ABUAD Journal of Engineering Research and Development (AJERD)
ISSN (online): 2645-2685; ISSN (print): 2756-6811

Volume 7, Issue 2, 511-520

Impact of Mixture Ratio on Bio-Composite Material from Bamboo and Recycled Polyethylene Terephthalate (PET)

Abiodun Ayodeji OJETOYE, Olutosin Olufisayo ILORI, Shalom Chitom IWEDI, Kelechi Valentine OBIECHEFU, Precious Arinze OKEZUE, Kareem FERANMI

Department of Mechanical Engineering, Adeleke University, Ede, Nigeria
abiodun.ojetoye@adelekeuniversity.edu.ng/ilori.olutosin@adelekeuniversity.edu.ng
iwedishalz@gmail.com/kelechiobiechefu.ko@gmail.com/okezuearinze070@gmail.com
Feranmikareem9@gmail.com

Corresponding Author: ilori.olutosin@adelekeuniversity.edu.ng, +234-8034821432
Date Submitted: 12/08/2024
Date Accepted: 19/12/2024
Date Published: 26/12/2024

Abstract: *The study investigated the impact of mixture ratio on various physico-chemical and mechanical properties of a bio-composite material made from bamboo and recycled polyethylene terephthalate (PET). The bamboo and recycled PET bottles were sourced from Adeleke University, Ede research farm and waste buckets in male hostels of the same university, respectively. The weight percentages (wt%) of bamboo and PET powder were adjusted as follow: 60 wt% bamboo and 40 wt% PET, 65 wt% bamboo and 35 wt% PET, 70 wt% bamboo and 30 wt% PET, 75 wt% bamboo and 25 wt% PET, and 80 wt% bamboo and 20 wt% PET, respectively. The findings indicate that as the mixture ratio of the constituents varied, the composite samples exhibited a decrease in density (from 915.45 – 819.24 kg/m^3), flammability (from 25.84 – 19.93 s), hardness (from 88.55 – 55.57 BHN), compressive strength (from 14.78 – 9.10 N/mm3), and wear resistance (from 0.0096 – 0.0011 cm/cm3). In contrast, the composite exhibited an increase in oil and water absorption rates ranging from 0.0010% to 0.0810% and from 0.0112% to 0.12%, respectively, as the mixture ratio varied. Furthermore, the ratio of the mixture does not impact the acidity or alkalinity of the resulting composite material. Hence, the mixture ratio that yields optimal attributes result in excellent performance, tailored to the specific requirements of industries such as automotive and aeronautics. Finally, the diverse combination of bamboo and PET powders provides a practical approach to creating efficient, environmentally-friendly bio-composite materials suitable for various industrial applications.*

Keywords: *Bamboo, Recycled PET Bottles, Density, Compressive Strength, Wear*

1. INTRODUCTION

Plastic waste can disrupt the marine food chain and present serious risks to both the environment and public health [1]. Plastic wastes are not biodegradable and end up in estuaries and drainage systems, leading to complex problems like significant floods during rainy seasons [2]. But because there is a growing recognition of the need to develop new materials that are environmentally friendly, biodegradable, and perform better, efforts are focused on recycling plastic waste. Plastic bottles are ubiquitous in our day-to-day existence. Water is packaged in plastic bottles, which are very popular because they don't affect the quality of the water enclosed in it. When creating plastic bottles, the most common material used is polyethylene terephthalate (PET). PET bottles are valuable because they can be recycled, and exhibit high tensile strength, low creep at elevated temperatures, high strength and torsion, and impact resistance [3], in addition to being lightweight [4]. PET bottles can be softened and shaped into useful shapes when heat and pressure are applied [5], but they also cool quickly before solidifying [6]. PET bottles are chemically stable, elastic, and resistant to corrosion [7]. Recycled PET bottles are used in this study as one of the constituent materials of the composite under study. It was specifically chosen due to its low weight, affordability, availability, low cost of transportation, waterproof nature, and break resistance. Reducing the environmental risks that Nigerians face is another important reason why PET bottles are taken into consideration for this study.

