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EXPERIMENTAL CHARACTERIZATION OF BANANA-PALM FIBER REINFORCED HYBRID POLYMER COMPOSITE

Composite materials are synthesized by using natural cellulose fibers with matrix, due to their improved properties. In this work, banana and palm fibers are treated with 2% and 8% NaoH, respectively, for the removal of lignin and hemicelluloses. The hybrid composite was fabricated by using epoxy resin as the matrix and both the fibers as reinforcement through the hand lay-up method. By varying the banana and palm fibers in the range of 5-15% wt. and 7.5-22.5% wt. in the composite of 20% wt. and 30% wt. reinforcement, respectively, The composite consists of 5/15% wt. treated fibers, having more influence on compressive strength of 222.46 MPa and flexural strength of 535 MPa. However, 7.5/22.5% wt. treated composite has a higher impact resistance of 14.6 J and 10/10% treated composite gained a higher water absorption percentage weight of 1.16% at 216 hours. From the experiment, the composite with 5/15% wt. fibers of 20% wt. reinforcement and 80% wt. epoxy is suitable for making kitchen slabs.

Keywords: Composites; Epoxy resin; Banana fiber; Palm fiber; Hand layup techniques

1. Introduction

There has been a continuous increase on environmental awareness; over the last decade and great focus has been placed on the development of recyclable and environmentally sustainable composite materials. In many countries, there is demand and provide support for products and materials which have high environmental sustainability. Companies are bound to consider the environment while designing their products at every stage of the life cycle, including recycling and final disposal. The knowledge of all these environmental challenges has greatly influenced the creation of composite materials which are recyclable and biodegradable. Therefore, Gironès et al. [1] mention that the researchers are more involved in the field of natural fibers as reinforcement particularly much attention in the material science and engineering discipline. Aisyah et al. [2] and Asyraf et al. [3] discuss the usage of natural fibers have potentially rapid growing due to their biodegradability, plenty, rational cost and low consumption of energy utilization in processing.

In comparison to conventional glass and carbon fiber for manufacturing advanced composites, natural fiber is thought to be a renewable resource that may be grown and harvested within a reasonable time and continuously available. Aditya Bachchan et al. [4] and Asyraf et al. [5] explain that the natural fibers are having outstanding characteristics such as high specific modulus, lightweight and excellent resistance to wear and tear. These fibers are added as reinforcement materials in polymer matrix composites of thermo-set and thermoplastics.

The polymer matrix reinforced with natural fiber can be used as new class materials for various light weight structural applications. The mechanical properties of natural fibers vary based on the conditions in which they grow. The fiber extraction technique influences the chemical composition, fiber form, fiber strength, flexibility and ability to stick to other fibers. Because of this difficulty, predicting the mechanical properties of natural fiber reinforced composites is difficult.

A fiber-reinforced composite material mostly contains the thermosetting resin as matrix and the fiber as reinforcement. The fibers are held in place at the desired positions by the matrix resin in order to transmit load. Widely used matrix materials include vinyl ester, epoxy, phenolic, polyester, polyurethane, and polyether ketone (PEEK). PEEK is the most utilized matrix among various resin materials. Compared to PEEK, epoxy resin provides greater adherence and less shrinkage. The fibers must be kept apart to prevent mutual abrasion while the composites are being deformed. Autar K. Kaw [6] describes that the matrix

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distributes the load into the fibers while composite are loaded. Because fibers are generally fragile and toughness of the composite materials based on the matrix properties.

Pecas et al. [7], Gaurav et al. [8], Sabaruddin et al. [9], and Asrofi et al. [10] reported that the benefits of natural fiber-reinforced polymer composite materials and their applications are rapidly growing in the industrial applications and fundamental research. It is a renewable, cheap, completely or partially recyclable and biodegradable which obtained from plants like banana, palm, flax, cotton, hemp, jute, sisal, kenaf, pineapple, ramie, bamboo, etc.

Similarly, lignocellulose fibers from wood are employed more frequently as the reinforcement in composite materials. These are a desirable natural alternative due to their accessibility, renewability, low density, affordability and good mechanical properties. These types of composites used to replace glass, carbon and other man-made fibers for the reinforcement of composites. Prakash Tudu [11], Antunes Leão et al. [12] and Torres et al. [13] have discussed that the natural fiber-containing composites are more environmental friendly and are used in transportation industries (automobiles, railway coaches, aerospace), military applications, building and construction industries (ceiling paneling, partition boards), packaging, consumer products etc.

