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Synthesis and Characterisation of Sugarcane Bagasse and Pineapple Leaf Particulate Reinforced Polyester Resin Matrix Composites

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Highlights

- Effects of particulate reinforcements on unsaturated polyester resin (UPR).
- Adoption of mould casting method for the production of the composite specimens.
- Microstructural and mechanical properties examination of the polymer matrix composites.
- Application of the composites in areas where low strength is required.

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Abstract

In this study, an experimental research was conducted in developing and characterising sugarcane bagasse and pineapple leaf particulate particulate reinforced polyester resin composites. Unsaturated polyester resin (UPR) was reinforced with sugarcane bagasse and pineapple leaf particulates in varied proportions (0 – 25 wt. %) by mould casting. Morphology and mechanical properties of the composites were examined. There was a good dispersion of particulates in the polyester resin. The sugarcane bagasse reinforced composite demonstrated the highest tensile strength, flexural strength, and impact energy of 84.94 MPa, 121.16 MPa, and 7.37 J respectively at 20 wt. % reinforcement. The tensile strength, flexural strength, and impact energy of the composites improved with increasing concentration of the reinforcement. This is an indication of the suitability of the reinforcing materials as fillers for unsaturated polyester resin and an indication of the potential the polymer matrix composite has for low strength applications.

1. INTRODUCTION

Polymers have limitations or disadvantages among which are low stiffness, low impact energy and generally lack of adequate mechanical properties required for application in many areas. Overcoming these shortcomings or disadvantages necessitates the development of polymer matrix composites (PMCs). PMCs are developed to enhance the mechanical properties of polymers for optimum performance. The term “composite” largely refers to materials that consist of a strong load bearing material which is referred to as reinforcement and a weaker material referred to as matrix. The reinforcement strengthens and supports the matrix while the matrix ensures the stability and shape of the reinforcement.

Different types of polymers are used as matrix for producing PMCs. Some of the widely used thermoset polymers are unsaturated polyester resin, epoxy resin, vinyl ester and polyamide [1]. Unsaturated polyester resin (UPR) is made via chemical reaction of saturated and unsaturated di-carboxylic acids and alcohols. It forms durable structures and coatings if cross-linked with a vinyl reactive monomer usually styrene. UPR is characterised by vinyl unsaturation in the polyester backbone and is dissolved in the reactive monomer [2]. UPR is characterised by toughness, rigidity, low moisture absorption and its widely used in transportation sector [3], production of pipes, containers, and paint industry [4].

Synthetic fibres usage as reinforcing materials for producing PMCs is being discouraged because of the high cost and toxicity of fibres. Hence, the need for the replacement of synthetic fibres with non hazardous materials that can serve the same purpose. This becomes imperative as a result of scarcity of resources and

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high level of pollution in many environments. Natural fillers (particulates and fibres) are being sought after in the development of composites because they are inexpensive and are able to reduce pollution of the environment due to the fact that they are biodegradable [2], thereby making these composites essential or relevant to mitigating the pollution of the environments. Natural fillers have desirable characteristics such as stiffness, impact resistance and flexibility. They are also renewable and are readily available in large quantities.

Studies have been done using natural fillers especially bio-particulates to reinforce polymers specifically UPR with appreciable physical and mechanical properties. The influence of difference in particle size and weight percentage on the tensile strength and modulus of elasticity of periwinkle shell reinforced polyester resin composites was studied. The tensile strength and modulus of elasticity increased as periwinkle shell particles size decreased. These properties also appreciated as wt. % of periwinkle particles increased in the matrix [5]. Micro composites of unsaturated polyester resin with different loading of eggshell powder of grain size (36 μm) ranging from 0 to 25 wt. % were developed. Effects of varied eggshell addition on the mechanical characteristics of the composites were studied. Mechanical characteristics reduced in values as eggshell addition increased but treating the filler (eggshell) with coupling agents (mainly stearic acid) enhanced the mechanical characteristics as eggshell addition increased [6].

