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Research Article

Physical and Mechanical Characterization of Bamboo Fiber/Groundnut Shell/Copper Particle/MWCNT-Filled Epoxy Hybrid Polymer Nanocomposites

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Current research finds the suitability of natural fiber-reinforced polymer composites for industrial, automotive, marine, aerospace, and military vehicle applications, among others; they process being lightweight, high strength, ecofriendly, recyclable, and biodegradable. Bamboo fiber (Bambusoideae) mat, groundnut shell (Cocos nucifera) powder, copper particle, and multiwalled carbon nanotubes (MWCNT) fillers with epoxy resin are the primary materials. The key responsibility of MWCNT as a nanofiller is to improve the performance of materials by more than 80% and to attract the desirable properties such as high specific energy absorption of CNTs. An extensive investigation was carried out to determine the weight ratio between the total density and the water absorption rate of the composite. The maximal tensile and flexural strengths derived from EBGCM2 (E: epoxy; B: bamboo; G: groundnut shell; C: copper particle; M: MWCNT) were 50.66 MPa and 59.03 MPa, respectively. Addition of MWCNTs to specimens EBGCM2 and EBGCM3 and bonding the filler matrix by homogeneous mixing, but few nanoparticles are seen agglomerated. Flexural abilities of groundnut fiber/filler loading to strengthen the hybrid nanocomposites and the impact strength both quite improved than EB1 specimen. The neat epoxy and bamboo fiber composite (EB1) achieved 87.5 Shore-D hardness. SEM revealed (EBGCM3) improved interfacial adhesion between fiber and epoxy resin, but few nanoparticles are agglomerated, small molecules linked between the fibrous matrix, and the binding elements trapped in neighboring atoms, forming structural chains by the polymerization process.

1. Introduction

Natural fibers have a crucial role in polymer composite materials. Natural fiber-based composite materials that are ecofriendly [1], biodegradable [2], and green composite were chosen by the researchers [3]. For material characterization purposes, researchers utilized synthetic compounds to modify the properties of the materials [4]. Furthermore, the density fluctuation practically differs from natural fiber to chemical substance; thus, the bulk of the agents comprising the composite material are thermoplastic and thermosetting to make the material suitable for the application [5–7]. Researchers are developing biodegradable, ecofriendly, and synthetic polymers towards ecological sustainability. For this purpose, natural fibers and natural fillers are widely used [8–10].

Supian et al. [11] fabricated date palm fiber, and bamboo fiber composites were tested for their tensile, flexural, and impact strength. The maximum tensile modulus and elongation were attained on the date palm fiber-based composite. They observed that the swelling thickness and water absorption test of date palm fiber, bamboo composite obtained the highest values of 27.68%. The composite tensile strength increased as it interacted more with the chemical agent and had a larger cellulose content. The fiber and filler can bond very strongly and favorably to flexural characteristics depending on the amount of lignin and hemicellulose present. Perremans et al. [12] discussed how accessibility of the discontinued UD bamboo fiber resulted in a positive result with a unidirectional technical fiber length of 50 mm. Shah and Sultan [13] have prepared mineral-based natural fibers for thermal stability cases. They have created neat epoxy/E-glass fiber-bamboo fiber composite (EP/G-BFC, EP-BFC) hybrid and EP-BFC nonhybrid composites. The superior property of the material, principally EP/G-BFC exposed to a high temperature of the organic component in glass fiber and sustain maximal thermal stability, is a hybrid composite. Because EP-BFC is a nonorganic chemical, the decline in performance is attributable to poor fiber-matrix adhesion caused by thermal deterioration.

Salim [14] fabricated three various hybrid composites: bamboo/pineapple leaves, bamboo/pineapple leaves/coconut fiber, and neat polyester bamboo composite. The mechanical qualities of coconut fiber improved as a result of the developed materials, with 38% higher mechanical performance than the other two variations. The hybrid composites' surface morphology was compared to their appearance. The strong link between the composed material and the bamboo fiber selection in the polymer matrix gave optimum mechanical strength while also assuring that the material was biodegradable and ecofriendly. Alothman and Jawaid [15] extracted fiber/filler material from the date palm trunk tree, and the date palm fiber polymer composite was fabricated. They have concentrated on thermal expansion and viscoelastic qualities. The thermogravimetric analysis (TGA) method revealed little weight loss and maximum heat stability of palm trunk tree fiber for maximum reside sources by 22%. During the experiment, the DPF (date palm fibers) weight loss was lower than neat epoxy, and DPF/epoxy weight loss was lower than neat epoxy because it was dissolved in the initial process, causing additional constituents hemicellulose, cellulose, and lignin to be produced.

