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Special Issue
A Themed Issue in Honour of Professor Clement Uche Atuanya on His retirement.

This themed issue pays tribute to Professor Clement Uche Atuanya in recognition of his illustrious career in Metallurgical and Materials Engineering as he retires from Nnamdi Azikiwe University, Awka. We celebrate his enduring legacy of dedication to advancing knowledge and his impact on academia and beyond through this collection of writings.

Edited by
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Wear resistance and tensile behaviours of bamboo fibre and mangifera indica particulate epoxy resin composite

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Abstract
Pursuing an eco-friendly environment has resulted in the recent creation of polymer matrix/green plant fibre composites. The study explored the effect of bamboo fibre and mangifera indica particulates on epoxy resin bio-composites structure and mechanical properties. The materials used are bamboo fibre, mangifera indica particulates, and epoxy resin sourced locally. After the thin layers of bamboo bark were carefully removed, the bamboo fibre was extracted manually by peeling down the cylinder culm of the bamboo to produce strips with varying diameters and lengths. Also, the mesocarps from Mangifera indica fruit were removed manually and the endocarps obtained were subjected to sun drying. The endocarps were then manually cracked and separated to obtain the required shells. The biocomposite samples were fabricated through the hand layup technique. The composite samples were fabricated in three separate groups of bamboo fibres of 5wt%, 10wt%, and 15wt% with variable percentages of Mangifera indica particulates of 5wt%, 10wt%, 15wt%, 20wt%, and 25wt% using epoxy resin. The tests carried out are tensile strength by ASTM 638-10 standard test and wear resistance test. A scanning electron microscope was conducted to analyze the results of tensile strength test. The results show that the tensile strength of composite samples reinforced with 10wt% bamboo fibre and varied percentages of Mangifera indica particulates were superior compared to those reinforced with 5wt% and 15wt% bamboo fibre and varying percentages of Mangifera indica particulates. The structural analysis revealed that significant improvements in tensile strength can be attributed to fibre-matrix interfacial bonding and fibre alignment along the direction of load application. The decrease in wear rate can be attributed to an increase in the reinforcing content, which hardened the hardness of the composites. It was also established that increasing the period of wear resistance testing causes an increase in wear rate across all weight fractions

Keywords: Epoxy resin, Bamboo fibre, Mangifera indica particulates, tensile strength wear rate

1. Introduction

The need for agricultural waste materials as an alternative to high-density, costly, and ecologically harmful organic reinforcement for composite materials has skyrocketed (Achebe et al. 2019; Ekwedigwe et al. 2023; Abdel-Salam et al. 2011). These naturally available wastes have good properties such as high strength, lightweight, cost-effectiveness, and free of hazardous chemicals during use. Research has proven the reliability of natural waste materials as a good replacement for glass fibre for polymer reinforcement (Adebisi et al. 2011; Aderiye, 2014). The emergence of agricultural waste materials will help curb the dangerous menace of environmental pollution posed by using synthetic materials or glass as reinforcement in composite production (Yawas et al. 2013; Zamri et al. 2011; Okoye et al. 2023). From previous studies, composite material reinforced with natural fibres has been identified with good resistance to chemical attack, better acoustic insulation; and good thermal and electrical properties (Ekwedigwe et al. 2023; Mohamed et al. 2021; Kannan et al., 2013).

The three main categories of natural reinforcements are fibres originating from plants, minerals, and animals. Fibres made from animals include silk, wool, goat hair, and horse hair. Wollastonite, fibrous brucite, and basalt are examples of mineral derivatives (Abdel-Salam et al. 2011; Okubo et al. 2005). Researchers are paying close attention to plant-based natural fiber composites due to their advantages over synthetic fiber-reinforced composites, which include less negative impacts on human health and environmental friendliness. Additionally, while machining composites, the presence of natural fibers reduces tool wear (Tokoro et al. 2008; Nwoye et al. 2023). Due to its low weight, natural fiber composites are being used in a variety of industries, including the automotive, construction, plastics, and biomedical sectors. Cotton, bamboo, jute, hemp, kenaf, ramie, coir, sisal, and date palm are examples of plant-based fibers. However, there are also increasingly uncommon but emerging species that produce abundant and environmentally beneficial fibers, such as Polyalthia Longifolia, Mangifera Indica, Palmyra, Calotropis Procera, Grewia Serrulata, Cyperus Pangorei, Phoenix SP., Grewia optiva, Bauhinia Vahlii, Himalayan Nettle, and Himalayan Agave fibers (Prihandani et al. 2016; Nwambu et al. 2024).

