Investigation of the Properties of Sugarcane Bagasse Particle Reinforced Epoxy Matrix Biocomposites

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Abstract
The stir casting technique was employed to produce sugarcane bagasse particle-reinforced epoxy matrix biocomposites. The microstructure, physical and mechanical properties of the composites were evaluated. The results obtained from the experiments revealed the presence of pores in the microstructure and distribution of reinforcing particles in the epoxy matrix. The control specimen possessed a density of 0.71 g/cm^3 while specimens S4, S5 and S6 possessed the highest density of 0.93 g/cm^3. Control specimen C1 demonstrated water absorption of 0.25 % while specimens S5 and S6 demonstrated the lowest water absorption of 0.19 %. Control specimen demonstrated the lowest tensile strength of 7.21 MPa whereas specimen S5 which contained 25 wt. % of bagasse particles demonstrated the highest tensile strength of 22.55 MPa. This is 213 % higher than that of the control specimen. Specimen S5 containing 25 wt. % of bagasse particles demonstrated the highest hardness value of 23.95 HV. The control specimen C1 demonstrated the highest impact energy of 4.87 J. The impact energy of the specimens decreased as weight percent (wt. %) of bagasse particles increased. The decrease in impact energy is suggested to be due to the presence of filler particles, which may represent points for localized stress concentration from which failure began.

Keywords: Biocomposites**,** epoxy matrix, properties, stir casting, sugarcane bagasse particle

1.0 INTRODUCTION

Large quantities of agricultural wastes are rapidly generated yearly worldwide with an average annual increase rate of 5-10 %, which causes adverse environmental effects because burning of such wastes leads to water, soil, and air pollution (Debnath *et al*., 2021; Riseh *et al*., 2024). Examples of agricultural (plant-based) wastes are leaves, shoots, cereal straw, grass, vine pruning, fruit peels, and forest residues such as trunks of old tree, pruning and roots (Riseh *et al*., 2024). Specifically, some of these wastes are sugarcane bagasse, rice and wheat husk and their straws, shells of various dry fruits and hemp fibre (Prasad *et al*., 2020). However, these abundant wastes can be utilised for composites production using modern technologies for sustainable development.

Natural fillers (fibres or particles) have different sources like sugarcane bagasse, bamboo, wood, cereal straw, pulp, cotton and vegetables such as ramie, sisal, jute, flax and hemp. The use of agricultural wastes for production of biocomposites with desirable properties such as lightweight, biodegradability, ecofriendliness, enhanced tensile strength, hardness and fracture toughness (Verma *et al*., 2012) is a welcome development.

Sugarcane is cultivated worldwide and the global sugar production is expected to increase from the current 175 metric tons per annum to 198 metric tons by 2032 and sugarcane, which is grown in mostly tropical and sub-tropical regions will continue to account for more than 85 % of the aggregate sugar crops output (OECD-FAO, 2023; WAOB-USDA, 2024). Bagasse is a residue of 30 % in the amount left after crushing sugarcane stalk in either alcohol or sugar mills. It is obtained from the sugarcane stalk, which consists of the crushed inner pith and the outside rind (Abedom *et al*., 2021).

Sugarcane bagasse and other plant fibres are biodegradable, which makes them environmentally friendly to the ecosystem as well as their cost advantage and high rigidity make them to be suitable reinforcing materials for applications requiring low density and high strength (Loh *et al*.,

2013). In addition, natural fibre-reinforced composites have become potential substitutes for synthetic fibres reinforced composites in various applications because they are readily available, biodegradable, cost-effective, non-toxic with high strength and stiffness, which make them to be very good substitutes for glass or carbon fibres for high strength application e.g. construction (Prasad *et al*., 2020). However, bagasse, a byproduct of agriculture and industry, poses environmental risks when burned as fuel

Many natural fibre-reinforced polymer composites (NFPCs) with high specific stiffness and strength have been developed by reinforcing polymers (thermoplastics or thermosets) with strong and lightweight natural fibres. However, natural fibres have some disadvantages. For example, the nature of natural fibres (cellulose, hemicelluloses, lignin, pectin, and waxy compounds) permits moisture to be absorbed from the environment causing weak fibre-polymer bonds (Cerqueira *et al*., 2011). In addition, the problems of incompatibility between fibres and polymer matrices, formation of aggregates during processing and low resistance to moisture limit the application of natural fibres as reinforcing materials/fillers in polymers (Cerqueira *et al*., 2011). To address these challenges, some steps have been taken, which include introduction of surface modifications to improve fibres-polymer matrices compatibility that can be physical or chemical according to modification technique to reduce hydrophilicity. Bleaching, esterification, plasma and silane treatments, use of compatibilizer, acetylation, alkali application and treatment with other chemicals (Cerqueira *et al*., 2011). All these have proven to be effective by properties enhancement.

Generally, the properties of composites are influenced by the properties of their constituent materials. Furthermore, some factors such as geometry/shape, size, and distribution of the reinforcement in the matrix also influence the properties of composites (Mahesha *et al*., 2019, Vidyashri *et al*., 2019). Another factor that influences the properties of composites is proper filler (fibre) alignment, which improved mechanical properties (Balasundar *et al*., 2019, Dinesh *et al*., 2020).