Sisal and unidirectional bamboo fiber-reinforced polyester composite was manufactured. Tensile and flexural strength were higher at 0° fiber orientation than at 90° orientation [16]. Sathish et al. [17] investigated the thermomechanical properties of the E-glass fiber epoxy composite. The equal proportionate fiber capacity of 20 : 20 provided remarkable mechanical and thermal qualities due to the close packing of the fibers and epoxy. However, the extraordinary performance of the flax fiber 40 : 0 combination may be linked to the exceptional quality of the separated material, which can withstand high temperatures and elongation (washing and ironing materials are textile applications). This study found that the combination 40 : 0 outperformed the other combinations (0 : 40, 10 : 30, 20 : 20, 30 : 10, and 40 : 0) in terms of tensile and flexural strength. Coffee bean natural filler-reinforced composite prepared by compression molding method. By the incorporation of coffee bean, microfiller (25%) improved overall mechanical performance, specifically fracture toughness due to the homogeneous distribution of coffee bean particulates in the matrix of epoxy polymer [18, 19]. Nor et al. [20] examined that implanted MWCNT in a bamboo/glass fiber hybrid composite showed good tensile and flexural characteristics in this study. MWCNT played (0.1, 0.3, 0.5, and 1.0%) a significant role and discovered that 0.5% MWCNTs recognized maximal mechanical behavior, which is 7.7% higher by weight than other CNTs. MWCNT 1% saturation level deviated greatly from the mechanical property (8.45% lower).

Prabhudass et al. [21] investigated the inclusion of MWCNT nanoparticle increased the composite's strength by more than 4% and improved interfacial adhesion between the particles. The maximum surface area per unit volume of MWCNT resulted in good particle interaction, which significantly improved the fiber-matrix composite. Alaneme et al. [22] discussed that the imported natural hybrid concept is to strengthen the material's properties. Pineapple leaf, groundnut shell, and coconut shell ash are used as filler materials in the matrix with the nonferrous material, resulting in a significant change in the physical and mechanical properties of the hybrid composites. The charging of rice husk, groundnut shell, and pineapple leaf ash has a higher percentage of elongation and flexural characteristics. Dhinakarraj et al. [23] fabricated banana fiber-reinforced epoxy composite that is added with rice bran particles as fillers towards developing biopolymer, and the machining conditions of this fabricated composite was discussed. Jawaid et al. [24] fabricated oil palm empty fruit bunches/jute fiber matrix polymer composite with a different sequence of fiber orientations were evaluated and compared the mechanical properties, specifically flexural and impact strength increased. Saba et al. [25] utilized hand lay-up method to make nanocomposites containing 0.5, 0.75, and 1% carbon nanofillers (CNFs) filler in epoxy resin. Chemical composition methods were linked to the mechanical properties of the produced CNFs.

Arjmandi et al. [26] developed the rice husk's constant fiber material and altered the synthetic agent to determine the innovative qualities of the materials. The material compositions and the addition of chemical agents determine the appropriate application. 6% and 10% NaOH-treated bamboo fiber composite with 48 hrs soaking duration achieved the highest tensile strength and flexural strength. It was found that more than 40% fraction volume exhibited the highest ranges of mechanical properties [27–29]. Mosisa and Batu [30] used sodium hydroxide concentrations of 5% and 8% to treat bamboo and sisal fibers, respectively, to remove lignin, cellulose, and other dirt particles and improve interfacial bonding between the fiber-matrix and composite performance. While the composite with a 15/20% volume fraction of sisal to bamboo fibers, fabricated with fiber ply orientation, and cured at 55°C, has higher hardness strength.