Many researchers have determined that agricultural biomass solid wood derived from bamboo is the largest source of natural fiber and cellulose fiber biocomposite, both of which are inexpensive and will revolutionize the manufacturing and production industries (Scurlock et al. 2000; Fowomola, 2010). In Africa, the amount of wasted mango seeds (which include crude protein, oil, ash, crude fiber, and carbs) reaches 4 million tons year, although the amount that can be utilized is at least 200 thousand tons annually. Despite the potential of Mangifera indica particulate and bamboo fibre nano cellulose, research on their combined use in bio nanocomposites remains limited (Fowomola, 2010). A study by Abdel-Salam, et al. (2011) revealed improvements in flexural strength, and hardness of high-density polyethylene by incorporating hybrids of maleic anhydride-treated banana fiber/fly ash cenospheres eco-friendly materials. The study also recorded an increase in stiffness and high-energy dissipation of the biocomposite.

Ekwedigwe, et al. (2023) in their study of the viscoelastic performance of epoxy/kenaf, epoxy/bamboo, and epoxy/bamboo charcoal biocomposites recorded a transition temperature range of 60 °C to 90 °C, with epoxy/bamboo charcoal biocomposites recording the maximum thermal stability at 348 °C while epoxy/kenaf biocomposite showed better stiffness and high energy storage capacity. The reinforcing materials play a significant role in determining the overall performance of the composites (Nwambu et al. 2023). Different approaches adopted to improve the performance of particulate-reinforced epoxy matrix include finding alternative and cheaper reinforcements for it. Industrial wastes and agro-waste derivatives are some of the alternative reinforcing materials that have been investigated (Achebe et al. 2019; Okoye et al. 2023). Plant fibers, because of their low density, their specific properties (property-to-density ratio), strength, and stiffness are comparable to the values of glass fibers. They are light compared to glass or carbon fibers. On the other hand, the biodegradability of plant fibers can contribute to a healthy ecosystem while their low cost and high performance fulfill the economic interest of the industry. Therefore, the study will focus on the tensile strength and wear resistance performance of bamboo fibre/Mangifera indica particulate/epoxy resin composites.

2.0 Material and Methods

High-grade epoxy resin and hardener were procured from Demolinks Enterprise Nigeria Limited, Awada Onitsha, Anambra State, Nigeria while the bamboo fibres and Mangifera Indica shell were sourced from Umuokpu Building Materials Market at Awka and Obolo Afor in Udenu Local Government Area of Enugu State, Nigeria, respectively. The sodium hydroxide for chemical treatment was sourced from Mexico chemical Nig. Ltd, Bridge Head market Onitsha, Anambra State, Nigeria. The reinforcing material utilized in this study was the column of giant bamboo. Fibres were extracted by scraping off manually with a sharp blade from soaked culms and sun-dried. The longitudinal orientation of the fibre matches with the column and corresponds to the original direction of the bamboo cellulose fibres. Then, the bamboo fibres were sun-dried for 72 days to remove any moisture. Finally, fibres were soaked in NaOH solutions at room temperature for 24 hours. After its alkali treatment, fibres were washed thoroughly with water to neutralize pH, and sun-dried in air for 48 hours.

The chemical treatment method enhances the interfacial adhesion (strength) between the natural fibres and the epoxy matrix. Generally, the modification of bamboo fibre (chemical treatment) is an effective method to take off the impurities and remove the bond between the natural fibres in which the resultant composites in various percentages will get different results of testing. The sourced Mangifera indica fruits will be washed properly with distilled water and dried adequately to remove sand and other impurities from the surface of the material. The mesocarps will be removed manually and the endocarps obtained will be subjected to sun drying. The endocarps will be manually cracked and separated to obtain the required shells. The shells will be subjected to alkalization treatment using 5% volume of sodium hydroxide solution at 40°C for 2 hours. The shell will be removed from the solution, washed using distilled water, and dried again under the sun. The treated Mangifera indica shells were ground to a fine powder and sieved to obtain a particle size of 63μm.

