University of Baghdad
College of Engineering
JE
JOURNAL OF ENGINEERING

Journal of Engineering

journal homepage: www.jcoeng.edu.iq

Volume 31 Number 2 February 2025

An Experimental Study of the Properties of Bamboo Particle Reinforced Epoxy Matrix Biocomposites

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ABSTRACT

Production of biodegradable polymer matrix biocomposites that are cost effective, sustainable, and environmentally friendly with desirable properties using particles as discontinuous phase (filler) is a welcome development. In this study, bamboo particle reinforced epoxy resin matrix biocomposites were developed by stir casting method. Varied weight percentages (5 to 30 wt. %) of 100 µm bamboo particles were added separately and blended with an epoxy resin – hardener matrix. The blends were fed into a fabricated wooden mould and allowed to cure at room temperature. After 24 hrs, the specimens were removed from the mould and subjected to microstructural examination using a Scanning Electron Microscope (SEM). Furthermore, the physical and mechanical properties characterisation of the specimens were also carried out. The results obtained from the experiments showed the presence of pores in the microstructure of the specimens and the distribution of reinforcing particles in the epoxy matrix. The reinforced composites (S2 to S6) demonstrated an appreciable increase in density when compared with the unreinforced control specimen (C1). Specimens (S2 to S6) demonstrated lower water absorption than C1. The composites demonstrated increased ultimate tensile strength with filler addition up to 25 wt. %. Similarly, the reinforced specimens demonstrated improved hardness as the weight percent (wt. %) of bamboo particles increased up to 25 wt. %. However, the composites demonstrated a reduction in impact energy as filler content increased when compared with the control specimen. Specimen S5 formulation, which contained 25 wt. % of reinforcing particles demonstrated the best properties in terms of density, water absorption, hardness, and ultimate tensile strength. These findings highlight the effectiveness of bamboo particles in enhancing the physical and mechanical properties of the developed ecofriendly biocomposites.

Keywords: Biocomposite**,** Bamboo particle, Epoxy resin, Stir casting, Properties.

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Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2025.02.01

Article received: 08/12/2024
Article revised: 13/01/2025
Article accepted: 20/01/2025
Article published: 01/02/2025

1. INTRODUCTION

Attention has been focused on the development and application of biocomposites because of the issue concerning the availability of synthetic fibers as they are obtained from fossil fuels **(Pizzol et al., 2014)**. Furthermore, the increasing call for a cleaner environment has propelled and generated widespread research on environmentally friendly materials with interest in the use of plant (cellulose) fibers obtained from renewable sources for the production of biocomposites **(Mustapha et al., 2021)**. This is because, coupled with their environmental benefits, natural fibers possess some advantages over synthetic fibers, which include wide accessibility at comparatively low cost, low density with desirable mechanical and other physical characteristics **(Satyanarayana et al., 2009)**. In addition, the need for sustainable and energy efficient materials for application in many fields has led to focusing attention on locally available renewable materials for producing degradable biocomposites **(Josep et al., 2016)**.

In general, composites consist of one or more discontinuous phase (reinforcement) that is placed in a continuous phase (matrix). The discontinuous phase is stronger and harder than the continuous phase. The characteristics of constituent materials influence the characteristics of composites and the characteristics of composites are approximated as the sum of weight fraction or volume of the properties of the constituent materials **(Devadiga et al., 2020)**. Researchers **(Khanam et al., 2011; Roslan et al., 2015; Josep et al., 2016; Devadiga et al., 2020; Ferede, 2020; Abedom et al., 2021; Mustapha et al., 2021)** have produced ecofriendly biocomposites with desirable characteristics using agricultural produce such as bamboo, sugarcane bagasse, wheat, paddy, sisal, hemp, coir, flax, jute, wood, banana, pineapple, etc. Such natural fibrous sources have served as fillers in forms like woven mats, chopped fibers, and powder/particles for producing polymer biocomposites. Natural fibers are from plants, which contain lignocellulosic substances and are environmentally friendly and desirable because of their availability, renewability, biodegradability, and strength **(Abedom et al., 2021)**. Natural fiber-reinforced composites are considered possible alternatives to inorganic synthetic fiber-reinforced composites because they have been reported to demonstrate enhanced physical and mechanical properties suitable for application in many areas **(Mustapha et al., 2021)**. Among the various natural fibrous sources, bamboo has proven to be a very effective or classical reinforcement. The production of bamboo started many years ago and it is rich in traditional elements. It is easily accessible worldwide with varieties of benefits. It is often used for producing paper sheet and for mitigating erosion. Because it is easy to process with other advantages such as high strength demonstration, eco friendliness with rapid growing cycle and its renewability, bamboo is a choice material **(Abedom et al., 2021)**.

Compared to glass fiber that is synthetic, bamboo fiber-reinforced composites are biodegradable and not harmful to the environment **(Abedom et al., 2021)**. Solid wood made from bamboo have been reported to be the largest source of natural fiber and cellulose fiber biocomposites, which are inexpensive and will bring a new development into production chain and manufacturing world **(Scurlock et al., 2000; Khanam et al., 2011)**. Bamboo demonstrates a very good elasticity and high strength, which make it a suitable material for construction purposes **(Abedom et al., 2021)**. When compared with other natural fibers, bamboo has a high growth rate and carbon dioxide (CO_2) atmosphere-fixing characteristics, which make it a very important plant fiber **(Abedom et al., 2021)**. It has been reported that over 1000 types of bamboo exist and about 70 groups naturally grow abundantly in various environments, especially in Asia and South America. In addition, bamboo demonstrates high strength, stiffness, lightweight, and biodegradability, keeps together the soil and protects it through the reflection of sunlight by its leaves and roots **(Abedom et al., 2021)**.

Studies on bamboo-based polymer composites have been conducted and the results showed enhanced mechanical properties **(Okubo et al., 2004; Hui et al., 2008; Kumar, 2014; Banga et al., 2015; Roslan et al., 2015; Khan et al., 2017; Sergio et al., 2017; Verma et al., 2017; Zhang et al., 2018; Huang et al., 2019; Osorio et al., 2019; Wenwen et al., 2019; Li et al., 2020; Rao et al., 2020; Mohammed et al., 2024).** The importance of using bamboo in composite production cannot be overemphasized. Hence, producing biodegradable polymer matrix composites that are cost-effective, sustainable and environmentally friendly with desirable properties using bamboo particles as a discontinuous phase is a welcome development.

Therefore, the aim of this study is to develop bamboo micro-particle reinforced epoxy matrix biocomposites and evaluate their physical and mechanical properties.

2. MATERIALS AND METHOD

2.1 Materials, Apparatus, and Production of Specimens

The epoxy resin and hardener used in this study were procured from a vendor in Lagos while the bamboo stems were obtained from a sawmill. The outer layers of the strip of the bamboo stems were peeled off using a sharp knife. They were split at the nodes and divided into sections along the fiber length and the culms were removed in order to aid softening of the strips. The strips were soaked in water for a week to soften them and aid in removing lignin and hemicellulose. The fibers were removed using a sharp knife and dried at room temperature (25 °C), 80 °C and 110 °C. They were ground into particulate form and sieved to 100 µm using British standardised sieves. A wooden mould, beakers, stirrers and an electronic digital weighing balance (model No. UW1020H, Shimadzu, Japan) with a sensitivity of ± 1 mg were used during the stir casting production of the polymer matrix composites. The mould was laminated with paper tape for easy removal of the specimens after solidification. Using the electronic weighing machine, measured quantities of the bamboo particles (5-30 wt. %) were added separately and blended with the epoxy–hardener matrix as presented in **Table 1**.

Table 1. Materials formulation in weight percent (wt. %)

Specimen	Bamboo particles	Epoxy resin	Hardener	Total
Control (C1)	0	80	20	100
S1	5	75	20	100
S2	10	70	20	100
S3	15	65	20	100
S4	20	60	20	100
S5	25	55	20	100
S6	30	50	20	100

For each of the formulation of the specimens, the materials were thoroughly mixed manually with a stirrer to obtain a good blend with a good distribution of the reinforcing particles in the epoxy matrix. The blends were poured into the wooden mould as shown in **Fig. 1**. Five production runs were carried out for the varied composition of the specimens, which were cured at room temperature for about 24 hrs. The production flow chart is shown in **Fig. 2**. Seven specimens were used for each of the physical and mechanical tests while four specimens were selected for the microstructural test.