Effect of varied particles dimension on the characteristics of polyester/palm kernel shell (PKS) particulate composites was investigated. Varied particulates (75, 150 and 300 μm) of palm kernel shell from 0 – 40 wt. % were used to reinforced polyester resin matrix. There was a better interaction of polyester resin and palm kernel shell particles at 300 μm sieve size. Density, water absorption, ultimate tensile strength and impact energy of the composıtes increased as wt. % of PKS particles increased with only hardness decreasing upon increase in wt. % of palm kernel shell [7]. Effect of date palm seed particles on the properties of reinforced polyester resin was also investigated. The tensile strength and hardness of the composites increased showing that date palm seed is suitable for improving characteristics of polyester composites [8].

Mechanical characteristics of snail shell particles reinforced unsaturated polyester composite was also investigated. Unsaturated polyester resin was reinforced with snail shell particulates ranging from 10 – 30 wt. %. Composite with 20 wt. % snail shell addition experienced significant increase in flexural strength. In addition, there was a tremendous increase in impact and hardness characteristics at 5 wt. % snail shell addition [9]. Effects of sunflower husk and pomegranate husk particles on physical and mechanical characteristics of unsaturated polyester resin was also investigated. Water absorption, tensile strength and modulus of elasticity tests were conducted on composite specimens. Results showed that reinforcing polyester resin with husks of pomegranate and sunflower to 10 and 7 wt. % respectively led to a higher tensile strength and modulus of elasticity. Reducing the particles size of the two reinforcing materials increased the tensile strength and Young's modulus [10].

Utilisation of bio-particulate wastes in developing viable engineering materials promotes the concept of waste to wealth. Hence, the objective of this study is to synthesize and investigate the influence of sugarcane bagasse and pineapple leaf particles addition on mechanical properties of UPR for wider engineering applications in areas where low strength is required.

2. MATERIALS AND METHOD

2.1. Materials

The sugarcane bagasse and pineapple leaves used as reinforcements were obtained in Oyingbo, Nigeria. Polyester resin (unsaturated), catalyst and accelerator were obtained from a registered vendor in Lagos. The apparatus used in the preparation of the specimens are wooden mould, masking tape, plastic containers, stirring rod, weighing balance and British standardised sieves (BSS). The photographs of some of these materials are presented in Figure 1.