Bamboo is widely distributed throughout Nigeria, with Bambusa vulgaris being the most common species and having a rapid growth rate. Although bamboo is plentiful in southwest Nigeria, its use is restricted to building construction and scaffolding, which highlights Nigeria's slowness in discovering other uses for this resource. According to [8], bamboo is more cost-effective than wood and is lightweight, flexible, tough, and durable [9, 10]. Bamboo is regarded as a vital plant fiber among natural fiber plants and has enormous potential in the bio-composite sector. Bamboo is regarded as an organic material for engineering. Bamboo's fiber has mechanical qualities that are comparable to those of traditional fibres [11]. High compressive and tensile strengths are found in bamboo [12]. The high strength to weight ratio of bamboo has attracted researchers' attention to maximize its potential in composites [13]. A study by [42] showed that bamboo has densities ranging from 0.54 – 0.76 g/cm³, [43] reported that the compressive strength of bamboo ranges between 40 and 50

MPa, [44] reported that bamboo has hardness value of 6.585 N, and according to [45], the range of bamboo's moisture content is between 14% and 19%.Bamboo in natural composites has been used widely in various applications, such as the interiors of vehicles and aircrafts, bicyclist helmets, and decks for leisure activities [14]. These qualities make bamboo the second constituent material of the composite this study will explore.

Composite materials are materials that have been altered through the combination of two or more different materials to create a single material with superior and distinct qualities. Composites can also be defined as a single material composed of two or more distinct materials with unique mechanical, chemical, and physical properties that, when combined, create a material with special characteristics. Importantly, the desired qualities of a chosen new material are taken into consideration when selecting the constituent materials [15, 23]. The main component, referred to as the matrix, accounts for a greater portion of the composite. The component acting as reinforcement is the other, and the matrix acts as the binder. By maintaining the settings of the reinforcements, the matrix phase encloses, embeds, and supports them. The unique mechanical and physical characteristics of the reinforcing material improve the matrix's qualities [16]. A study carried out by [46] on bamboo composite showed a compressive strength of 67.60 MPa, and it was reported by [47] that hardness values of polypropylene-bamboo/kenaf composite range between 70 and 90. The effect of mixture ratio was seen in a study by [48], as the impact strength of bamboo fiber reinforced biocomposite increased with increased wt% of bamboo but declined when the wt% of bamboo reached 40, conversely, the flexural strength decreased as the wt% of bamboo fiber was increased. The composite material under investigation in this study was made up of PET bottles, bamboo fiber, glass fiber, and epoxy resin. Previous studies have explored the performances of several biocomposites but have yet to fully explore the effect of varied mixture ratios of bamboo and PET on the mechanical properties of the composite material. The novelty of this study is in the investigation of a sustainable composite material made up of bamboo powder, which is a renewable resource, and recycled PET, addressing plastic waste reduction. This is in agreement with the global emphasis on sustainability, waste reduction and the need for environmentally-friendly products. To determine the composite sample with the best qualities, bamboo and PET fibres were combined in variations to produce composite samples for scrutiny in this study. The study aims to find the ideal ratio that enhances the strength of the resulting composite material and for structural applications.

2. MATERIALS AND METHODS

2.1 Materials

The materials used in carrying out the experiment include bamboo, PET bottles, glass fiber, and epoxy resin. The bamboos used for this study were as freshly harvested from the teaching and research farm of the Adeleke University, Ede, Nigeria. They were about 5 years old at the time of harvest. The species of the bamboo utilized is Bambusa Vulgaris, which is well known for its extreme strength and widely distribution within Southwestern Nigeria. The equipment utilized to perform the experiment include a hacksaw, hammer mill, mold, digital weighing scale, and cross-cutting machine.

2.2 Method

2.2.1 Production of bamboo powder

The bamboo was put through a number of processes before turning it into powder because the study needed the components of the composite materials to be in powder form in order to optimize the properties of the resulting product [18]. Prior to processing, the bamboo plants were harvested and sun-dried for a period of fourteen (14) days in order to reduce its moisture content [25]. To remove any last traces of moisture, the bamboo culms were further dried at 50°C in an electric oven. After drying, circular saw was used to slice the bamboo culms before being fed into the hammer milling machine and were ground to powder form with a hammer milling machine.

