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Research Article

Mechanical Properties of Bone Particulate and E-Glass Fiber Reinforced Hybrid Polymer Composite

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The present study is focused on investigating the mechanical properties of hybrid polymer composites. The reinforcement materials are animal bone (ox) particulate and E-glass fiber. The matrix material is epoxy resin. The following combinations are considered for investigation: (a) bone particulate weight percent (20%, 30%, and 40%), (b) E-glass fiber weight percent (20%, 30%, and 40%), and (c) bone particulate (10%, 20%, and 30%) and E-glass fiber (30%, 20%, and 10%) with epoxy resin 60% by weight percent. The test specimens are prepared as per the required ASTM standard for tensile, compressive, and flexural tests. The test results show that maximum tensile and compressive strength observed in 40% of E-glass fiber with 60% of epoxy matrix, correspondingly, is 254.964 MPa and 37.52 MPa. The maximum flexural strength observed in E-glass fiber reinforced composites is 250.43 MPa.

1. Introduction

Composite material is the combination of two or more materials with different physical and chemical properties to get a new desirable property, which is suitable for the required application [1, 2]. The reinforcing can be in the form of fiber, particles, or sheets. The reinforcing material is embedded by another material, which is called the matrix. The matrix material is mainly a polymer, whereas the fiber material can be metallic, ceramic, or polymer. In a composite material, the fiber is stiffer and stronger than the matrix, which leads to the primary load carrying member [3]. The composite material has been used other than the structural application. It has been used for electrical, thermal, tribological, and environmental application [4]. Composite material has a new generation of materials that can be used as structural materials in the fast-growing industries of automobiles and aerospace. A composite material is a man-made material in which two or more materials with different properties are combined. The properties of composite materials depend on length, size, orientation, volume/weight, and fiber fraction. Today, consumers and industrial markets are seeing an increase in the daily use of compounds. In the future, due to better performance in different measures, materials used in engineered products will be replaced by composite materials. For this reason, composite materials are used in different fields of application, such as aerospace, marine technology, chemical industry, automotive industry, construction, electricity, and other fields of application [5]. Hybrid composite materials must be composed of two or more different reinforcing materials and matrix materials. Due to the shearing effect of reinforcing fibers, this composite material has higher mechanical properties than simple reinforced fiber composite materials. Hybrid composites offer a wide range of applications, including aerospace interiors, naval, civil building, industrial, sporting goods [6], and interior and exterior automotive applications [7]. Hybrid composites are used for environmentally friendly applications like food packaging and furniture [8–9], solar energy applications [10], and epoxy-based hybrid composites are used in thermal interface materials and adhesives [11]. The needs of material development and research on different properties of composite materials have become indispensable. In many fields, such as medical care, automobiles, furniture, packaging, and construction, the use of composite materials is increasing year by year. Hence, a large number of discarded animal bones exist in our environment [12].

The animal bone (ox) contains a mineral fiber known as collagen fiber. To be specific, the type and name of the bone used for investigation are the femur and humerus bone of the ox. There are many types of synthetic fibers, the most commons are glass fiber, carbon fiber, aramid fiber, and Kevlar fiber [13]. Glass fiber is one of the most widely used man-made fibers. Glass fibers with polymeric materials have been used in different commercial products, such as car cardboard, sporting goods, pipes, tanks, and robots. Biodegradable polymers are sought after in the modern world due to their inherent, intrinsic properties, such as biodegradability, abundance, environmental friendliness, flexibility, and ease of processing [14].

The tensile and flexural strength of cattle bone particulate reinforced epoxy polymer composites was investigated by Harish et al. in 2018 [15]. Carbonized cattle bone particles have more strength than uncarbonized bone particles. This is due to an increase in the amount of cattle bone particles added to the epoxy composite. It was also revealed that the percentage of elongation decreased.

The wear rate increased when the applied load moved from 5 to 15 N, and it could be reduced when the CBP was from 0 to 15%. The work has shown that carbonized bone can be used to make polypropylene composites more durable [16]. Basvarajappa et al. [17] conducted wear tests on glass fiber reinforced epoxy composites containing SiC and graphite fillers. The wear resistance of composites is increased to a greater extent when fillers are added. Additionally, the optimal parameters for wear studies were reported using the Taguchi approach. Additionally, it has been reported that the load and sliding distance have a greater effect on wear than the sliding velocity.