Material hybridization is categorized by the uniqueness of the constituents as found from the literature review. Mechanical, thermal, dielectric, morphological structure, viscoelastic, and hydrophilic/hydrophobic characters vary with varying quantities of material loading. This research article eventually focused the research gap on the fiber loading, filler ratios, and combination of the materials and extra

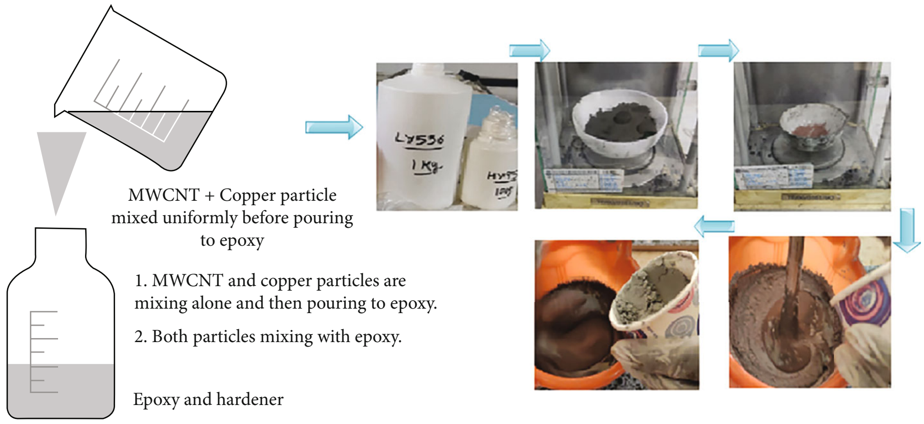

FIGURE 1: Micro- and nanoparticle mixing with epoxy resin.

TABLE 1: Material properties of reinforcements.

Materials	Density (g/cm^3)	Specific gravity (g/cm^3)	Elongation (%)	Cellulose (%)	Hemicellulose (%)	Lignin (%)
Bamboo fiber	0.8	0.85	11	46-57	20-25	20-30
Groundnut Shell	1.15	0.6	15-40	45	11	36
MWCNT	2.3	2.6	10.8	—	—	—

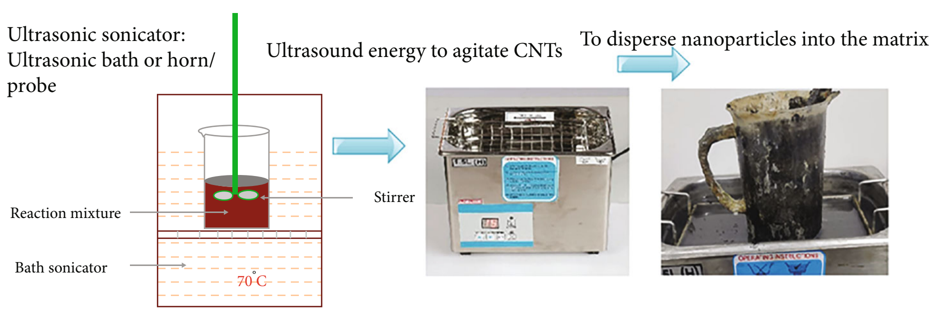

FIGURE 2: Sonication process.

nonferrous material partially filled with the composites to improve the mechanical and thermal characteristics, established with the methodology of the work. The novelty of this work is the incorporation of fine and ultrafine particles of different size fractions in a bamboo fiber matrix using a vacuum deposition technique. Selected compositions of composite materials meet thermomechanical, biodegradable, and environmental performance requirements.

2. Materials and Methods

Epoxy (LY556) and hardener (HY951), bamboo fiber material, copper particle, and MWCNT (Dia. ranges from 10 to 20 nm) fillers are purchased from Metro Composite, Chennai, India. Groundnut shell is collected from modern mill Kanchipuram, India, and segregated to have a particle size of 300 to 600 μm. The groundnut shell is dried in the sunlight for 8 hours before being crushed. 99% pure MWCNT is purchased from Ad-Nano Technologies. During addition of MWCNTs, epoxy (LY556) and hardener (HY951) react with Bisphenol A as epichlorohydrin and, subsequently, homopolymerize by interacting with nucleophilic and electrophilic via the hardener (Figure 1).

Table 1 provides the physical properties and composition of the considered materials for fabricating the hybrid polymer matrix composite.

