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Research Article

Experimental determination of mechanical properties and characterization of selected crop residues

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ABSTRACT

The management of huge waste generated from crop harvesting and processing has continued to create challenges and constitute an environmental nuisance. Inappropriate disposal and open-air burning of crop residues exacerbate environmental pollution, escalate bush burning and deforestation, and impact human health. Mixing, processing, and conversion of crop residues to form useful composites for various applications remain one of the economical, eco-friendly, and sustainable strategies for its management. The study constructed composites by mixing different ratios of unripe plantain peel (UPP) and coconut fibre (CCF) with an appropriate binder and hardener. The fabricated composites were subjected to mechanical, compositional, and morphological analyses. The outcomes of the tests show that the hardness, tensile strength, and impact strength only UPP is 97.8 RHN, 411 MPa, and 9 818 J/m^2, respectively while the CCF/UPP composite is 98.5 RHN, 538 MPa, and 12 273 J/m^2, respectively. The wear rate of UPP is 0.56 cm^3/m while that of the CFF/UPP composite is as high as 0.73 cm^3/m and increases with increased load. Silicon, oxygen, and aluminium are the major constituents of the composite samples as revealed by the compositional analysis. The tensile strength, hardness, impact, and wear rate of UPP can be boosted by the blending of CFF to form homogenous composites. The outcome of this study will deepen the literature and escalate research into the conversion and utilization of crop residues for diverse applications. The usage of innovative technologies and energy-efficient techniques should be adopted for the processing, modification, and conversion of crop residues.

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INTRODUCTION

Sustainable waste management is one of the challenges facing humanity in this generation. The problem of waste management has been exacerbated by increased waste generation across various sectors and countries. Due to escalating global population, increased food production and consumption, industrialization, and urbanization, global waste generation has continued to rise. From available data, the total waste generation which was 2 billion metric tons (BMT) in 2016 has been estimated rise to 2.6 BMT in 2030 and further to 3.4 BMT in 2050, globally [1]. The agricultural sector contributes significantly to global waste generation and the trend is expected to continue into the foreseeable future. Increased production, processing, and consumption of food to feed the human beings and animals and provide the needed raw materials for the industries are some of the contributors to increased waste from the agri-

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cultural sector. Crop residues form a significant part of the waste generated from the agricultural sector. The agricultural sector produces an average of 23.7 million tons of food daily, worldwide [2]. Food production from the agricultural sector has increased significantly over the last few decades due to accelerated population growth, the introduction of innovative agricultural practices, the development of high-yielding crops, and the introduction of technological and mechanized farming [3]. Crop residues are leftovers or remnant materials after agricultural products have been harvested, eaten, or processed. Common classifications of crop residues include peels, straws, husks, bagasse, shells, cobs, stovers, stubbles, etc. [4].

Plantain peel (PP) is the fleshy outer covering of a plantain fruit. It is bright green when unripe but becomes light yellow when ripe. Plantain is a major source of carbohydrates and is mostly consumed in Africa, the Caribbean, Latin America, Asia, and the Pacific. Plantains are usually cooked, roasted, boiled, and steamed, and can be processed into flours, snacks, and animal feed, and used as raw materials for food and beverage industries [5]. Nigeria, Cameroon, Ghana, and Uganda have dominated global plantain production in recent years with Nigeria producing 3.09 million metric tons (MMT), 3.08 MMT, and 3.8 MMT in 2016, 2020, and 2021, respectively (Fig. 1) [6–8]. Inappropriate disposal of plantain peels constitutes sanitation hazards, attracts flies, cockroaches, and other pathogens, and impacts human health. Plantain peel helps in wound healing, treatment of skin disorders, and hastens cell regeneration [4].

Coconut fiber (CCF) is a natural fiber extracted from the husk of a coconut. It is the outermost part of the coconut and directly shields the coconut shell. Coconut is one of the world's most versatile products and it is a drupe consisting of a fruit, seed, and nut. The fiber of an average coconut weighs about 0.80 kg and constitutes about 47.75% of the weight of the coconut [9]. The global production of coconut increased from 51. 66 MMT in 2000 to 59.85 in 2016 and further to 63.7 MMT in 2021 with over 84% coming from Asia [10]. India, the Philippines, and Indonesia have dominated global coconut production in recent years with 14.3 MMT, 14.7 MMT, and 17.2 MMT in 2021, respectively [11]. Over the past few years, Nigeria's coconut production has hovered around 0. 225 MMT (Fig. 2) [10]. CCF can be burned or converted to activated carbon, biochar, or made into briquettes for cooking. It can also be used as aggregate for concrete and road construction, as a natural filler in composites for thermal lagging, as production of phytochemicals and biofuels, as absorbents, and in automotive and construction applications [12].