2.2.2 Preparation of PET powder with glass fiber

Polyethylene terephthalate (PET) was sourced from post-consumer plastic bottles. The waste PET bottles were gathered from refuse dumps of Adeleke University, Ede, Nigeria. The waste PET bottles were cleaned by washing them to remove dirt, cut into smaller sizes, air-dried and then melted in a crucible placed in a furnace at 250˚C. The melt was allowed to cool down and solidify, afterward pulverized to powder form [26]. Also, used glass bottles were sourced locally. The waste glass bottles were pulverized with hammer mill and finely ground into powder [27]. In order to restore the strength of the recycled PET powder, glass powder was added and thoroughly mixed [28, 29].

2.2.3 Formulation of composite samples

The composite constituents include bamboo and PET powders, which were mixed and bound by using epoxy resin. The bamboo powder constitutes reasonable percentage than PET powder. The composite was poured into a mold and compacted by using a 20-ton hydraulic press for 1 hour. These samples were allowed to cool before tests were conducted on them. The formulation of the composite samples was replicated twice. The mixture ratios in terms of percentage weights (wt%) of the samples are as stated in Table 1 at constant volume of epoxy resin [24]. Sample A consists of 60 wt% of bamboo powder and 40 wt% of PET powder [30]. Also, sample B consists of 65 wt% bamboo powder and 35 wt% PET powder [31]; and sample C consists of 70 wt% bamboo powder and 30 wt% PET powder [32]. Likewise, sample D consists of 75 wt% of bamboo powder and 25 wt% PET powder [33]. Lastly, sample E consists of 80 wt% of bamboo powder and 20 wt% PET powder [34] (Table 1). The wt% of bamboo powder and PET powder were consistently increased and decreased respectively. The reduction in wt% of PET power is augmented by increasing the wt% of bamboo powder in order to obtain a composite material with enhanced structural integrity and rigidity, which is a requirement in automobile component production.

Table 1: The mixture ratios of the constituents

Sample	Bamboo powder (wt%)	PET powder (wt%)
A	60	40
B	65	35
C	70	30
D	75	25
E	80	20

2.3 Physical, Chemical and Mechanical Tests

The following tests were conducted on each sample and repeated twice to obtain average results.

2.3.1 Density test

This test was carried out to determine the sample that is most closely packed [18]. Equation (1) was used to determine the density for each sample. The samples were weighed and recorded, while the volume of the samples was given by the volume of the mold used.

$$Density = \frac{Mass}{Volume} \quad (1)$$

2.3.2 Absorption test

Absorption test was used to determine the amount in percentage of liquid (oil, and water) that each sample absorbed after being immersed for more than 24 hours [18] by calculating with equation (2) the difference between the weight of the sample after it has been immersed in either water or oil and the weight of the sample before immersion in either water or oil. The results obtained showed how porous each composite sample produced could be.

$$\text{Absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100 \quad (2)$$

where,
W_1 = weight of the sample before immersion,
W_2 = weight of the sample after immersion [39].

2.3.3 Acidity and alkalinity test

The acidity and alkalinity test were performed on bamboo and PET powders using blue and red litmus papers as the indicator [35]. The result obtained was recorded.

2.3.4 Flammability test

The flammability test was conducted on samples by utilizing a simple method that calculates the time to ignition, which implies the time taken for each sample to ignite [36]. This test was aimed at determining how each of the bamboo powder, PET powder and the composite samples ignites. The time required for each sample to ignite under a steady flame of 25^{o}C was recorded.

2.3.5 Hardness test

Each sample was subjected to hardness test using a Brinell testing apparatus (HUATEC HBRV-187.5E electric Brinell) in accordance with standard procedure (ASTM D1037). The resistance to permanent indentation deformation was ascertained by doing this test [37, 40, 41]. The values of Brinell hardness were measured and recorded.