Fabrication of a composite material is the result of mixing the fiber reinforcement and polymeric resin. Therefore, the final properties of the composite mainly depend on the fiber orientation and bonding strength matrix. Manufacturing process is very important to align the fibers in desired direction to enhance its properties. Sabu Thomas et al. [14] noted that the important processing methods such as hand lay-up, bag molding process, filament winding, pultrusion, bulk molding, sheet molding, resin transfer molding and injection molding.

The natural fibers are usually classified into three main categories: plant or vegetable fibers (such as banana, palm, sisal, bamboo, hemp, or flax), animal/protein fibers (such as hair, wool, silk, or chitin), and mineral fibers (i.e. asbestos, etc.). The plant fibers are one of these major classes and due to their strong mechanical characteristics and recyclable aspect; they are frequently used for reinforcement in polymer matrix. The market for fiber-reinforced polymeric composites is extremely active. Kozlowskiy et al. [15] reported that the synthetic fibers are utilized to produce pipes, tanks and sports goods, construction of bridges, boat hulls, automotive industry and aircraft secondary structure while thermo-set resins as matrices. But thermoplastic resins require natural fiber. The commonly used natural fibers are from banana, palm, sisal, flax, hemp, bamboo and other as reinforcement for producing composite materials. Lau et al. [16] reported that the natural fibers are used with the condition of their chemical constituents such as hemicelluloses, cellulose and lignin. However, variations in the fiber diameter, length and specific gravity in certain extent of different physical and mechanical properties.

Several researchers analyzed the chemical compositions of banana fibers. Madhukiran et al. [17] reported that banana fiber contains 63-64% cellulose, 5-10% lignin, 19% hemi-celluloses, 6-19% waxes and about 1% ash by weight. And also, Reddy et al. [18] stated that cellulose and lignin contents of banana vary from 60 to 65% and 3.7 to 4.40% respectively depending on the age of the plant. The length of banana fiber was between 1.0 m and 1.5 m and the diameter was about 100±300 mm. The processing methods for extracting banana fibers have been described by Murherjee et al. [19].

2. Materials and methods

In the present study, banana-palm fibers and epoxy resin were used to prepare a kitchen slab. The epoxy resin System 2000 was used as matrix material. To initiate curing, epoxy resin needs a hardener. Hardener commences the chemical process that turns the liquid epoxy resin and monomer ingredient into the solid that, when combined with resin, hardens the adhesive. The final properties and appropriateness of the epoxy coating for a given environment were determined by the precise choosing and combination of the epoxy and hardener components. Therefore, the hardener (curing agent) used for this research work was System 2060.

After manufacturing the composite samples, it was cut into the required dimensions for various tests such as compressive, hardness, and flexural as per the ASTM standard. Compressive strength is an important requirement for kitchen slab materials. The proposed material of hybrid composite for the kitchen slab was applied the axial compression loading using the UTM, the dimensions of the specimen were prepared as per ASTM D3410. An impact test was performed on the proposed material to know the ability of a material to absorb energy. The Charpy impact test was carried out for the hybrid composite samples as per ASTM E23. Most of the researchers performed the bending test in composite material to deal with the fracture characteristic of the material. This test has been carried out by using a universal testing machine through three-point bending method. The dimension of the specimen was prepared as per ASTM D3410 standard.

The effect of water absorption on hybrid (banana-palm) composite material specimens was carried out with dimensions in accordance with ASTM D570. The specimens were dried by sunlight for three days and then allowed to cool until they reached room temperature. The dried spacemen were weighed before and after being immersed in the moisture. Water absorption tests of hybrid banana-palm FECM were conducted by immersing the composite specimen in distilled water in a glass jar at room temperature for different time durations. These tests were repeated three times and the mean value of the results obtained is considered.

Sodium Hydroxide (NaoH), an alkaline solution was used to bleach and clean the surface of natural fibers in order to increase the effectiveness of the fiber as reinforcement. It improves the surface morphology of natural fibers. Sodium hydroxide can be dissolved in ethanol, water and methanol. Nguyen et al. [20] noted that the NaoH treatment effectively removed noncellulose and other impurities from the fiber surface and made smooth surface. TABLE 1 shows the various compositions of composite samples.