The samples are fabricated as per the ASTM standard for different characterization techniques. Primary work removes stain and fine particles from the plate before applying wax. Once wax is spread over on the plate, it allows a few seconds for short curing, and small amount of epoxy and hardener is applied as coating and further bamboo fiber mat piling is placed over the viz., plate. Nabinejad, et al. [31] fillers are mixed with epoxy and hardener, groundnut shell/Cu microparticle and continuously stirred manual to obtain homogenous mixing, following which additional MWCNT fillers are added over the epoxy resin, and to avoid agglomeration, sonication process is adopted by ultra sonicator machine PCI analytics 1.5 L capacity (Figure 2). After sonication and liquefied agents are applied over the bamboo fiber mat ,allowed to cure for a few seconds, the second layer is piled over the applied epoxy resin and again pouring the epoxy resin; the final layer is piled over the mat, and the final

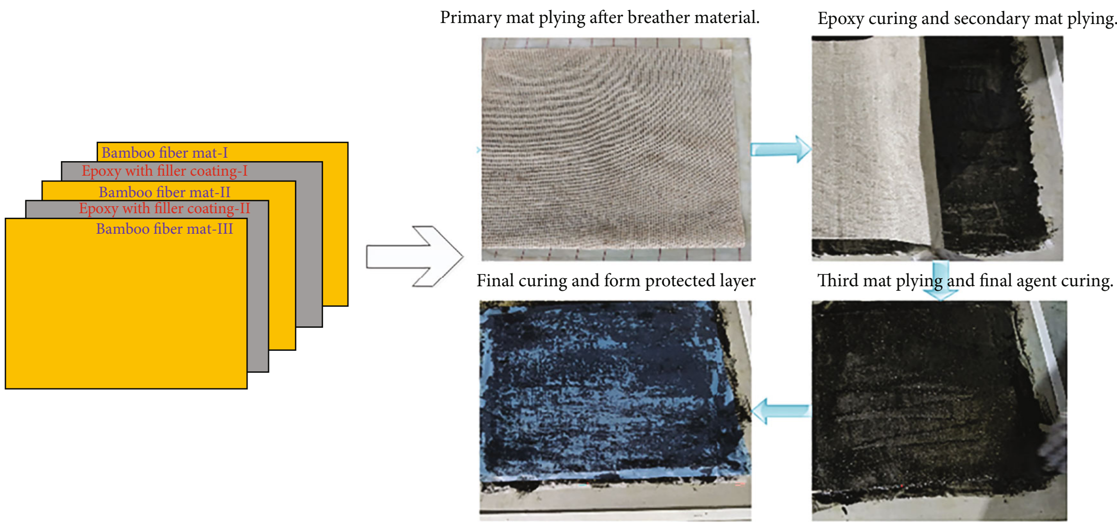

Figure 3: Fiber and filler-matrix assembly.

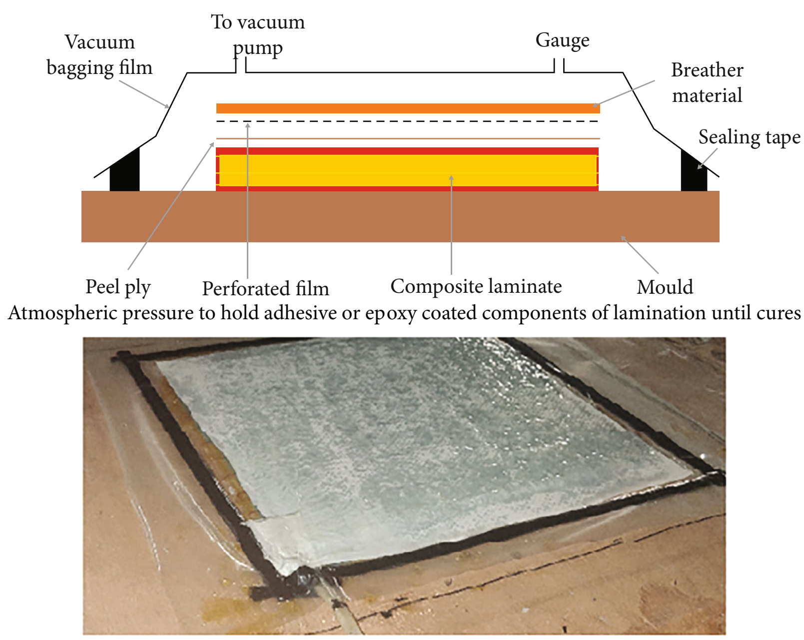

Figure 4: Vacuum lay-up process.

curing process is completed using the remaining synthetic agents (Figure 3) [32, 33]. Furthermore, particle/polymer and particle/particle interactions of micro- and nanoparticles were extensively investigated [34]. Finally, before bagging the specimen, rolling, trapping, and releasing the capillary were done to remove the voids and bubbles (Figure 4).