2.3.6 Compression test

Compression test was performed on the composite samples in order to ascertain how the material behaved when crushing loads are applied [38]. Using a compression testing machine (WA-300B digital display universal testing machine), the samples for each of the five mixture-ratios were tested at a constant speed rate of 0.01 mm/s in accordance with standard procedures. The maximum load each sample can withstand before failure as well as its corresponding compressive strength were recorded.

3. RESULTS AND DISCUSSION

3.1 Impact of Mixture Ratio on Physical Properties of the Composite Produced

3.1.1 Impact of mixture ratio on density

The average density for each mixture ratio is as presented in Table 2. Samples A, B, C, D, and E have densities of 915.45 kg/m³, 900.87 kg/m³, 895.04 kg/m³, 865.89 kg/m³ and 819.24 kg/m³, respectively. The findings established that sample A with 60 wt% of bamboo powder and 40 wt% of PET powder has the highest density, indicating that the sample is more tightly packed when compared to others. Thus, the density of each sample decreases as the wt% of PET powder is decreased. PET exhibits a higher density than bamboo, resulting in a more compact and tightly packed mass of composite samples at higher PET powder concentrations compared to those at lower concentrations. This agreed with the work of [17, 18], through microstructure analysis, that high-density composite materials are tightly packed with tiny space between the particles and have adequate interfacial bonding. In order to determine consistency in the density across the samples, the Microsoft Excel app was used to find the errors in the average density values, and are plotted in Figure 1. The error bars indicate minimal variation across the density of the samples.

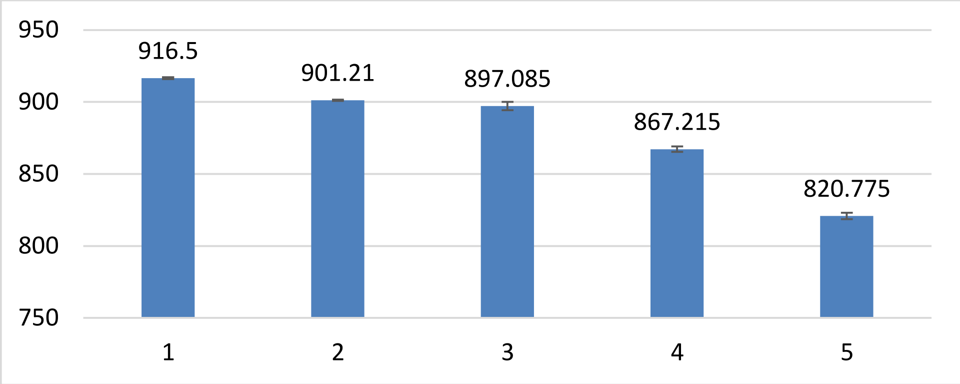

Figure 1: Density of the composite samples

Table 2: Effect of mixture ratio on physical properties of the composite samples

Sample	Density (Kg/m^3)		Absorption Rate (%)	
			Oil	Water
A	915.45	916.43	0.0010	0.0112
B	900.87	901.55	0.0224	0.0333
C	895.04	899.13	0.0512	0.0453
D	865.89	868.54	0.0648	0.0767
E	819.24	822.31	0.0810	0.1200

3.1.2 Impact of mixture rate on absorption rate

Table 2 shows the average result of absorption test used to determine the amount of liquid (oil, and water) absorbed by each composite sample. It was observed that as the mixture ratio constituent varied, the oil and water absorption rates of the samples increased from 0.0010 – 0.0810 % and 0.0112 – 0.1200 %, respectively, due to the reduction in the bonding ability of the composite. Figure 2 demonstrates the differences in these absorption rates. The result showed that sample E absorbed oil and water more (at 0.0810 % and 0.1200 %, respectively), which can be attributed to increase in the percentage weight of bamboo powder and decrease in the proportion of PET because PET augments the binding ability of resin mixed with the composite materials. This suggests that the lesser the wt% of PET powder in a composite material, the more absorptive the composite material becomes and is in agreement with the work of [19], which asserted that PET serves as an optimal binder for compaction of powder and diminishes water absorption.