TABLE 1

Composition of Hybrid Composite Specimen

Composite Sample	Composition of Hybrid composite		
	Epoxy wt. (%)	Banana wt. (%)	Palm wt. (%)
S_1	80	15	5
S_2	80	10	10
S_3	80	5	15
S_4	70	22.5	7.5
S_5	70	15	15
S_6	70	7.5	22.5

The theoretical density of epoxy-banana-palm hybrid composites was determined by using the rule of mixture. The actual densities of the epoxy-banana-palm composite were measured with the help of Archimedes' principles.

The volume content of voids was calculated by using the following equation

$$v_v = \frac{(\rho_t - \rho_a)}{\rho_t}$$

Where ρ_t and ρ_a represents the theoretical density and actual density of the hybrid composite respectively.

Water absorption test is very important to determine the water absorptivity of the material. The percentage of water absorption in the composites was calculated by weight difference between the samples immersed in distilled water and the dry samples using Eq. (1). The test was carried out at 24, 48, 72, 96, 120, 144, 168, 192, 216 and 240 hours at room temperature. The weights of each sample were measured before and after the samples were immersed in water.

$$\%\text{ of water absorption} = \frac{w_f - w_i}{w_i} \times 100 \quad (1)$$

Where w_f – Mass of composite samples after water absorption in gram, w_i – Mass of composite sample at dry condition in gram.

3. Preparation of fibers

The banana stem was obtained from southern Ethiopia. The fibers were removed manually by cutting them out with a knife. The stem was initially cut into strips in a longitudinal way to make fiber extraction easier. The peel was carefully dragged through while being clamped between the wood board and knife. It removed the resinous particles. In order to loosen and separate the fiber until individual fibers were obtained, the extracted fiber was then rinsed in pure water. The extracted fibers were then sun dried to make the fiber whiter. The banana fibers can be used to make composite materials once they have become completely dried. The extracted banana fibers are shown in Fig. 1.

Fig. 1. Dried Banana Fiber

The palm fiber was extracted from the stem which sliced into long strips and submerged in water for 3 weeks. Then, it was dried in the sunlight for 4 days. The fibers were cut to a length of about 3 cm by using scissor. In this research, Palm Fibers were used as the reinforcing phase while fabricating the composites and the fibers is shown in Fig. 2.

Fig. 2. Dried Palm Fiber

Palm fiber diameter 100-500 µm with length of 20 to 100 mm. banana fiber diameter 300 µm. The moisture content of the fibers was 13 and 10.5% for palm and banana respectively. The content of the fiber in the epoxy matrix was decided based on the properties required for the final product such as the kitchen slab. Fiber content is a significant factor while designing polymer-reinforced composites which mainly controls the mechanical, thermomechanical, and tribological performance. Therefore, for precise claims, it is important to recognize how the polymer composite performance is revealed with respect to the fiber content in various operating circumstances. In this research, the reinforcement contents were used by using the data from previous research articles. However, there is no fixed rule exists to describe how fiber content influences the tribological response of a composite.

3.1. Hybrid fiber preparation

Banana and palm fiber has been cut into the required length of 2-10 cm and then fibers were chopped as shown in Fig. 3 and Fig. 4. Then the required quantities of reinforcement fibers were mixed with epoxy resin.

Fig. 3. Chopped Banana fiber

Fig. 4. Chopped palm fiber

4. Preparation of epoxy and hardener

System 2000 epoxy resin and System 2060 hardener were mixed to prepare the matrix of composite materials. The weight ratio of chopped banana fiber-palm fiber with epoxy and hardener was 2:1. Anhydrides (acids), amines, polyamides, dicyandiamide, etc. were all used as hardeners. For about 1-2 minutes continuously, the mixer was stirred as shown in Fig. 5. The mixing was slowly done to avoid excess air bubbles enter into the resin.