2.2 Sample Manufacturing

A galvanized iron mold of dimension 280mm × 280mm × 4mm produced the composite samples. The mold was laid on a clean smoothed surfaced wood and wax was applied inside the molding area to easily remove the samples. By using traditional hand-lay-up techniques, the hybrid reinforced epoxy resin composites were created using three different weight proportions of dry bamboo fiber (5wt%, 10wt%, and 15wt%) as suggested by Mohamed et al. (2021) and Ayedh et al. (2021) to provide the best mechanical properties combined with varying percentages of Mangifera indica particulate (5wt%, 10wt%, 15wt%, 20wt%, and 25wt%). The volume fraction of each of bamboo fibre samples (0.05, 0.1. 0.12, 0.17 & 0.19) and Mangifera Indica particulates (0.08, 0.13, 0.16, 0.2 & 0.26) in the composite. For uniformity concerns, the mangifera indica particle was completely distributed throughout the matrix material using a Digital Sonicator (Q-700-200, Qsonica, Newton, USA). The supplier and existing literature, Debnath et al. (2013), advised blending the low-temperature curing epoxy resin and matching hardener in a 10:1 weight ratio. Before the bamboo fiber mats were reinforced in the matrix body, the mixing was carefully done. A modified hand lay-up approach and light compression molding were used to create the composite slabs. Applying a releasing agent ensured an easy release of the composite from the mold once it had cured (Silicon spray).

Mangifera indica powder-filled epoxy composites were handled carefully to guarantee a homogenous sample because mixed solid particles tend to clump and tangle. Before being taken out of the mold, the composites had to cure for 24 hours while bearing a 25 kg weight. After being taken out of the mold, the composite slabs were post-cured in the air for an additional twenty-four hours. Using a diamond cutter, specimens of the sizes required by the relevant standards were cut from the prepared composite slabs for testing. During the fabrication process, great care was taken to maintain the homogeneity of the composite. Sixteen composite samples were generated from the experiment procedure, ''SP'' to denote specimens of fabricated composites. The composite samples that are reinforced with 5wt% of bamboo fibre and (5wt%, 10wt%, 15wt%, 20wt%, and 25wt%) of Mangifera indica particulate are designated as SP1, SP2, SP3, SP4, and SP5. Also, 10wt% of bamboo fibre and (5wt%, 10wt%, 15wt%, 20wt%, and 25wt%) of Mangifera indica particulate are designated as SP6, SP7, SP8, SP9, and SP10. Furthermore, 15wt% of bamboo fibre and (5wt%, 10wt%, 15wt%, 20wt%, and 25wt%) of Mangifera indica particulate are designated as SP11, SP12, SP13, SP14, and SP15.

2.3 Mechanical Test

2.3.1 Tensile test

The tensile strength measurements were performed on a testometric testing machine at the University of Lagos, Nigeria. For the tensile test, the dry composite samples were 160mm×20mm× 4mm in dimension by ASTM 638-10 standard test method for tensile properties of the polymer. The tests were performed at a constant strain rate of 0.5mm/min. the maximum tensile strength was calculated by the equation:

$$Rt = \frac{Pmax}{Bd} \quad (1)$$

Where,

B = width of the reduced cross-section of the specimen measured in dry conditioning (mm), D = thickness of the specimen measured in dry condition, Pmax = maximum tensile load (N), R_t = maximum tensile stress (MPa).

2.3.2 Wear resistance test

The wear test was conducted at the Mechanical Department Laboratory of the University of Lagos, Nigeria. Wear rate measurements were performed using friction and wear testing equipment (Tabar Abrasion Tester). To evaluate the durability of the materials in sliding contact with another surface under different conditions (load, distance, time, and weight fraction), prepared samples were tested under dry sliding wear conditions. Dry sliding wear was carried out using a pin on disc equipment. Cylinder specimens of 15 mm diameter and 25 mm height were used as test samples. Wear studies were conducted under varying conditions of load and sliding velocities. Measurement of wear loss of the pin was used to evaluate the volumetric loss (VL) during the wear test. The load was varied from 4.5N while the disc speed was fixed at 123 rpm and time duration of 30s, 60S, and 90s per wear session. All the tests were conducted in the air at room temperature. The weight loss method was used to calculate the wear rates. The wear rates of all the specimens were obtained. Furthermore, the specific wear rate of the samples was calculated using the weight loss method given in Equation 1. The determination of the specific wear rate was based on derivations of Wear rate, Wear volume, Sliding distance, and Weight loss. The formulas used are given in Equation (1)-(5).

$$\text{Weight loss} = W_0 - W_1 \quad (2)$$

Sliding Distance (m) = $2\pi NDt$ (3)

Where, N=radial speed (rpm=123.3), t=time, ΔW=Change in weight, D=disc diameter (100mm)

Wear Volume (m3) = $\frac{Weight\ loss\ (g)}{Density\ (\frac{g}{cm3})} x1000$ (4)

Wear rate (mm3/m) = $\frac{Wear\ Volume}{Sliding\ Distance}$ (5)