Studies on sugarcane bagasse-based polymer composites have been conducted and the results showed an improvement in the mechanical properties. For instance, Vidyashri *et al*., (2019) investigated chemically treated sugarcane bagasse fibre reinforced epoxy composites. The results revealed an increase in the tensile strength and modulus of elasticity of the composites Balaji et al. (2019) worked on comparative mechanical, thermal and morphological study of untreated and NaOH-treated bagasse fibre-reinforced cardanol green composites. The results indicated an increase in the tensile strength and impact energy of the composites with higher thermal stability. Jafrey et al. (2019) investigated the influence of bagasse/sisal fibre stacking sequence on the mechanical characteristics of hybrid-epoxy composites. The results also indicated an increase in tensile, flexural and compressive strengths of the reinforced composites with improved impact energy and higher biodegradation.

There is need to intensify the usage of bagasse in composites production because it will lead to increased revenue generation and employment opportunities. Improvement on the properties of polymers via blending with natural fillers to produce polymer matrix composites is a welcome development. Therefore, the aim of this study is to produce sugarcane bagasse particle-reinforced epoxy matrix biocomposites and evaluate their physical and mechanical properties.

2.0 MATERIALS AND METHOD

2.1 Materials, Apparatus and Production of Specimens

Sugarcane bagasse (pith and rind), which was employed in this study as filler was sourced from sugarcane dumpsite. The epoxy resin and hardener were sourced from a chemical shop in Ojota, Lagos. The bagasse (piths and rinds) were soaked in hot water (100 ^{0}C) for 1 hour and rinsed with

water to remove extracted sugar. They were then soaked in 1 % NaOH solution for two hours to remove lignin and wax content. From literature, alkaline (5 % NaOH) treatment influenced reaction sites on the fibre surface with increased surface roughness, which enhanced mechanical properties (Bam et al., 2019). These are the reasons for the alkaline treatment. After alkaline treatment, they were rinsed in water and sun dried for three hours. Thereafter, they were ground to particles using a grinding machine and sieved to 149-µm using 100 U.S. mesh/sieve size. A wooden mould, plastic beakers, stirrers and an electronic digital weighing balance (model No. UW1020H, Shimadzu, Japan) with sensitivity of ± 1 mg were used during the stir casting production of the polymer matrix composites. The mould was laminated with a paper tape for easy removal of the specimens after solidification. Using the electronic weighing machine, measured quantities of the sugarcane bagasse particles (5-30 wt. %) were added separately and blended with the epoxy – hardener matrix as presented in Table 1. 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 Figure 1. Five production runs were carried out for the varied composition of the specimens, which were cured at room temperature for about 24 hrs. Seven specimens were used for each of the physical and mechanical tests while four specimens were selected for the microstructural test. The production flow chart is shown in Figure 2.

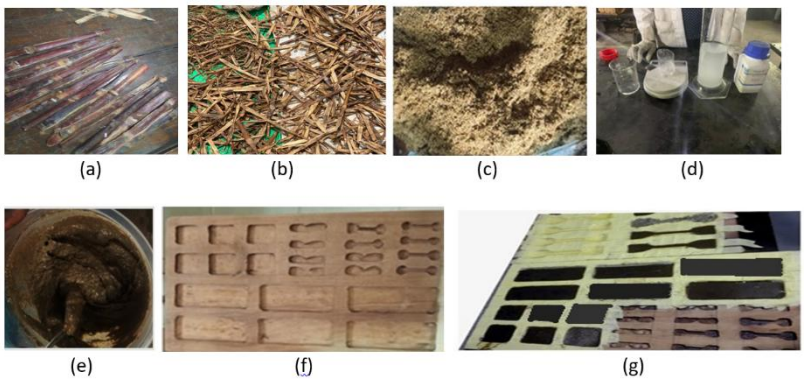

Figure 1: (a) Peeled sugarcane rinds (b) sun dried sugarcane bagasse (piths and rinds) (c) ground and sieved 150-µm sugarcane bagasse particles (d) NaOH solution preparation (e) Mixed blend (f) Wooden mould (g) Mixed blend in the mould before curing

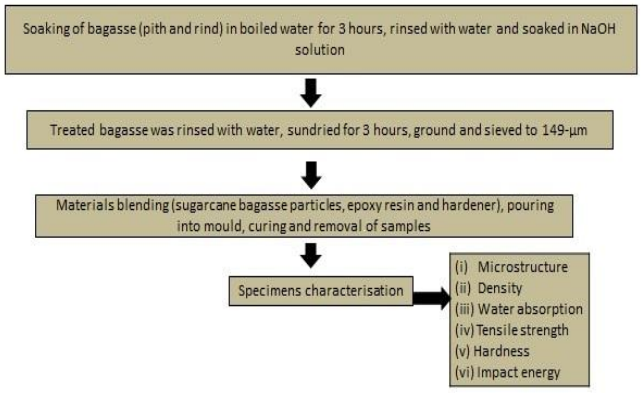

Figure 2: Production flow chart of the specimens

Natural fillers (fibres or particles) from agricultural produce such as sugarcane, bamboo, ramie, wheat, coir, sisal, pineapple, coconut, paddy, flax and banana have been used by researchers to produce biocomposites with desirable properties (Prasad *et al*., 2020). The main composition of

these fibres are cellulose, hemicelluloses, lignin and pectin with little amount of extractives (Cerqueira *et al*., 2011). The composition of sugarcane bagasse in weight percent (wt. %) as reported by Ramleea et al., (2019) was cellulose 49.44, hemicellulose 23.19, lignin 12.56 and ash/extractives 14.8 while that of bagasse obtained in this study by using an X-ray fluorescence spectrometer (Epsilon 1 model) is shown in Table 2. There is a similarity between these results in terms of content and amount.