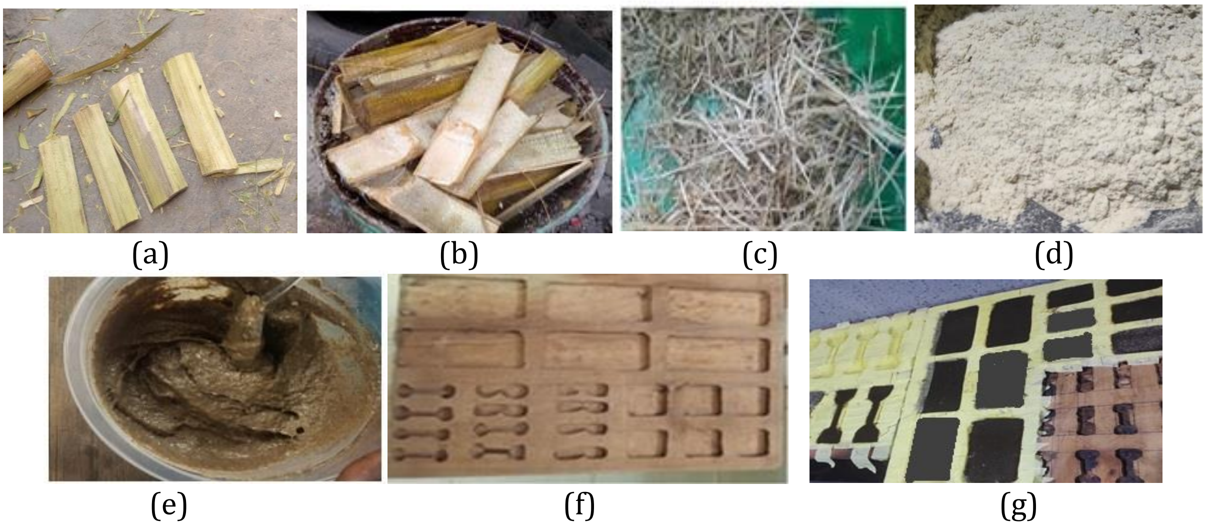


Figure 1. (a) Split bamboo stems (b) Water retting of bamboo stems (c) Dried bamboo fibers (d) Ground and sieved 100-µm bamboo particles (e) blended materials (f)Wooden mould (g) Blended materials in the mould before curing.

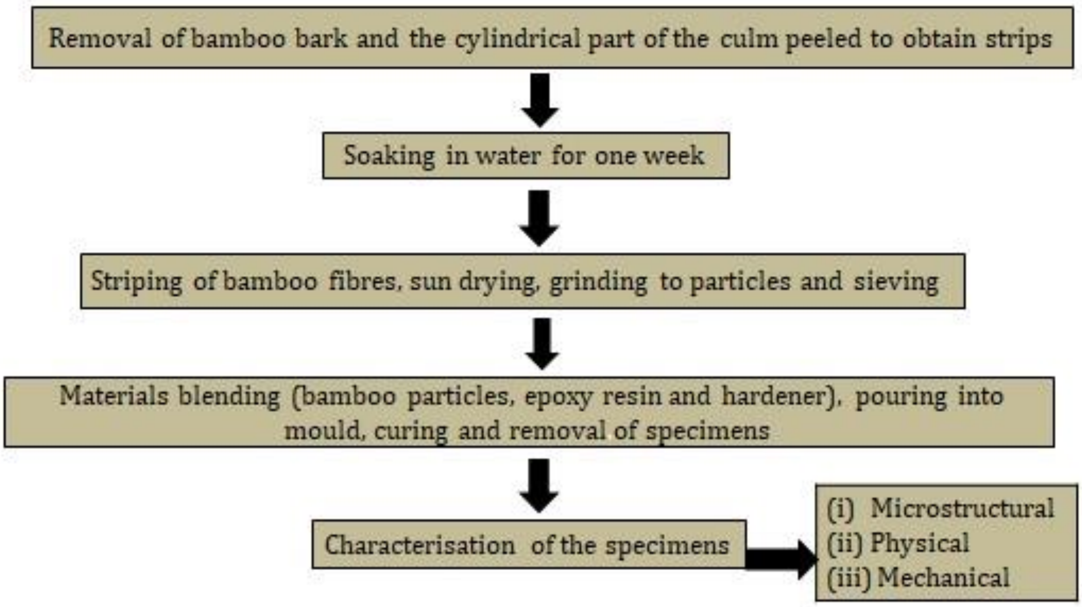


Figure 2. Production flow chart of the specimens.

2.2 Microscopy, Physical, and Mechanical Testing of Specimens

Surface cleaning was done on the specimens after which a microstructural examination was conducted on four of the specimens of 20 mm square-shaped dimension using ASPEX 3020 variable pressure Scanning Electron Microscope (SEM) with Energy Dispersive X-ray (EDX) facility as shown in **Fig. 3.** The density of the specimens was determined using the Archimedes' principle. The mass of the specimens in the air was measured. Thereafter, they were separately immersed in water contained in beakers and the volume of water displaced was measured. The density of each specimen was determined by applying Eq. (1) **(Aigbodion et al., 2010; Olabisi et al., 2016)**.

$$Density\ (\rho) = \frac{M}{V} \quad (1)$$

Where M = mass of specimen in gram (g) and V = volume of water displaced in cm^3

The water absorption test was carried out by immersing the specimens in water contained in beakers for 24 hrs after which they were removed in accordance with **(ASTM D570-98, 2018)** standard. The water absorption was determined using Eq. (2) **(Islam et al., 2013; Mat-Shayuti et al., 2013)**.

$$Water\ absorption\ (W_A) = \frac{W_{1-W_0}}{W_0}\ x\ 100 \quad (2)$$

where W_A = water absorption in %, W_0 = specimen's weight before immersion, and W_1 = specimen's weight after immersion

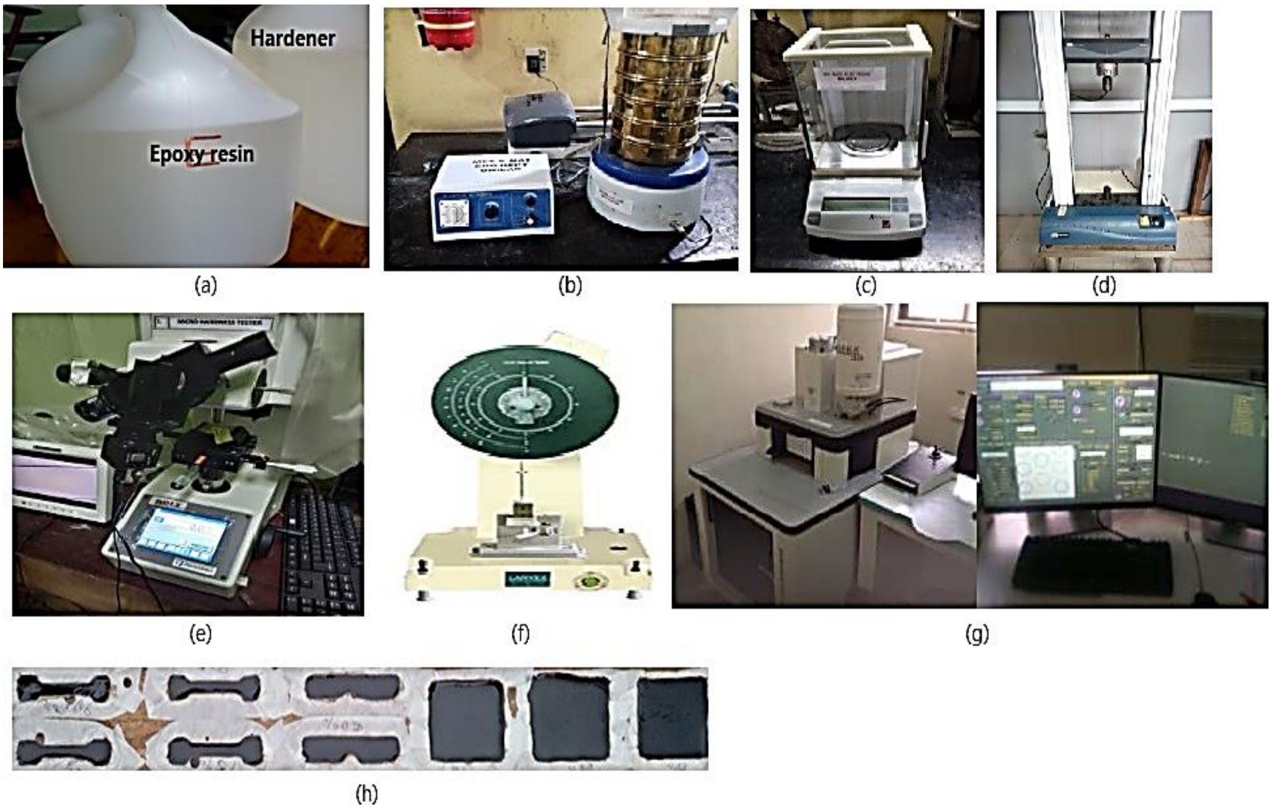


Figure 3. (a) Epoxy resin and hardener (b) sieves with vibrator (c) electronic weighing machine (d) Instron tester (e) Vickers micro hardness tester (f) Izod impact tester (g) ASPEX 3020 variable pressure Scanning Electron Microscope (SEM) with Energy Dispersive X-ray (EDX) facility (h) some of the specimens.