Three different concentrations are evaluated in this discussion forum. This section compared pure epoxy-bamboo fiber, 0.5% MWCNT, and 1% MWCNT-bamboo fiber composites. Ultimate focuses on incorporating three concentrations to improve mechanical properties and adding micro- and nanofillers to improve the thermal activity of the material. Table 2 presents the various composition of epoxy, bamboo fiber, coconut shell, copper particle, and MWCNTs.

3. Result and Discussions

After fabricating 3 specimens, they are tested to identify their physical properties. The water absorption properties are determined as per ASTM D570 standard. The water absorption can increase bamboo fiber/groundnut shell filler density and instantly altered the chemical compositions of the hybrid polymer composite. Typically, cellulose contents are rich in natural fiber and hydrophilic in nature, but the water absorption rate is slightly higher, because lignin content is higher in coconut fiber than in bamboo fiber. The hydroxyl group (-OH group) attracts water molecules and generates hydrogen bonding with them, enabling cellulose molecules which will draw the water molecules towards them. The rate of water absorption increases which depends

Table 2: Designation of the composite in %.

Composite designation	Epoxy (%)	Bamboo fiber (%)	Groundnut shell (%)	Cu particle (%)	MWCNT (%)
EB1	90	10	—	—	—
EBGCM2	84	10	5	0.5	0.5
EBGCM3	78.5	10	10	0.5	1.0

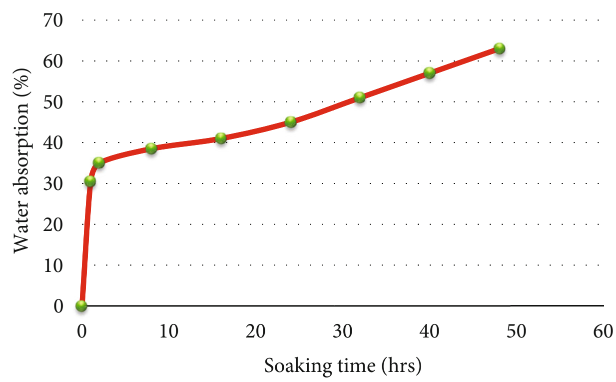

Figure 5: Water absorption in % vs. soaking time in hrs.

upon the absorption of the fiber/filler and the soaking rate (Figure 5).

The bulk density of the fabricated specimens is determined based on Equation (1), and the % of water absorption is determined based on Equation (2).

$$\text{Bulk density } (D) = \frac{\text{Weight of the sample}}{\text{Length of the sample} \times \text{Width of the sample} \times \text{Height of the sample}},$$

$$(D) = \frac{Wt}{L \times W \times H} = 1.309 \frac{\text{g}}{\text{cm}^3}, \quad (1)$$

$$\text{Water absorption in\%} = \frac{Wi - Wf}{Wf} \times 100, \quad (2)$$

where W_i is the initial weight and W_f is the final weight after water absorption. Figure 6 presents the comparison of water absorption qualities of fabricated polymer composites for different soaking time observation presents that, with higher soaking time, higher quantity of water is absorbed, due to the hydrophilic nature of the bamboo fiber-reinforced in epoxy matrix.

The bulk density of the bamboo and groundnut shell fiber-matrix composite increased with the increase in the fiber content in the samples [35]. The difference between the initial and final rates of absorption allows the immersion specimen to measure the water uptake. Figures 5 and 6 show that after one hour the fiber take up 36% of the water content then the water absorption quality progressively increases based on the soaking duration. Based on the rate of soaking, it revealed that the hydrogen bond occurs between the hydroxyl groups of the cellulosic chain. The fabricated specimens are also subjected to mechanical testing as per ASTM standards, and the observed values are recorded in Table 3.

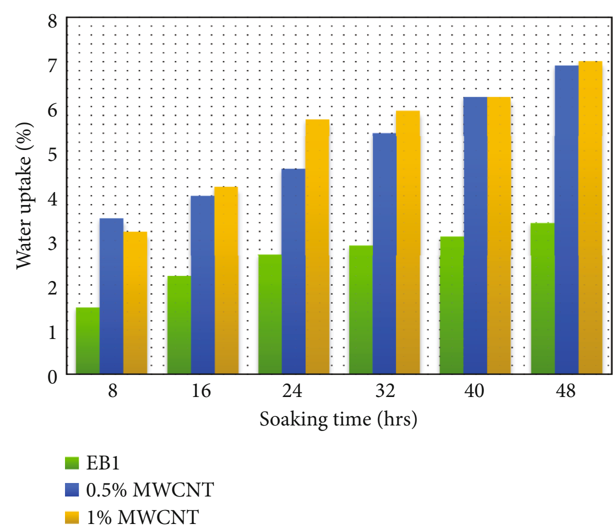

Figure 6: Water uptake in % vs. soaking time in hrs.

