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PHYSICAL, MECHANICAL AND MICROSTRUCTURAL CHARACTERIZATION OF TERNARY HYBRID BIOCOMPOSITES AT VARIED COMPOSITIONS FOR AUTOMOTIVE APPLICATIONS

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Abstract
Growing awareness of the need for new resources that can be biodegradable and environmentally friendly for producing composite materials with higher performance has led to the use of bamboo (B), oil palm trunk (OPT), and plastic waste (P) to create biocomposite materials with greater strength and durability. The P was waste, while B and OPT were sourced locally, processed and produced at varied weight percentage (wt%). Characteristics of each of the materials and impacts of mixture ratio on the composites' properties were investigated and reported. B exhibited the greatest hardness (87.88±0.02 HV), compressive strength (28.32±0.22 N/mm²), and impact strength (437.14±1.43 J/m²) compared to OPT, and P, and the composition with the highest wt% of bamboo showed the highest hardness (95.37±1.73 HV), compressive strength (34.03±0.29 N/mm²), and impact strength (913.81±10.00 J/m²). OPT absorbs more oil (0.4280%) compared to B, and OPT. The micrographs showed reasonable particle reinforcement and interfacial bonding in the material with the highest wt% of B, which validated the mechanical findings. The composite is suitable for structural and semi-structural automotive parts such as bumper reinforcements, fenders, interior trims, dashboard frames, and door panels where durability and resistance to localised stresses are necessary.

Keywords
Bamboo, Biocomposite material, Compressive strength, Impact strength, Structural automotive parts

1. INTRODUCTION

The global automobile industry is being increasingly challenged to go green, utilize sustainable materials and reduce the environmental footprint of automobile production. One solution lies in the production of bio-composites. Biocomposites are sustainable materials produced from natural fibers or agricultural wastes mixed with polymers. Biocomposites not only contribute to waste valorisation but also have better mechanical properties and lower weights compared to conventional materials [1, 2]. Bamboo and oil palm trunk are readily available natural resources in the tropics, particularly in Nigeria. Bamboo has a high strength-to-weight ratio, high growth rate, and ease of processing [3], while oil palm trunk, which is usually considered farm waste, has enough lignocellulosic material that is suitable for composite material reinforcement [4]. At the same time, plastic waste management has become a real challenge since it lingers in the environment. Reuse of recycled plastic as a polymer matrix during composite production has the ability to minimize environmental hazard and provide an economic source of income [5]. Most of the research has touched on the use of natural fibers or recycled plastics alone, or both [6], yet the synergistic behaviour of bamboo, oil palm trunk, and plastic waste for use in hybrid composites is less explored. There is scarce overarching data on how various weight percentages of these materials influence mechanical properties critical to load-bearing applications. Thus, a study on the mechanical behavior of biocomposites at varying compositions is pertinent and timely. The blending of bamboo, oil palm trunk fibers, and plastic waste presents a new composite material for future use in non-structural and structural motor vehicle components. Besides, bamboo and oil palm trunk are renewable, biodegradable, and abundant. By turning them into composite materials, the research not only contributes towards developing sustainable materials but also towards utilizing local content in the automotive sector. Natural fiber composites have been observed to be gaining attention due to biodegradability, renewability, and competitiveness in mechanical performance.

Bamboo fibers exhibit high tensile strength and satisfactory stiffness and are therefore identified as being suitable as structural composite reinforcements [7]. Oil palm trunk fibers, while not being mechanically strong, save cost and weight without sacrificing sufficient compressive resistance in hybrid applications [8]. Recycled plastic matrices, such as polypropylene (PP), polyethylene terephthalate (PET), and high-density polyethylene (HDPE) have been studied with regard to processability and recyclability [9]. A study by [10, 11] showed that hardness increases with weight fraction of bamboo fibers. Higher weight percentage of plastic in a bamboo-based composite leads to higher hardness of the composite [12], while [13, 14] reported that higher percentage of fibers results in enhanced compressive strength. According to [15], increased percentage of bamboo fibers in polypropylene composite resulted in increased elongation at break.