The tensile test was conducted on the test specimens of size 160 x 12.5 x 45 mm with a reduced section of 12.5 mm adhering to standard **(ASTM D638, 2014)** using a digital XLC universal tester. Each of the specimens was placed in the center of the tester and load was applied until fracture occurred. Microhardness test was conducted on the specimens of size 40 x 40 x 10 mm adhering to standard **(ASTM E384-17, 2022)** using a Vickers hardness tester with a test load of 1.91N. Impact testing was conducted on the test specimens of size 60 x 12.5 x 4 mm that have a 8 mm deep V-notch at the center using an Izod impact-tester adhering to standard **(ASTM D256-10, 2018)**. The striking pendulum was released from a height of 1.4 m at a speed of 4 m/s hitting the specimens to fracture. Additional photographs of some of the materials and equipment used for this study with some of the specimens are shown in **Fig. 3**.

3. RESULTS AND DISCUSSION

3.1 Microstructure of the Specimens

The microstructures of the specimens reveal the presence of pores as shown by scanning electron micrographs (SEM) of **Figs. 4** to **7**. The pores reduce with increasing amount of bamboo particles in the epoxy matrix as shown in **Figs. 5** to **7** compared to the control specimen C1. The microstructure of the composites shows that the phases are not homogeneous as bamboo particles are well dispersed in the epoxy matrix as shown in **Figs. 5** to **7.** The Energy Dispersive X-ray (EDX) spectra confirm the presence of the revealed phases with elemental constituents (O, C, K, and Mg) and some indistinguishable phases in traces or minute amount in the specimens. That is, oxygen (O), carbon (C), potassium (K) and magnesium (Mg). It has been established in literatures that when particles are uniformly/well distributed in the matrix of composites, their mechanical properties are enhanced **(Kaewpirom and Worrarat, 2014; Balaji et al., 2019)** coupled with strong interfacial bond between the particles and the epoxy matrix.

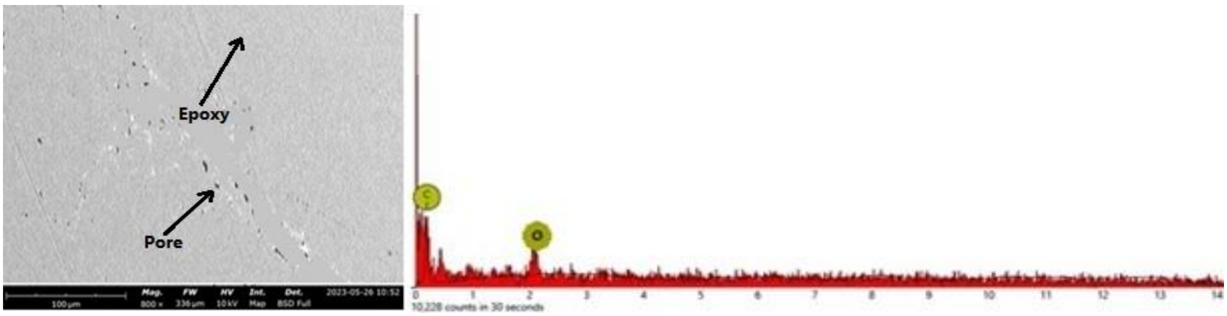


Figure 4. SEM and EDX spectrum of the control (unreinforced) specimen C1.

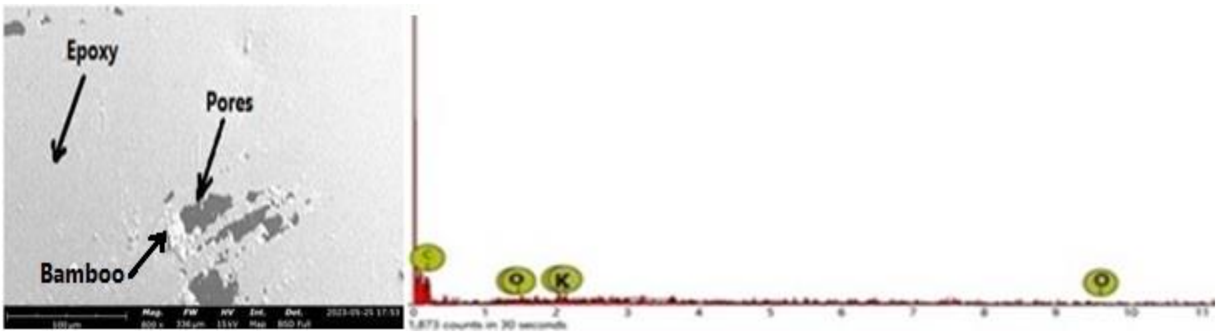


Figure 5. SEM and EDX spectrum of specimen S1.

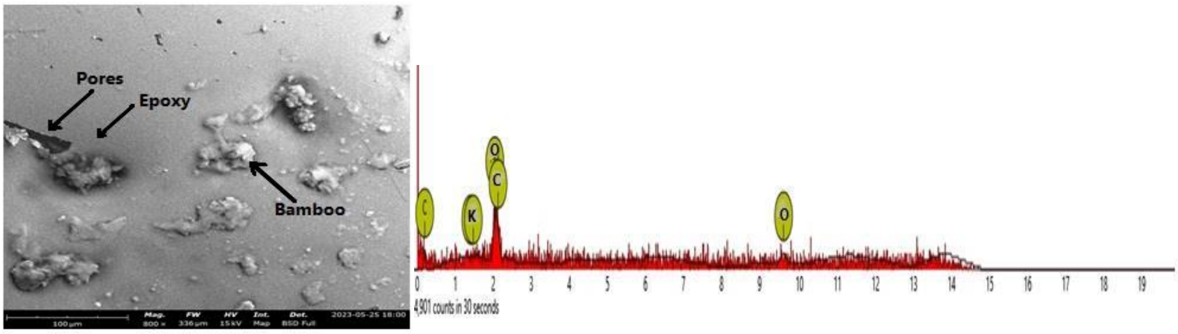


Figure 6. SEM and EDX spectrum of specimen S2.

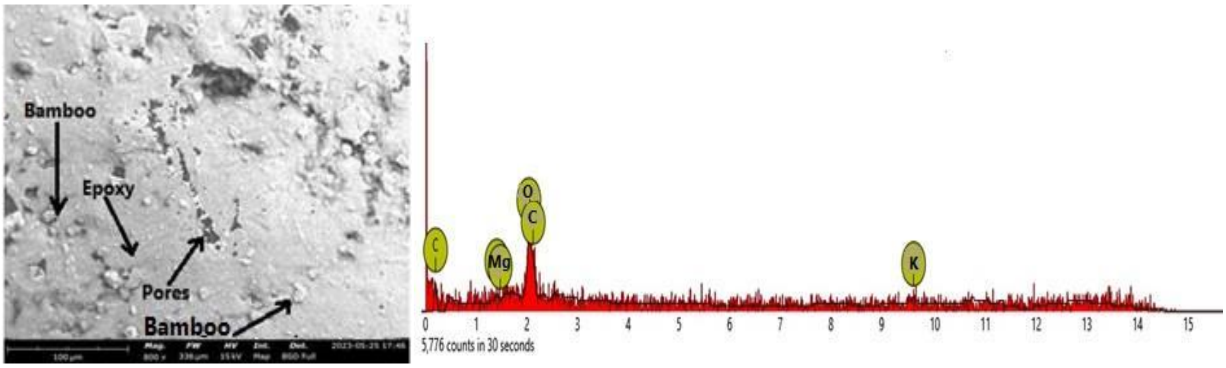


Figure 7. SEM and EDX spectrum of specimen S6.

3.2 Density

As shown in **Fig. 8**, there is an appreciable rise in the density of the composites when compared with the unreinforced control specimen C1. The density of the control specimen C1 is 1.13 g/cm^3 while specimens S4, S5 and S6 have the highest density of 1.3 g/cm^3. The increase in density must have been due to the addition of increasing weight percent of bamboo particles.