Tensile testing experiments are conducted by the universal testing machine (UTM) Dak System 7000 as per the ASTM E83. Tensile strength of the EBGCM2 polymer nanocomposite is 50.66 MPa. Figure 7 presents the tensile strength of all fabricated composite. When the tensile stress acting over the material, it can withstand the maximum yielding stress initially, but once it started to fracture, it will propagate rapidly and the fractured area generates more epoxy crystals [36]. Once the instant load is applied on the materials, it should be ready for elongation, but the EB1 specimen contains the majority of epoxy resin; as the adjoining material gets fractured, then, it will lose the crystal packing and then propagate towards the entire crack zone instantly. From Figure 7, it is observed that EBGCM3 played

Table 3: Mechanical properties of composites.

Composite designation	Tensile strength (MPa)	Flexural strength (MPa)	Impact strength (J)	Hardness (Shore-D)
EB1	26.09	53.45	33.5	87.5
EBGCM2	50.66	59.03	65.7	81
EBGCM3	41.58	47.68	73.5	76

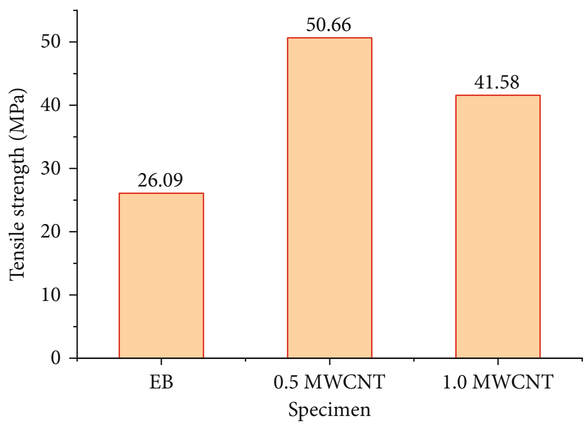

Figure 7: Tensile strength of the composite with and without MWCNT.

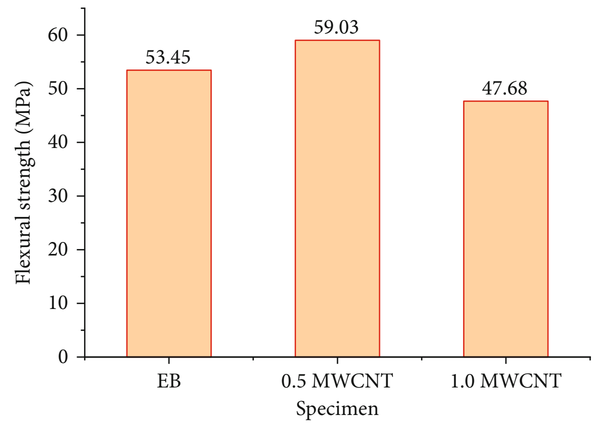

Figure 8: Flexural strength of the composite with and without MWCNT.

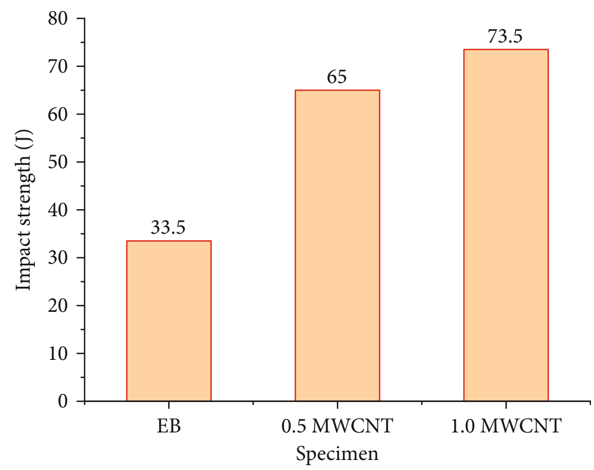

Figure 9: Impact strength of the composite with and without MWCNT.

an important role as the MWCNT/Cu particle weight % increases, and the values slightly decrease with further increase of the fillers. When the MWCNTs are loaded more than the optimal level significantly, the tensile strength recorded is 41.58 MPa which is lower, but the values are slightly higher than EB1 specimen. The maximum loading of fine filler particles faced poor agglomeration, stacking between the particles, poor dispersion, and adhesion between the fiber-matrix. Promisingly, uncertainty particle dispersion and stacking fiber are more at the failure zone due to poor agglomeration (EBGCM3). The tensile strength is abruptly changed by the incorporation of MWCNT; the addition of copper particles present in certain areas results in the maximum yield point never being reached when applying a load against tension.