For applications such as interior panels, fenders, and dashboards, crucial properties such as hardness, compressive strength, and percentage elongation at break are important indicators of performance and durability, which is why this study is carried out to investigate the physical, mechanical and microstructural characteristics of a ternary composite made of bamboo, oil palm trunk and plastic waste at varied weight percentages. For the purpose of increasing local capacity in the production of auto parts, a three-component hybrid will be investigated. This study will analyse the mechanical performance of four different weight-percent formulations and the best combination will be determined.

2. MATERIALS AND METHOD

2.1. Materials

The materials utilised in this study include bamboo, oil palm trunk, plastic waste, epoxy resin and hardener. Bamboo was categorized as B, Oil Palm Trunk as OPT, and Plastic waste as P, which was identified as high-density polyethylene (HDPE).

2.2. Tools and Equipment

A chainsaw, hack saw, cross-cutting machine, digital scale, head pan, machete, infrared thermometer, hammer mill, and magnetic stirrer are utilized in this investigation.

2.3. Methods

2.3.1. Production of bamboo powder

According to literature [16], the upper region of bamboo has the best mechanical properties, therefore, the upper portions of bamboo sticks were cut. In order to reduce the effect of water on the mechanical properties of the bamboo, it was dried in the sun [17, 18]. Afterwards, the bamboo culms were cut into strands with a hacksaw and cross-cutting tools. Next, a hammer mill was used to grind the strands into powder (Figure 1).

Figure 1: Processing of Bamboo

2.3.2. Production of oil palm trunk powder

An OPT lying waste after its economic life was obtained and cut into small trunks using a chainsaw. In order to lower its moisture content, the OPT was sundried [17]. Afterwards, a cross-cutting machine and hacksaw were used to cut the OPT into strands (Figure 2). A hammer mill was then used to grind the fiber into powder.

Figure 2: Processing of OPT

2.3.3. Production of plastic powder

Plastic wastes were collected and cut into chips using a hack saw, before being soaked in water for about twenty-four hours to remove impurities, then air-dried. These were melted in a heat between 261 and 310 °C, with the aid of an infrared thermometer. The resulting molten plastic was allowed to cool and solidify. It took around 45 minutes to solidify at room temperature. The cakes were pulverized with a hammer mill (Figure 3).

Figure 3: Processing of Plastic

2.3.4. Fabrication of composite

Following ASTM D5687 guidelines, the constituent parts were first created using the previously synthesised powders from B, OPT, and P. A 2:1 epoxy resin and hardener was used, as per the manufacturer's instructions [19, 20]. 100 weight percent (wt%) of B, OPT, and P were bound, using the resin, respectively. The resin was then used to bond 17 wt% OPT and 83 wt% B, as well as samples A, B, C and D (Table 1). Using a magnetic stirrer, these mixtures were thoroughly mixed for 15 minutes and allowed to cool at room temperature before being moulded. Eight (8) samples—four (4) control samples and four (4) composites—were duplicated and moulded using the compression moulding process to improve data reliability and accuracy. The samples were molded in lubricated Polyvinyl Chloride (PVC) pipes and hoses in compliance with standard procedures, and were held in vices for about 30 minutes for compaction and to reduce porosity. After removal, the samples were left to cure at room temperature for 24 hours but samples made for oil absorption tests were further dried in an electric oven set at 50°C for 12 hours and allowed to cool in a desiccator before being weighed. Following a 24-hour immersion in oil, the samples were taken out and weighed once more in compliance with ASTM F716 guidelines.