Pinho et al. [18] presented composite structure that combines microparticles and nanofibres in reinforced polymer composites that are strong. The tensile properties of the sample (8 wt. percent bone particle reinforced) were sufficient to meet the structural and surface conditions required for biomedical application [19]. Tensile, flexural, and hardness properties, as well as wear behavior, were investigated using a particulate goat bone reinforced epoxy composite. It was observed that composites with a higher weight percentage of reinforcement (16–20 wt.%) had improved mechanical properties when compared to composites with a lower weight percentage (2–14 wt.%). From a 16 wt.% bone particulate reinforced epoxy composite, the better tensile and flexural properties, as well as good and favorable hardness properties were obtained [20]. Stir casting was used to make zinc-aluminum alloy (ZA-27) hybrid metal matrix composites reinforced with lamb bone ash (LBA) and boron carbide (B_4C). In comparison with single-reinforced composites, mechanical properties such as hardness, compressive strength, and tensile strength improved significantly in hybrid composites [21]. E-glass fibers are the most extensively utilized fibrous reinforcement by many orders of magnitude. Their low cost and early development relative to other fibers are the key reasons for this. The best tensile and flexural performances were obtained from a bone particle reinforced epoxy composite, which also has good and favorable hardness qualities [20, 22]. Therefore, all the known advantages of natural fiber-based composites still have some shortcomings/limitations that require further improvement. Such limitations include variable yield strength, low compressive strength, high moisture absorption during processing, poor adhesion to synthetic fibers, and lack of specific mechanical properties for the intended application. The purpose of this research is to study the mechanical properties of hybrid composite by using animal bone particulate and E-glass fiber with epoxy resin. Different tests including tensile, compression, and bending and water absorption tests are conducted.

2. Materials and Methods

2.1. Bone Particulate Preparation. The ox bone is procured from Gondar abattoir enterprises, treated with acetic acid, and dried for four weeks in sun. This treated and dried animal bone (ox) is first crushed manually by using a hammer. Once the bone is suitable for feeding in to roller bone crushing machine, it is degraded in to powder and dropped through sieve having a size of 2 mm. The final bone particulate used for study is shown in Figure 1(a).

2.2. E-Glass Fiber. E-glass fiber is one of the most important reinforcement materials, especially for polymer composites. It is a lightweight and durable material used in various industries. E-glass fiber has good mechanical properties, best compatibility with epoxy, easily available, and low cost. Figure 1(b) shows E-glass fiber used for hybrid composite.

2.3. Epoxy and Hardener. The commercially available epoxy (C501) resin was mixed with hardener (Araldite HY951) with blending of epoxy and hardener weight ratio 10 : 1. It has low viscosity cure at room temperature, good mechanical strength, good resistance to atmosphere, and chemical degradation. Anhydrides, polyamides, dicyandiamide, and other hardeners are among them. The mixing is done in the containers. Although the bowl melting could be avoided during the process with the tongue depressor, the bowl is prepared with nickel; the combination is done carefully to avoid inducing any surplus air bubbles in the resin.

2.4. Hand Lay-Up Method. The weight percentage of each fiber and matrix material (epoxy with hardener) is weighted using an electronic balance according to the weight

(a) (b)

Figure 1: Reinforcement materials: (a) bone particulate and (b) E-glass fiber.

percentage of the composition. The epoxy resin and the hardener are mixed; the mixture was stirred properly in order to reduce the air bubble formed during mixing. Table 1 shows the description and corresponding weight percentage for each composition. Different samples were synthesized based on compositions. Then, this different composition is subjected to load, so as to avoid the air bubble formed during the synthetization of composition by using hydraulic press machine. After applying the load by using press machine, the composition is left for 24hrs, removed from the mold, and then allowed to cure at room temperature for three weeks.