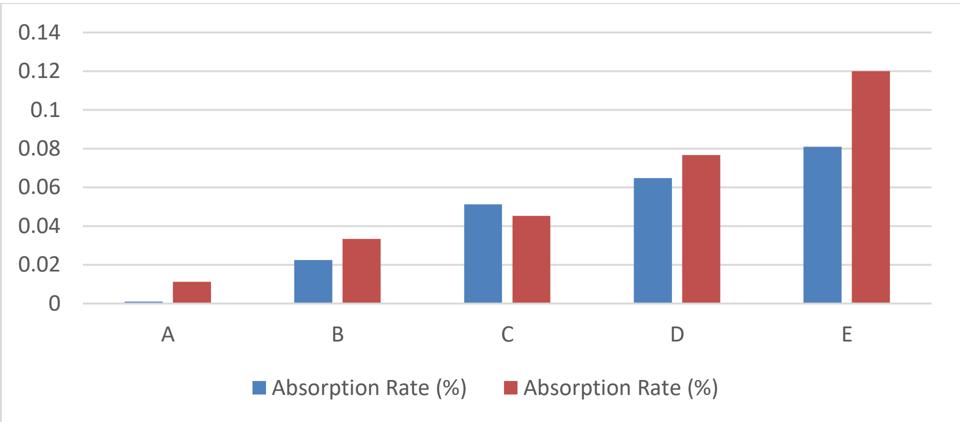

Figure 2: Absorption rate

3.1.3 Impact of mixture ratio on acidity and alkalinity

The pH status of the distilled and demineralized water, bamboo powder solution, PET powder solution, and bamboo and PET powder solution are described in Table 3. This Table shows that each of the distilled and demineralized water, bamboo powder, PET powder, and bamboo and PET powder solutions has no effect on the blue and red litmus papers respectively, indicating that the solutions are distinctly neutral. The testing procedure is shown in Figure 3. The neutrality of these solutions to blue and red litmus papers suggest that they are neither acidic nor basic, which can be said to be an attestation that these materials are environmentally friendly. Thus, mixture ratio has no effect on the acidity and alkalinity of the composite. Figure 3 illustrates the samples process.

Figure 3: Acidity and basicity test

Table 3: Acidity and basicity test

Solution(s)	Litmus Papers	
	Blue	**Red**
Distilled and demineralized water	No effect on litmus paper	No effect on litmus paper
Bamboo powder	No effect on litmus paper	No effect on litmus paper
PET powder	No effect on litmus paper	No effect on litmus paper
Bamboo and PET powder (at varying mixture ratio)	No effect on litmus paper	No effect on litmus paper

3.1.4 Impact of mixture ratio on flammability

The time to ignition was used to establish sustained flaming on the sample surface. The time to ignition for flaming combustion of bamboo powder, PET powder and the composite samples under a steady flame of 25^{o}C was observed. Each of the samples was tested at three different times and the average values are as shown in Table 4. The average values of the ignition time of bamboo powder, PET powder and the composite samples at steady flame of 25^{o}C are 10.14 s, 64.10 s, 25.84, 24.39 s, 23.62 s, 21.51 s and 19.93 s, respectively (Figure 4). The results demonstrated that the time to ignition of bamboo powder was lowest compared to PET powder and the composite samples when exposed to heat source. The PET powder took highest time to ignite due to the fact that it melted before igniting when the flammable volatile concentration at the PET-heat source contact reached a certain threshold. Also, the time to ignition of the composite samples was higher than bamboo powder due to their polymer matrix. However, among the composite samples, the time to ignition decreased as the wt% of PET powder is decreased. Therefore, the flammability of the composite samples produced reduced with increased wt% of PET powder in the mixture ratio, and influences how long they were able to withstand exposure to heat source. In order to determine consistency in the time each sample takes to ignite, Microsoft excel app was used to find the errors in the average time to ignition and are plotted in Figure 4. The error bars indicate minimal variation across the time to ignition of the samples.