Table 1: Materials Composition

Sample	B (wt%)	OPT (wt%)	P (wt%)	Epoxy: Hardener
B	100	-	-	2:1
OPT	-	100	-	2:1
BOPT	83	17	-	2:1
P	-	-	100	2:1
A	50	10	40	2:1
B	55	10	35	2:1
C	45	15	40	2:1
D	50	15	35	2:1

2.4. Tests

2.4.1. Mechanical tests

i. Hardness test: Hardness test was carried out to determine the materials ability to resist indentation, scratching, or abrasion [20]. Composite material with higher hardness will be suitable in automotive applications as such can withstand surface damage from traffic, weather, and other environmental effects. In this study, a Vickers Hardness (HV) testing machine was used to investigate hardness according to ASTM E384. Dimension of the samples is 25 x 6 mm. To increase the accuracy and dependability of the results, the average values of eight samples consisting four control samples and four composites were created and replicated. In order to determine consistency in the hardness across the samples, the Microsoft Excel app was used to find the errors in the average hardness values and reported in Vickers hardness (HV).

ii. Compression test: The ability of a material to bear loads that tend to diminish its size is known as the material's compressive strength. Compressive test is carried out with a universal testing machine (UTM)

according to ASTM D6641 standard. Dimension of the samples was 70 x 7 mm. To increase the accuracy and dependability of the results, the average values of eight samples consisting four control samples and four composites were created and replicated. In order to determine consistency in the compressive strength values across the samples, the Microsoft Excel app was used to find the errors in the average compressive strength values and reported in MPa.

iii. Elongation test: In order determine the ductility of the materials, elongation test was carried out to measure the extension of the materials before breaking under tensile force. Original length of the sample was 30 mm. Equation 1 was used to calculate the percentage elongation.

$$\% \text{ elongation} = \frac{final\ length - original\ length}{original\ length} \times 100 \quad (1)$$

To increase the accuracy and dependability of the results, the average values of eight samples, four control samples and four composites, were created and replicated. In order to determine consistency in the elongation values of the samples, the Microsoft Excel app was used to find the errors in the average elongation values and reported in mm.

iv. Impact test: Impact test was carried out to determine how the materials absorb energy and resist fracture under sudden shock without breaking. The impact test was carried out using the Izod impact testing technique with a 2.7 J hammer in accordance with ASTM D256 guidelines [20]. The specimens were 6 mm by 7 mm in size. To improve the precision and dependability of the findings, eight (8) samples consisting of four control samples and four composites were duplicated, and their average values were calculated. In order to determine consistency in the hardness across the samples, the Microsoft Excel app was used to find the errors in the average values and reported in J/m.

2.4.2. Physical test

i. Oil absorption test: To find out whether the materials can absorb spilled engine oil under specific conditions, an oil absorption test was conducted according to ASTM F726. Sample dimension was 30 mm x 30 mm. Eight samples consisting of four (4) control samples and four (4) composites were produced. Equation 2 was used to obtain the absorption percentages, with D_1 being the initial dry mass sample, and D_2 representing the final wet mass sample.

$$\text{Oil absorption (\%)} = \frac{D2 - D1}{D1} \times 100 \quad (2)$$

2.4.3. Microstructural test

Microstructural test was conducted to reveal the microscopic structure, defects, and phase distribution of the composite materials in order to predict their degradation or failure mechanisms. Scanning electron microscopy (SEM) was used to conduct the microstructural test. Dimension of the sample was 7.5 x 7.5 x 7.5 mm.

3. RESULTS AND DISCUSSION

3.1. Mechanical Properties

3.1.1. Hardness

As presented in Table 2, among the constituents, B exhibited the highest hardness (87.8800±0.0200 HV) compared to OPT (82.4200±0.6500 HV) and P (35.2100±0.1100 HV). Optimizing B with OPT (BOPT) led to an enhanced hardness (97.9000±0.3300 HV) by 11.4019% [21], indicating an existing synergy between both materials and improved interfacial bonding. B contributed to stiffness while OPT provided rigidity. Among the composite samples, Sample B exhibited the highest hardness (95.3700±1.7300 HV) compared to the constituents and other composites samples, and Sample C showed the lowest hardness (81.8300±0.8900 HV). Sample A had 84.2400±3.0300 HV and sample D revealed 91.9200±0.6500 HV. The results demonstrated that sample B with the highest wt% of B and sample C with the lowest wt% of B showed the highest and lowest hardness, respectively [22]. However, the addition of P to BOPT resulted in declined hardness which ranged from 2.6528 to 19.6383%. The inaccuracies in the average hardness values were found using Microsoft Excel application and the results are presented in Figure 4. The error bars show that the deviation in the hardness of the samples is minimal.