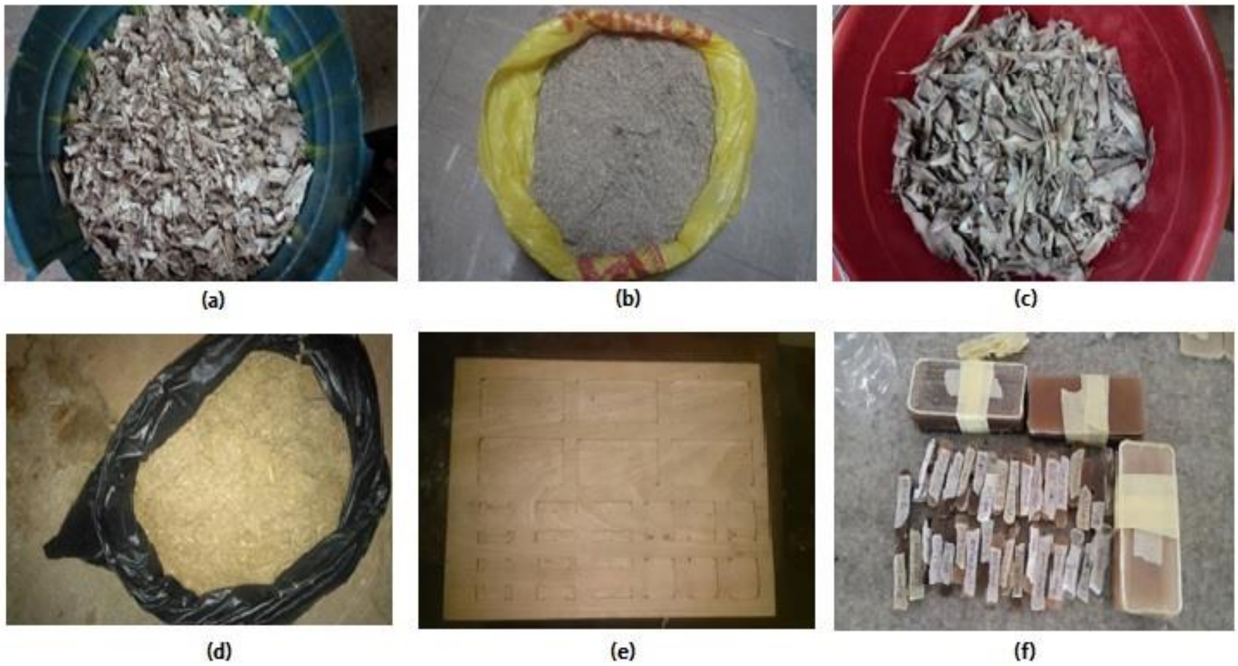


Figure 1. *Details of the materials (a) Dried sugarcane bagasse before grinding (b) 150 μm sugarcane bagasse (c) Dried pineapple leaves before grinding (d) 150 μm pineapple leaves (e) Wooden mould (f) Some of the composite specimens*

2.2. Production of the Composite Specimens

The sugarcane bagasse and pineapple leaves were sun-dried for two weeks. Thereafter, a grinding machine was used to grind the sun-dried sugarcane bagasse and pineapple leaves and sieved to 150 µm using the British standardised sieves (BSS). Measured quantities of polyester resin and hardener were poured into a beaker using a mixing ratio of 2:1 (polyester: hardener). For the first batch, each formulation containing polyester resin (matrix) and sugarcane baggasse particulate were blended in different ratios (Table 1). The blend was properly stirred using a stainless steel rod in order to ensure proper dispersion of the particulate in the matrix and prevent clustering/agglomeration. The blends were fed into a fabricated wooden mould already lined with paper tape that served as a releasing agent. The specimens were stipped from the mould after curing at room temperature. The same procedure was adopted for the second batch containing polyester resin and pineapple leaf particulate.

Table 1. *Materials formulationequat*

Reinforcement (wt. %)	Matrix (wt. %)	Total (g)
0	100	100
5	95	100
10	90	100
15	85	100
20	80	100
25	75	100