In other to enhance the physicochemical, mechanical, thermal, electrical, structural, and compositional properties and behaviour of some materials or machine parts, other materials are added. Composite waste is a heterogeneous mixture of powder produced from some waste materials to advance the properties and enhance the applicability of the new materials. Various mechanical including tensile, hardness, wear, impact, etc., and compositional,

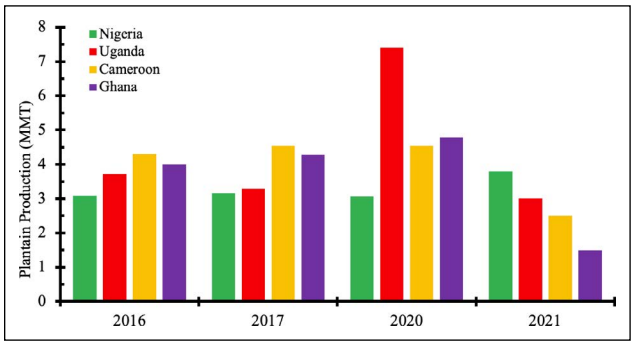

Figure 1. Top four plantain producing countries compiled from [6–8].

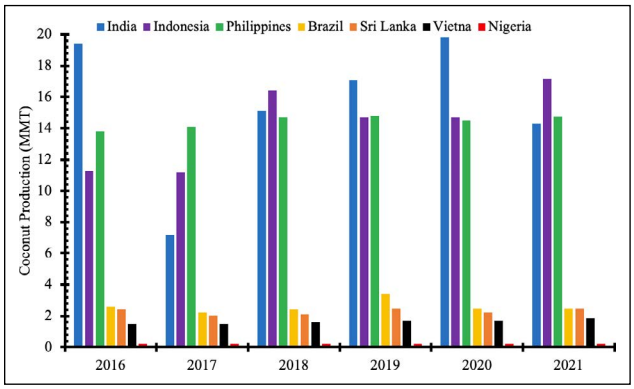

Figure 2. Coconut production in selected countries adapted from [10, 11].

morphological, and thermal techniques including scanning electron microscopy (SEM), thermos gravimetric analysis (TGA), Derivative Thermo gravimetry (DTG), Fourier transform infrared spectroscopy (FTIR), energy dispersive x-ray (EDX), x-ray diffraction (XRD), etc. have been deployed to characterize composites. Akash et al. [13] Mathew et al. [14], and Vinod et al. [15] carried out tensile, hardness, corrosion resistance, morphology, FTIR, XRD, SEM, TGA, etc. of some waste-derived composites. These tests and characterization technologies are performed to predict the features, behaviour, and potential application of composites. In a series of studies, Dwivedi et al. [16], Sujin Jose et al. [17], and Suresh Kumar and Mohanavel [18] demonstrated how the addition of CCF powder reinforced and improved the physical, mechanical, thermal, structural, and fire resistance properties of different materials for various applications. Similarly, Adeniyi et al. [19], Kilani et al. [20], and Akpan et al. [21] reported that the reinforcement of polyester and epoxy composites with PP powder enhanced the surface finish, workability, consistency, impact, compressive and tensile strengths, hardness, anti-corrosion, and other mechanical properties of the composites. The use of crop residues as composite materials are cost-effective, eco-friendly, biodegradable, renewable, sustainable, and recyclable. Also, the crop residues are readily available, easy to modify, and to ensures material recovery, and their applications contribute to circular economy [22–24].

Figure 3. Preparation of UPP sample **(a)** UPP as collected, **(b)** sundried UPP, **(c)** grinding process, **(d)** sieving of UPP sample.

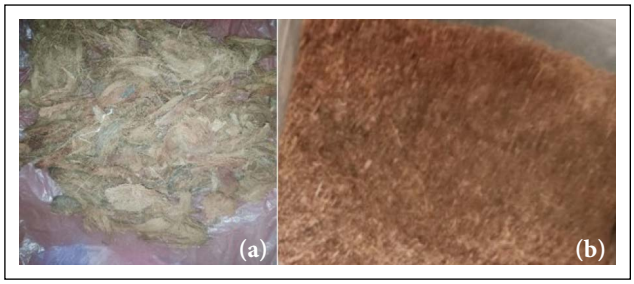

Figure 4. Preparation of CCF sample **(a)** CCF as collected, **(b)** pulverized CCF sample.

Table 1. Details of samples composition

Sample notation	UPP (g)	CCF (g)	Epoxy resin (g)	Hardener (g)
A	30	20	100	50
B	35	15	100	50
C	40	10	100	50
D	50	0	100	50

UPP: Unripe plantain peel; CFF: Coconut fiber.