The mold has been filled with an adequate amount of epoxy resin mixture and layers of bone particulate (random), starting and ending with resin layers, and E-glass fiber was added layer by layer using the hand lay-up method (Figure 2). The size of the mold used for the study was $310 \times 220 \times 7$ mm. The prepared composites with 20% E-glass and 80% epoxy are shown in Figure 3.

2.5. Mold Release. The release of the mold is crucial to avoid the epoxy from adhering to the mold when the composite is separating. Although different forms of mold release are employed based on the mold material and the desired qualities of the produced item, the most typical type utilized for this process is wax and aluminum foil for better surface finishing of the composite. In the present work, the mold was covered by wax. This wax functions as a releasing agent for safe removal of the composite from the mold.

2.6. Testing and Characterization. The test specimens are prepared dimensions of $250 \times 25 \times 4$ mm with ASTM D3039 standard for tensile testing shown in Figure 4. The experimental setup (UTM) used for tensile and compression tests is shown in Figures 5(a) and 5(b) correspondingly. The tensile test is conducted using the universal testing machine (UTM) at a fixed crosshead speed of 2 mm/min and a gauge length of 150 mm by loading until the test specimen failed. For analysis and characterization purposes, the ultimate tensile strength and percent of elongation of three test specimens were considered for measurement for each composition. The specimen for compression test is prepared according to ASTM D3410, which has a square dimension of 50×50 mm and thickness of 4 mm. In this case, the load is applied inward to each other by squeezing the specimen in between. For bending test, the specimen is supported at the opposite end and a load is applied at the middle of the specimen. The test specimen was prepared with ASTM D790 standard for bending test with $150 \times 20 \times 4$ mm dimension.

Water absorption test was performed for composites. The specimen prepared for this test has a dimension of $28 \times 25 \times 4$ mm. The specimen mass was calculated before and after immersion water for 24 hrs. Three trials for each composition were measured, and the average value is considered for water absorption test.

3. Results and Discussion

3.1. Tensile Test. Figure 6 clearly shows the tensile strength of different composition. Figure 6 shows that, among all composition, the composition E-glass fiber 40% with 60% epoxy matrix show the maximum average tensile strength. The maximum tensile strength obtained by this composition is 254.96 MPa. Figure 6 clearly shows the highest tensile strength obtained in glass fiber reinforced composites. The fibers carry the majority of the load and offer increased rigidity. Tensile strength is mostly determined by the fibers. So, if the fiber content increases in the composition, then the maximum tensile strength also increases [24]. It was found that the lowest tensile strength is obtained in bone particulate reinforced composites. The hybrid composites exhibit moderate results between the bone particulate and the E-glass fiber reinforced composites. The reason behind is due to poor adhesion between the animal bone particulate and the E-glass fiber with epoxy matrix or due to the presence of air bubbles inside the composition.

The E-glass fiber with epoxy matrix composition as the fiber content increases the maximum tensile strength tends to increase. From Figure 6, it is shown that bone particulate with epoxy matrix has very low tensile strength as compared with E-glass fiber with epoxy composition and the hybrid one. Gopinath et al. [25] studied the mechanical properties and microstructure of polyester and epoxy resin matrices reinforced with jute, E-glass, and coconut fiber. The maximum tensile strength of epoxy with E-glass fiber reinforced composites was discovered to be around 170 N/mm^2 and compared with other combinations.

Table 1: Designation and composition of composite.

Composition	Epoxy resin (wt. %)	Bone particulate (wt. %)	E-glass fiber (wt. %)
B1	60	40	—
B2	70	30	—
B3	80	20	—
BG1	60	10	30
BG2	60	20	20
BG3	60	30	10
G1	60	—	40
G2	70	—	30
G3	80	—	20

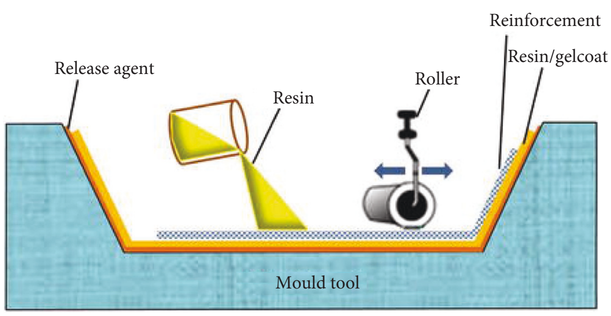


Figure 2: Hand lay-up [23].