2.3. Characterisation of Specimens

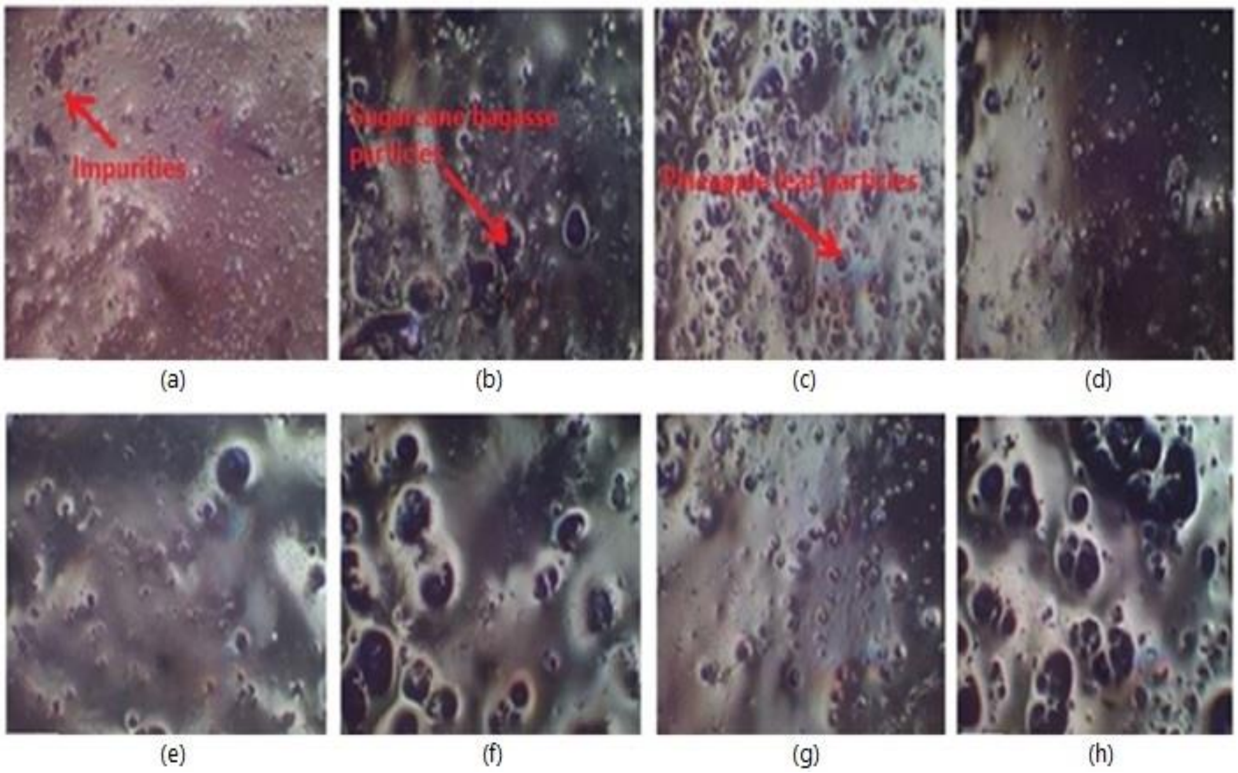
The microstructural features of the specimens were examined using an optical microscope with a camera fitted on it. Tensile test was carried out in accordance with ASTM D412 standard [11] with the aid of an Instron electro-mechanical machine at a rate of 500 ± 50 mm/min until the specimen failed . Flexural test was carried out in accordance with ASTM D7264 standard [12] using crosshead speed of 30 mm/min and span of 100 mm. The energy absorbed before fracture of the specimens was determined according to ASTM

D6110 standard [13] using a Charpy impact tester. Microhardness of the specimens was determined using a Rockwell hardness tester in accordance with ASTM D785 standard [14] using a tester having a 1.59 mm ball indenter and a load of 981 N on a B scale. Three indentations were made on each of the specimens and the average of the hardness numbers corresponding to each of the indentations was obtained.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1. Microstructure

There are impurities appearing as dark particles in microstructure of virgin polyester resin specimen as illustrated in Figure 2a. Some dark particles exist in Figures 2b and 2c that can be attributed to the pineapple leaf and sugarcane bagasse reinforcements. The micrographs show that the reinforcements are evenly dispersed in the polyester matrix. The micrographs of Figures 2d, 2e, 2f, 2g, 2h and 2i also show an increasing amount of particulates in the polyester resin composite. These particulates are also well dispersed in the polymer matrix as seen in specimen micrographs of Figures 2g, 2h, and 2i representing specimens of 15 wt. % pineapple leaf reinforced, 20 wt. % pineapple leaf reinforced, and 20 wt. % sugarcane bagasse reinforced respectively. There is pronounced appearance of more dark patches with agglomeration/clustering of the particulates in the matrix of the micrographs of Figures 2j and 2k representing specimens of 25 wt. % sugarcane bagasse reinforced and 25 wt. % pineapple leaf reinforced. This agglomeration which is attributed to poor distribution of reinforcing particles in polyester resin caused restriction of polyester resin chain movement due to the increased particles concentration and possible reduction in the composites' mechanical characteristics. This agrees with the earlier report by [15].