Fig. 5. Mixing of epoxy resin and hardener

5. Fabrication of hybrid composites

The simplest way for processing composites is the hand lay-up technique. Thin plastic sheets were placed at the top and bottom of the mold plate to get a good surface finish. Then the banana fiber reinforcement in the form of chopped fiber was cut and placed at the surface of mold, which was placed on above the plastic sheet. Then epoxy resin and prescribed amount of hardener were mixed thoroughly in suitable proportion. The mixed resin was poured on the surface of banana chopped fiber already placed in the mold. Then the resin was uniformly spread with the help of brush. Next chopped palm fiber was placed on the polymer surface and a roller was moved with pressure. The slight pressure was applied to remove air trapped as well as the excess polymer present. The process was repeated for each layer of epoxy resin and fibers, till the required layers were stacked. Then, curing was done at 40°C temperature. After curing, the developed composite part was taken out from the mould. The normal curing time at room temperature for epoxy-based systems was 24 to 48 hours. This technique is best suited for thermoset-

Fig. 6. (a) Impregnation, (b) Hand roller process, (c) Hand Layup finishing process

ting polymer-based composites. In this study, 36 hours were used as curing time.

The schematic forming and finishing process of hybrid composite is shown in Fig. 6(a) to 6(c). Generally the fiber hybrid composite is having the usual steps of forming such as preparation of banana and palm fiber separately, mixing of resin and hardener, laying fiber, Impregnation, hand roller process and hand layup techniques. Biresaw et al. [21] stated that the fabrication of composite based on the mass percentage ratio of fiber, matrix and orientation of fiber by using the hand layup method.

6. Results and discussion

6.1. Physical characteristics

Physical characteristics are having major role to build the materials properties and also it desires the behavior of composite for various situational applications. Different types of physical properties of the hybrid composite are discussed.

6.1.1. Density and Void Fraction

The comparison between the theoretical and experimental density is shown in Fig. 7. The data on void content is a necessary prerequisite for estimating the actual quality of composites. The less void content in the composite means the better engineering properties. However, the presence of voids is unavoidable, especially in the composite made in hand-lay-up technique.

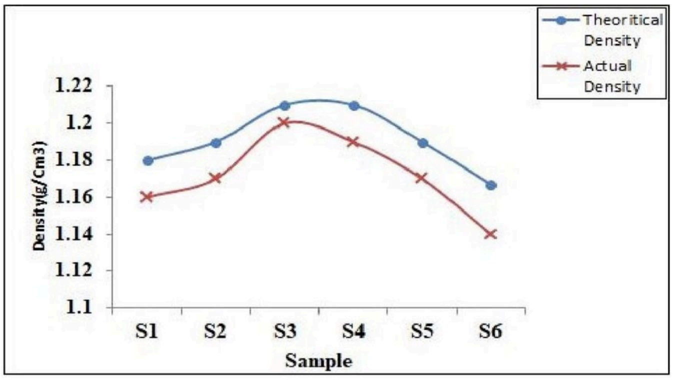

Fig. 7. Theoretical and actual density of hybrid epoxy composite

The existence of void content in the composites significantly reduces the mechanical and physical properties of the composites. Tan et al. [22] showed that the formations of void in the composites which can reduce the mechanical properties of composite such as hardness.

In all composite samples, the actual density was slightly lower than the theoretical density. Although sample S3 had, the highest theoretical and actual density values and sample S6 had the lowest as shown in Fig. 7. However, higher amount of porosity was observed in the hybrid composite samples but lowest voids were observed in the S3 as shown in Fig. 8. When the fiber content increases in the epoxy composites, densification also varied with respect to the reinforcement amount. The highest and lowest densifications are observed in the S3 and S4 hybrid composites respectively. Vijaya Bhaskar et al. [23] observed that the theoretical density values are higher than the experimental density values due to voids present during the fabrication of composites.

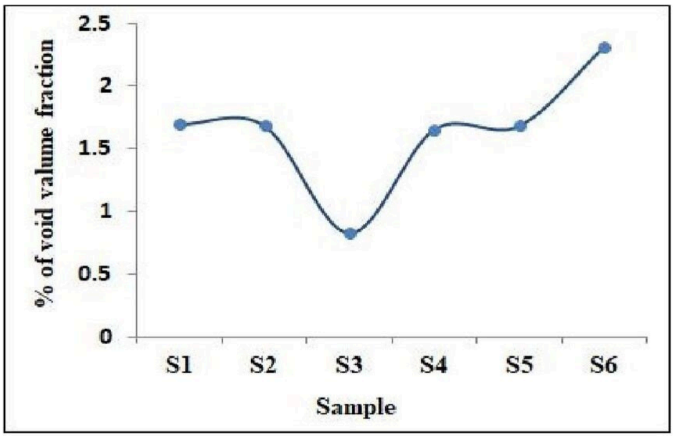

Fig. 8. Percentage of void in hybrid epoxy composite

The hybrid composite sample S3 having 5% wt. banana fiber and 15% wt. palm fiber exhibits the highest densification as 99.17% and lowest void content. This phenomenon showed that higher interfacing bonding was achieved between epoxy and fibers. Other hybrid composites were having week interfacing strength as compared to S3 sample.

