An Experimental Study of the Properties of Sugarcane Bagasse Particle Reinforced Epoxy Matrix Biocomposites

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Abstract
The stir casting technique was used in the production of sugarcane bagasse particle reinforced epoxy matrix biocomposites. The microstructural, physical and mechanical properties of the composites were evaluated. The results obtained from the experiments showed 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 of 23.95 HV. 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 because of formation of a weak structure.

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

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). Millions of tons of agricultural wastes are generated as a result of increase in the production of agricultural products (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/particles) have different sources like sugarcane bagasse, bamboo, wood, cereal straw, pulp, cotton, bark, and vegetable such as ramie, sisal, jute, flax and hemp. The main composition of these fibres are cellulose, hemicelluloses, lignin and pectin, with little amount of extractives (Cerqueira *et al*., 2011). Natural fillers (fibres and particles) from agricultural products as sugar cane, bamboo, ramie, wheat, coir, sisal, pineapple, coconut, paddy, flax, banana, etc., have been used by researchers to produce biocomposites with desirable properties (Prasad *et al*., 2020). The use of agricultural wastes for production of biocomposites with desirable characteristics 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 had a production output of 1.7 billion tons in 2011. 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). Bagasse is the dry pulpy residue left out after the

extraction of sugarcane (Prasad *et al*., 2020). Sugarcane bagasse is a plant fibre, which is also known as lignocellulosic fibre and like most plant fibres, has been gaining attention in its usage in composites due to its unique characteristics with any other reinforcing materials in composite design. 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 suitable reinforcing materials for applications requiring low density and high strength (Loh *et al*., 2013).

Natural fibre-reinforced composites have become potential substitutes for synthetic fibres reinforced composites in various applications because they are readily available, cost-effective, non-toxic, and are biodegradable (Prasad *et al*., 2020). In addition, they demonstrate desirable characteristics like high strength and stiffness, which make them to be very good substitutes for glass or carbon fibres for high strength applications e.g. construction (Prasad et al., 2020). Generally, a composite is any multiphase material that exhibits a significant fraction of each constituent phase's qualities, resulting in a better combination of properties. In line with the principle of combined action, improved property demonstration is expected from the combination of two or more separate elements (Abedom *et al*., 2021).

Many natural fibre 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). However, some steps have been taken to address these challenges. For instance, introduction of surface modifications to improve fibres-polymer matrices compatibility, which can be physical or chemical according to modification technique to reduce hydrophilicity. Furthermore, treatments like bleaching, esterification, plasma and silane treatments, use of compatibilizer, acetylation, alkali application and treatment with other chemicals have also been adopted (Cerqueira *et al*., 2011) and these have proven to be effective and have led to 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; Yashas *et al*., 2018). Another factor that influences the properties of composites is proper filler (fibre) alignment, which causes 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 of the composites (Saw *et al*., 2011; Agunsoye and Aigbidion, 2013; Arrakhiz *et al*., 2013; Mittal and Sinha, 2015; Athijayamani *et al*., 2016; Candido *et a*l., 2017; Omrani *et al*., 2017; Rossignolo *et al*., 2017; Balaji *et al*., 2019; de-Pavia *et al*., 2019; Jafrey *et al*., 2019; Vidyashri *et al*., 2019). Being a waste from agricultural and industrial processes, bagasse could be detrimental to the environment when utilised as fuel. Thus, in developing countries where this biodegradable waste is being generated in large quantities, the use of bagasse in composites production will definitely make such nations to be parts of the global composites industry. This will definitely lead to increased revenue generation and employment opportunities. Improvement on the properties of polymers via blending with natural fillers (particles or fibres) to produce polymer matrix composites is a welcome

development. Therefore, the aim of this study is to produce epoxy matrix/sugarcane bagasse micro particle composites and evaluate their physical and mechanical characteristics.

2.0 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 juice free sugarcane bagasse (piths and peeled rinds) were collected from an open dumpsite. The bagasse (piths and rinds) were soaked in hot water (100 ^{0}C) for 1 hr and rinsed with water to get rid of the easily extracted sugars and colouring matter. They were then soaked for 2 hrs in 1 % NaOH solution (obtained by mixing 1 g of NaOH pellet with 100 ml of water) for lignin and wax content removal. Thereafter, they were washed in water; sun dried, and ground using a grinding machine. The ground powder was sieved to 150 µm using British standardised sieves. Alkaline (NaOH) treatment influences reaction sites on the fibre surface with increased surface roughness, which enhances mechanical characteristics (Bam *et al*., 2019). A wooden mould, beakers, stirrers, and electric weighing machine were used during production and the polymer matrix composites were produced by stir casting. The mould was laminated with a paper tape to ease the removal of the specimen after solidification. A mixture ratio of 2:1 (epoxy: hardener) was used. Measured amounts (5-30 wt. %) of the sugarcane bagasse particles were added to the epoxy as presented in Table 1 and mixed together. The mixtures 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. Chemical composition of sugarcane bagasse is presented in Table 2.