Table 4: Flammability of produced samples

Sample	T1(s)	T2(s)	T3(s)	Average time to ignition (s)
Bamboo	12.22	9.43	8.78	10.14
PET powder	59.34	62.92	70.04	64.10
Composite A	24.50	26.02	27.00	25.84
Composite B	25.50	24.07	25.60	24.39
Composite C	23.60	22.90	25.36	23.62
Composite D	20.34	21.16	23.03	21.51
Composite E	18.10	19.40	22.29	19.93

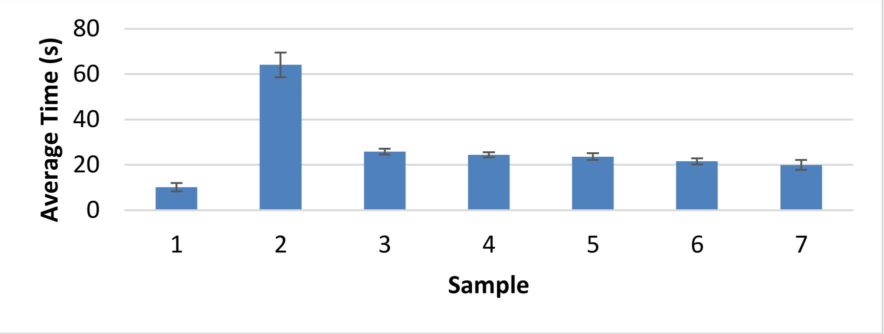

Figure 3: Time to ignition

3.2 Impact of Mixture Ratio on Mechanical Properties of the Composite Produced

This section discussed the results of effect of mechanical properties on the composite samples.

3.2.1 Hardness

The hardness test performed on the composite samples was to identify the mixture ratio with the highest resistance to permanent indentation. Table 5 shows the average hardness value for each mixture ratio. The average hardness values of the samples A, B, C, D and E are 88.55, 85.78, 76.98, 65.60 and 55.57 BHN, respectively (Figure 5). According to the result, the mixture ratio of 60% bamboo powder and 40% PET powder has the highest hardness value. Also, the mixture ratio of 80% bamboo powder and 20% PET powder has the least hardness value. This implies that an increase in wt% of PET powder influences the resistance to permanent indentation of the samples of composite which attests to the density of the samples. The composite samples with higher wt% of PET powder demonstrated higher density and mixture ratios with higher density results in higher hardness; this disagrees with the reports of [20, 21, 22] who had reported that whenever the filler content in a composite material increases the hardness value will increase.

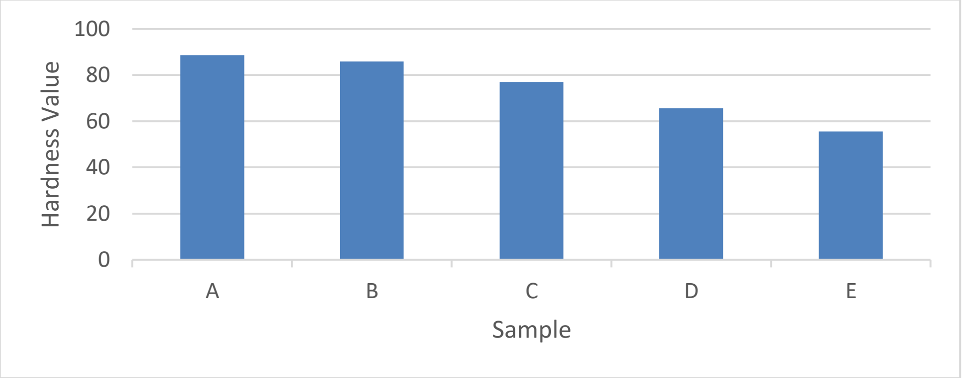

Figure 5: Hardness

Table 5: Average values of mechanical properties

Specimen	Hardness (BHN)	Compressive Strength (N/mm^2)	Wear Resistance (cm/cm^3)
A	88.55	14.78	0.0096
B	85.78	14.58	0.0053
C	76.98	14.32	0.0040
D	65.60	14.29	0.0028
E	55.57	9.10	0.0011