Specific wear rate (mm3/Nm) = $\frac{Wear\ rate}{Load}$ (6)

3.0 Results and Discussions

3.1 Tensile strength of the fabricated composite samples

The effects of bamboo fibre and Mangifera indica particulate on the tensile strength of the epoxy polymer matrix are presented in Figure 1.0. In general, as the weight percentage of bamboo fiber and mangifera indica particle increases, so does the tensile strength of the reinforced composite samples. When compared to other composite samples, the samples reinforced with 10wt% bamboo fibre and 20wt% Mangifera indica particles had the best tensile strength (113MPa). Furthermore, the composite samples with 10wt% of bamboo fibre and Mangifera indica particulates exhibit higher tensile strength values than the samples with 5wt% and 15wt% of bamboo fibre and mangifera indica particulates, respectively. These significant improvements can be linked to the fibre-matrix interfacial bonding and fibre arrangement along the direction of the load application. As shown in Figure 1.0, the increase in the concentration of reinforcements up to 25% led to a slight decrease in the ultimate tensile strength as seen in composite sample SP5, SP10 and SP15. This can be associated with less binding force, making the composite brittle. The ultimate tensile strengths of the samples with less reinforcement materials, SP1, SP6, and SP11, are, however, lower at 28.15 MPa, 43.38 MPa, and 56.03 MPa, respectively. This outcome is consistent with the epoxy biocomposite study findings of Ekwedigwe et al. (2023).

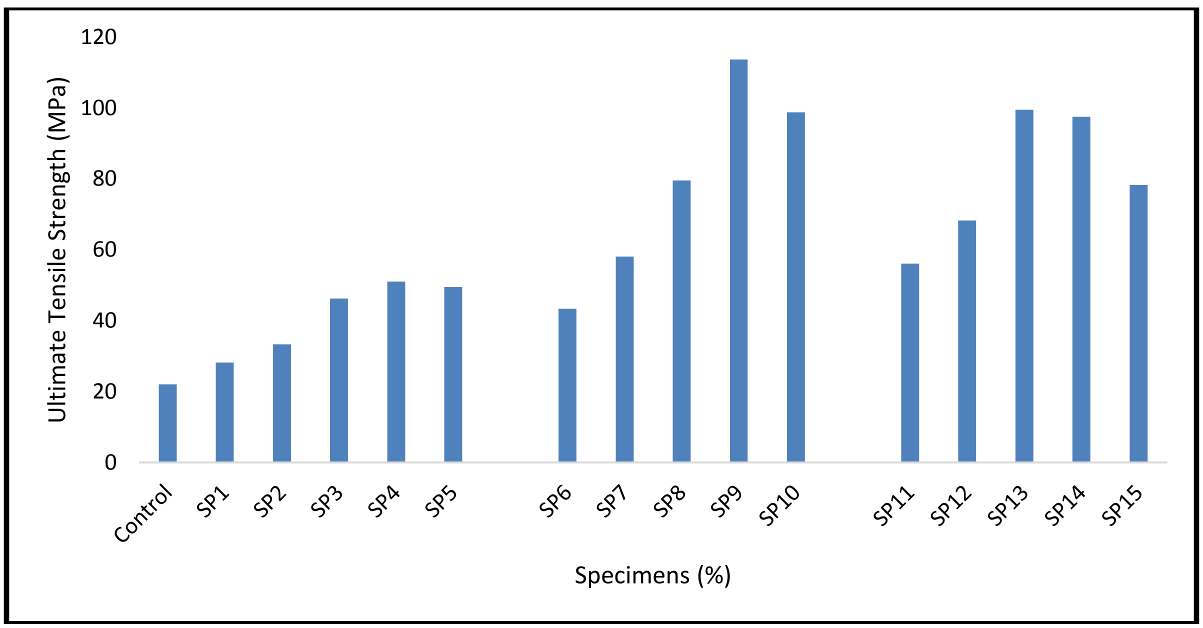

Figure 1.0: Effect of bamboo fibre and mangifera indica particulate on the tensile strength of epoxy composite.

3.2 Wear resistance behavior of the composite samples

Weight loss describes the amount of worn debris occurring during dry sliding wear and is fundamental to explaining the tribological behaviour of materials. The composite samples designated as specimen A, specimen B, specimen C, specimen D, and specimen E were chosen for the wear resistance test. These samples are reinforced with 10wt% bamboo fiber and (5, 10, 15, 20, & 25) wt% Mangifera indica particle. Figure 2.0 shows the weight loss in gram of bamboo fibre and Mangifera indica particulate /epoxy composites at loads of 4.30N while the disc speed was fixed at 123 rpm and time duration of 30s, 60S, and 90s per wear session. There is a general reduction of weight loss of composite samples tested under time duration of 30 seconds when compared to the specimens tested under time duration of 60 and 90 seconds. The significant reduction is attributed to increase in volume fraction of reinforcements in the matrix. This outcome is consistent with that of Nanda and Satapathy (2020), who found that longer wear resistance test durations are predicted to result in greater weight loss.