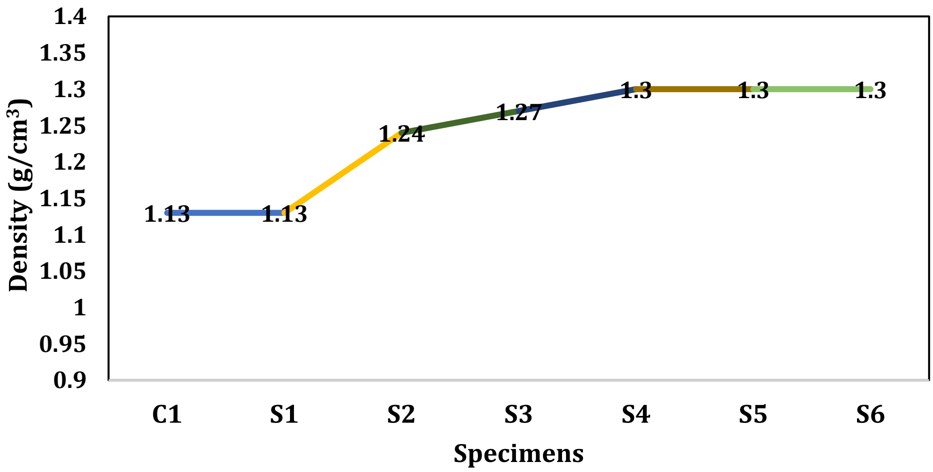


Figure 8. Density of the specimens.

3.3 Water Absorption

The control specimen C1 demonstrated water absorption of 0.25 % while composites S5 and S6 demonstrated the lowest water absorption of 0.18 %. Generally, the composites demonstrated lower water absorption than C1 as shown in **Fig. 9**. Pores exist in the specimens as shown in the microstructure, which aided the penetration of water into them. Bamboo particles contain hemicellulose, which is hydrophilic. The hydrophilic hydroxyl (-OH) group caused water to be absorbed and diffusion of water can lead to structural change, flexibility increase, and break-up, which can negatively affect their mechanical characteristics **(Pantyukhov et al., 2016)**. This can increase the space of the polymer molecules with decreased bonds and lower their resistance to applied stress **(Mat-Shayuti et al., 2013)**. However, a strong bond between the particles and the epoxy matrix caused a decrease in pores formation, which reduced water absorption **(Balaji et al., 2019; Ferede, 2020; Durowaye et al., 2022)**.

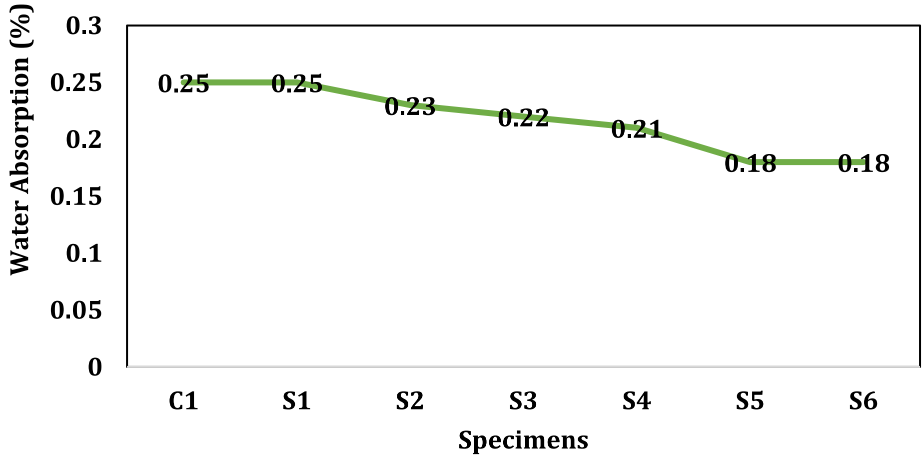


Figure 9. Water Absorption of the specimens.

3.4 Ultimate Tensile Strength

The control specimen demonstrated the lowest tensile strength of 12.43 MPa. Specimen S5 containing 25 wt. % of bamboo particles demonstrated the highest ultimate tensile strength (UTS) of 29.02 MPa, which is 133.5 % higher than that of C1 as presented in **Fig. 10**.

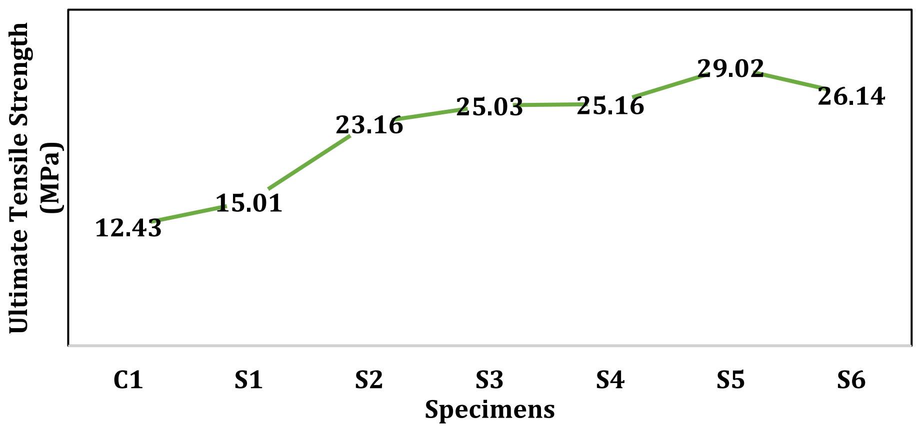
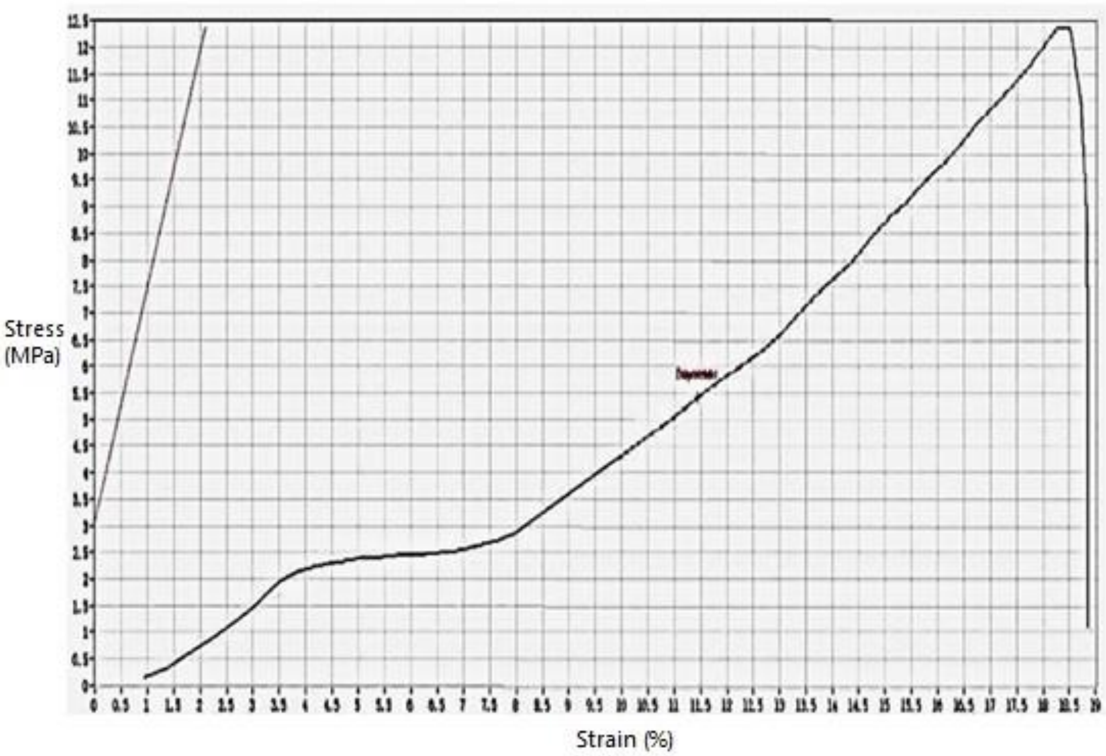
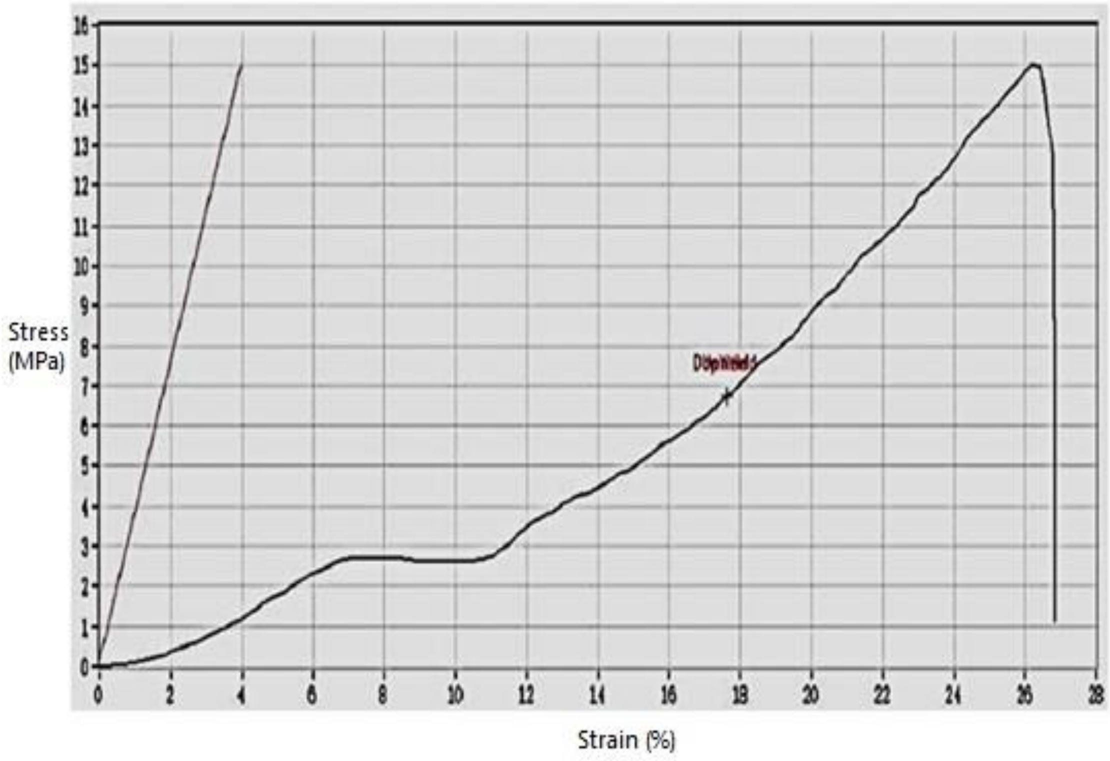