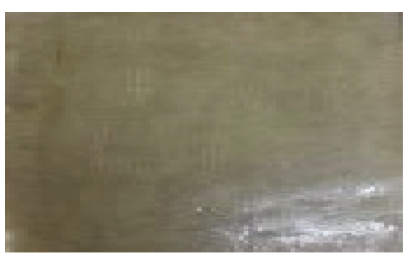


Figure 3: Prepared polymer composites.

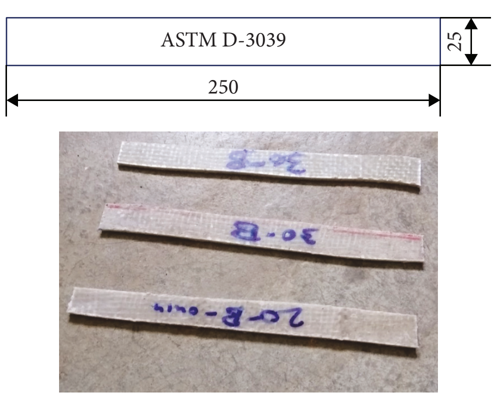


Figure 4: Test specimens with the ASTM D 3039 standard.

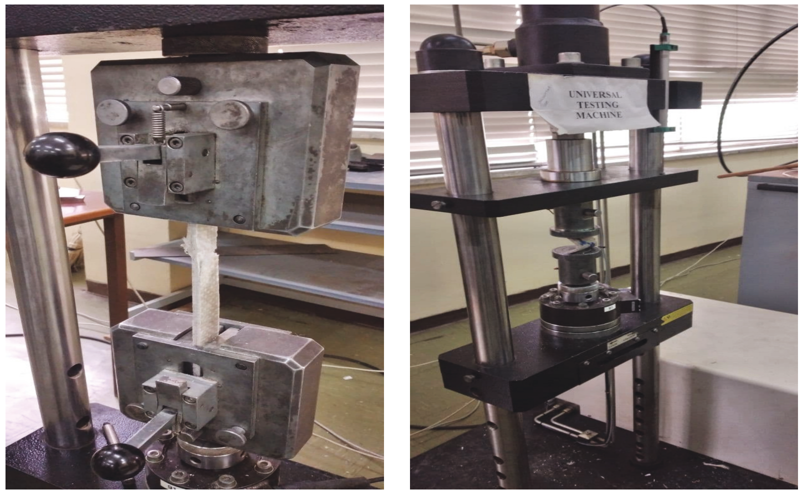
3.2. Compressive Test. Figure 7 shows the average maximum compressive strength for all compositions of composite. From the figure, it shows that, among all composition, the composition G1, which is 2 40% of E-glass fiber with 60% of epoxy matrix, show the maximum average compressive strength. The maximum compressive strength achieved by this composition is 37.52 MPa. This is due to good adhesive bonding between the fibers and matrix material. Not only this, during the synthetization of this composition, the void content created very less compared with other composition. The bone particulate with epoxy has very low compressive strength as compared with glass fiber with epoxy composition and hybrid one.

The maximum compressive strength is shown in the composition having 40% of E-glass fiber with 60% of epoxy matrix. This composition has also high tensile strength as discussed above. This shows that under this composition the fibers and the matrix material are highly compatible, have high adhesion propertyies, and have less porosity. Similar to tensile strength, the bone particulate reinforced composites exhibited the lowest compressive strength.

3.3. Flexural Test. Figure 8 shows the flexural strength of all compositions. As shown from Figure 8, it indicates that the maximum bending strength is achieved with 40% of E-glass with 60% of epoxy matrix. The maximum flexural strength observed by this composition is 250.52 MPa. Next to this composition, 30% of E-glass fiber composition has also good flexural strength, which is 183.73 MPa.