Despite the outcome of a plethora of research works on this subject matter, in the opinion of the authors, there are still not many investigations on the use of a blend of unripe plantain peel (UPP) and CCF as composites. This is the motivation for the present intervention. The study aims to investigate the mechanical properties of various blends of UPP and CCF as composite materials. Specifically, the composite generated from the blend of UPP and CCF is subjected to hardness, impact, tensile, and wear tests. The samples are also characterized by SEM and EDX. The scope of the current research is restricted to laboratory mechanical and characterization investigations of composites produced by the combination of UPP and CCF. The outcome of this laboratory investigation will update the information available on the mechanical, compositional, and morphological properties of the produced composites. The novelty of this work is in the determination of the effects of the mixing ratio of UPP and CCF on the mechanical properties and characterization of the fabricated composites.

MATERIALS AND METHODS

Materials Collection and Preparation

The UPP was collected from roadside plantain roasters and other consumers within Ado Ekiti metropolis and transported to the laboratory in a plastic bag. At the laboratory, the UPP was washed in running distilled water to eliminate any unwanted substance. The clean UPP were first sundried for 7 days, further dehydrated in an oven maintained at 70 ^{o}C for 5 h, crushed by mortar and pestle, pulverized into a fine powder with an electric coffee grinder, and sieved using a 75 µm mesh sifter. The powdered UPP was deposited in a dry airtight glass vial for analysis. Figure 3 shows the pictures of the UPP sample preparation process.

The CCF wastes were collected at the point of extraction in the coconut farms near the University campus and conveyed to the laboratory in a clean plastic bag. The UPP was washed in running distilled water to remove the dirts and other impurities, sundried for 10 days, dried at 70 ^{o}C for 10 h in an oven, crushed by mortar and pestle, pulverized into a fine powder with an electric coffee grinder, and sieved using a 75 µm mesh sifter. The CCF powder was stored in a dry airtight glass vial for analysis. Figure 4 shows the pictures of the CCF sample preparation process.

Epoxy resin and hardener, in analytical grade, were purchased from chemical store in Ado Ekiti. The UPP, CCF, epoxy resin, and hardener were carefully measured and weighed using a digital weight balance, thoroughly mixed together, poured into a prepared mould, and labelled as samples A – D as shown in Table 1.

Methodology

The prepared samples A – D were subjected to hardness, impact, tensile, wear, SEM, and EDX analysis. The reading for each sample was taken three time to improve the accuracy of the result. The average of the three value is recorded and tabulated.

Hardness Test

The hardness test was carried out using a Rockwell Hardness Tester (MVH03, Hardness gauge, China), as shown below using a 0.83325 mm diameter diamond indenter, as per the ASTM E384 standard. A 100 kgf load was applied for an average of 18 s. Following that, the readings were taken from the A scale while taking the appropriate precautions. The purpose of this test was to determine the specimen's Rockwell hardness number. The procedures include secur-

ing the clean sample on the anvil and ensure the load lever is in position A. Note the diameter of the ball and elevate the specimen so that it comes into contact with the indenter and ensure the deflecting meter on the small scale doesn't exceed the red point. The sample is put under a preliminary load by selecting 60 N on the load selector. The load lever was moved from position A to position B and left for at least 15 s as the load is gradually applied. The pointer is allowed to come to rest and reading on the hardness scale B is read. The sample was removed from the support table to allow for the identification of the indentation made using microscope and measurement of the indentation diameter 'd' through the attached micrometer. The process is repeated three times to ensure accuracy. The procedures are repeated for other samples.

Tensile Test

A computerized Instron Testing Machine (INSTRON 3365, Engstrom, United States) was used to carry out the tensile strength of the samples according to ASTME 8 standard at room temperature. Three identical test specimens were produced from each sample and were tested with a strain/loading rate of 5 mm/min. Load displacement plots were obtained on a X – Y recorder. The ultimate tensile strength, yield strength and percentage elongation values were calculated from this load displacement diagrams.

To start with, the required length of the sample was measured and inserted into the grips of the machine. The load and displacement on the digital indicator were set to zero and the load application was initiated by pressing unload (blue) button on the tensile machine and record load versus elongation data. The process is continued until the sample fractures. The length of the fracture specimen was measured to get the total elongation at fracture. The process was repeated for all the samples.