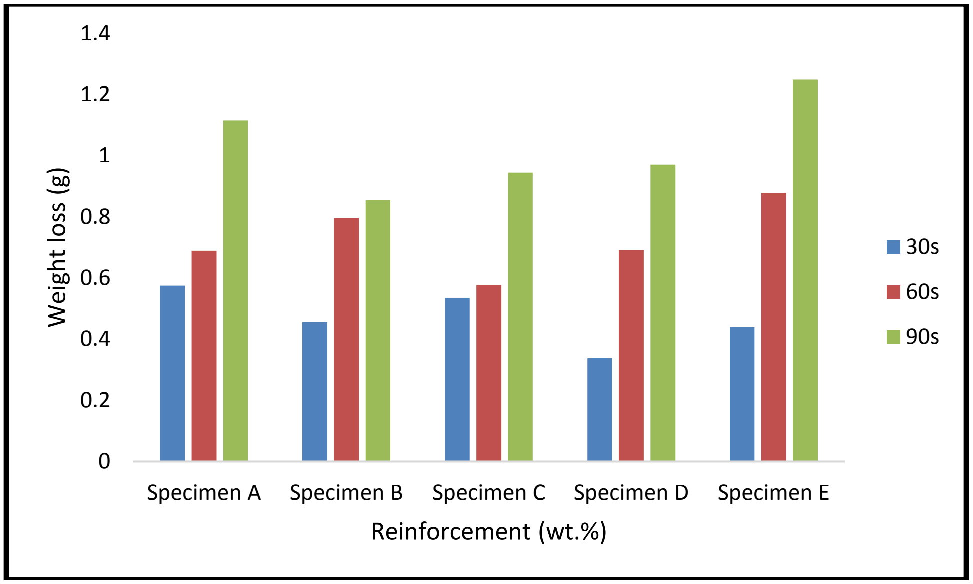

Figure 2.0: Weight loss of bamboo fibre/Mangifera indica particulate /epoxy composite

Wear rate and Specific wear rate

Figures 3.0 and 4.0 show the wear rate and specific wear rate of bamboo fibre/Mangifera indica particulate /epoxy composites at 4.30N while the disc speed was fixed at 123 rpm and time duration of 30s, 60S, and 90s per wear session. For specimen A composites, show higher wear rate when compared to other composite samples with higher reinforcement materials. The decrease in wear rate can be attributed to increase in the content of reinforcement materials which are expected to heighten the hardness of the composites. This suggests that presence of bamboo fibre and mangifera indica particulate play a significant role in determining the wear rate of the bio composite (Nanda and Satapathy, 2020).

Generally, all the composites tested under higher time duration show the highest specific wear at across board. The reinforcement materials are expected to protect the matrix from wearing off while the reinforcement form a tribo layer to resist wear, thus, the expected improved wear reduction. It is observed that increase in testing duration leads to increase in wear rate and specific wear rate at all weight fractions. This indicate that wear testing time is a determinant factor in evaluating bio composite wear rate.

3.3 Micro structural analysis of the fractured surface

The scanning electron microscope (SEM)JEOLJSM-6480LV was used to analyze the fracture composite samples after mechanical test. Figures 5.0 to 8.0 show different phase structure of selected composite samples with the best mechanical performance, (Control, SP8, SP9 and SP10). The composite samples after the tests were cut to specific dimensions cleaned properly and mounted cross section wise on the Scanning electron microscope. Figure 5.0 shows that the specimen is mainly matrix failure. Figure 6.0 shows that failure of the specimen is mainly because fibres are being pulled out from matrix. Since the tensile and flexural strengths were higher, more bending forces are required to fracture fibre and pulled them out from the matrix. The interfacial adhesion between fibre and matrix is much better as shown in Figure 7.0. However, according Figures 8.0 greater fibre-matrix bonding was experienced in the hybrid composite samples which lead to higher flexural and tensile strength.