3.1.2. Compressive strength

As shown in Table 2, among the individual materials, B exhibited the highest compressive strength (28.3200±0.2200 N/mm²) compared to P (20.2700±0.1700 N/mm²), and OPT (16.9200±0.4200 N/mm²) [23]. OPT's lowest compressive strength can be due to porosity [24], hydrophilicity [25], high wear rate [26] and infestation [25]. B's highest compressive strength can be due to its stiffness [27], which led to strong resistance to compressive loads. P's intermediary compressive strength can be attributed to its non-porous molecular structure and density [28]. Adding OPT to B (BOPT) slightly enhanced B's compression strength (29.7300±0.53 N/mm²) by 4.9788% [29].

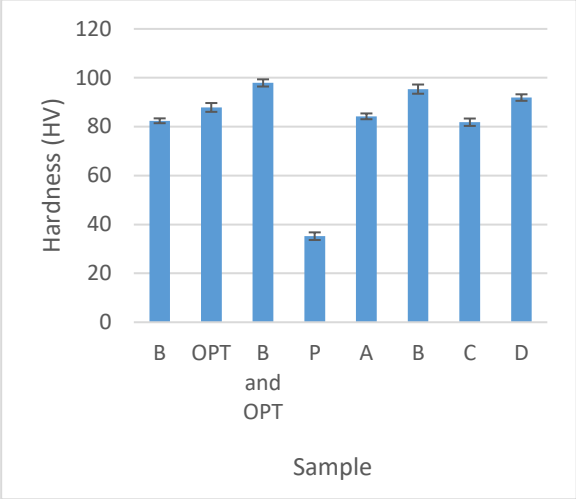

Figure 4: Hardness

The enhanced strength can be attributed to OPT's rigidity, and is in agreement with literature [30, 31]. Afterwards, adding P to BOPT increased the compressive strength further, which can be due to P influencing the load distribution [32]. Sample B showed the highest compressive strength (34.0300±0.2900 N/mm²) among the composite samples, which can be due to increased weight percentage of B. Sample A exhibited a reduced compressive strength (32.6600±0.2300 N/mm²) compared to Sample B, which is an effect of decreased wt% of B, while the compressive strength of Sample D decreased further (31.2500±0.1700 N/mm²) which can be due to a decreased wt% of P and increased wt% of OPT. Sample C shows the lowest compressive strength (30.2600±0.1600 N/mm²) among the composite samples, which can be attributed to decreased wt% of B and increased wt% of OPT. The results demonstrated that the addition of P after optimizing B with OPT resulted in enhanced compressive strength which ranged from 1.7827 to 9.8554%. The inaccuracies in the average compressive strength values were found using Microsoft Excel application and the results are presented in Figure 5. The error bars show that the deviation in the compressive strength of the samples is minimal.