Three-point bending test methods are utilized for the performance to acquire the flexural properties of the composite as per ASTM E83. Researchers compared bamboo fiber epoxy composite prepared from treated and untreated bamboo. Untreated bamboo fiber composite had reached its maximum flexural strength [37, 38]. It is illustrated that the bamboo fiber mat and optimal proportionate filler specimen reach the expected flexural strength. Figure 8 indicated that the EBGCM2 hybrid composite material demonstrated an increment of flexural strength by 23% higher than the EBGCM3. Therefore, bamboo EBGCM3 fiber mat takes uniform loading along with optimal Cu particle/MWCNT fillers that contribute towards excellent flexural properties of the hybrid nanocomposites. Neat epoxy with bamboo fiber mat also achieves better flexural properties (53.45 MPa). Natural fiber-treated hybrid composite attributed maximum interfacial adhesion between them, which contributed to attractive flexural strength [39]. Furthermore, bamboo fiber/groundnut shell filler additional MWCNT/Cu particle inclusion influences the interfacial adhesion between the particle and fiber added epoxy matrix.

Impact strength of the fabricated specimens is determined as per ASTM D256. Figure 9 reports the impact strength of all the fabricated composite. The maximum impact strength absorbed is 73.5 J for EBGCM3. The significance of the filler particle stacking is more in EBGCM3. Micro- and nanoparticles are homogeneously combined with good adhesion between the matrixes that can enhance prominent mechanical properties, preferably impact strength. But sonication process is helpful to changing phases by good interfacial interaction between the MWCNTs and the matrix, at the same time, stacking of filler particles reduces the EB1 and EBGCM2 properties impact strength gradually slanted down to 65 MPa and 33.5 MPa, respectively.

The hardness value was measured by using Shore Durometer (Shore-D) as per ASTM D2240. For testing, five locations are preferred for each specimen. Figure 10 shows hardness variation, progressively increasing in reciprocal

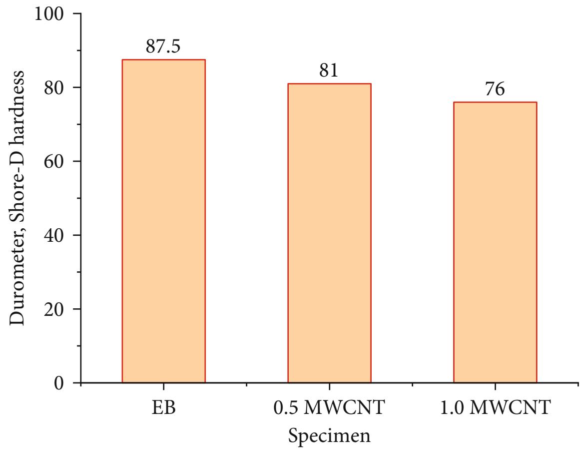

FIGURE 10: Hardness Shore-D of the composite with and without MWCNT.

FIGURE 11: SEM image of the tensile-fractured surface for EBGCM2.

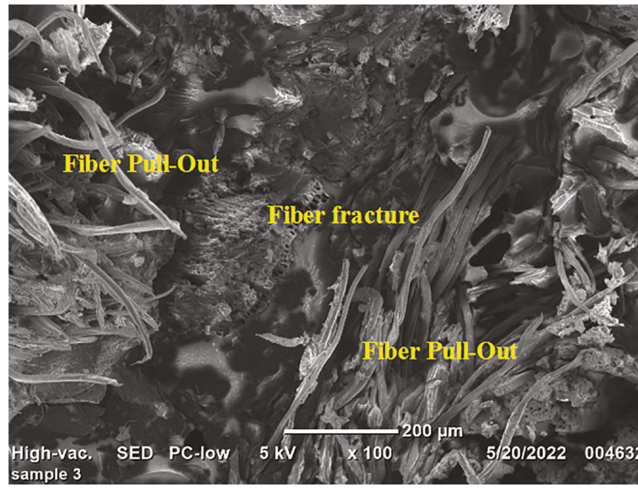

FIGURE 12: SEM image of the flexural-fractured surface for EB1.