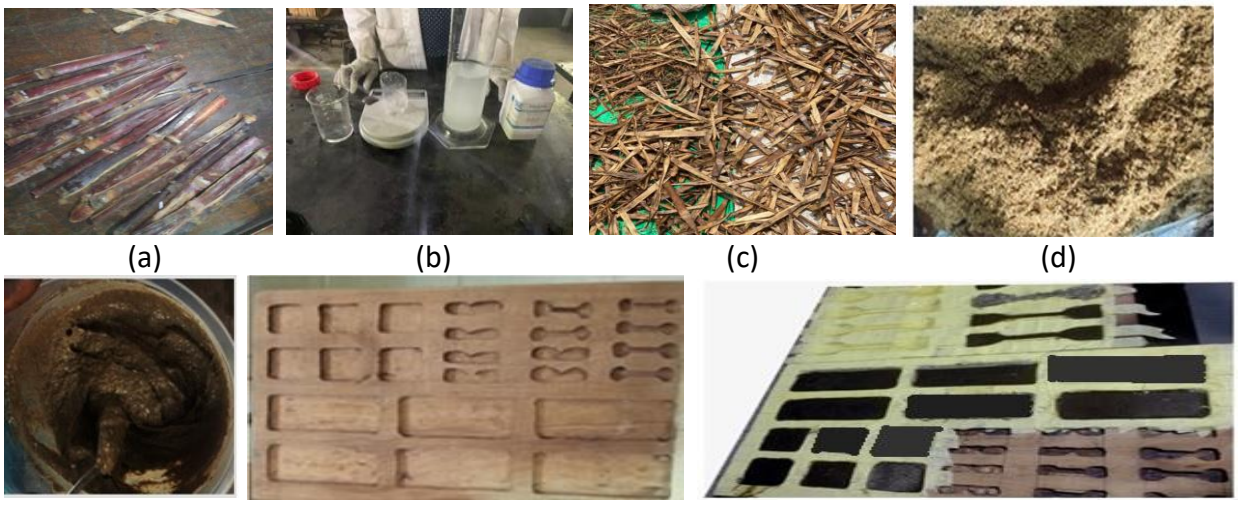


Figure 1: (a) Peeled sugarcane rinds (b) NaOH solution preparation (c) sun dried sugarcane bagasse (piths and rinds) (d) Ground and sieved 150-µm sugarcane bagasse particles (e) Mixed blend (f) Wooden mould (g) Mixed blend in the mould before curing

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 (Ramleea *et al*., 2019)

Component	Weight (%)
Cellulose	49.44
Hemicellulose	23.19
Lignin	12.56
Ash and extractives	14.8

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. 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 their densities were then 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 adhering to standard (ASTM D570-98, 2018) and was determined by applying Eq. (2).

$$Water\ absorption\ (\%) = \frac{W_1 - W_0}{W_0}\ x\ 100 \quad (2)$$

Where:

W_0 = specimen's weight before immersion

W_1 = specimen's weight after immersion

Tensile test was conducted on the specimens 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 centre of the tester and load was applied until fracture occurred. Microhardness test was conducted on the specimens 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 55 mm x 10 mm x 10 mm that have a 2 mm deep V-notch at the centre 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.

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 (SEM) of Figure 2 to 5. The pores reduced with increasing amount of sugarcane bagasse-rind particles in the epoxy matrix as shown in Figure 3 to 5 compared to the control specimen C1. The microstructure of reinforced specimens shows that the phases are not homogeneous as bagasse particles are dispersed in the epoxy matrix as shown in Figure 3 to 5. The EDS spectra confirm the presence of the revealed phases and some indistinguishable phases, which indicates traces of other elements. The good distribution of bagasse particles in the epoxy matrix and the strong interfacial bonding between them caused improved mechanical characteristics (Kaewpirom and Worrarat, 2014).