Figure 10. Ultimate tensile strength of the specimens

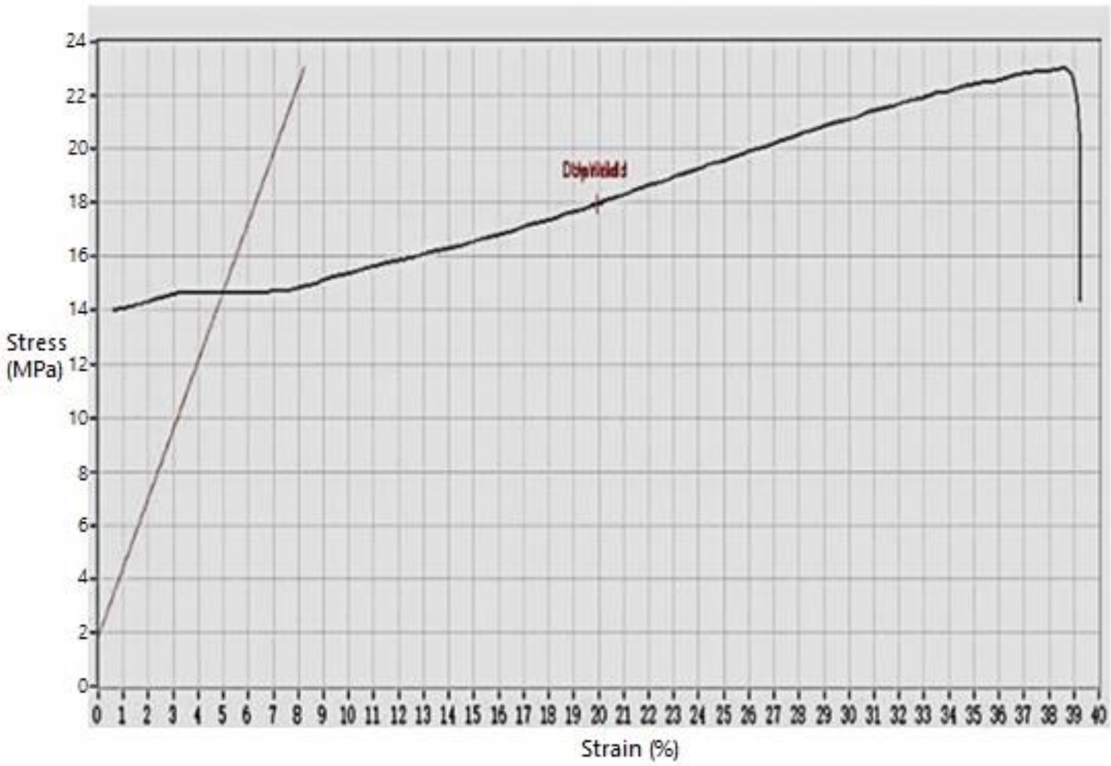
Generally, the composites demonstrated increased UTS with filler addition up to 25 wt. %. Improvement in UTS may be because of the strong interfacial bonding of bagasse particles with epoxy matrix **(Kaewpirom and Worrarat, 2014; Balaji et al., 2019; Durowaye et al., 2022)**. However, there is a decrease in the UTS when filler addition is beyond 25 wt. %. The decrease may be due to voids or defects that were formed during the processing of the composite, which was very difficult to avoid or control at higher wt. % reinforcement **(Mustapha et al., 2021)**. In addition, the decrease in UTS may be due to particle clustering/agglomeration in the matrix as particles increased beyond 25 wt. % **(Cerqueira et al., 2011; Mustapha et al., 2021)** and weak/inadequate interface bonding between the particles and matrix **(Mohammed et al., 2024)**. Generally, the reinforced specimens exhibited improved tensile strength compared to the control specimen. The stress-strain relationship of the specimens is shown in **Fig. 11**. The tensile modulus is an indication of the relative stiffness of the specimens and can be obtained from the stress-strain graphs. It is shown in **Fig. 11** that within its elastic range, the strain produced in each of the specimens is proportional to the stress applied. However, there is the deformation of the specimens as they demonstrated a low elastic range with final breaking. The specimens as shown in **Fig. 11** demonstrated the three typical types of stress-strain behaviour that are found in polymeric materials. They demonstrated curves for brittle, plastic and elastic polymers. They demonstrated stress-strain character for a brittle polymer, since they fractured while deforming elastically. The specimens also demonstrated behaviour for a plastic material with initial deformation that is elastic, which is followed by yielding, a region of plastic deformation and breaking.



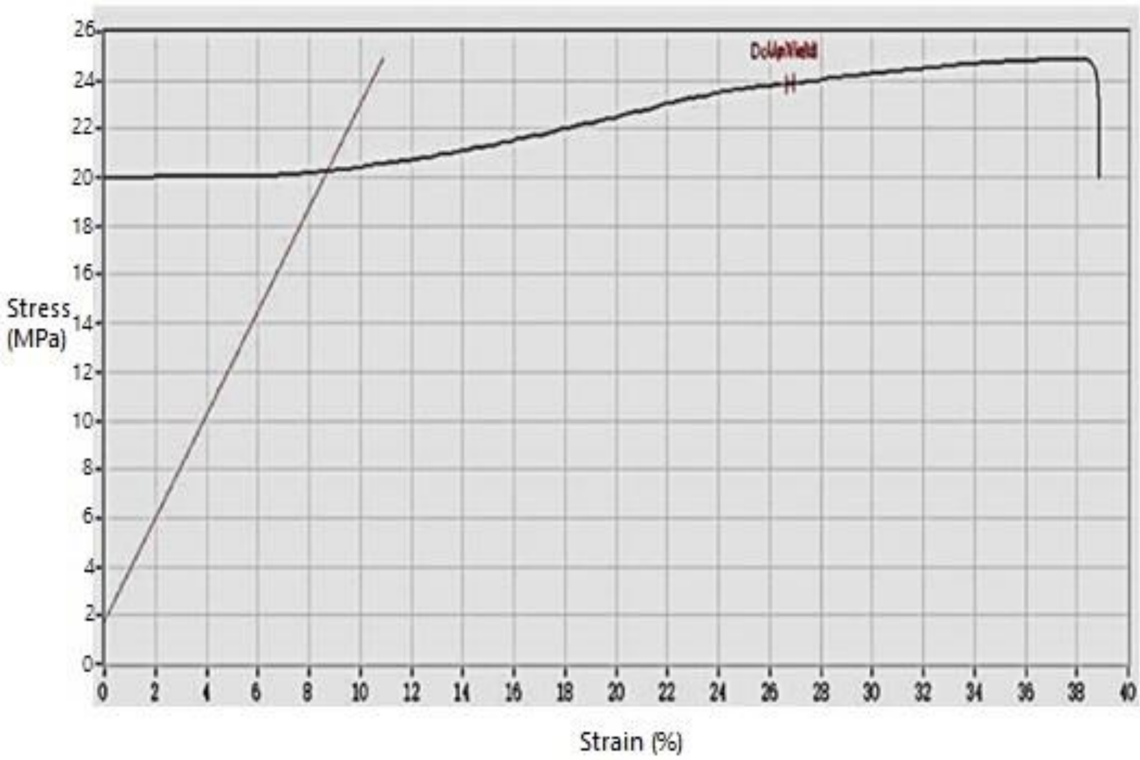
(a)