3.2.2 Compressive strength

The result of samples subjected to compressive test is depicted in Table 5. The average values of compressive strength of the samples A, B, C, D and E are 14.78, 14.58, 14.32, 14.29 and 9.10 N/mm^2, respectively. The load each sample can withstand varies despite having the same surface area (of 4900 mm^2), which is attributed to the mixture ratios constituents. For instance, sample A has compressive strength of 14.78 N/mm^2 and can sustain a load of 72.40 KN without failing. Also, sample B with compressive strength of 14.58 N/mm^2 will withstand a load of 71.45 KN. Likewise, sample C with compressive strength of 14.32 N/mm^2 can bear a load of 70.18 KN. Similarly, samples D and E with compressive strengths of 14.29 N/mm^2 and 9.10 N/mm^2 can withstand loads of 70.04 KN and 44.59 KN, respectively (Figure 6). The finding shows that sample A with 60 % bamboo powder and 40% PET powder has the highest compressive strength, thus signifying a better ability to resist deformation when external loads are applied. This can be attributed to the influence that

PET power has on the mixture ratio, such that a higher compressive strength is obtained as the wt% of PET powder is increased [23].

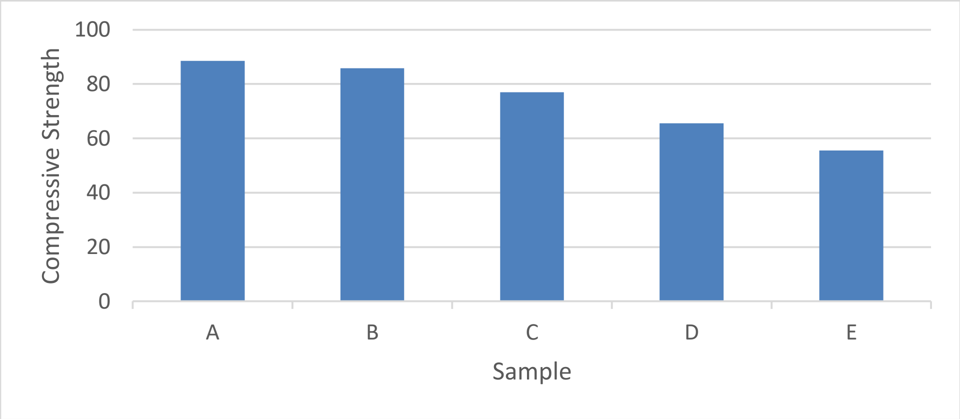

Figure 6: Compressive strength

3.2.3 Wear resistance

Table 5 shows the values of resistance of the reinforced composite samples produced to wear. The average values of the wear resistance for samples A, B, C, D and E are 0.0096, 0.0053, 0.0040, 0.0028 and 0.0011 cm/cm^3, respectively (Figure 7). This implies that the resistance to wear of each sample decreases as the mixture ratio of the sample varied. The ability of these samples to resist material loss by some mechanical actions or withstand the effect of two materials rubbing against each other which can take many forms including adhesion, abrasion, scratching and scouring against one another decreased with the PET powder ratio. The samples of the composite material produced have different hardness property; the softest sample wears easily while the hardest sample resists the effect of wear. This demonstrates the influence that PET powder has on wear resistance of mixture ratios of polymer matrix composite. Decreased wt% of PET powder in the mixture ratio resulted in reduced wear resistance of the composite samples.