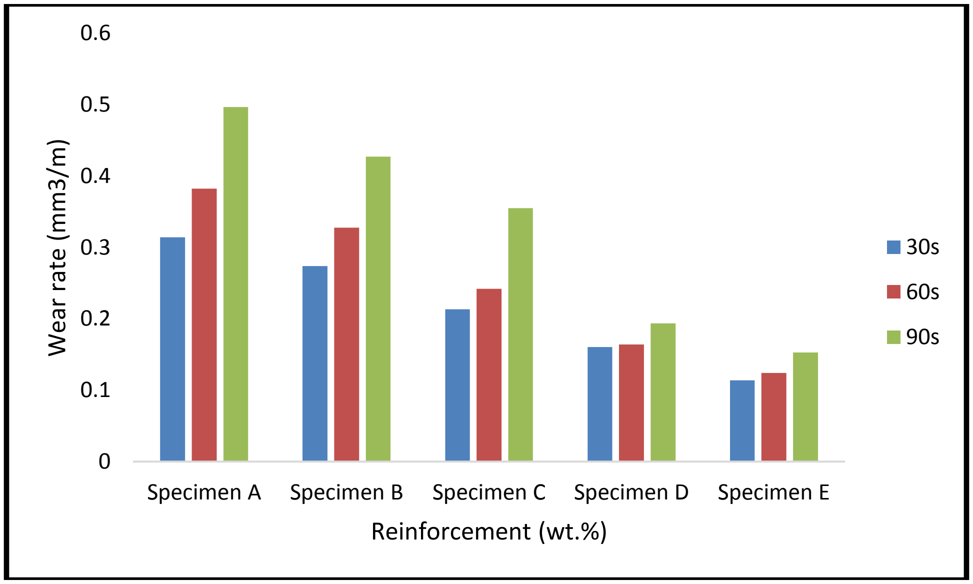

Figure 3.0: Wear rate of bamboo fibre/mangifera indica particulate/epoxy composites

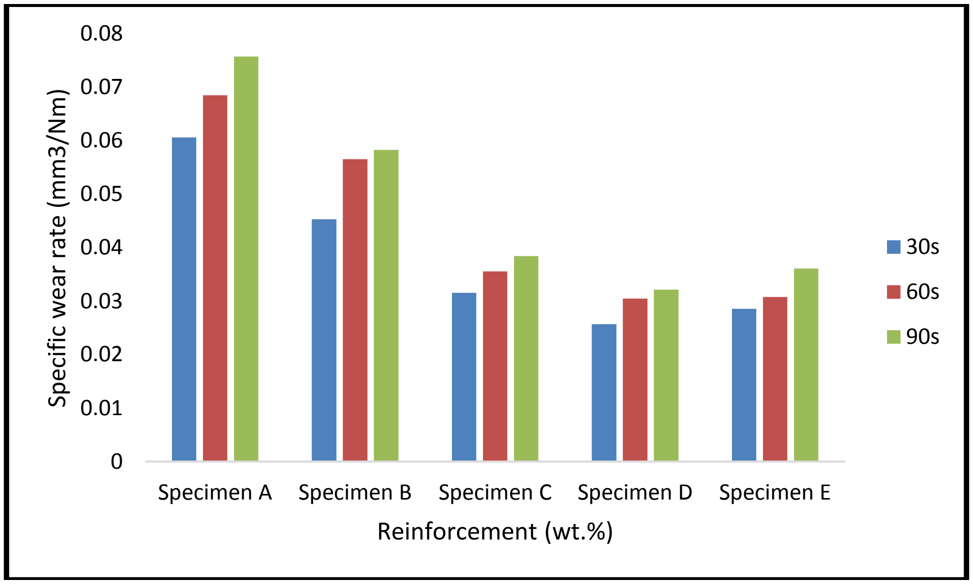

Figure 4.0: Specific wear rate of bamboo fibre/Mangifera indica particulate/epoxy composites.

Also, it was observed that the morphology from Figure 4.15 possess a finer phase and equiaxed structure when compared to other samples, which attributes to their better mechanical properties. These support the earlier study that as the grain size become finer, there will be improved bonding which will enhances the mechanical properties of the biocomposites (Atuanya et al. 2006).