(b)



(c)


DoUpYield
Stress (MPa)
Strain (%)
0
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6
8
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30
32
34
36
38
40

(d)


DoUpYield
Stress (MPa)
Strain (%)
0
2
4
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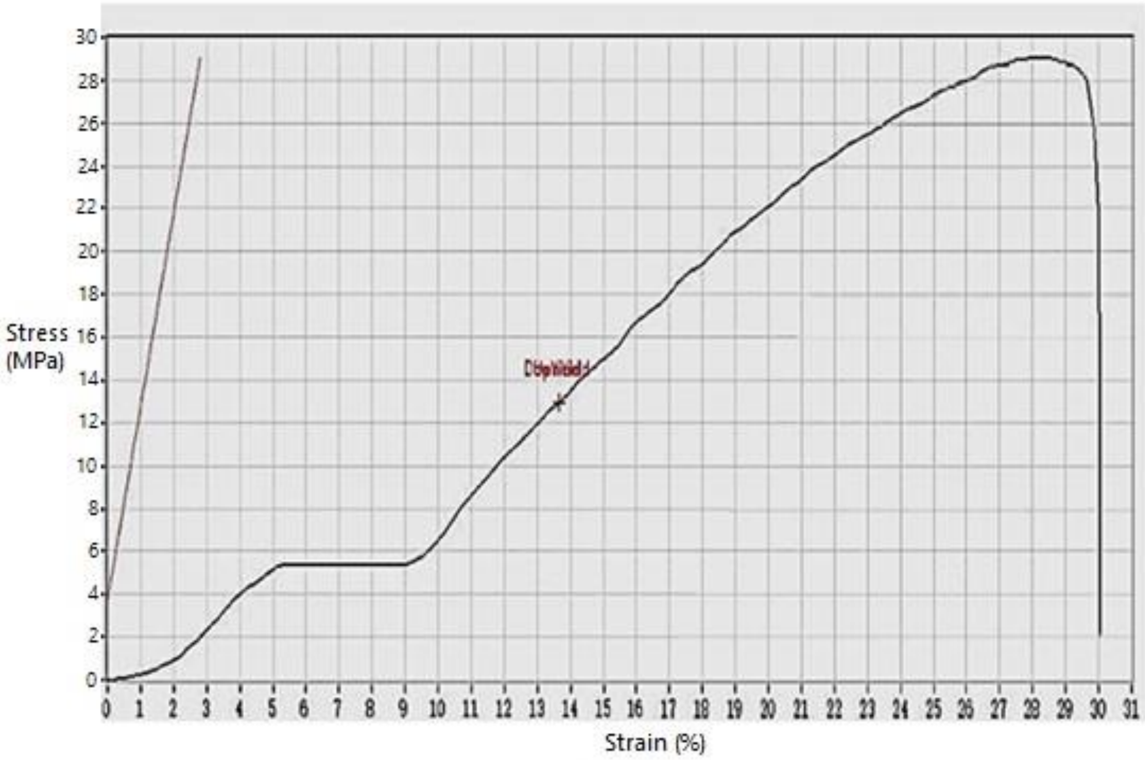
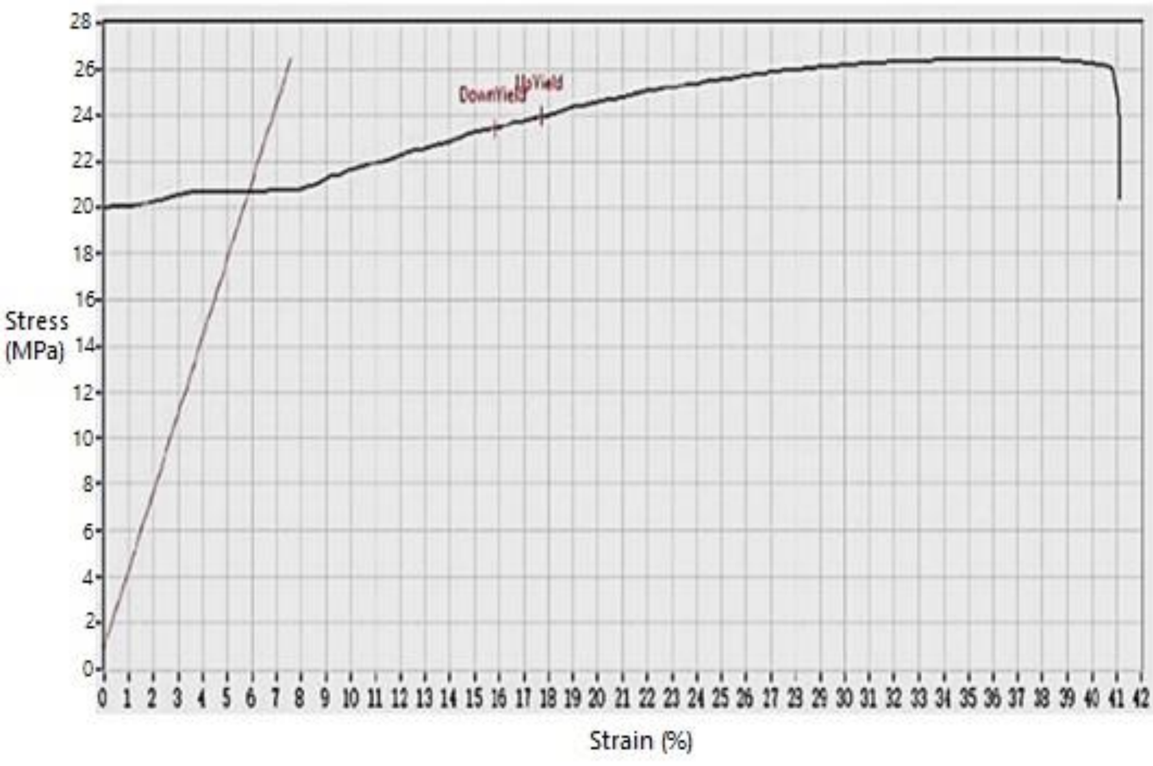
(e)



(f)



(g)

Figure 11. Stress – strain graphs of the specimens (a) C1 (b) S1 (c) S2 (d) S3 (e) S4 (f) S5 and (g) S6.

3.5 Hardness

The control specimen demonstrated a hardness of 18.2 HV as shown in **Fig. 12**. As the weight percent (wt. %) of bamboo particles increases, there is a gradual increase in the hardness of the specimens. Specimen S5 which contains 25 wt. % of reinforcing particles demonstrated the highest hardness of 24.7 HV. The increase in hardness may be because of a strong bond between bamboo particles and epoxy matrix that impeded or restricted the movement of dislocation **(Seshappa et al., 2018)**. However, there is a decrease in hardness when filler addition is beyond 25 wt. %. The decrease may be due to voids or defects formed during the processing of the composite and particles clustering/agglomeration in the matrix **(Cerqueira et al., 2011; Mustapha et al., 2021)** and weak/inadequate interface bonding between the particles and matrix **(Mohammed et al., 2024)**.

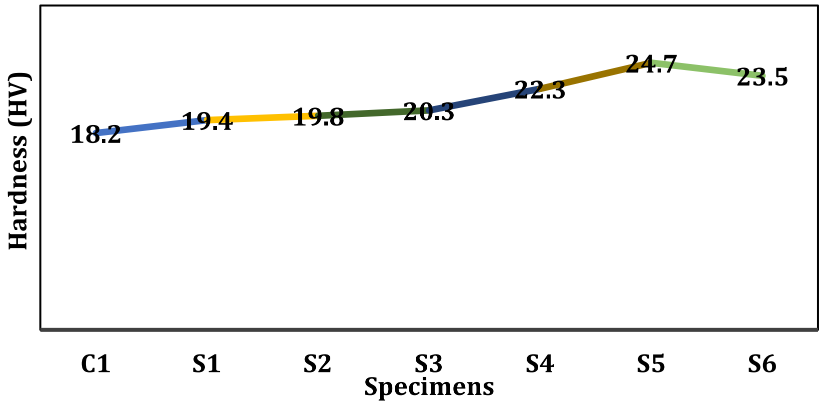


Figure 12. Hardness of the specimens.