Table 1: Materials Formulation in Weight Percent (wt. %)

Specimen	Sugarcane bagasse (pith and rind) 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

Table 2: Composition of Sugarcane Bagasse

Component	Weight (%)
Cellulose	48.87
Hemicellulose	23.61
Lignin	12.83
Ash and extractives	14.69

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 Figure 3 with other equipment**.** The density of the specimens was determined using the Archimedes' principle. The mass of the specimens in 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)

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 then removed. The water absorption (W_A) was determined using Eq. (2) (ASTM D570-98, 2018).

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

Where:

W_0 = specimen's weight before immersion

W_1 = specimen's weight after immersion

Tensile test was conducted on the specimen using a dimension 12.5mm according to (ASTM D638, 2014) using a digital XLC universal tester (Intron's 6800 Series). Each of the specimens was placed in the centre of the tester and load was applied until fracture occurred. Microhardness

test was conducted on the specimens according to standard (ASTM E384-17, 2022) using a Vickers hardness tester model VM-50 with a test load of 1.91N. Impact testing was conducted on the test-specimens of size 55 mm x 10 mm x 10 mm that have a 2 mm deep V-notch at the centre using an Izod impact-tester model 50J according 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.

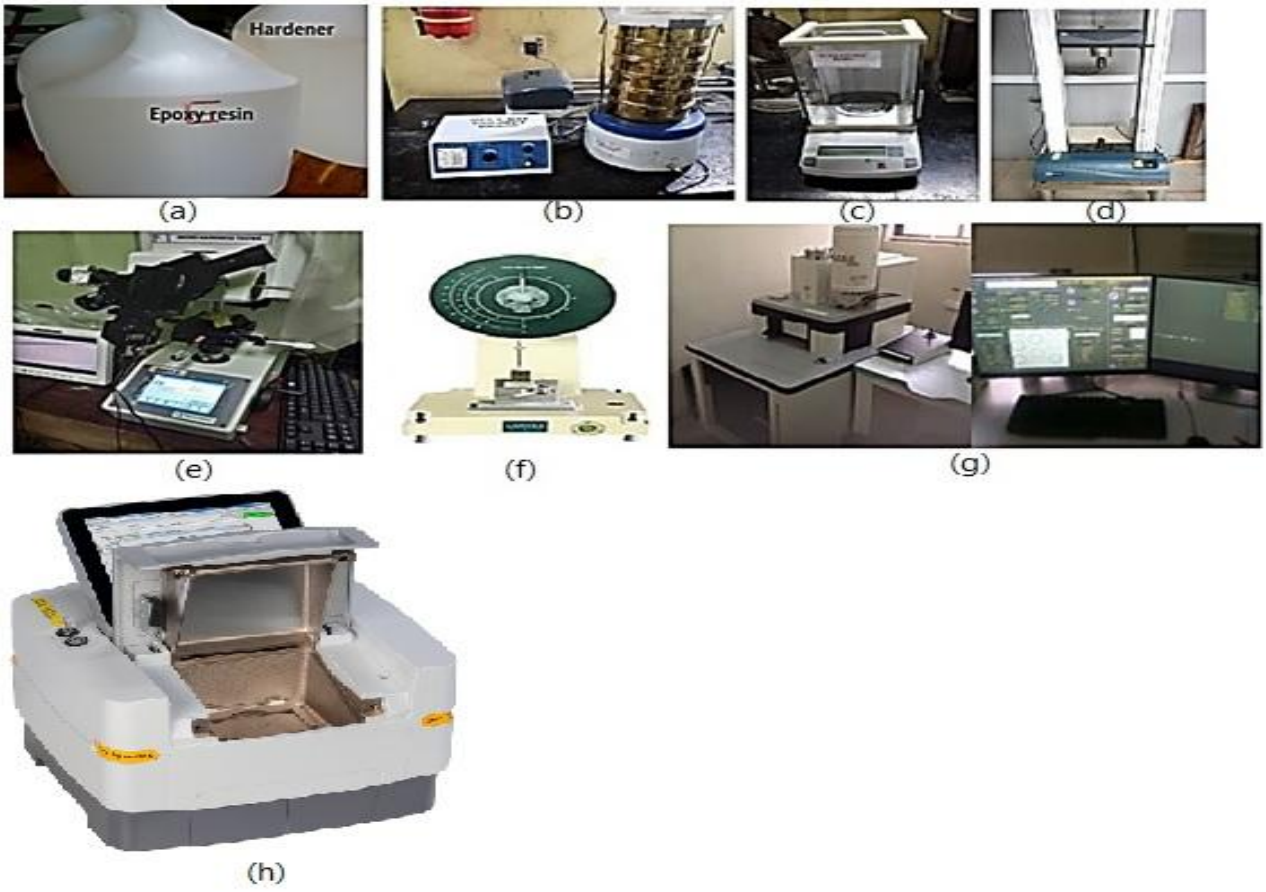

Figure 3: (a) Epoxy resin and hardener (b) Sieves with vibrator (c) Electronic weighing machine (d) Instron tester (e) Vickers micro hardness tester (f) Izod impact tester (g) ASPEX 3020 variable pressure Scanning Electron Microscope (SEM) with Energy Dispersive X-ray (EDX) facility (h) An X-ray fluorescence spectrometer (Epsilon 1 model)

3.0 RESULTS AND DISCUSSION

3.1 Microstructure of the Specimens

The microstructures of the specimens revealed the presence of pores as shown by scanning electron micrographs of Figures 4-7. The pores reduced with increasing amount of sugarcane bagasse-rind particles in the epoxy matrix as shown in Figure 5-7 compared to the control specimen C1. The microstructure of the composites shows that the phases are not homogeneous and bagasse particles are well dispersed in the epoxy matrix as shown in Figure 5-7. The Energy Dispersive X-ray (EDX) spectra confirmed the presence of the revealed elemental constituents such as oxygen (O), carbon, potassium (K) and some indistinguishable elements in traces or minute amount in the specimens. 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.

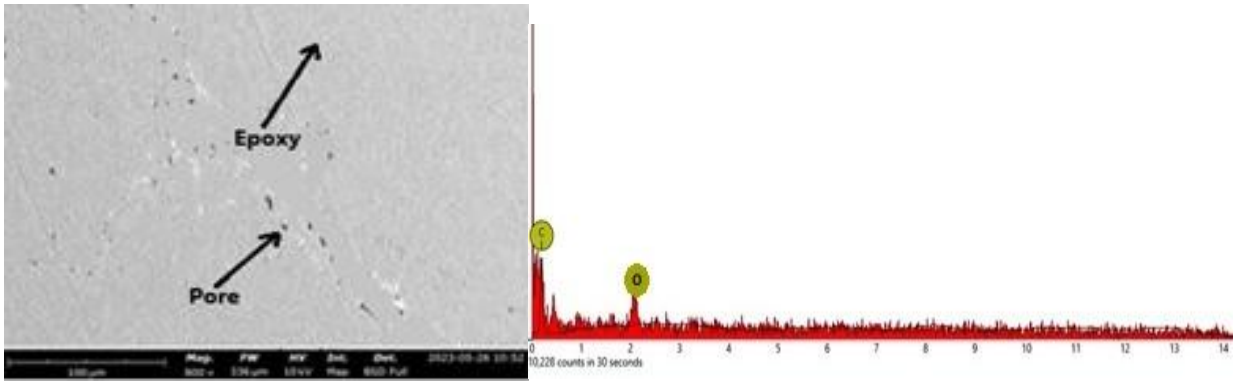

Figure 4: Scanning electron micrograph with EDX spectrum of control (unreinforced) specimen C1