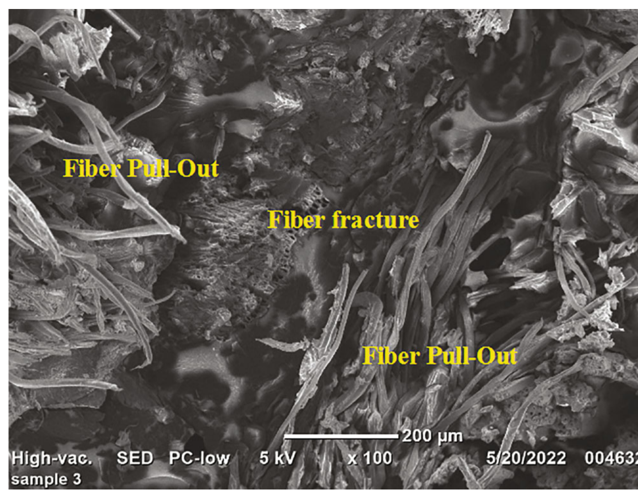

FIGURE 13: SEM image of the impact-fractured surface for EBGCM3.

order of the hardness value compared to other properties, maximum hardness reached for EB (specimen 1) 87.5 Shore-D hardness. But other two specimens, EBGCM2 and EBGCM3, hardness declined gradually from 81 to 76, respectively. The main reason towards higher hardness is the composite must possess more matrix content in the specimen, and filler material also supports fully for withstanding maximum hardness and fiber content trying to yield the specimen. For this criterion, specimen 1 reached higher Shore-D hardness than the other two specimens, EBGCM2 and EBGCM3. But for the specimen consideration, all the mechanical characters met EBGCM2, and it is the observed 81 Shore-D hardness nearer to the EB1.

The surface and fractured morphology structure is investigated by SEM images tensile, for the flexural and impact tested specimens. Low-magnification images of each of the compositions have been used to identify the fiber ordering and filler distribution in the epoxy composite. Figure 11 indicated that the fiber and filler debonding region and cavities over the surface area are due to the agglomeration of the matrix (EBGCM2). Fiber pull-outs are observed in tensile fractography because of weak interfacial adhesion between the fiber matrixes. When a load is applied to EB1, it demonstrates that the fiber mat's maximum yielding has been stretched, which is known as fiber pull-out. However, some fibers are fractured as a result of the inclusion of microparticles stacked at a specific zone (Figure 12). Mechanical properties of EBGCM3 (Figure 13) have a significant influence on various factors, including fiber stretches, extension, fracture, fiber-matrix adhesion, fiber piling, voids, and porosity as measured by the SEM morphology [40]. The filled MWCNT composite (EBGCM2) showed lower agglomeration and uniform distribution throughout the matrix due to the improved mechanical properties of the hybrid composite.

4. Conclusion

In this research, characterization of epoxy, bamboo fiber, rice husk, copper polymer composite with and without the addition of MWCNTs is carried out. The outcomes of the research are the following:

(i) Water absorption tests are carried out for up to 48 hours, depending on the degree of soaking of fiber; water uptake % increases after one hour of immersion (36%) for EBGCM2

(ii) The addition of MWCNT plays a vital role in improving mechanical properties, particularly 0.5% MWCNT, which contributed the overall improvement in mechanical properties such as tensile and flexural properties of 50.66 MPa and 59.03 MPa, respectively. EBGCM3 containing 1% MWCNT achieved a significantly higher impact strength of 73.5 J than the other two combinations. The Shore-D hardness of neat epoxy with bamboo fiber composite (without MWCNT) alone is 87.5. But with MWCNT the hardness tends to lower, since these proportions of the filler matrix are larger, composite (hardness) failure occurs earlier over EB1 and EBGCM2

(iii) The hybrid composite's surface and fractured morphology for EBGCM2 have fewer voids that appear between the particles as a result of better bonding between the fillers and matrix. 0.5% MWCNT demonstrated attractive mechanical performance due to the absence of agglomeration between the fiber/filler and matrix

(iv) The addition of the copper particle is to improve thermal performance as well as misaligned atoms to integrate with the Cu microparticle to continue the adhesion between tiny particles to get a streaming line of continuous heat conduction through the polymer matrix

Data Availability

The data used to support the findings of this study are included within the article. Should further data or information be required, these are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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