3.6 Impact Energy

As presented in **Fig. 13**, the composites demonstrated a reduction in impact energy as filler content increased. Control specimen demonstrated the highest impact energy of 5.34 J while specimen S6 demonstrated the lowest impact energy of 3.97 J. The decrease in impact energy may be because of the filler particles, which may represent points for localized stress concentration from which failure began because of formation of a weak structure. In addition, an increase in concentration of filler reduces the ability of the matrix to absorb energy thereby reducing the toughness, so impact energy decreases **(Hameed and Fahad, 2015)**. This may be due to possible increase in stress concentration because of agglomerated bamboo particles Iinthe matrix **(Cerqueira et al., 2011; Ardanuy et al., 2015; Mustapha et al., 2021)**.

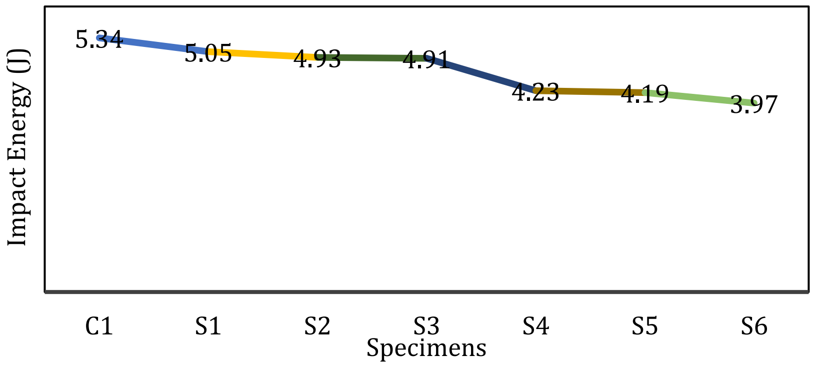


Figure 13. Impact energy of the specimens.

4. CONCLUSIONS

Production of biodegradable polymer matrix composites that are cost effective, sustainable and environmentally friendly with desirable properties using particles as discontinuous phase (filler) has been undertaken in this study by stir casting method. Furthermore, the microstructural, physical and mechanical properties evaluation of the composites were also carried out. The key findings from the experimental test results are:

- The micrographs confirmed the presence of pores in the microstructure of the specimens and distribution of bamboo particles in the reinforced specimens.
- The reinforced composites (S2 to S6) demonstrated an appreciable increase in density when compared with the unreinforced control specimen (C1).
- Specimens (S2 to S6) demonstrated lower water absorption than control specimen C1.
- The composites demonstrated increased ultimate tensile strength with filler addition up to 25 wt. %. Similarly, the reinforced specimens demonstrated improved hardness as the weight percent (wt. %) of bamboo particles increased up to 25 wt. %. However, the composites demonstrated a reduction in impact energy as filler content increased when compared with the control specimen.
- Specimen S5 formulation, which contained 25 wt. % of reinforcing particles demonstrated the best properties in terms of density, water absorption, hardness and ultimate tensile strength.
- These findings highlight the effectiveness of bamboo particles in enhancing the physical and mechanical properties of the developed ecofriendly biocomposites.

Credit Authorship Contribution Statement

Stephen Durowaye: Supervision, Investigation, Methodology, Formal analysis, Writing – original draft, Writing review & editing. Amos Abayomi: Investigation, Methodology, Formal analysis, Writing – original draft, Writing review & editing. Charles Ochulor: Investigation, Methodology, Formal analysis, Writing – original draft, Writing review & editing. Comfort Akindutire: Investigation, Methodology, Formal analysis, Writing – original draft. Victor Okafor: Investigation, Methodology, Formal analysis, Writing – original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

Abedom, F., Sakthivel, S., Asfaw, D., Melese, B., Solomon, E., and Kumar, S.S., 2021. Development of natural fiber hybrid composites using sugarcane bagasse and bamboo charcoal for automotive thermal insulation materials. *Advances in Materials Science and Engineering*, 1, pp. 1-10. https://doi.org/10.1155/2021/2508840.

Aigbodion, V.S., Agunsoye, J.O., Kalu, V., Asuke, F., and Ola, S., 2010. Microstructure and mechanical properties of ceramic composites. *Journal of Minerals and Materials Characterization and Engineering*, 9(6), pp. 527-538. https://doi.org/10.4236/jmmce.2010.96037.

Ardanuy, M., Josep, C., and Filho, R.D.F., 2015. Cellulosic fiber reinforced cement-based composites: a review of recent research. *Construction and Building Materials*, 79(102), pp. 115-128. https://doi.org/10.1016/j.conbuildmat.2015.01.035.

ASTM D256-10, 2018. Standard test methods for determining the Izod pendulum impact strength of plastics. American Society of Testing Materials (ASTM), 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA, 19428-2959, USA.

ASTM D570-98, 2018. Standard test method for water absorption of plastics. ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA, 19428-2959, USA.

ASTM D638, 2014. Standard test method for tensile properties of plastics. ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA, 19428-2959, USA.

ASTM E384-17., 2022. Standard test method for micro indentation hardness of materials. American Society of Testing Materials (ASTM), 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA, 19428-2959, USA.

Balaji, A., Karthikeyan, B., and Swaminathan, J., 2019. Comparative mechanical, thermal, and morphological study of untreated and NaOH-treated bagasse fiber-reinforced cardanol green composites. *Advanced Composites and Hybrid Materials*, 2, pp. 125-132. https://doi.org/10.1007/s42114-019-00079-7.

Banga, H., Singh, V.K., and Choudhary, S.K., 2015. Fabrication and study of mechanical properties of bamboo fiber reinforced bio-composites. *Innovative Systems Design and Engineering*, 6(1), 84-99.

Cerqueira, E.F., Baptista, C.A.R.P., and Mulinari, D.R., 2011. Mechanical behaviour of polypropylene reinforced sugarcane bagasse fibers composites. *Procedia Engineering*, 10, pp. 2046-2051. https://doi.org/10.1016/j.proeng.2011.04.339.

Devadiga, D.G., Bhat, K.S., and Mahesha, G.T., 2020. Sugarcane bagasse fiber-reinforced composites: Recent advances and applications. *Cogent Engineering,* 7(1), pp. 1-12. https://doi.org/10.1080/23311916.2020.1823159.

Durowaye, S., Kanu D., Awotunde, O., and Alao, S., 2022. Effect of particulate of mild steel and aluminium dross on the physical and mechanical properties of epoxy-resin matrix composites. *Scientific Journal of Mehmet Akif Ersoy University, Techno-Science*, 5(1), pp. 1-8.

Ferede, E., 2020. Evaluation of mechanical and water absorption properties of alkaline-treated sawdust-reinforced polypropylene composite. *Hindawi Publishing Corporation, Journal of Engineering*, ID 3706176, pp. 1-8. https://doi.org/10.1155/2020/3706176.

Hameed, S.S., and Fahad, B.M. 2015. Improve the impact strength of polymer-polymer composites after post curing. *International Journal of Modern Engineering Research (IJMER)*, 5(7), pp. 40-45.

Huang, J.K., Young, W.B., 2019. The mechanical, hygral, and interfacial strength of continuous bamboo fiber reinforced epoxy composites. *Composites Part B: Engineering*, 166, pp. 272-283. https://doi.org/10.1016/j.compositesb.2018.12.013.

Hui, W., Rui, C., Kui-chuan, S., Mehrdad, A., and Xiang-qun, Q., 2008. Impact response of bamboo–plastic composites with the properties of bamboo and polyvinylchloride (PVC). *Journal of Bionic Engineering*, 5(S1), pp. 28-33. https://doi.org/10.1016/S1672-6529(08)60068-2.

Josep, C., Fernandez-Carrasco, L.J., Ventura, H., and Ardanuy, M., 2016. Natural fiber nonwoven reinforced cement composites as sustainable materials for building envelopes. *Construction and Building Materials*, 115, pp. 230-239. https://doi.org/10.1016/j.conbuildmat.2016.04.044.

Kaewpirom, S., Worrarat, C., 2014. Preparation and properties of pineapple leaf fiber reinforced poly(lactic acid) green composites. *Fibers and Polymers*, 15(7), pp. 1469-1477. https://doi.org/10.1007/s12221-014-1469-0.

Khan, Z., Yousif, B.F., and Islam, M., 2017. Fracture behaviour of bamboo fiber reinforced epoxy composites. Composites Part B: Engineering, 116, pp. 186-199. https://doi.org/10.1016/j.compositesb.2017.02.015.

Khanam, P.N., Abdul-Khalil, H.P.S., Reddy, G.R., and Naidu, S.V.V., 2011. Tensile, flexural and chemical resistance properties of sisal fiber reinforced polymer composites: effect of fiber surface treatment. *Journal of Polymers and the Environment*, 19(1), pp. 115-119. https://doi.org/10.1007/s10924-010-0219-7.