The porosity of composites increases in the hybrid composite having higher palm fiber content due to the poor compatibility between fibers and matrix. It can be seen that the void fraction in the composites increases with the amount of reinforcement fiber increase. It is observed that composition of fiber reinforcement significantly influences the density of composites.

6.1.2. Compressive strength

The compressive test specimens were prepared from the hybrid banana-palm fiber reinforced with resin matrix. Three specimens were tested for each sample to measure the compressive strength and average compressive strength was determined for plotting results as shown in Fig. 9. The adhesion between hybrid (banana-palm) fiber and matrix were most important parameter in controlling the compressive properties of random orientation hybrid composite.

The increased compressive strength of chopped fiber reinforced composite material was observed while mass of fiber varies in different ratios of banana-palm fiber/matrix composite specimen S1 to S3. But the compressive stress starts to decrease while further increase the composition of fiber reinforcement in the composite samples S4 to S6.These results clearly indicate that 20% of fiber reinforcement in epoxy resin gives better compressive strength as compared to 30% of fiber reinforcement in the composite. In S1 sample, lower amount (5%) of banana fiber, higher amount (15%) palm fiber and 80% of epoxy resin were added which shows lower compressive strength as shown in Fig. 9.

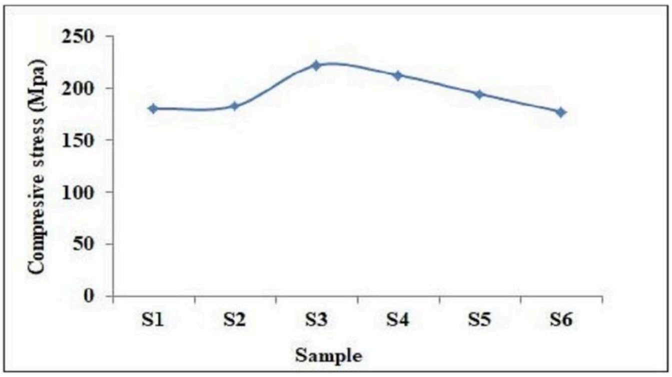

Fig. 9. Compressive Stress of void in hybrid epoxy composite

In S2 and S3 amount of banana fiber gradually increases and amount of palm fiber decreases in the hybrid composite composition. It is evident that compressive strength also gradually Increases from the sample S1 to S3 but compressive strength starts to decrease while further increasing amount of banana fiber in the 70% of epoxy resin and 30% of reinforcement hybrid composites. The maximum compressive strength of 222.46 MPa was observed in the sample S3and the minimum compressive strength of 177.53 MPa in S6 as shown in Fig. 3. It indicates that lower amount of fiber reinforcement induces the higher compressive strength as compared to higher amount of fiber reinforcement. The compressive strength of the composite was found to increase by 20% (S1) from 180.52 MPa to 222.46 MPa (S3). The further addition of the banana fiber, the compressive strength of hybrid composite increases steadily and recorded the growth of 23.23% when 15% wt. of banana and 5% wt. palm fiber content. This is happened due to the higher banana fiber content and it improves the composite axial load carrying capacity. Aldousiri et al. [24] indicated that the addition of the natural fiber leads to increase the compressive strength gradually under the condition of orientation of the fiber.

The banana fiber influences the compressive strength than the palm fiber in the hybrid epoxy/banana-palm composite sample, but 15% wt. of banana fiber and 5% wt. of palm fiber gets maximum compressive strength. Beyond 15% wt. of banana fiber addition makes reverse effect on compressive strength with irrespective of palm fiber addition in the hybrid composites. Banana fiber transfers the compressive stress faster than palm fiber, while external load was applied on the hybrid composite samples. Due to these phenomena, more stress concentration takes place in the higher percentage of palm fiber hybrid composites, so failure of stress transfer in the palm fiber leads the composites to fail. This compressive strength of the hybrid composites is enough to make kitchen slab since there is no critical load applied on the kitchen slab.