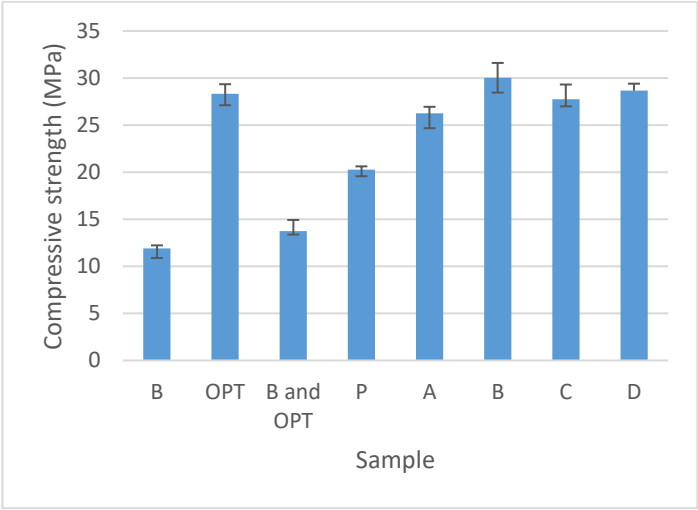

Figure 5: Compressive Strength

3.1.3. Elongation properties

As presented in Table 2, among the individual materials, P shows the highest percentage elongation at break (1.2919±0.0019 mm) compared to B (1.0166±0.0036 mm) [33], and OPT (0.7002±0.0002 mm) [34], which can be due to P's ductile nature, and B and OPT's brittle nature, respectively. Adding OPT to B (BOPT) resulted in decreased elongation (0.8499±0.0049) with 19.6140%, however, adding P to BOPT resulted in improved tensile properties. Sample A demonstrated the highest percentage elongation at break (1.4225±0.0025), which can be attributed to moderate, and average weight percentages of P and B. Sample C exhibited a reduced percentage elongation (1.3556±0.0056), which could be an effect of decreased wt% of B. Samples B (1.2389±0.0049), and D (1.0389±0.0039) demonstrated lower percentage elongation at break and least elongations at break compared to samples C, and A, respectively, which can be due to decreased weight

percentage of P. The findings showed that addition of P to the combination of B and OPT increased the tensile properties with a range of 22.2379 and 67.3726%. These results are plotted in Figure 6.

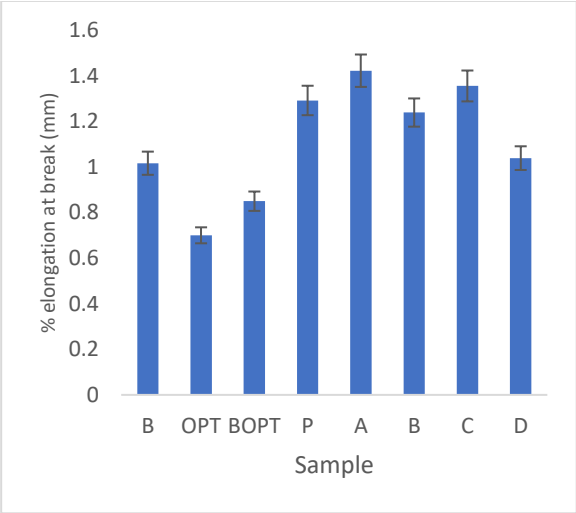

Figure 6: Elongation

3.1.4. Impact strength

As presented in Table 2, B exhibited the highest impact strength (437.1400±1.4300 J/m²) compared to P (408.0900±0.4800 J/m²) [33], and OPT (382.1400±1.1900 J/m²) [21]. Although B enhanced the impact strength of OPT (BOPT) [35], OPT decreased the impact strength of B (420.9500±2.3800 J/m²) when combined, with 3.8461%. The higher impact strength of bamboo can be attributed to its stiffness [36]. Among the composite samples, sample B showed the highest impact strength (913.8100±10.0000 J/m²) which can be due to increased wt% of B, while A revealed a decreased impact strength (829.2900±8.8100 J/m²) and can be an effect of reduced wt% of B. The impact strength decreased further in sample D (788.8300±5.7100 J/m²) which can be due to increased wt% of OPT, and sample C with the least impact strength (738.8100±9.0500 J/m²) can be attributed to decline in wt% of P. The findings showed that addition of P to the combination of B and OPT increased the impact strength with a range between 75.5102 and 117.0828%. These results are plotted in Figure 7.