Kumar, D., 2014. Mechanical characterization of treated bamboo natural fiber composite. *International Journal of Advanced Mechanical Engineering*. 4(5), pp. 551-556.

Li, M., Pu, Y., Thomas, V.M., Yoo, C.G., Ozcan, S., Deng, Y., Nelson, K., Arthur J., and Ragauskas, A.J., 2020. Recent advancements of plant-based natural fiber–reinforced composites and their applications. *Composites Part B: Engineering*, 200, pp. 108254. https://doi.org/10.1016/j.compositesb.2020.108254.

Mat-Shayuti, M.S., Abdullah, M.Z., and Megat-Yusoff, P.S.M., 2013. Water absorption properties and morphology of polypropylene/polycarbonate/polypropylene-graft-maleic anhydride blends. *Asian Journal of Scientific Research*, 6(2), pp. 167-176. https://doi.org/10.3923/ajsr.2013.167.176.

Mohammed, K., Zulkifli, R., Tahir, M.F.M., and Gaaz, T.S., 2024. A study of mechanical properties and performance of bamboo fiber/polymer composites. *Results in Engineering*, 23(102396), pp. 1-10. https://doi.org/10.1016/j.rineng.2024.102396.

Mustapha, K., Sogoye, M., Ottan, A.S., Danyuo, Y., Azeko, S.T., and Annan, E., 2021. Strength and fracture resistance of cellulose fiber reinforced cement composite. *Technoscience Journal for Community Development in Africa*, 2(1), pp. 29-37.

Okubo K., Fujii, T., and Yamamoto Y., 2004. Development of bamboo-based polymer composites and their mechanical properties. *Composites Part A: Applied Science and Manufacturing*, 35(3), pp. 377-383. https://doi.org/10.1016/j.compositesa.2003.09.017.

Olabisi, A.I., Adam, A.N., and Okechukwu, O.M., 2016. Development and assessment of composite brake pad using pulverized cocoa beans shells Filler. *International Journal of Materials Science and Applications*, 5(2), pp. 66-78. https://doi.org/10.11648/j.ijmsa.20160502.16.

Osorio, L., Trujillo, E., Vuure, A.W.V., and Verpoest. I., 2019. Morphological aspects and mechanical properties of single bamboo fibers and flexural characterization of bamboo/epoxy composites. *Journal of Reinforced Plastics and Composites*, 30(5), 396-408, https://doi.org/10.1177/0731684410397683jrp.sagepub.com.

Pantyukhov, P., Kolesnikova, N., and Anatoly P., 2016. Preparation, structure, and properties of biocomposites based on low-density polyethylene and lignocellulosic filler. *Polymer Composites*, 37(5), pp. 1461-1472. https://doi.org/10.1002/pc.23315.

Pizzol, V.D., Mendes, L.M., Frezzatti, L., Savastano, H., and Tonoli, G.H.D., 2014. Effect of accelerated carbonation on the microstructure and physical properties of hybrid-cement composites. *Minerals Engineering*, 59, pp. 101-106. https://doi.org/10.1016/j.mineng.2013.11.007.

Rao, H.R., Reddy, K.M., Reddy, P.V., and Reddy, R.M., 2020. Effect of fiber orientation on mechanical properties of hardwika binata and bamboo fiber reinforced epoxy composites. *Materials Today Proceedings*, 21(2), pp. 1265-1269. https://doi.org/10.1016/j.matpr.2020.01.116.

Roslan, S.A.H., Hassan, M.Z., Rasid, Z.A., Zaki, S.A., Daud, Y., Aziz, S., Sarip, S., and Ismail, Z., 2015. Mechanical properties of bamboo reinforced epoxy sandwich structure composites. *International Journal of Automotive and Mechanical Engineering (IJAME)*, 12, pp. 2882-2892. http://dx.doi.org/10.15282/ijame.12.2015.7.0242.

Satyanarayana, K.G., Gregorio, G.C., Arizaga, G.G.C., and Wypych, F., 2009. Biodegradable composites based on lignocellulosic fibers-an overview. *Progress in Polymer Science (Oxford)*, 34(9), pp. 982-1021. https://doi.org/10.1016/j.progpolymsci.2008.12.002.

Scurlock, J.M.O., Dayton, D.C., and Hames, B., 2000. Bamboo: An overlooked biomass re- source? Biomass and Bioenergy, 19, pp. 229-244. https://doi.org/10.1016/S0961-9534(00)00038-6.

Sergio, N.M., Frederico, M.M. Fábio, d.O.B., Fernanda, S.D.L., and Noan, T.S., 2017. Weibull analysis of the tensile strength dependence with fiber diameter of giant bamboo. *Journal of Materials Research and Technology*. 6(4), 317-322. https://doi.org/10.1016/j.jmrt.2017.07.001.

Seshappa, A., Kumar, G.K.K., and Sankar, C.B., 2018. Analysis of mechanical characteristics of silicon carbide reinforced with aluminum metal matrix composites. *International Journal of Scientific Development and Research (IJSDR)*, 3(11), pp. 125-131.

Verma, C.S., Purohit, R., Rana, R.S., and Kumar, M.H., 2017. Mechanical properties of bamboo laminates with other composites. *Materials Today Proceedings*, 4(2), pp. 3380-3386. https://doi.org/10.1016/j.matpr.2017.02.226.

Wenwen, G., Ehsan, N.k., Xin, W., Weiyi, X., Ping, Z., Lei, S., and Yuan, H., 2019. Processing bulk natural bamboo into a strong and flame-retardant composite Material. *Industrial Crops and Products*, 138(1), pp. 11478, https://doi.org/10.1016/j.indcrop.2019.111478.

Zhang, K., Wang, F., Wenyan Liang, W., Wang, Z., Duan, Z., and Yang, B., 2018. Thermal and mechanical properties of bamboo fiber reinforced epoxy composites. *Polymers*, 10(608), pp. 1-8. https://doi.org/10.3390/polym10060608.

دراسة تجريبية لخصائص المواد المركبة الحيوية من جسيمات البامبو المعززة بمصفوفة راتنج الإيبوكسي

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الخلاصة

إنتاج مواد مركبة ذات مصفوفة بوليمرية قابلة للتحلل الحيوي، تكون منخفضة التكلفة ومستدامة وصديقة للبيئة وذات خصائص مرغوبة باستخدام الجسيمات كطور متقطع (حشوة)، يُعد تطورًا مرحبًا به. في هذه الدراسة، تم تطوير مواد مركبة من جسيمات البامبو المقواة بمصفوفة راتنج الإيبوكسي باستخدام طريقة الصب بالتحريك. تم إضافة نسب وزنية متنوعة (5% إلى 30%) من جسيمات البامبو بحجم 100 ميكرومتر وخلطها مع مصفوفة راتنج الإيبوكسي والمصلب. ثم تم صب الخلطات في قوالب خشبية مُعدة مسبقًا وتركت لتتصلب في درجة حرارة الغرفة. بعد 24 ساعة، تم استخراج العينات من القوالب وخضعت لفحص البنية المجهرية باستخدام المجهر الإلكتروني الماسح .(SEM) بالإضافة إلى ذلك، تم إجراء دراسة خصائصها الفيزيائية والميكانيكية. أظهرت النتائج التجريبية وجود المسامات في البنية المجهرية للعينة وتوزيع جسيمات التعزيز داخل مصفوفة الإيبوكسي. أظهرت المواد المركبة المعززة (S2 إلى S6) زيادة ملحوظة في الكثافة مقارنة بعينة التحكم غير المعززة .(C1) أظهرت العينات (S2 إلى S6) امتصاصًا أقل للماء مقارنة بعينة التحكم. كما أظهرت المواد المركبة زيادة في مقاومة الشد القصوى مع إضافة الحشوة حتى 25%. وبالمثل، تحسنت صلابة العينات المعززة مع زيادة النسبة الوزنية لجسيمات البامبو حتى 25%. ومع ذلك، لوحظ انخفاض في طاقة الصدم مع زيادة محتوى الحشوة مقارنة بعينة التحكم. أظهرت صيغة العينة S5، التي تحتوي على 25% وزني من جسيمات التعزيز، أفضل الخصائص من حيث الكثافة، وامتصاص الماء، والصلابة، وقوة الشد القصوى. تسلط هذه النتائج الضوء على فعالية جسيمات البامبو في تعزيز الخصائص الفيزيائية والميكانيكية للمواد المركبة المطورة الصديقة للبيئة.

الكلمات المفتاحية :المادة المركبة الحيوية، جسيمات البامبو، راتنج الإيبوكسي، الصب بالتحريك، الخصائص.