6.1.3. Flexural test

The flexural strength was determined with Instron Universal Testing Machine 4301 as per the ASTM D790. The dimensions of the sample for flexural testing were 127 mm×12.7 mm×3 mm. The crosshead speed was 1.3 mm/min and the support span length 48 mm. The average flexural strength of hybrid epoxy/banana-palm fiber composites was shown in Fig. 10. From the random orientation directional reinforcement of 15% wt. of banana fiber and 5% wt. of palm fiber with 80% wt. of epoxy matrix shows highest flexural strength as compared to other weight fraction of hybrid composites. Balaji et al. [25] stated that the average flexural strength increases gradually up to 15% wt. for both 10 mm and 20 mm length banana fiber reinforcement. The random orientation with high amount of epoxy and more banana fiber ratio (FS1) was increased by 40.06% compared with high amount of palm fiber and low amount matrix (FS6). It indicates that the maximum bending strength was observed in this composite.

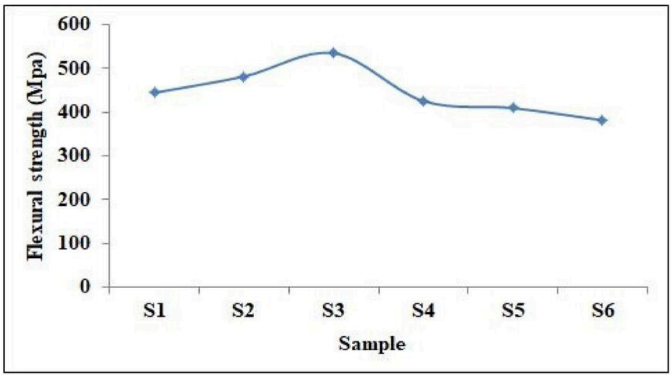

Fig. 10. Flexural Strength of hybrid epoxy composite

Due to the increase in amount of banana fiber in the resin matrix of the composite, the flexural strength increases from 381.97 MPa to 535 MPa in S1 and S6 respectively as shown in Fig. 10. It is also observed that flexural strength linearly decreases while the palm fiber content increases from 7.5 to 22.5% wt. and banana fiber content decreases 22.5% to 7.5% wt. The flexural strength of the composite materials mostly depends on the interfacial strength between matrix and reinforcement fibers. Higher interfacial bonding provides better transfer of the applied load from matrix to the dispersed phases of the reinforcements. Composites are having high flexural strength and builds strong interfacial bonding among the banana fiber, epoxy and palm fiber. So particularly mechanical interlocking between banana fiber and epoxy is more. The flexural strength of the hybrid composite is endurable and load bearing capacity increases for making the kitchen slab.

6.1.4. Impact strength

Impact test was carried out for the hybrid composite samples and samples were prepared as per ASTM D256 standard to do Izod impact test by using an impact testing machine. The sample size was 55×12.7×3 mm, while the notch length was 2.54 mm. Three samples for each composition were tested and the average results were shown in Fig. 11.

It was observed that impact strength of the composites was found to decrease from the sample S1 to S3 but it makes reverse effect from S4 to S6 as shown in Fig. 11. It reveals that the presence of banana and palm fiber reinforcement compositions makes great variation in the impact strength. When impact load was applied on the composite materials, load was absorbed by the polymer matrix and transferred to the fiber reinforcement.