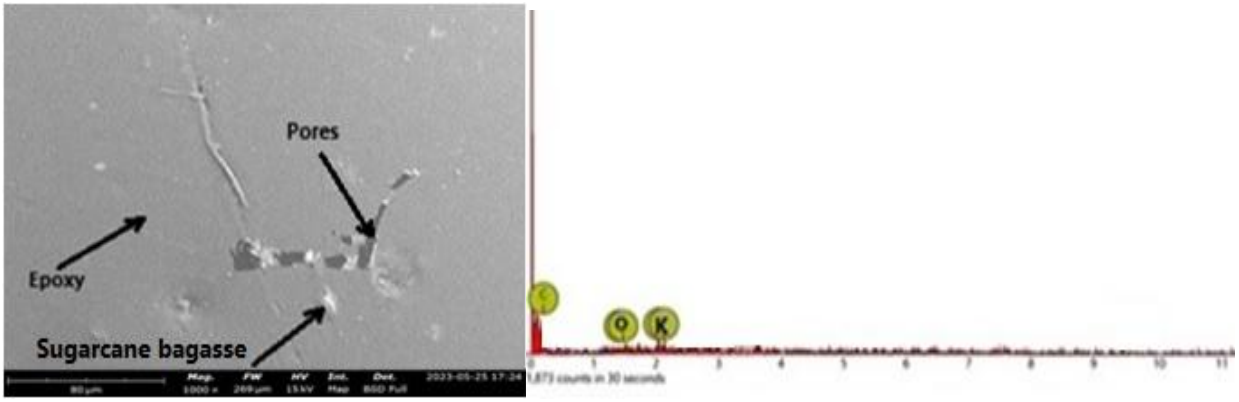

Figure 5: Scanning electron micrograph with EDX spectrum of specimen S1

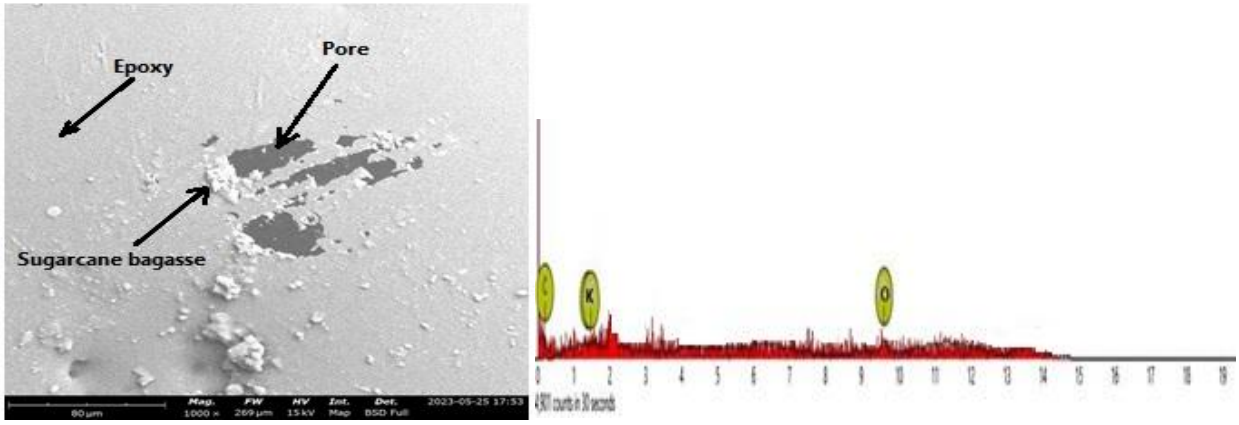

Figure 6: Scanning electron micrograph with EDX spectrum of specimen S2

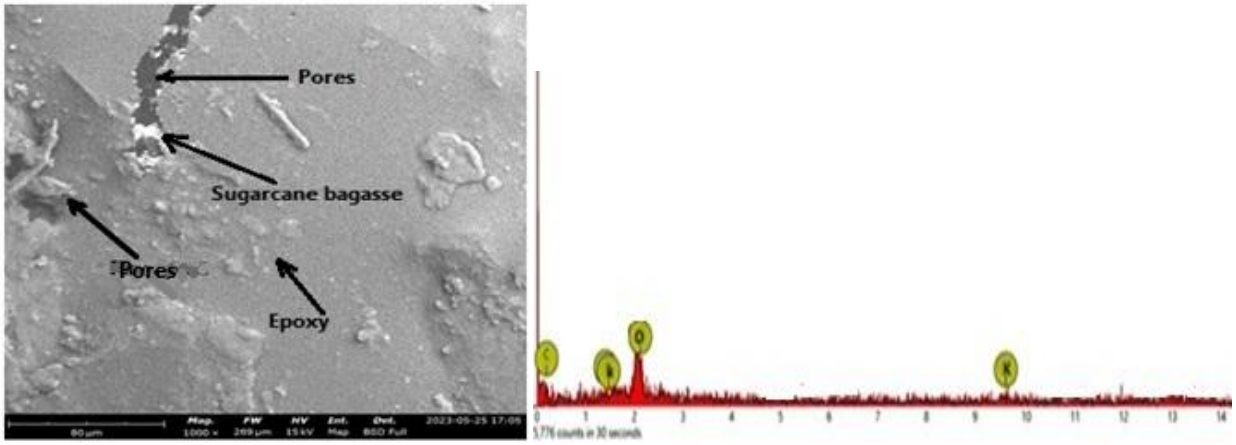

Figure 7: Scanning electron micrograph with EDX spectrum of specimen S6

3.2 Density

As shown in Figure 8, there is an appreciable increase in the density of the reinforced composites compared to the control specimen C1. The control specimen possessed a density of 0.71 g/cm^3 while specimens S4, S5 and S6 possessed the highest density of 0.93 g/cm^3. The increase in density is suggested to be caused by the addition of composition of sugarcane bagasse.