Impact Test

The samples were machined into the standard impact test specimen dimension (55 mm x 10 mm x 10 mm), a 2 mm deep V-notch was grooved into the center of the specimen A at 45 °, as shown in Figure 5. The impact test was carried out at room temperature using Charpy Impact Tester (PCICIT-1, Pacorr Testing Instruments Pvt. Ltd., India). During the process, the specimen is placed in the Charpy Impact Testing machine's vice in such a way that the notch backing the hammer and is positioned centrally on the vice and the hand brake for the pendulum was pulled and the pendulum returned to its locked position. The Impact Energy (IE) absolved was read out from the scale and recorded. The Impact Energy (IE) and Impact Strength (IS) of each sample were calculated using equations 1 and 2 and the procedure was repeated for all the samples.

$$Impact\ Energy\ (IE) = \frac{I_1+I_2}{2}\ (J) \quad (1)$$

$$Impact\ Strenght\ (IS) = \frac{E}{A}\left(J/_{m^2}\right) \quad (2)$$

Where: E= Energy required to fracture the sample (J) and A= Surface Area of the sample (m^2).

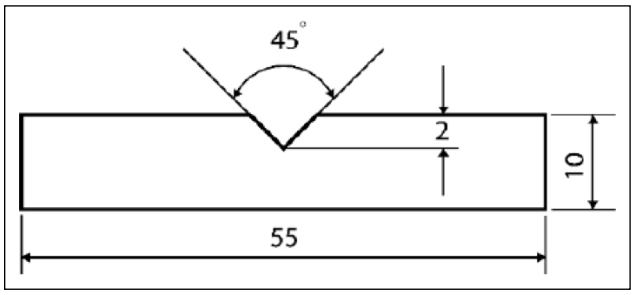

Figure 5. Impact test specimen.

Wear Test

The wear test was performed using Anton Paar GmbH (CSM Instruments Austria). During the process, the tribometer is connected to the computer system installed with the appropriate software. Key in the input parameters such as track diameter, linear speed (cm/s), speed (RPM), distance travelled/laps, and load. The test sample is mounted on the Jaw Chuck of the machine, while the tribometer arm that grips the ball is lowered on the sample. Initiate the test and at the end of the set distance, the tribometer stops automatically and the recorded result is saved. The procedure is repeated for other samples.

Scanning Electron Microscopy Analysis

The SEM analysis was performed on the samples using SEM (Phenom ProX, phenomWorld Einhoven, Netherlands). The sample was mounted on double adhesive on a sample stub and coated with 5 nm gold using a quorum technologies model Q150R sputter coater. It was then delivered to the SEM machine's chamber, where it was examined through NaVCaM for focusing and minor adjustments, then transferred to SEM mode, where it was focused and brightness contrasting was automatically changed, and the morphologies at a magnification of x9000 under vacuum condition were obtained. This process was repeated for other samples.

Energy Dispersive X-ray Analysis

The compositional analysis was performed on the samples using the EDX detector attached to the SEM (Phenom ProX, phenomWorld Einhoven, Netherland). The samples which were prepared under similar conditions described in Section 2.2.5 were loaded into the scanning electron microscopy system with a magnification of x9000 under vacuum condition. From the EDX scan of the loaded sample, the EDX spectra and the element percentage composition by weight were obtained.

Statistical Analysis

The data were subjected to descriptive statistical analysis. The descriptive statistical analysis involves the calculation of the mean, standard deviation (SD), coefficient of variation (CV %), and standard error of the mean (SEM) of the data obtained from the results.

Where $SD = \sqrt{\frac{\sum(x_i-\mu)^2}{N}}$ (3)

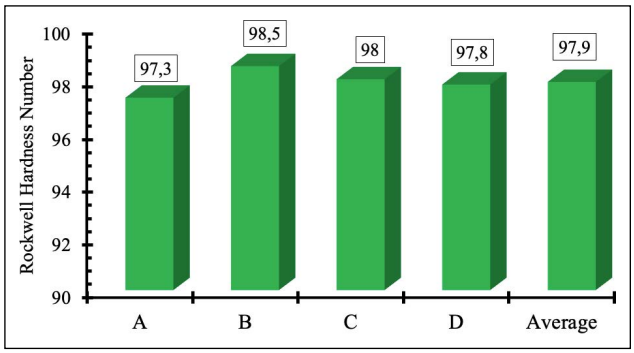

Figure 6. Hardness of samples.

$$CV\% = \frac{SD}{Mean} \times 100 \quad (4)$$

$$SEM = \frac{SD}{\sqrt{N}} \quad (5)$$

N= Population size, x_i = each value from the population, and μ= mean.