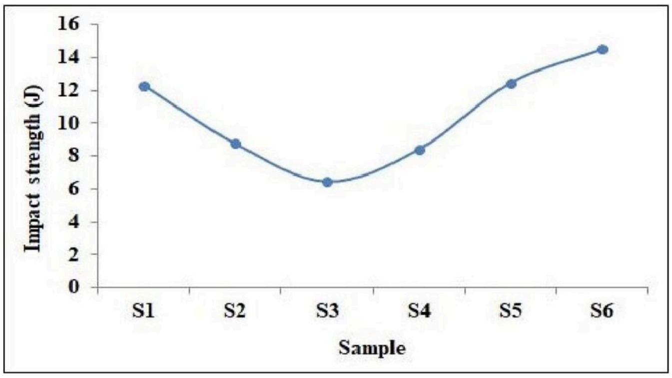

Fig. 11. Average Impact Strength of hybrid epoxy composite

Load transferring capability mostly depends on the interfacial strength between fiber and polymer. If the interfacial strength is weaker, composite matrix phase fail to transfer load to the fiber. Due to the weak interfacial strength and cracks were initiated in the interface. These experimental results show that increasing the fiber weight fraction from 20% to 30% wt., the impact strength linearly increases. The hybrid composites had lower fiber tenacity and higher fiber-matrix adhesion, resulting in a significant increase in impact energy. Shireesha et al. [26] has already reported that an increase in quantity of fibers in the hybrid composite leads to an increase in the tensile strength and impact strength of the composites. The experimental result shows that impact strength of 14.45 J was the maximum in S6 as compared to other composite samples. Impact strength of sample S6 hybrid composite has higher value such as 121%, 50.2%, 16.8%, 72.2% and 17.23% of S1, S2, S3, S4 and S5 respectively.

The results as shown in Fig. 11 clearly indicates that S6 absorbs more impact energy as 14.45 J, while S3 exhibits the lowest impact energy as 6.45 J. At higher level of palm fiber (22.5% wt.) reinforced composites show 72.2% increase in impact strength as compared to low level palm fiber (7.5% wt.) fiber reinforced composites. Conversely, 16.8% increase in the impact strength is observed in the composite having low level of palm fiber (15% wt.) and 5% wt. banana reinforced hybrid composite. The hybrid composite shows more impact strength as the palm fiber reinforcement percentage increases in the hybrid composite.

The hybrid composite sample having 5% banana and 15% palm fiber shows higher impact energy as 89.39% more than sample of 15% banana and 5% palm fiber reinforced composites. As a result, a kitchen slab made of local composite material withstands impact loads without any major structural problem. This developed hybrid epoxy-banana-palm composite is capable to absorb up to 12.61 J of energy without suffering from critical damage. As a result, the hybrid composite is suitable for the product of a kitchen slab.

6.1.5. Water absorption properties of hybrid fiber composites

Water absorption is the most important to determine the quality of kitchen slab. Low water absorption limits the amount of water that may originate the failure by cyclic salt attack in the material structure. So, moisture absorption must be very low for the better performance and durable life. The weight difference between the samples immersed in distilled water and the dry samples was used to calculate the amount of water absorption in the composites. The test was carried out between 24 and 240 hours with time interval of 24 hrs. The percentage of weight gain in various composites with time duration is shown in Fig. 12. Lower water absorption results from a higher adhesion (bond) between the matrix and the fiber. According to the literature, alkalis such as sodium hydroxide treated fiber leads to minimize the water absorption rate in the composite sample. Bachtiar et al. [27] observed that the sodium hydroxide treatment efficiently reduced palm fiber water absorption, removed surface impurities, improved fiber properties and enhanced fiber/matrix interaction.

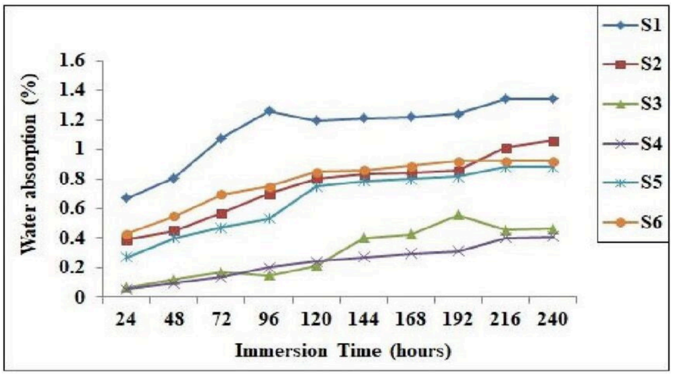

Fig. 12. Water absorption percentage of hybrid epoxy composite

Maximum water absorption was exhibited by S1 as compared to other samples as shown Fig. 12. From S1 to S3, rate of water absorption decreases but from S4 to S6 rate of moisture absorption increases. Banana fiber reinforcement makes more influences to reduce the moisture absorption than the palm fiber reinforcements. Ravi Bhatnagar et al. [28] reported that addition of banana fiber in epoxy matrix up to 50% wt. exhibited an increasing the mechanical and thermal properties but decreasing the moisture absorption rate.