As shown in Figure 8, the flexural strength of pure bone particulate with epoxy increases as the content of the bone in the composition increases. The ability of the composite to resist the applied load increases proportionally as the fiber content increases up to a specific percentage. After this percentage, significant reduction on the mechanical property is observed because of the presence of fiber agglomeration in the same area. A similar observation was found with the previous work [26]. The result also shows that the flexural strength increases as the E-glass fiber content increases in pure E-glass with epoxy composition, but it could be reduced in the hybrid composition.

3.4. Water Absorption Test. Figure 9 shows water absorption by each composition. As shown from the result, the minimum amount of water absorbed is shown in E-glass fiber reinforced composite, which is 20–40% of E-glass fiber with 60% of epoxy matrix composition, and the maximum amount of water absorbed is shown in B1 composition, which is 40% of bone particulate with 60% of epoxy resin. This indicates that the presence of bone particulate in the



(a) (b)

FIGURE 5: (a, b) Universal testing machine: (a) UTM-tensile test and (b) UTM-compression test.

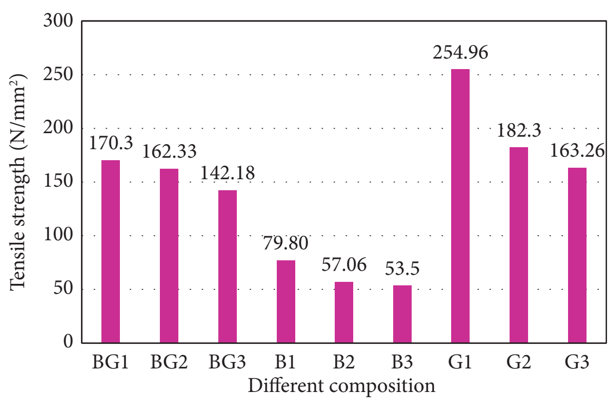


FIGURE 6: Tensile strength of all compositions.

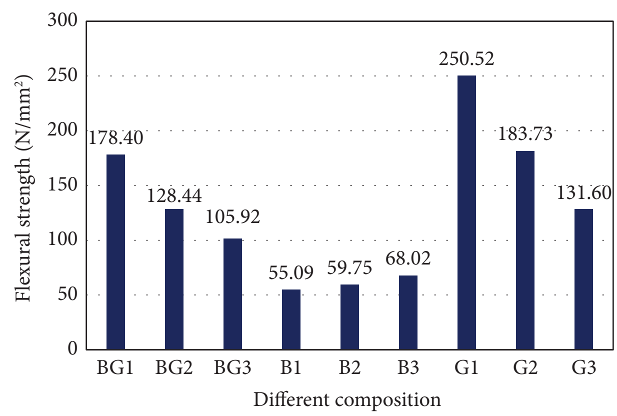


FIGURE 8: Flexural strength of all composition.

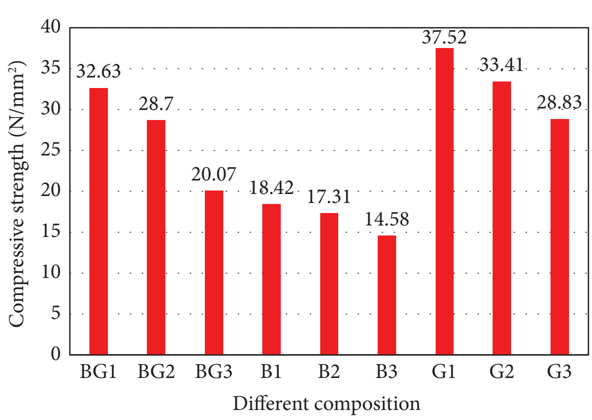


FIGURE 7: Compressive strength of all composition.