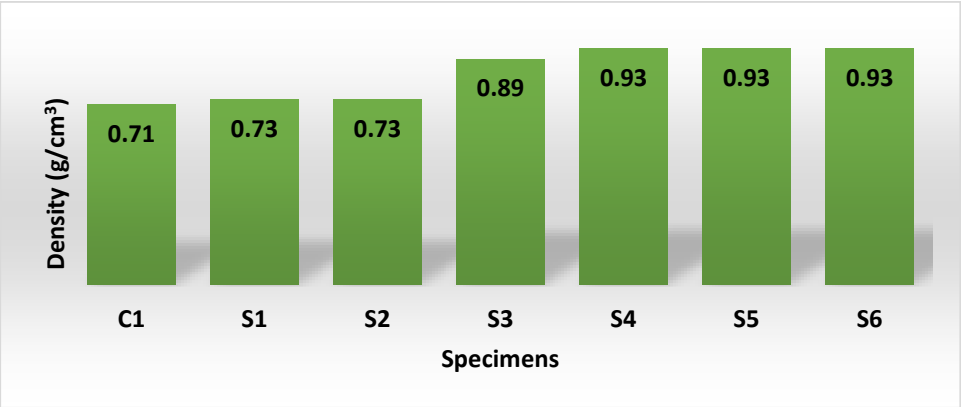

Figure 8: Density of the specimens

3.3 Water Absorption

The control specimen C1 exhibited water absorption of 0.25 % while specimens S5 and S6 exhibited the lowest water absorption of 0.19 %. Generally, all the specimens exhibited low water absorption as illustrated in Figure 9. Composites S3, S4, S5 and S6 exhibited reduced water absorption level compared to the control specimen. The pores in the specimens aided the penetration of water. Sugarcane bagasse-rind particles contain hemicellulose, which is highly hydrophilic. The hydrophilic hydroxyl (-OH) group caused water to be absorbed by the reinforced specimens and diffusion of water can lead to structural change, flexibility increase and break-up that can negatively affect their mechanical characteristics (Pantyukhov *et al*., 2016). This can increase the space of the polymer molecules with decreased bond and lower their resistance to applied stress (Mat-Shayuti *et al*., 2013). However, chemical treatment of the filler with NaOH during production of the specimens must have enhanced their resistance to water absorption. In addition, strong bond of particles and epoxy matrix decreased porosity thereby reducing water absorption (Balaji *et al*., 2019, Ferede, 2020, Durowaye *et al*., 2022).

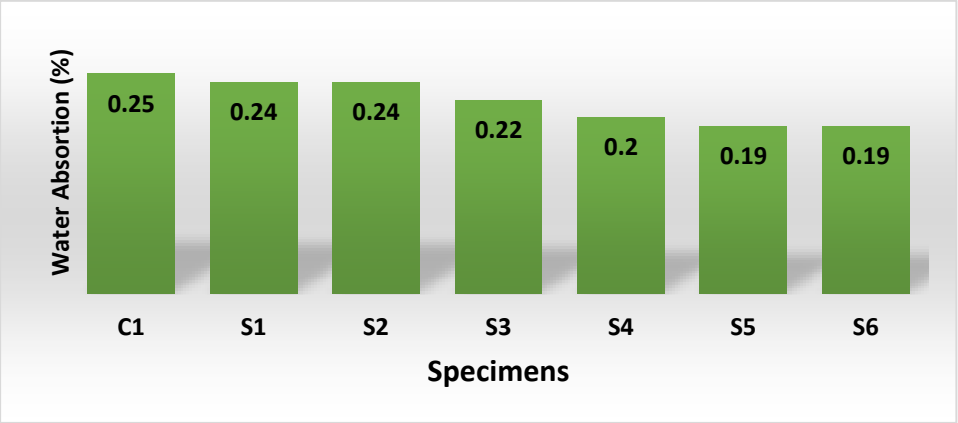

Figure 9: Water absorption of the specimens

3.4 Ultimate Tensile Strength

Generally, the reinforced specimens (S1-S6) exhibited improved tensile strength values compared to the epoxy resin specimen in Figure 10. The control specimen has the lowest tensile strength with 7.21 MPa while S5 has the highest tensile strength value of 22.55 MPa with composition of 25 wt. % of bagasse particles. This is 213 % higher than that of the control specimen. The alkaline (NaOH) treatment influenced reaction sites on the fibre surface and wax layer removal with increased surface roughness, which enhanced mechanical properties (Bam *et al*., 2019). The good distribution of bagasse particles in the epoxy matrix and their strong interfacial bonding caused an improvement in the UTS of the composites (Kaewpirom and Worrarat, 2014, Balaji *et al*., 2019). The decrease in UTS when bagasse particles addition is beyond 25 wt. % could be due to voids that were formed during the processing of the composite, which was very difficult to control at higher wt. % reinforcement (Mustapha *et al*., 2021). In addition, the decrease may be due to particles clustering/agglomeration in the matrix (Cerqueira *et al*., 2011, Mustapha *et al*., 2021).