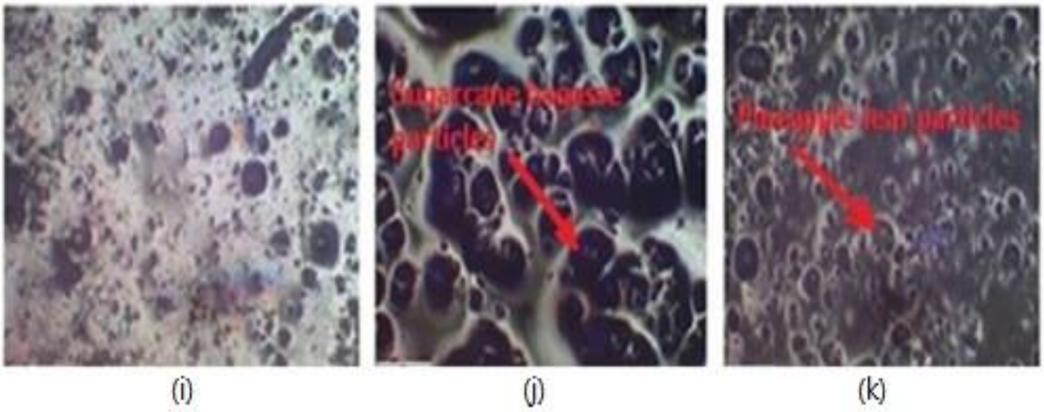


Figure 2. *Micrographs of specimens (a) unreinforced polyester resin (b) 5 wt. % sugarcane bagasse reinforced (c) 5 wt. % pineapple leaf reinforced (d) 10 wt. % sugarcane bagasse reinforced (e) 10 wt. % pineapple leaf reinforced (f) 15 wt. % sugarcane bagasse reinforced (g) 15 wt. % pineapple leaf reinforced (h) 20 wt. % pineapple leaf reinforced (i) 20 wt. % sugarcane bagasse reinforced (j) 25 wt. % sugarcane bagasse reinforced (k) 25 wt. % pineapple leaf reinforced x200*

3.2. Tensile Strength of Specimens

Increased tensile strength was exhibited by the reinforced composite specimens as particles concentration (reinforcement) increased as shown in Figure 3. The virgin/unblended polyester resin specimen exhibited a tensile strength value of 49.92 Mpa. The composite specimen that was blended with pineapple leaf particles exhibited a tensile strength of 73.76 MPa at 20 wt. % reinforcement. This is 48 % higher than virgin/unblended polyester resin specimen. Furthermore, composite specimen that was blended with sugarcane baggase particles exhibited a tensile strength of 84.94 MPa at 20 wt. % reinforcement. This is 70 % higher than virgin/unblended polyester resin specimen. Improvement in tensile strength was because of reduced pores in the specimens and strong interfacial bonding of particulate and polyester resin matrix that led to stress transfer from the reinforcing particles to the polyester matrix. This agrees with the report of [16]. Most likely, there was improved or better interfacial interaction of the sugarcane bagasse particles as well as good dispersion in the matrix, which resulted in enhanced/higher mechanical properties when compared with the results of the pineapple leaf particles reinforced specimens. Beyond 20 wt. % particles addition, reduced tensile strength was demonstrated by the specimens. This was because of reduction in inter-particles spacing as reinforcement increased which increased inter-particles stress concentration overlap and caused debonding because of poor stress transfer between the particles-matrix. This agrees with the report by [17] and [18].