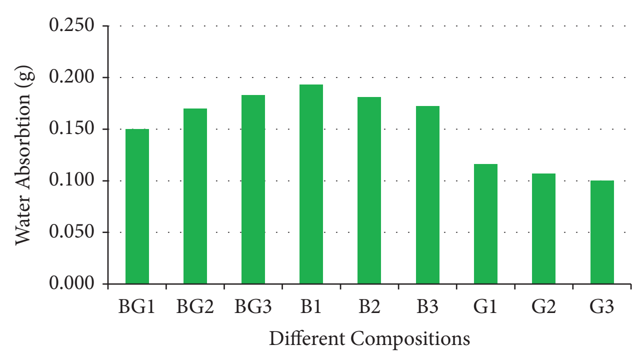
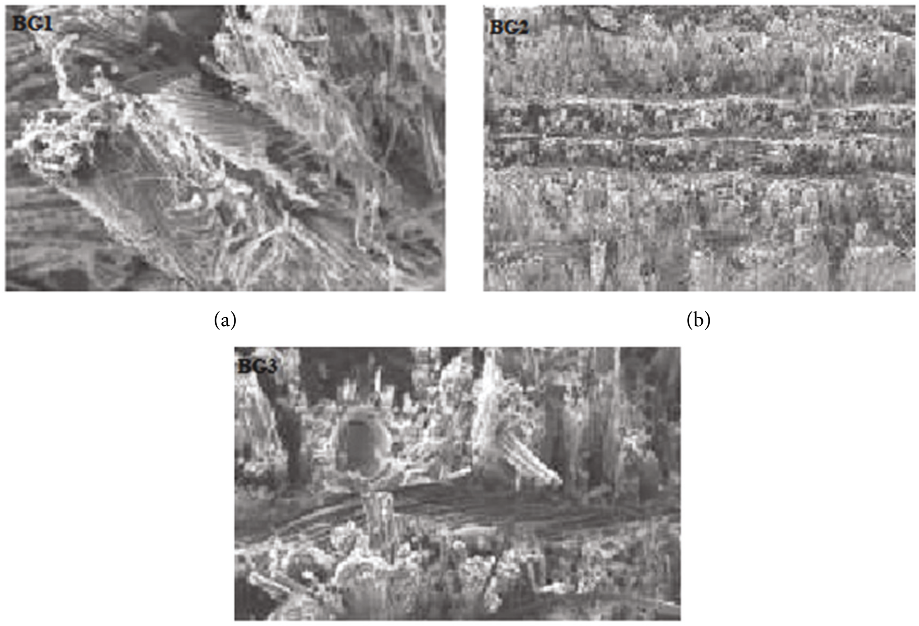


FIGURE 9: Water absorption of composites.

composition has a high effect in the water absorption property. In hybrid composite, the water absorption capability of the composition increases as the bone particle content increases.

From optical microscope images, Figures 10(a)–10(c) observe the fiber pulls out, fiber dislocation due to the applied load, fiber breakage, matrix breakage, and interfacial bonding between the fiber and matrix is clearly observed. The magnification factor used for all specimen in the optical microscope is 400x. From Figure 10(c), the more fiber pullout is readily visible in the pictures, indicating poor fiber-matrix adhesion. These may result in a significant drop in composite strength. Similar observation was found in the



(a) (b)

(c)

Figure 10: (a–c) Optical microscope images for hybrid composite: (a) BG1, (b) BG2, and (c) BG3.

reduction of strength of epoxy with E-glass fiber reinforced composites [25].

4. Conclusion

In the present study, bone particulate and E-glass fiber reinforced with epoxy matrix composite were synthesized by using the hand lay-up technique. The sample specimens are prepared as per ASTM standards. The sample specimen is subjected to tensile, compressive, and flexural loading to get their property. In addition to this, the water/moisture absorption property also investigated. From the analysis of the result, the following conclusions are drawn:

The maximum tensile strength of 254.96 MPa is observed in the E-glass fiber with epoxy matrix having the composition of 40% E-glass fiber with 60% epoxy matrix.

The tensile strength of the hybrid composite tends to decrease because of poor interface interaction between the fibers (bone particulate and E-glass) and the epoxy. The maximum compressive strength was also obtained by the composition of 40% of E-glass fiber with 60% of epoxy. The maximum compressive strength observed by this composition is 37.52 MPa.

The maximum flexural strength is achieved by E-glass fiber with epoxy having a composition of 40% of E-glass with 60% of epoxy matrix. The maximum flexural strength observed by this composition is 250.52 MPa.

The minimum water absorption property is observed in E-glass fiber with epoxy composite. As the bone particulate content increases, the water absorption property of the composite also increases significantly.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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