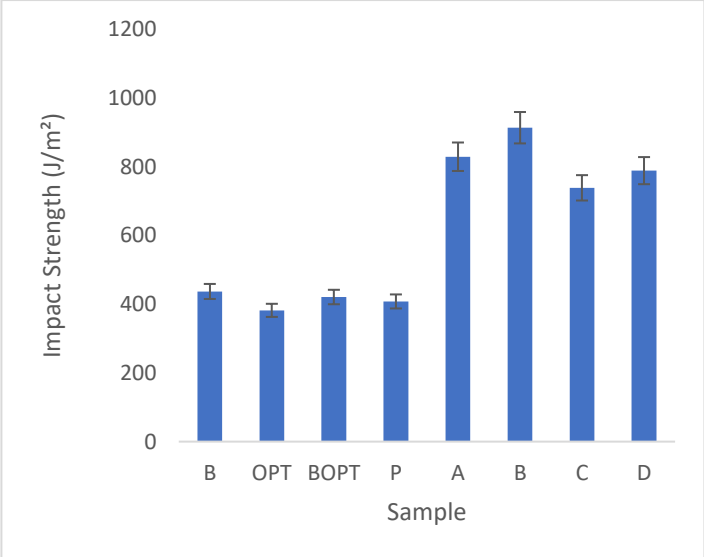

Figure 7: Impact strength

3.2. Physical Properties

3.2.1. Oil absorption

Table 2 shows the percentage of oil absorption of the individual, and composite samples. OPT absorbed the highest quantity of oil (0.4280±0.0005%) compared to B (0.3680±0.0008%), and P (0.3400±0.0010%), which can be attributed to OPT's porosity [37]. Sample D absorbed the highest quantity of oil (1.2000±0.0005) compared to individual and other composite samples. This can be due to increased wt% of OPT and decreased

wt% of P, sample C showed a decreased quantity of oil absorption (1.1760±0.0006) which could be an effect of decreased wt% of B, while sample B absorbed a much lower quantity of oil (1.1200±0.010), and can be due to decreased wt% of OPT, and sample A showed the least oil absorption (1.1150±0.0010). These findings are reported in Figure 8.

3.3. Microstructural Properties

The morphology of the composite materials was determined using SEM. Composite samples A, B, C, and D morphologies are displayed in Figure 9. The 7.5 mm x 7.5 mm x 7.5 mm sample was positioned between 9.8 and 10.5 mm from the lens with a horizontal field of view between 120 and 122 µm and a scale bar showing a distance between 50 and 100 µm. The sample was magnified 9000 times. Although the particles and matrix in sample A indicate strength, the cavity, and debonding affect its mechanical properties. Sample B shows fibers, matrix and particles which influence the strength of the material positively, while sample C reveals layers, debonding, pores, with some particles. The particles indicate reinforcement but the layers, pores, and debonding point to poor integration of the constituent materials. Sample D shows fibers arranged horizontally with interface between the fibers and matrix, as well as visible pores [20]. These indicate that while the fibers enhance the strength of the composite material, the pores adversely reduce it. Overall, sample B generally shows better microstructural properties compared to samples D, A, and C. These microstructural characteristics confirms the mechanical properties of the composite samples.