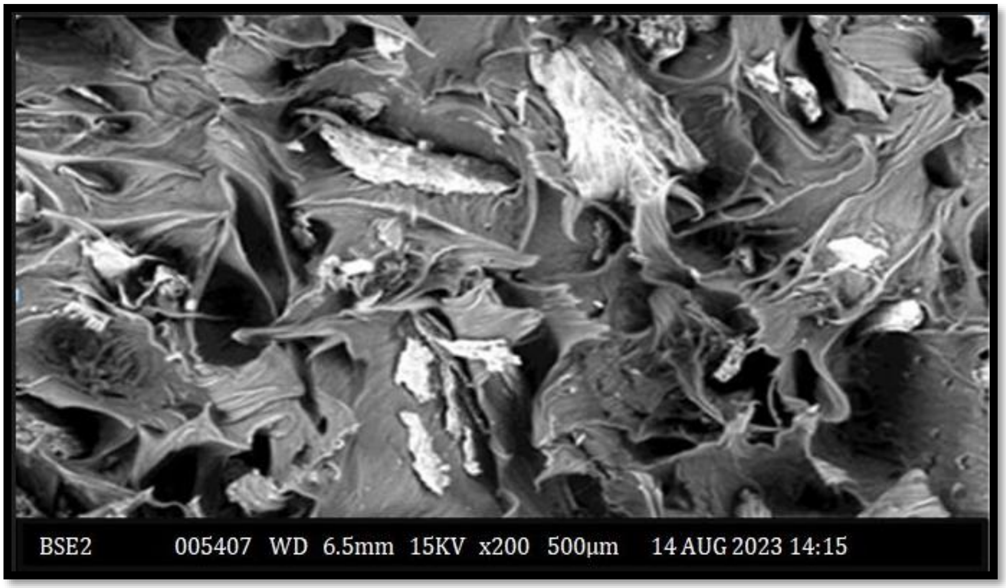

Figure 5.0: SEM fracture surface for composite sample without reinforcement, the epoxy polymer (control sample).

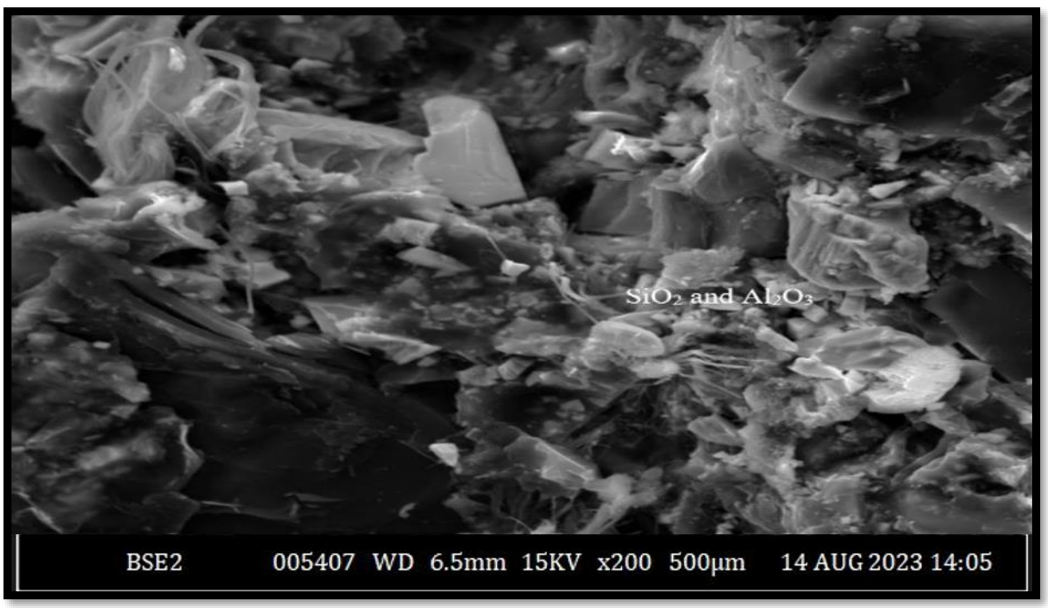

Figure 6.0: SEM fracture surface for 10wt% bamboo and 15wt% mangifera indica particulate (SP8) composite sample.