Hybrid composites having 20% wt. fibers reinforcement and 80% wt. of epoxy matrix exhibits more to less moisture absorption rate from samples S1 to S3. Samples S1 to S3 high amount of banana fiber and low amount of palm fiber reinforcements were used. It clearly indicated that higher amount of banana fiber (15% wt.) and lower amount of palm fiber (5% wt.) hybrid composite absorbs lower amount of moisture as 0.455% at 240 hours And also, clearly it shows that rate of change of moisture absorption was very low from 24 to 72 hours and again it is slightly increases but from 192 to 240 hours it is almost saturated. Similar trends were followed by the sample S4 up to 192 hours but after that moisture absorption rate suddenly increases up to 216 hours and maintained steadily till the 240 hrs. At sample S4 interfacial boding was affected due to moisture absorption after certain limit. This type of problem occurs due to the higher amount of reinforcement (30% wt.) in the hybrid composite. So, the lower moisture absorption can be achieved at the hybrid composite made with 20% wt. fiber reinforcement than 30% wt. fiber reinforcement fiber composites.

Fiber matrix interface plays an important role in the composite properties such as strength and moisture absorption. If the interfacial bonding is stronger, it improves resistance to moisture-induced degradation of the interface of composite material.

Porosity is also having vital role in the moisture absorption so it is required to produce the composite samples with less porosity. Sample S3 was having lowest porosity as compared to other composite samples, so sample S3 gained minimum water absorption than the other composites. Sample S4 also having less moisture absorption as like S1 but beyond 192 hours immersion time, moisture absorption increases drastically up to 216 hours and then maintained constantly.

It was observed from the Fig. 12 that with higher fiber loading promotes water absorption gradually. The main reasons in the composite such as lumen, the cell wall and gaps to reside water in the composite. These types of issues happened due to weak interface adhesion between the matrix and reinforcements.

The hybrid composite of 15-5% wt. banana-palm fiber attains saturation earlier than the rest specimen. When water absorption gain was more, water molecules interlocked in the composites was less. Thus, the water molecules have the opportunity to assault the interface adhesion, which leads to the internal bonding of the fiber and matrix in the composite. As a result, it was evidently clear that the immersion period had an impact on absorption behavior of the composite material.

7. Conclusions

Hybrid composites of epoxy/banana-palm were fabricated through hand layup method and conducted various tests. Through the analysis of the data some remarkable conclusions are made as follows.

1. Highest densification was achieved when the hybrid composite made of 20% wt. fibers and 80% wt. of epoxy resins and particularly at the sample S3 having 15% of banana fiber and 5% palm fiber reinforcement.
2. Void fraction plays important role in the composite samples and lower void fraction of 0.833% is achieved in the hybrid composite sample having 15% wt. of banana fiber and 5% wt. palm fiber reinforcement (S3) as compared to other composite samples.
3. 20% wt. of fiber reinforcement in epoxy resin gives better compressive strength as compared to 30% wt. of fiber reinforced composites. Particularly, a composite having composition of 15% wt. banana and 5% wt. of palm fibers exhibits dominant compressive strength due to higher interfacial bonds between fibers and epoxy matrix.
4. Banana fiber influences more on the flexural properties of composites than palm fiber. The flexural strength of the hybrid composite having 5, 15 and 22.5% wt. of banana fiber were 444.7 MPa, 535 MPa and 425.7 MPa respectively. Maximum flexural strength occurs in the hybrid composite while reinforcing 15% wt. banana fiber and lowest amount of palm fiber (5% wt.).
5. Highest and lowest impact strength observed at the higher amount (30% wt.) and lower amount of reinforcement (20% wt.) respectively. Toughness of the material was more when providing higher amount fibers in the composite materials due its capability to absorb more energy while applying external load.
6. Moisture absorption of the hybrid composite depends up on the fiber reinforcement and interlocking of fibers. Epoxy/banana-palm fiber hybrid composites having 15% wt. banana and 5% wt. palm fiber produces lowest moisture absorption even up to 240 hours and hence this hybrid composite possible to make a kitchen slab.
7. Hybrid composite having 15% wt. banana fiber and 5% wt. palm fiber reinforcement with epoxy resin can be effectively used for kitchen slab because most of the conventional kitchen material properties coincided with hybrid composite sample S3.

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