Figure 2. SEM and spectrum of the control (unreinforced) specimen C1

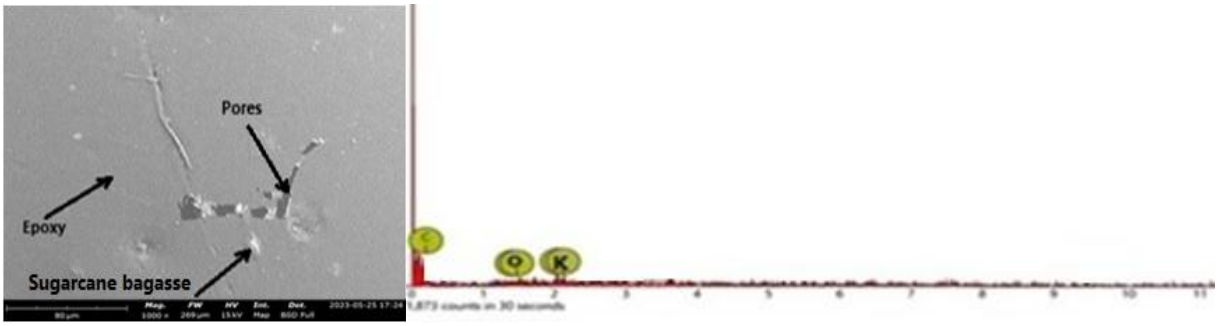


Figure 3. SEM and spectrum of specimen S1

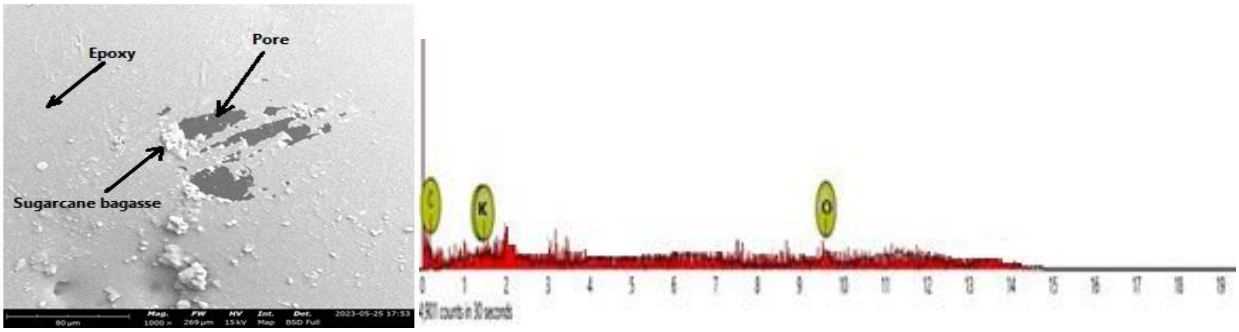


Figure 4. SEM and spectrum of specimen S2

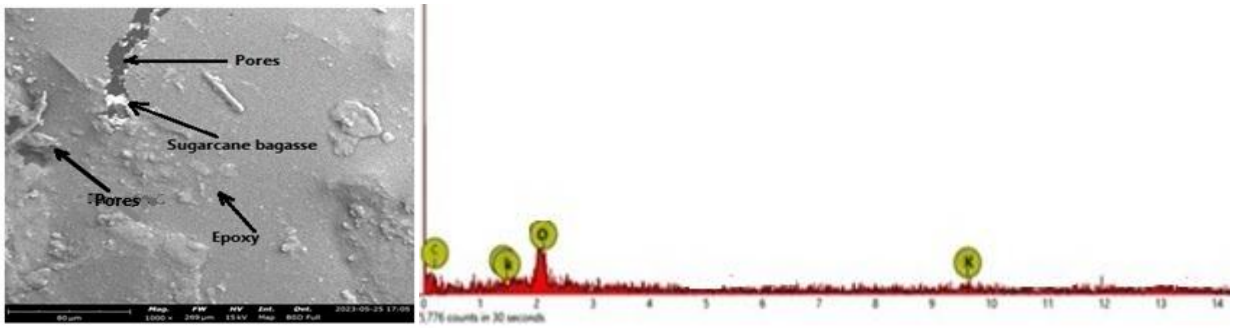


Figure 5. SEM and spectrum of specimen S6

3.2 Density

As shown in Figure 6, there is an appreciable increase in the density of the reinforced composites compared to the unreinforced 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 must have been due to the addition of increasing weight percent of sugarcane bagasse particles.