RESULTS AND DISCUSSION

Hardness

The result of the Rockwell hardness test shows that there is no substantial disparity in the values for the samples. Sample B presented the highest hardness of 98.5 while sample A hardness number was 97.3. The average hardness for samples was 97.9, as shown in Figure 6. These results show that the addition of CCF to UFP has a very slight impact on the hardness of the UPP. However, the addition of CCF to UPP to form a composite slightly increased the hardness value when compared with the hardness value for the UPP. These results are in harmony with earlier submission of Jacob et al. [25] and Akpan et al. [21]. The implication of this test is that mixing CCF with UPP does not significantly increase the hardness of the composite and supports its utilization as concrete admixture and other industrial applications.

Tensile

The tensile strength, breaking load, and stress of the samples are shown in Figure 7. The average tensile strength for the composite is 428 MPa while the average breaking load is 705 N. The addition of CCF increases the tensile strength, breaking load, and stress of the UPP. Sample A with the UPP and CCF mixture at a ratio of 3:2 presents the highest breaking load, tensile strength, and stress when compared with other samples and is higher than the average values. One of the ways to enhance the tensile strength and breaking load of UPP is to add some percentage of CCF or other agricultural waste powder to it. This will promote the composite tensile strength and empower it to withstand more load before breaking [21, 26].

Impact

The impact test results show that sample D which is wholly UPP and has no CCF has an impact energy of 216 J and impact strength of 9818 J/m^2 which is lower than the average value of 233 J for impact energy and 10625 J/m^2 for impact strength. The impact strength for samples A, B, and C is 10182 J/m^2, 10227 J/m^2, and 12273 J/m^2, respectively, as shown in Figure 8. The result implies that one feasible way to improve the impact strength and impact energy of UPP composite is to blend it with CCF [27, 28]. Composites with enhanced impact strength are used for various industrial products and other specialized purposes.

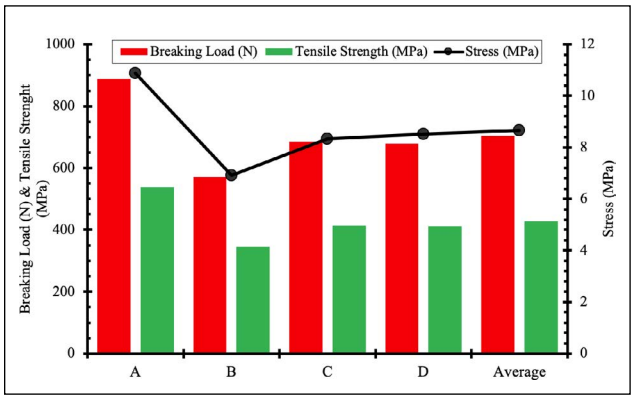

Figure 7. Breaking load, tensile strength, and stress of samples.

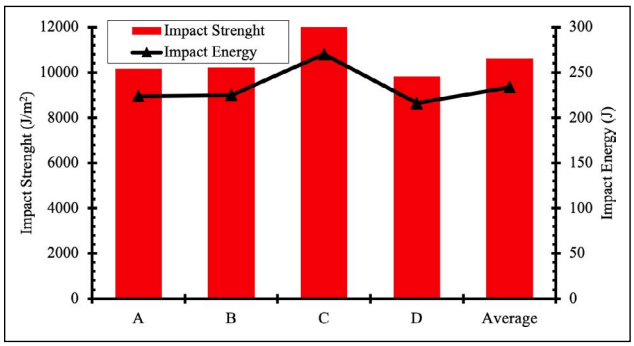

Figure 8. Impact strength and impact energy of samples.

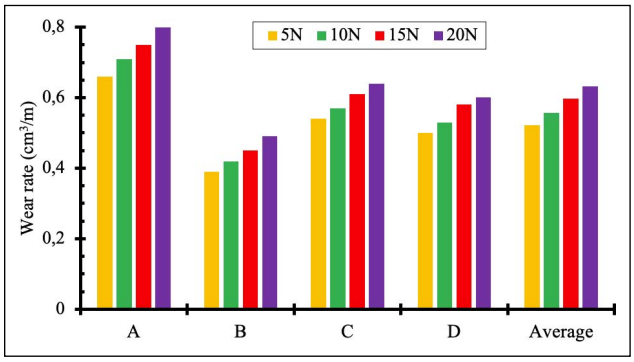

Figure 9. Wear rate of samples at different load.