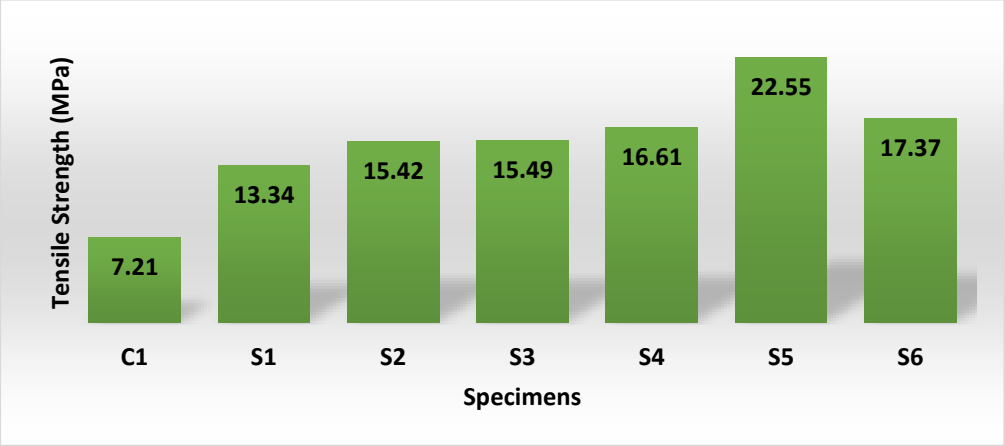

Figure 10: Ultimate tensile strength of the specimens

3.5 Hardness and Impact Energy

Figure 11 shows the hardness value of all the specimens with C1 having the lowest hardness value of 18.7 HV while S5 has the highest hardness value of 23.95 HV. The increase in hardness may be because of strong bond between bagasse particles and epoxy matrix that impeded or restricted movement of dislocation (Seshappa *et al*., 2018, Balaji *et al*., 2019, Durowaye *et al*., 2022). However, there is a decrease in hardness when filler content 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 a*l., 2011, Mustapha *et al*., 2021) and weak/inadequate interface bonding between the particles and matrix (Mohammed *et al*., 2024). In Figure 12, the control specimen C1 demonstrated the highest impact energy of 4.87 J. There is a decrease in impact energy as weight percent (wt. %) of bagasse particles increases. The decrease in impact energy may be because of the filler particles, which may represent points for localized stress concentration from which failure began (Sana *et al*., 2015). 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 (Sana *et al*., 2015).

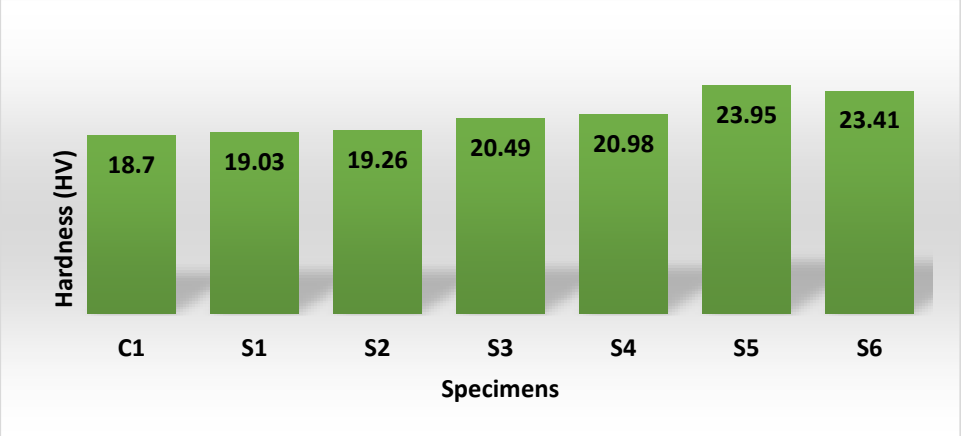

Figure 11: Hardness of the specimens

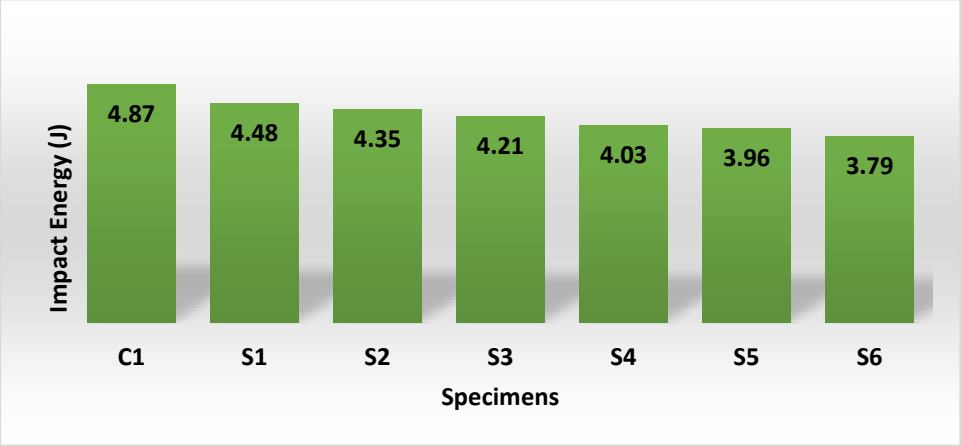

Figure 12: Impact energy of the specimens

4. CONCLUSION

The stir casting technique was successfully used to produce sugarcane bagasse particle reinforced epoxy matrix biocomposites. The microstructure, physical, and mechanical properties of the composites were evaluated. The followings are the conclusions drawn from the experimental test results:

- Microstructure of the specimens revealed the presence of pores and good dispersion of the bagasse particles in the epoxy matrix.
- The control specimen possessed a density of 0.71 g/cm^3 while specimen S6, which contained the highest amount of reinforcing particles possessed the highest density of 0.93 g/cm^3.
- Control specimen C1 demonstrated water absorption of 0.25 % while specimens S5 and S6 demonstrated the lowest water absorption of 0.19 %.
- Specimen C1 demonstrated the lowest UTS of 7.21 MPa while specimen S5 that contained 25 wt. % of bagasse particles demonstrated the highest UTS of 22.55 MPa, which is 213 % higher than that of the control specimen.
- Specimen S5 containing 25 wt. % of bagasse particles demonstrated the highest hardness value of 23.95 HV while the control specimen demonstrated the highest impact energy of 4.87 J.
- Generally, specimen S5 containing 25 wt. % of bagasse particles is the most desirable among the specimens with appreciably good physical and mechanical properties.