There is clustering of reinforcing particles in polyester resin as revealed by micrographs of 25 wt. % filler concentration (Figures 2j and 2k) and this indicates agglomeration. Basically, aggregated or agglomerated particles are assumed as large particles [19]. High surface area of particles coupled with strong attractive interaction between them led to the aggregation/agglomeration [20,21]. The aggregation/agglomeration of particles decreased the potential enhancement of the mechanical characteristics of composites because of restriction of interfacial area [22,23]. Furthermore, high concentration (25 wt. %) of the particles enhanced aggregation and decreased the interfacial area and induced negative or adverse effects on the mechanical characteristics of the composites [24]. This is because each particle introduced a stiffening effect in polymer matrix by mechanical involvement of polymer chains. The extent of stress sharing between polyester resin and particles depends on interfacial area and stiffness of particles. When isolated and dispersed particles are agglomerated, it is assumed that large particles are developed. The characteristics of the particles are affected and will have adverse effects on the mechanical characteristics of the composites. Large particles generate weak interfacial characteristics and poor tensile strength and modulus of elasticity even at high concentration [19].

The mechanical characteristics of composites decrease when the size of particles enlarges because of agglomeration. Thus, isolating and distributing uniformly the particles in polyester resin at small size to obtain desirable characteristics is important because particles aggregate/agglomerate. Hence, modifying their surfaces or functionalising polymer chains by increasing the chain movement of the polymer can prevent accumulation/agglomeration of particles [20,25]. Thus, supressing or reducing the attractive forces between particles generating aggregation is essential.

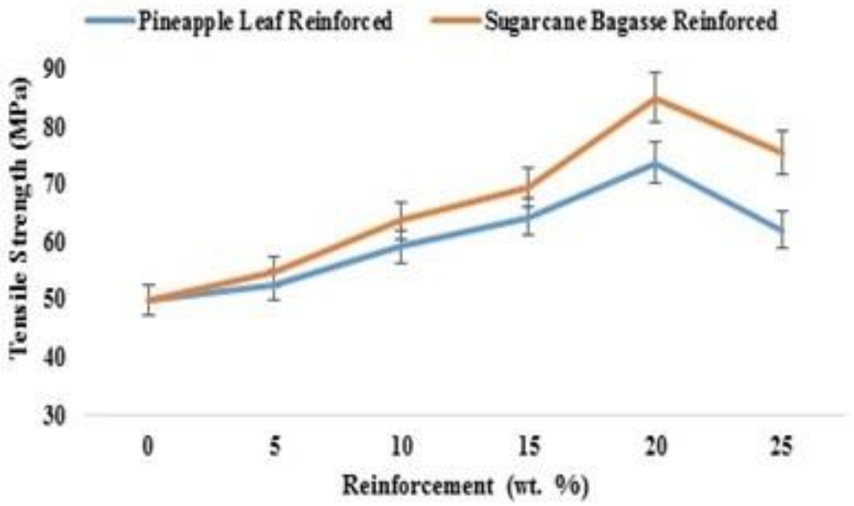


Figure 3. *Line graph of tensile strength against reinforcement of the specimens*

3.3. Flexural Strength of the Specimens

Generally, the composite specimens exhibited higher flexural strength as particles concentration increased in the matrix up to 20 wt. % as illustrated (Figure 4). The virgin/unblended unsaturated polyester resin demonstrated flexural strength value of 63.92 MPa. However, the pineapple leaf reinforced composite demonstrated a flexural strength value of 107.74 MPa at 20 wt. % reinforcement, which is 69 % higher than the unblended polyester resin specimen. Furthemore, the sugarcane bagasse reinforced specimen demonstrated the greatest flexural strength value of 121.16 MPa at 20 wt. % particles addition which is 90 % higher than the unblended polyester specimen. The reinforced specimens demonstarted improved flexural strength because the particles were properly distributed in the polyester resin coupled with strong interfacial bonding of particulates and polyester resin. This agrees with the report by [26] and [27]. Beyond 20 wt. % reinforcement, the flexural strength of the specimens decreased. This might be because of clustering of particles in polyester resin which led to weak particles-matrix interfacial bonding. The adverse or negaitve effect of particles aggregation/agglomeration as discussed under tensile strength is also applicable under flexural strength.