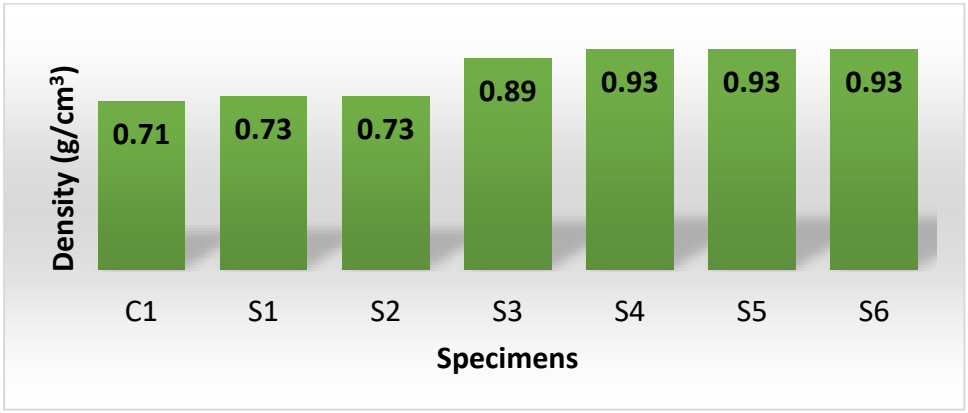


Figure 6. Density of the specimens

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 7. Composites S3, S4, S5 and S6 exhibited reduced water absorption level compared to the control specimen. There are pores in the microstructure of specimens, which aided the penetration of water into them. 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).

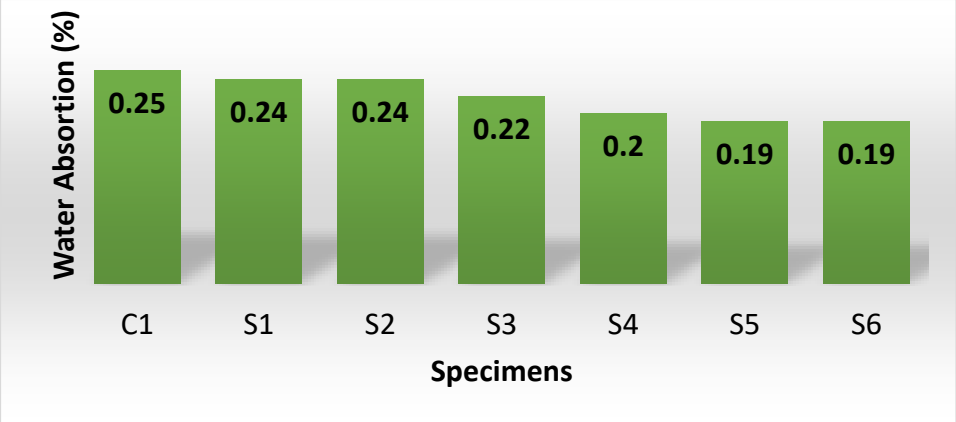


Figure 7: Water absorption of the specimens

3.4 Ultimate Tensile Strength

Generally, the composites (S1 to S6) exhibited improved tensile strength values compared to the epoxy resin specimen in Figure 8. The unreinforced specimen exhibited an ultimate tensile strength (UTS) of 7.21 MPa while specimen S5 containing 25 wt. % of bagasse particles demonstrated the highest UTS of 22.55 MPa, which is 213 % more than C1(control specimen). Alkaline (NaOH) treatment influences reaction sites on the fibre surface and wax layer removal with increased surface roughness, which enhances mechanical characteristics (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).

