximum flexural strength of 118.3MPa is observed for composites with 10wt% fibre loading at 15mm length.

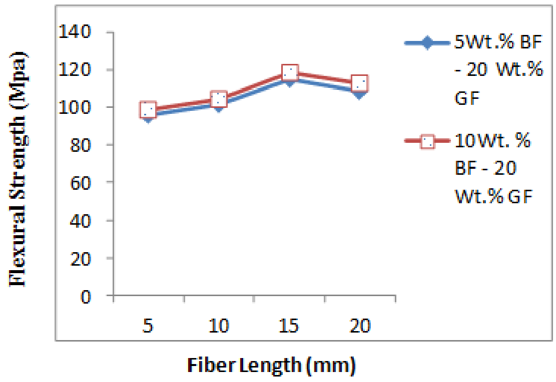

Fig: 19 Influence of fibre loading and length on Flexural strength of composites

Influence of fibre loading and length on Impact strength of composites:

The influence of fibre loading and length on Impact strength of composites is shown in Figure 20. The Impact energy values of different composites recorded during the impact tests are given in Table 3. It shows that the resistance to impact loading of banana fiber reinforced epoxy composites improves with increase in fiber length as shown in Figure20.Impact loads may be expected in many engineering applications of composite materials. The suitability of a composite for such applications should therefore be determined not only by usual design parameters, but by its impact energy absorbing properties.

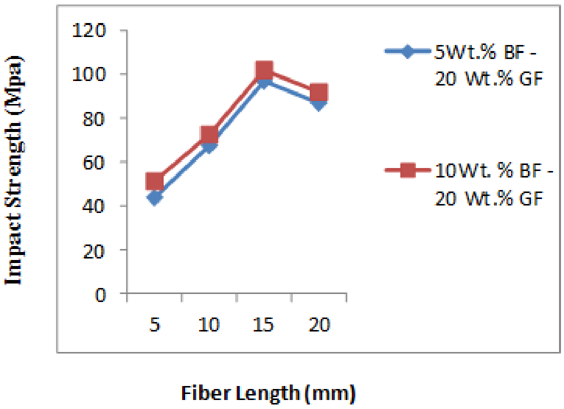

Fig: 20 Influence of fibre loading and length on Impact strength of composites

Influence of fibre loading and length on Hardness of composites:

Surface hardness of the composites is considered as one of the most important factor that governs the wear resistance of the composites. Figure 21 shows the influence of fibre loading and length on hardness of composites. The test results show that with the increase of fibre length, hardness of the banana/glass epoxy composites is improved. As far as the influence of fibre loading is concerned composites with 5wt% fibre loading shows better hardness value as compared to 10wt%. The hardness properties of the composites along and across the fibers are carried out. Generally, fibers that increase the moduli of composites increase the hardness of the composite. This is because hardness is a function of the relative fiber volume and modulus.

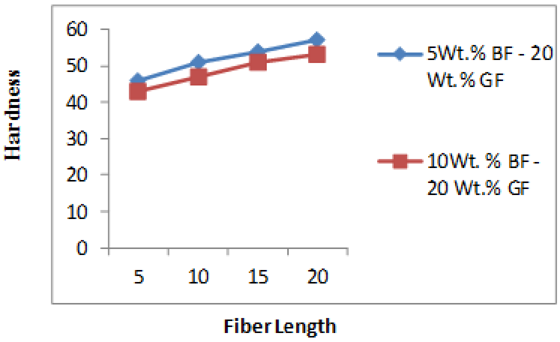

Fig: 21 Influence of fibre loading and length on hardness of composites

Water absorption properties of composites: The influence of fibre loading and length on the water absorption of the banana/glass fibre a reinforced composite with increase in immersion time is shown in Figure 22. It is marked from the figure that the rate of moisture absorption increases with increase in fibre lengths. Generally, the rate of water absorption is greatly influenced by the materials density and void content. It has been reported by earlier researchers that the incorporation of long banana fibres into the mix decreased workability and increased the void space [30]. Subsequently, the longer the fibre, the higher is the water absorption. As far as influence of fibre loading is concerned composites with 10wt% fibre loading shows higher water absorption rate as compared to 5wt% fibre loading. The reason may be due to that banana fibres contain abundant polar hydroxide groups, which result in a high moisture absorption level of natural fibre reinforced polymer matrix composites and are a major hurdle for preventing wide applications of these materials [30]

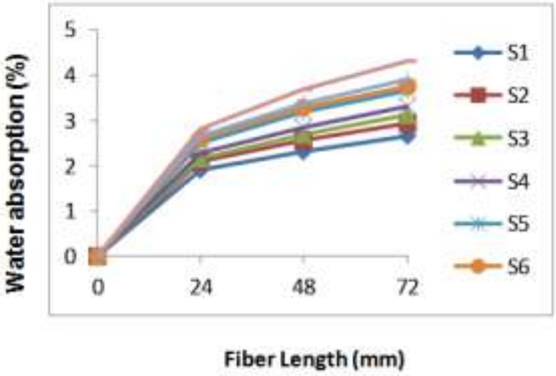

Fig: 22 Influence of fibre loading and length on water absorption of composites

The minimum water absorption rate is perceived for composites with 5wt% fibre loading and at 5mm fibre length. It is also spotted from the figure that the water absorption rate generally increases with immersion time, reaching a certain value at a saturation point where no more water is absorbed. The maximum weight gain from 2.65% to 4.31% is observed by the composite specimens at room temperature.

VI.CONCLUSIONS

The mechanical properties and water absorption of the hybrid composites using banana and glass fiber reinforced epoxy resin composites were studied in this work. The composites were fabricated by hand layup technique and tested according to ASTM standard. From the experiment the following conclusions have been drawn.

It has been observed that the various properties of the composites are greatly influenced by the fibre loading and fibre length.

From the ASTM mechanical property tests, a gradually increase in tensile, flexural and impact strength can be observed with the increase in the fibre length up to 15 mm of composites, Conversely, further increase in fibre length i.e. 20 mm there is a decrease in the strength properties. The hardness value increases with increase in fibre length. As far as the influence of fibre loading is concerned composites with 5wt% fibre loading shows enhanced hardness value as compared to 10wt%.

The rate of moisture absorption increases with increase in both fibre loading and fibre lengths. The maximum water absorption rate is observed for composites with 10wt% fibre loading and at 20mm fibre length.

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International Journal of Engineering Research and Applications (IJERA) is **UGC approved** Journal with Sl. No. 4525, Journal no. 47088. Indexed in Cross Ref, Index Copernicus (ICV 80.82), NASA, Ads, Researcher Id Thomson Reuters, DOAJ.

P.prasanna. “Synthesis, characterization of Banana / Glass Fiber Reinforced Epoxy Based Hybrid Composites .” International Journal of Engineering Research and Applications (IJERA), vol. 7, no. 9, 2017, pp. 47–57.