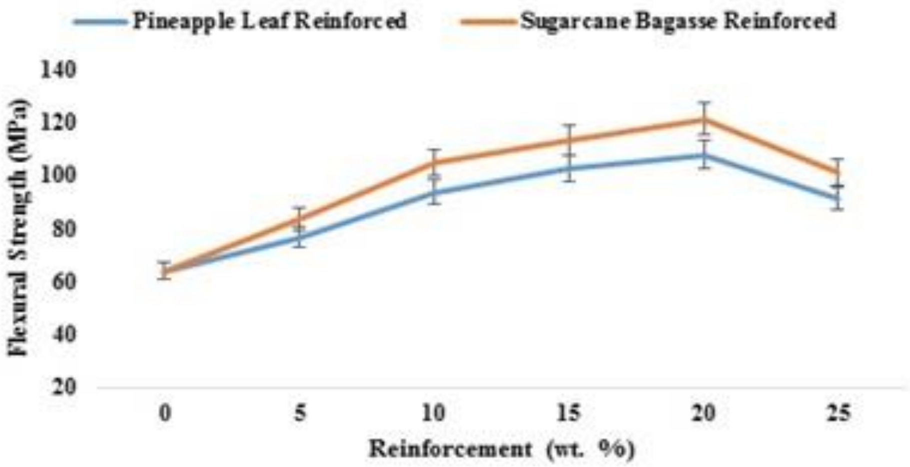


Figure 4. *Line graph of flexural strength against reinforcement of the specimens*

3.4. Impact Energy of the Specimens

The impact energy indicates amount of energy the specimens absorbed prior to fracture. The virgin/unblended unsaturated polyester resin specimen exhibited an impact energy value of 4.68 J as shown in Figure 5. However, the composite specimens exhibited higher impact energy as particles concentration increased in the matrix up to 20 wt. %. The composite specimen that was blended with pineapple leaf particles exhibited an impact energy value of 6.59 J which represents 41 % increase when compared with the virgin unsaturated polyester resin specimen. Futhermore, the composite specimen that was blended with sugarcane baggase particles exhibited an impact energy value of 7.37 J. This represents 58 % increase when compared with the virgin unsaturated polyester resin specimen. The increase in impact energy was as a result of good distribution of particulates in polyester resin and possibly due to strong interfacial bonding of particles and polyester resin. This agrees with the earlier report by [16]. However, when reinforcement was above 20 wt. %, impact energy reduced which could be because of clustering of particles in the resin and adverse effect of particles agglomeration on the mechanical characteristics has been discussed. Generation/development and propagation of cracks during impact [28] could also be responsible for the reduction in impact energy.