Table 2. The wear rate of samples

Sample	Wear rate (cm^3/m)
A	0.73
B	0.44
C	0.59
D	0.56

Table 3. Statistical analysis of the data

Parameters	Samples				Mean	SD	CV (%)	SEM
	A	B	C	D				
Hardness number	97.3	98.5	98	97.8	97.9	0.49	0.51	0.249
Tensile strength (Mpa)	538.6	345.9	414.2	411.5	427.6	80.49	18.82	40.243
Breaking load (N)	888.8	570.8	683.4	678.9	705.5	132.84	18.83	66.419
Stress (MPa)	10.9	6.9	8.3	8.5	8.7	1.66	19.08	0.831
Impact strength (J/m^2)	10182	10227	12273	9818	10625	1113.82	10.48	556.912
Impact energy (J)	224	225	270	216	233.7	24.5	10.48	12.25
Wear rate (cm^3/m)	0.73	0.44	0.59	0.56	0.58	0.12	20.55	0.059

SD: Standard deviation; CV: Coefficient of variation; SEM: Standard error of the mean.

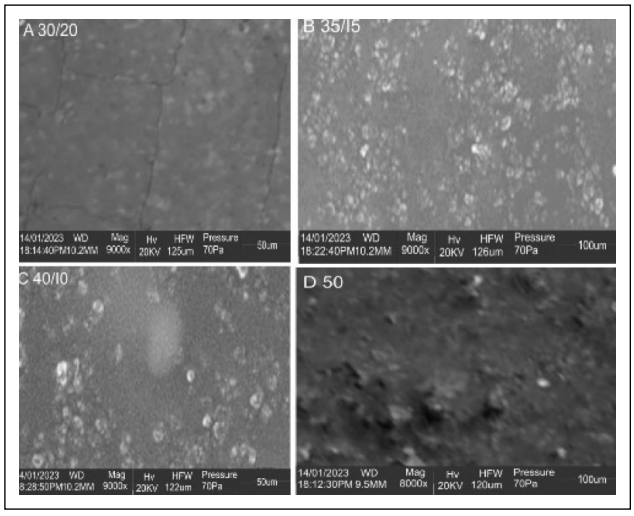

Figure 10. SEM images of samples.

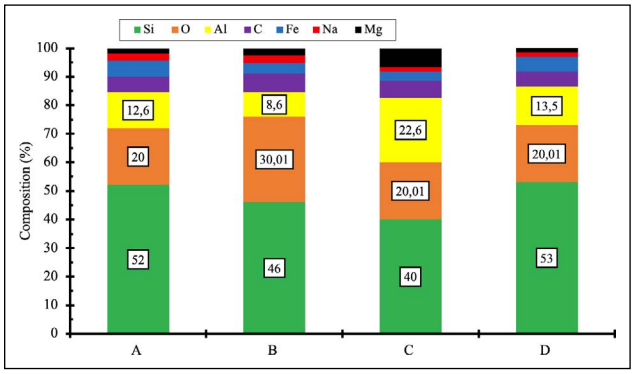

Figure 11. EDX results of samples.

Wear

As shown in Table 2, the wear rate of UPP (sample D) is 0.56 cm^3/m while that of the CFF/UPP composite is as high as 0.73 cm^3/m. The wear rate of the composite samples at different loads is shown in Figure 9. The wear rate increases as the applied load increases. Sample A displays the highest wear rate across the tested loads when compared with other samples and is higher than the average wear rate. The resistance to wear is highest in sample D and lowest in sample A. This shows that the addition of CCF increases the wear rate and reduces the resistance to wear of the composite of UPP. Sample B shows the lowest wear rate and consequently possesses the highest resistance to wear. The outcome of the wear rate conforms with previous results reported by Adeniyi et al. [26], Ohaga et al. [27], and Xie et al. [28].

SEM

The SEM micrograph of the samples are shown in Figure 10. It was observed that the addition of CCF to UPP distorted the homogenous nature of the base epoxy resin micrograph. Samples A, B, and C demonstrated a uniform coverage with a visible line crack on sample A. The observed crack might be due to the thermal stress during the formative stage of the epoxy resin substrate. Although the grain refinability of UPP nanoparticles is documented in the literature [21], continuous excessive addition. reduces the degree of homogeneity and surface coverage displayed by samples A, B, C, and D with the increasing presence of pores in the micrograph.

EDX

Silicon, oxygen, and aluminium are the major constituents of the samples. As shown in Figure 11, the concentration of silicon in sample D increased to 53% due to the addition of CCF. However, the addition of CCF to UPP increases the concentration of magnesium, sodium, and carbon in the composite. As shown in Figure 11, silicon, oxygen, and aluminium are the major constituents of the explored composite samples with traces of carbon, iron, sodium, and magnesium.

Results of the Statistical Analysis

Table 3 shows the outcome of the descriptive statistical analysis of the data. The low SD of hardness number, stress, impact energy, and wear rate shows the data for those parameters are not dispersed in relation to the mean while those of tensile strength, breaking load, and impact strength are well dispersed and scattered in relation to the mean. The CV (%) is a measure of the dispersion of the data around the mean. From the table, the CV% is generally low and ranges between 0.5% and 20.5%. The standard error of the mean measures the degree of discrepancy expected in the sample. The SEM is less than 1 in hardness number, stress, and wear rate while the SEM for impact strength is about 556.