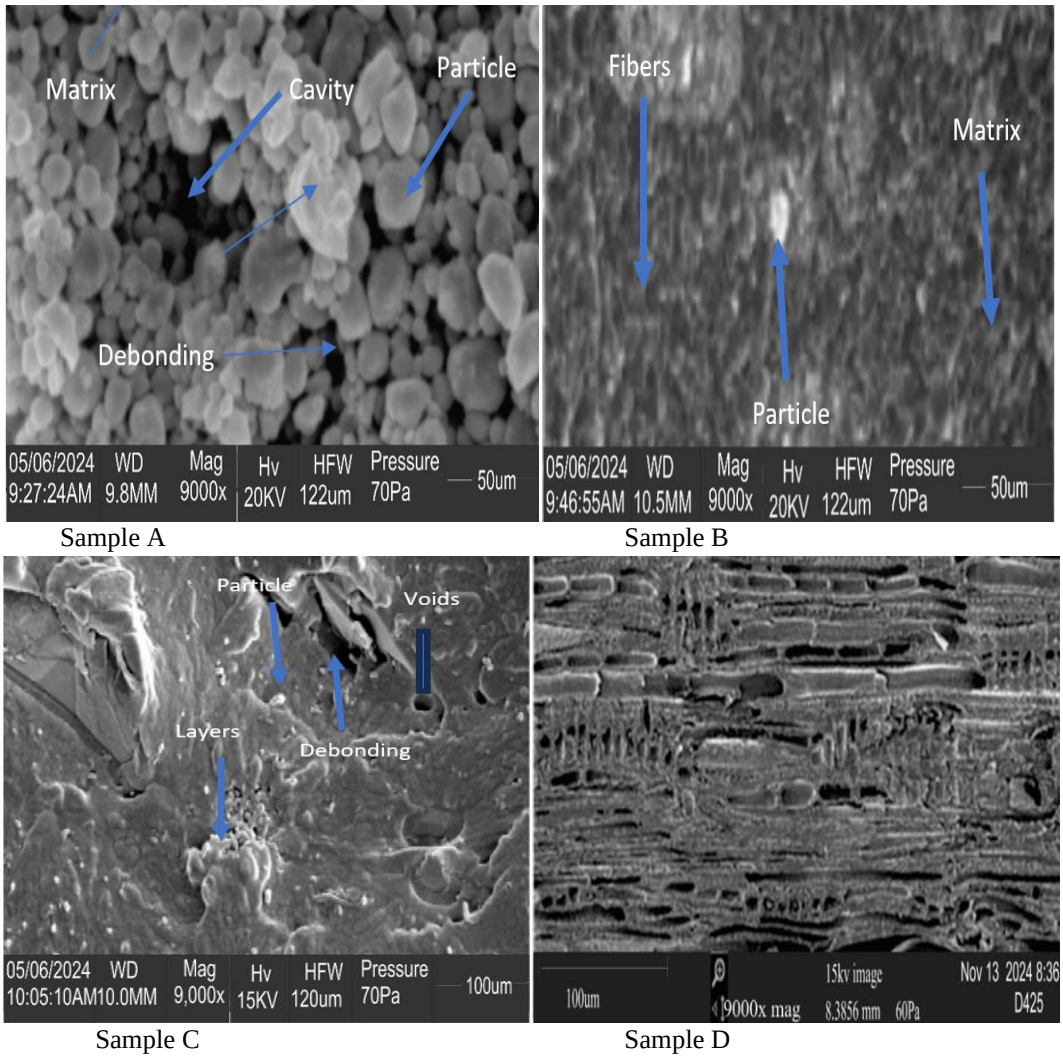

Figure 9: Micrographs of the composites

4. CONCLUSION

The results of this study demonstrated the impact that increase in the weight percentage of bamboo, oil palm trunk, or plastic has on the properties of composites made of the three materials bonded with epoxy resin. The outcome demonstrated that increased weight percentage of oil palm trunk enhanced the hardness, and

compressive strength of bamboo, and the further addition of plastic to the combination significantly improved the compressive strength, but decreased the hardness. Elongation at break of the composite largely depended on the weight percentage of plastic in the mixture, as the higher the weight percentage of plastic, the higher the deformation before failure. Increased weight percentage of bamboo significantly enhanced the impact strength of the composite. Microstructural examination reveals the behavior of the composite samples, and aligns with the mechanical strengths. The material with the highest weight percentage of bamboo largely demonstrated the best mechanical and microstructural properties. This study offers significant insights into the production of sustainable materials, by supporting the reuse of plastic wastes, and oil palm pseudo-trunks that have lost their economic value rather than burning them and harming the environment. The materials' performance can be considered and used in the production of automobile components, with respect to desired mechanical properties of the proposed component. These composite materials have applications in automobile components such as fender, brake pad, switch control panel, door trims, and underbody shields. These findings will assist local manufacturing and reduce the overdependence on imported car parts. Through the integration of renewable resources, waste valorisation, and decreased embodied energy, the material delivers quantifiable environmental gains over traditional automotive composites despite containing synthetic resin. However, in order to reach totally renewable composite materials while upholding automotive performance standards, future study will include bio-based resin, which is presently under study.

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