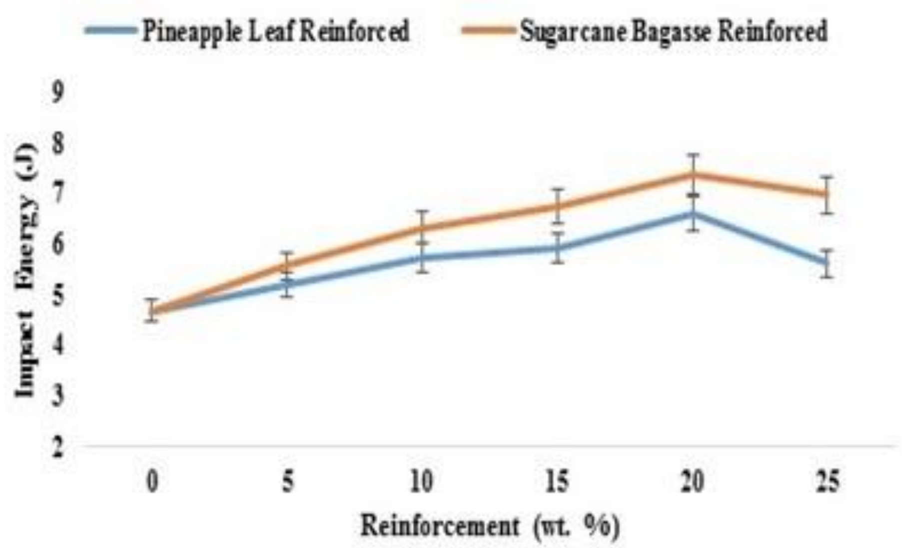


Figure 5. *Line graph of impact energy against reinforcement of specimens*

3.5. Hardness of the Specimens

The virgin/unblended polyester resin specimen exhibited a hardness value of 74.41 HRB as illustrated in Figure 6. The composite specimen blended with pineapple leaf particles exhibited a hardness value of 96.12 HRB at 5 wt. % reinforcement while the specimen blended with sugarcane bagasse particles demonstrated the greatest hardness of 110.17 HRB at 5 wt. % particles addition. However, hardness of composites gradually reduced as particles reinforcement increased beyond 5 wt.%. The reduction was because of clustering of particles in polyester resin. Similar submission was report by [15] and [18] and the adverse effect of particles agglomeration on the mechanical characteristics (hardness inclusive) has been discussed.

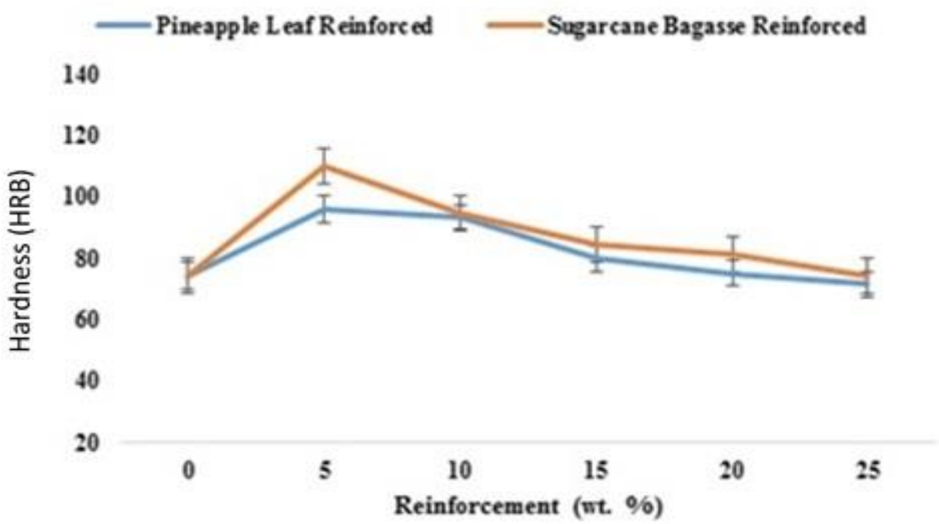


Figure 6. *Line graph of hardness against reinforcement of the specimens*

4. CONCLUSION

Sugarcane bagasse and pıneapple leaf particulate reınforced polyester resın composıtes were developed and characterised. The morphology and mechanical characteristics of the composites have been examined. The composite specimen blended with sugarcane bagasse demonstrated greatest tensile strength of 84.94 MPa at 20 wt. % particles addition. This is 70 % higher than the virgin/unblended polyester resin specimen. It also demonstrated greatest flexural strength of 121.16 MPa at 20 wt. % particles addition which is 90 % higher than the virgin/unblended polyester resin specimen. Furthermore, it demonstrated greatest impact energy of 7.37 J at 20 wt. % particles addition. This is 58 % higher than the virgin/unblended polyester resin specimen. The composites mechanical characteristics were impaired by agglomeration/clustering of particulate in polyester resin. Improved characteristics demonstrated by the composites indicate that particulate of sugarcane bagasse and pineapple leaf are good or suitable fillers for unsaturated polyester resin matrix and the polymer matrix composites have potentials for low strength engineering application.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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