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: 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): 527-538. https://doi.org/10.4236/jmmce.2010.96037.

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 D638-14. (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: 125-132. https://doi.org/10.1007/s42114-019-00079-7.

Balasundar, P., Narayanasamy, P., Senthil, S., Dhabi, N. A. A., Prithvirajan, R., Kumar, R. S., Ramkumar, T. and Bhat, K. S. (2019). Physico-chemical study of pistachio (Pistacia vera) nutshell particles as a bio-filler for eco-friendly composites. *Materials Research Express*, 6 (10): Article number 105339. https://doi.org/10.1088/2053-1591/ab3b9b.

Bam, S. A., Gundu, D.T. and Onu, F.A. (2019). The effect of chemical treatments on the mechanical and physical properties of bagasse filler reinforced low-density polyethylene composite. *American Journal of Engineering Research*, 8 (4): 95-98.

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: 2046-2051. https://doi.org/10.1016/j.proeng.2011.04.339.

Debnath, B., Haldar, D. and Purkait, M. K. (2021). A critical review on the techniques used for the synthesis and applications of crystalline cellulose derived from agricultural wastes and forest residues. *Carbohydrate Polymers*, 273: 118537. https://doi.org/10.1016/j.carbpol.2021.118537.

Dinesh, S., Kumaran, P., Mohanamurugan, S., Vijay, R., Singaravelu, D. L., Vinod, A., Sanjay, M.R., Siengchin, S. and Bhat, K. S. (2020). Influence of wood dust fillers on the mechanical, thermal, water absorption and biodegradation characteristics of jute fiber epoxy composites. *Journal of Polymer Research*, 27 (1): Article number 9. https://doi.org/10.1007/s10965-019-1975-2.

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): 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: 1-8. https://doi.org/10.1155/2020/3706176.

Jafrey, D. J., Manoharan, S., Saikrishnan, G. and Arjun, S. (2019). Influence of bagasse/sisal fibre stacking sequence on the mechanical characteristics of hybrid-epoxy composites. *Journal of Natural Fibers*, 17 (7): 1-11. https://doi.org/10.1080/15440478.2019.1581119.

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

Loh, Y. R., Sujan, D., Rahman, M. E. and Das, C. A. (2013). Review Sugarcane bagasse - The future composite material: A literature review. *Resources, Conservation and Recycling*, 75: 14-22. https://doi.org/10.1016/j.resconrec.2013.03.002.

Mahesha, G. T., Subrahmanya B. K. and Padmaraja, N. H. (2019). Biodegradable natural fiber reinforced polymer matrix composites: Technical updates. *International Conference on Inventive Material Science Applications,* 2166 (1): 1-9. https://doi.org/10.1063/1.5131588.

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): 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): 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): 29-37.

OECD-FAO (2023): OECD-FAO Agricultural Outlook 2023-2032, pp. 170-183.

Olabisi, A. I., Ademoh, N. A. 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): 66-78. https://doi.org/10.11648/j.ijmsa.20160502.16.

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): 1461-1472. https://doi.org/10.1002/pc.23315.

Prasad, L. Kumar, S., Patel, R.V., Yadav, A., Kumar, V., Yadav, A., Kumar, V. and Winczek, J. (2020). Physical and mechanical behavior of sugarcane bagasse fiber-reinforced epoxy composites. *Materials*, 13 (23): 1-13. https://doi.org/10.3390/ma13235387.

Ramleea, N. A., Jawaid, M., Zainudinb, E. S. and Yamani, S. A. K. (2019). Tensile, physical and morphological properties of oil palm empty fruit bunch/sugarcane bagasse fibre reinforced phenolic hybrid composites. *Journal of Materials Research and Technology*, 8(4): 3466-3474. https://doi.org/10.1016/j.jmrt.2019.06.016.

Riseh, R. S., Vazvani, M. G., Hassanisaadi, M. and Thakur, V. K. (2024). Agricultural wastes: A practical and potential source for the isolation and preparation of cellulose and application in agriculture and different industries. *Industrial Crops & Products*. 208: 1-16. https://doi.org/10.1016/j.indcrop.2023.117904.

Sana, S., 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): 40-45.

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): 125-131.

Verma, D., Gope, P. C., Maheshwari, M. K. and Sharma, R. K. (2012). Bagasse fiber composites-A review. *Journal of Materials and Environmental Science*, 3 (6): 1079-1092.

Vidyashri, V., Lewis, H., Narayanasamy, P., Mahesha, G. T. and Bhat, K.S. (2019). Preparation of chemically treated sugarcane bagasse fiber reinforced epoxy composites and their characterisation. *Cogent Engineering*, 6 (1): 1-11. https://doi.org/10.1080/23311916.2019.1708644.

WAOB-USDA (2024): Sugar: World Markets and Trade. World Agricultural Outlook Board (WAOB)/United States Department of Agriculture (USDA), Foreign Agricultural Service (FAS), USA. https://public.govdelivery.com/accounts/USDAFAS/subscriber/new, Accessed 18/01/2025