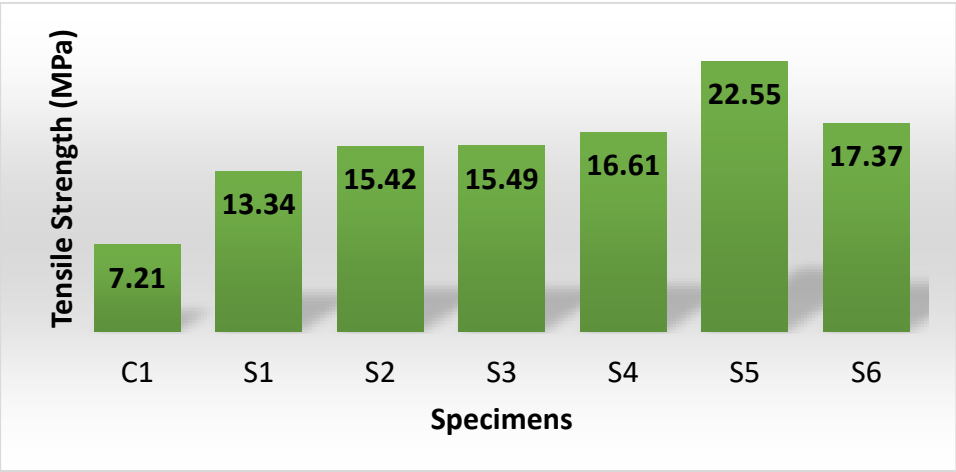


Figure 8. Ultimate tensile strength of the specimens

3.5 Hardness and Impact Energy

Specimen C1 (control) demonstrated a hardness of 18.7 HV as shown in Figure 9. However, specimen S5 containing 25 wt. % of bagasse particles demonstrated a hardness of 23.95 HV, which is the highest. 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 10, 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 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 (Sana *et al*., 2015).

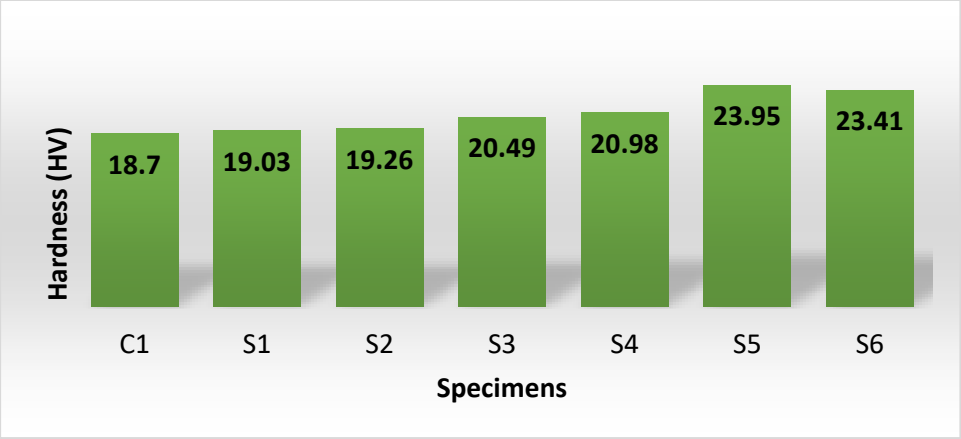


Figure 9: Hardness of the specimens

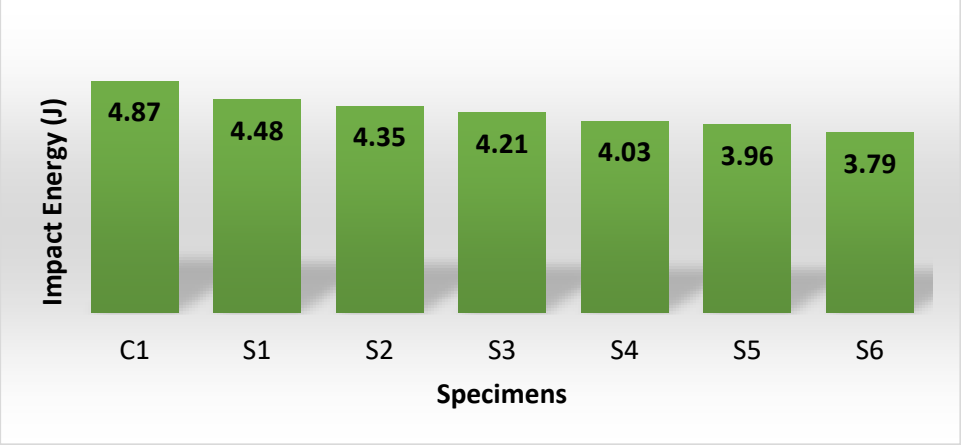


Figure 10: Impact energy of the specimens

4. CONCLUSION

Stir casting technique was used in the production of sugarcane bagasse particle reinforced epoxy matrix biocomposites. The microstructural, physical, and mechanical properties of the composites were evaluated. The followings are the distinguished 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 of 23.95 HV.
- Control specimen demonstrated impact energy of 4.87 J, which is the highest.
- Particles addition led to an improvement in the physical and mechanical properties of the composites except impact energy.

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