CONCLUSION

Unregulated waste generation, inappropriate waste disposal, and ineffective waste management strategies result in poor sanitation, environmental pollution, and contamination of aquatic ecosystems. Burning of crop residues generates toxic smoke and unburnt hydrocarbon, reduces air quality, exacerbates bush burning and deforestation, and impacts human health. The fabrication of composites from crop residues and other agricultural wastes is one of the cost-effective and sustainable approaches for waste management. The mechanical properties of the composites fabricated from the blending of UPP and CCF show that the tensile strength, hardness, impact strength, impact energy, and wear rate of the composites are higher than that of UPP (sample D). Specifically, the hardness of UPP is 411 MPa compared with the value of 538 MPa for the CCF/UPP composite while the impact strength becomes 12 273 J/m^2 for the CCF/UPP composite compared with the value of 9 818 J/m^2 recorded for the UPP sample. The wear rate of UPP is 0.56 cm^3/m while 0.73 cm^3/m was reported for the CFF/UPP composite. Silicon, oxygen, and aluminium are the major constituents of the composite samples as revealed by the compositional analysis. The descriptive statistical analysis of the data shows a low coefficient of variation for each parameter.

The outcome of this study shows that blending UPP with CCF increases the tensile strength, hardness, impact strength, impact energy, and wear rate of the samples. The import of these is that the tensile strength, hardness, impact, wear rate, and other mechanical properties of a give crop residue can be modified by blending it with another crop residue. Scientific-based strategies for safe waste collection and handling should be introduced and adopted to ease the difficulty and encumbrances involved in waste handling, disposal, collection, and processing. Policies and financial incentives are needed to encourage more investments in waste conversion for resource recovery and industrial raw materials.

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DATA AVAILABILITY STATEMENT

The author confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

USE OF AI FOR WRITING ASSISTANCE

Not declared.

ETHICS

There are no ethical issues with the publication of this manuscript.

REFERENCES

[1] Statista, "Global municipal solid waste generation projection 2016-2050," Available: https://www.statista.com/statistics/916625/global-generation-of-municipal-solid-waste-forecast/. Accessed ON Aug 20, 2023.

[2] FAO, "Strategic work of FAO for sustainable food and agriculture," Available: http://www.fao.org/3/a-i6488e.pdf. 2017. Accessed on Aug 20, 2023.

[3] M. Duque-Acevedo, L. J. Belmonte-Ureña, F. L. Cortés-García, and F. Camacho-Ferre, "Agricultural waste: Review of the evolution, approaches and perspectives on alternative uses," Global Ecology and Conservation, Vol. 22, Article e00902, 2020. [CrossRef]

[4] O. Awogbemi and D. V. V. Kallon, "Application of biochar derived from crops residues for biofuel production," Fuel Communications, Vol. 15, Article 100088, 2023. [CrossRef]

[5] M. Arora, P. Rasane, J. Singh, S. Kaur, M. Bakshi, and J. Kaur, "Reinventing plantain as a functional food: A processing based approach," Current Nutrition & Food Science, Vol. 18(8), pp. 752–764, 2022. [CrossRef]

[6] "The World's leading plantain producers." https://www.worldatlas.com/articles/the-world-s-leading-plantain-producers.html. Accessed on Aug 20, 2023.

[7] "Top 10 plantain producing countries," https://www.mapsofworld.com/world-top-ten/plantain-producing-countries.html. Accessed on Aug 20, 2023.

[8] "Top 10 plantain producing countries 2017," https://www.bluemarblecitizen.com/rankings/top-plantain-producing-countries. Accessed on Aug 20 2023.

[9] G. Y. Obeng, D. Y. Amoah, R. Opoku, C. K. Sekyere, E. A. Adjei, and E. Mensah, "Coconut wastes as bioresource for sustainable energy: Quantifying wastes, calorific values and emissions in Ghana," Energies, Vol. 13(9), Article 2178, 2020. [CrossRef]

[10] FAOSTAT, "Production of coconuts, in shell," 2022. https://www.fao.org/faostat/en/#data/QCL/visualize. Accessed on Aug 20, 2023.

[11] M. Shahbandeh, "Global leading producers of coconuts 2021," https://www.statista.com/statistics/1040499/world-coconut-production-by-leading-producers/. 2022. Accessed on Aug 22, 2023.