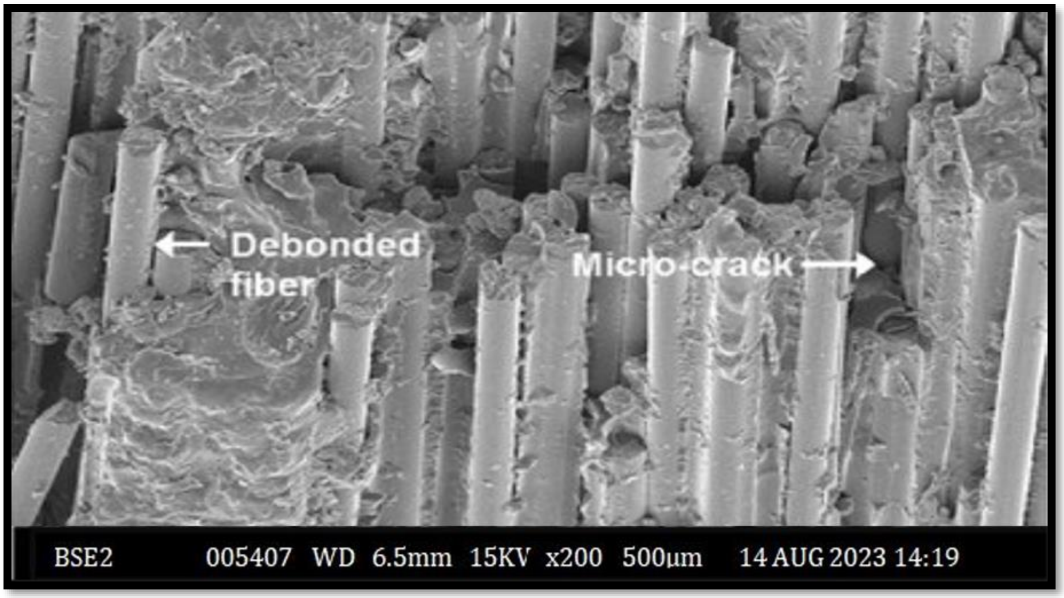

Figure 7.0: SEM fracture surface for 10wt% bamboo fibre and 20wt% mangifera indica particulate (SP9) composite sample.

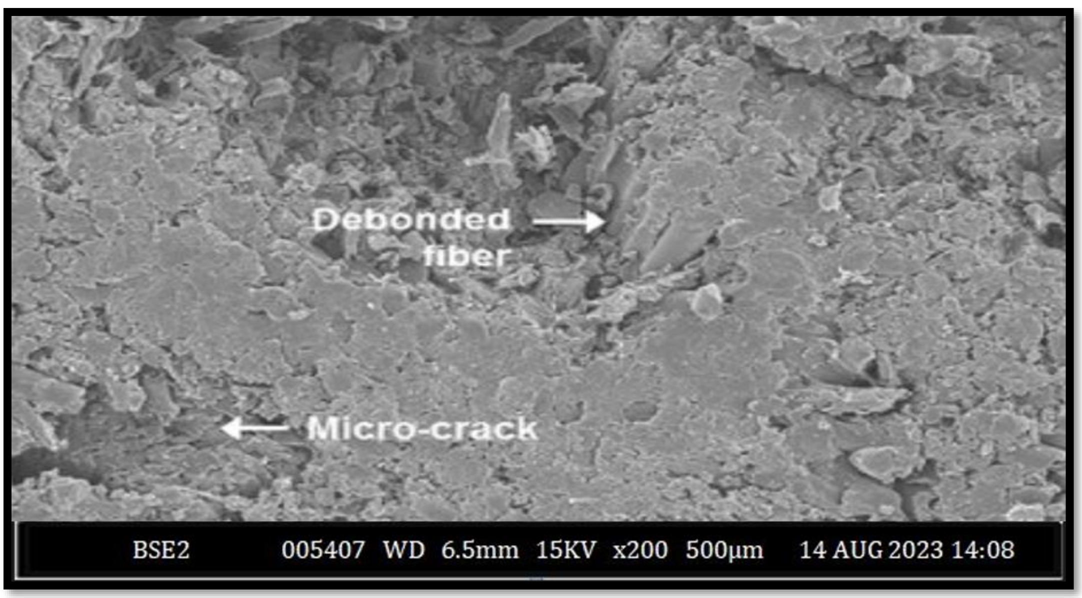

Figure 8.0: SEM fracture surface for the 10wt% bamboo fibre and 25wt% mangifera indica particulate (SP10) composite sample.

4.0. Conclusion

In this experimental study, the effects of bamboo fibre and mangifera indica particulates on the tensile strength and wear resistance of epoxy composite were explored. It was established the tensile strength of composite samples reinforced with 10wt% bamboo fibre and varied percentages of Mangifera indica particulate performed better than those reinforced with 5wt% and 15wt% bamboo fibre and varying percentages of mangifera indica particle. The microstructural investigation revealed that significant improvements in tensile strength can be attributed to fibre-matrix interfacial bonding and fibre placement along the direction of load application. The decrease in wear rate can be attributed to an increase in the reinforcing content, which is projected to heighten the hardness of the composites. It has been discovered that increasing the period of wear resistance testing causes an increase in wear rate across all weight fractions. This suggests that the duration of wear resistance testing is one of the determining elements in assessing biocomposite wear rate.

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