[12] N. A. Basha, T. Rathinavel, and H. Sridharan, "Activated carbon from coconut shell: Synthesis and its commercial applications-a recent review," Applied Science and Engineering Progress, Vol. 16(2), pp. 6152–6152, 2023. [CrossRef]

[13] R. Akash, R. Muraliraja, R. Suthan, and V. S. Shaisundaram, "Synthesis and testing of aluminium composite using industrial waste as reinforcement," Materials Today: Proceedings, Vol. 37, pp. 634–637, 2021. [CrossRef]

[14] G. Mathew, K. V. Kumar, and S. Vijaykumar, "Effect of Agro Waste Reinforcements on the Mechanical Properties of Aluminium Composites," in Proc. Int. Conf. Intelligent Manufacturing and Automation:

ICIMA 2022, Singapore: Springer, pp. 451–462, 2023. [CrossRef]

[15] A. Vinod, M. Rangappa, R. Srisuk, J. Tengsuthiwat, A. R. Ramnath, and S. Siencgchin, "Agro-waste Capsicum Annum stem: An alternative raw material for lightweight composites," Industrial Crops and Products, Vol. 193, Article 116141, 2023. [CrossRef]

[16] S. P. Dwivedi, A. Saxena, and N. Srivastava, "Effects of MgO Powder addition on mechanical, physical and thermal properties of Al waste bagasse composite," Materials Testing, Vol. 63(5), pp. 462–469, 2021. [CrossRef]

[17] A. Sujin Jose, A. Athijayamani, and S. P. Jani, "A review on the mechanical properties of bio waste particulate reinforced polymer composites," Materials Today: Proceedings, Vol. 37, pp. 1757–1760, 2021. [CrossRef]

[18] S. Suresh Kumar and V. Mohanavel, "An overview assessment on magnesium metal matrix composites," Materials Today: Proceedings, Vol. 59, pp. 1357–1361, 2022. [CrossRef]

[19] A. G. Adeniyi, J. O. Ighalo, and D. V. Onifade, "Banana and plantain fiber-reinforced polymer composites," Journal of Polymer Engineering, Vol. 39(7), pp. 597–611, 2019. [CrossRef]

[20] A. Kilani, A. Olubambi, B. Ikotun, O. Adeleke, and O. Adetayo, "Structural performance of concrete reinforced with banana and orange peel fibers-a review-Journal of Sustainable Construction Materials and Technologies, Vol. 7(4), pp. 339–357, 2022. [CrossRef]

[21] B. J. Akpan, I. G. Akande, O. S. I. Fayomi, and K. M. Oluwasegun, "Investigation of hardness, microstructure and anti-corrosion properties of Zn-ZnO composite coating doped unripe plantain peel particles," Case Studies in Chemical and Environmental Engineering, Vol. 5, Article 100187, 2022. [CrossRef]

[22] S. Saravanabhupathy, "Recent Advancements in Agricultural Residue Valorisation into Bio-Products," in Agricultural Waste: Environmental Impact, Useful Metabolites and Energy Production, K. Ramawat, J. M. Mérillon, and J. Arora, (Eds.), pp. 523–542, 2023. [CrossRef]

[23] O. Awogbemi, D. V. V. Kallon, and V. S. Aigbodion, "Trends in the development and utilization of agricultural wastes as heterogeneous catalyst for biodiesel production," Journal of the Energy Institute, Vol. 98, pp. 244–258, 2021. [CrossRef]

[24] O. Awogbemi, D. V. V. Kallon, and K. A. Bello, "Resource Recycling with the Aim of Achieving Zero-Waste Manufacturing," Sustainability, Vol. 14(8), Article 4503, 2022. [CrossRef]

[25] J. Jacob and P. A. P. Mamza, "Mechanical and thermal behavior of plantain peel powder filled recycled polyethylene composites," Ovidius University Annals of Chemistry, Vol. 32(2), pp. 114–119, 2021. [CrossRef]

[26] A. Adeniyi, S. Abdulkareem, J. Ighalo, and D. Onifade, "Utilisation of waste plantain (musa paradisiaca) peels and waste polystyrene in the development of reinforced polymer composites," International Polymer Processing, Vol. 35(3), pp. 331–337, 2020. [CrossRef]

[27] S. Ohaga, I. O. Igwe, and C. Nwapa, "Mechanical and end-use properties of high density polyethylene (HDPE) filled with plantain peel powder," SSRG International Journal of Polymer and Textile Engineering, Vol. 6(3), pp. 17–25, 2019. [CrossRef]

[28] J. Xie, Y. Zhang, S. Klomklao, and B. K. Simpson, "Pectin from plantain peels: Green recovery for transformation into reinforced packaging films," Waste Management, Vol. 161, pp. 225–233, 2023. [CrossRef]