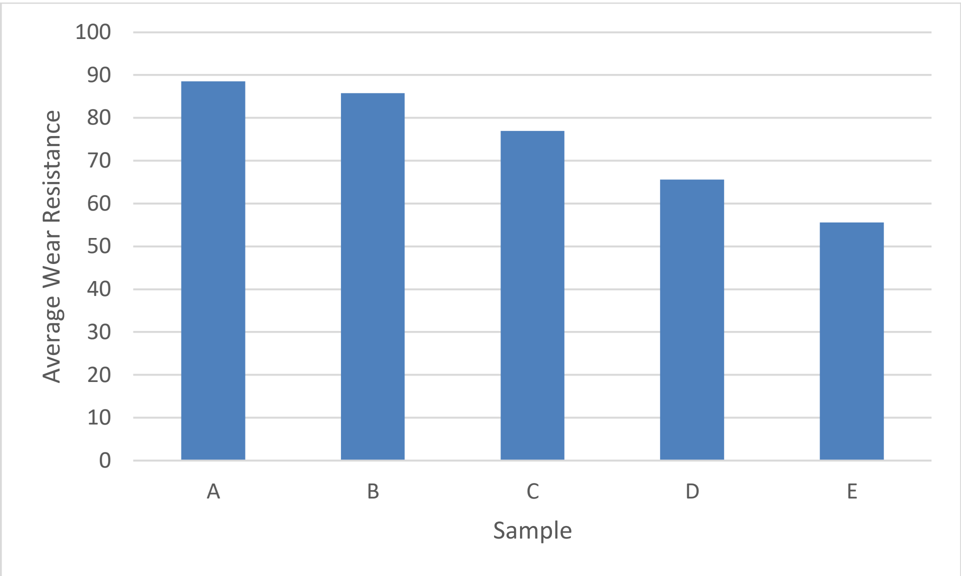

Figure 7: Wear resistance

4. CONCLUSION

The study examined the effect of mixture ratio on the composite material produced from bamboo and PET powders in order to determine the mixture ratio with the optimum physical, chemical and mechanical properties. The findings indicate that the density of the bamboo and PET composite material is affected by the PET powder, resulting in a denser and more compact product at higher weight percentages of PET. Similarly, PET influences the oil and water absorption rates of bamboo and PET powders as the mixture ratios with higher wt% of PET absorbs less water, and oil resulting in a less porous product. Both bamboo and PET powders have no effect on blue and red litmus papers indicating that they can be used for the production of ecofriendly components. The higher the wt% of PET in the mixture ratio, the higher the time it takes the composite material to ignite. Higher wt% of PET powder also leads to a composite material with higher resistance to indentation, and increased ability to withstand crushing loads, and even enhanced resistance to wear. In general, 80 wt% bamboo powder and 20 wt% PET powder has the highest characteristics suitable for the production of high performing, eco-friendly products which include automotive, wall panels, bicycle frames, and interior components of an aeroplane.

ACKNOWLEDGMENT

The authors acknowledge the facilities and support of farm power laboratory, concrete laboratory, foundry shop and wood workshop of the Faculty of Engineering, Adeleke University, Ede, Osun State, Nigeria.

REFERENCES

[1] Turri, E.M. & Leterme, S.C. (2023). How plastic debris and associated chemicals impact the marine food web: A review. Environmental pollution, 321(1), 1-12. doi:10.1016/j.envpol.2023.121156.
[2] Honingh, D., Emmerik, T.V., Uijttewaal, W., Kardhana, H., Hoes, O. & Giesen, N. (2020). Urban river water level increase through plastic waste accumulation at a rack structure. Frontiers in earth science, 8(28), 1-8. doi: 10.3389/feart.2020.00028.
[3] Cubas, A.L.V., Bianchet, R.T., Reis, I.M.A.S., Gouveia, I.C. (2022). Plastics and microplastic in the cosmetic industry: Aggregating sustainable actions aimed at alignment and interaction with UN sustainable development goals. *Polymers*, 14(21), 1-16. doi: 10.3390/polym14214576.
[4] Benyathiar, P., Kuma, P., Carpenter, G., Brace, J. & Mishra, D. (2022). Polyethylene terephthalate (PET) bottle-to-bottle recycling for the beverage industry: A review. Polymers, 14(12), 1-29. doi: 10.3390/polym14122366.
[5] Sarda, P., Hanan, J.C., Lawrence, J.G. & Allahkarami, M. (2021). Sustainability performance of polyethylene terephthalate, clarifying challenges and opportunities. Journal of polymer science, 60(1), 7-31. doi: 10.1002/pol.20210495.
[6] Evode, N., Qamar, S.A., Bilal, M., Barcelo, D. & Iqbal, H.M.N. (2021). Plastic waste and its management strategies for environmental sustainability. Case studies in chemical and environmental engineering, 4(4), 1-8. doi: 10.1016/j.cscee.2021.100142.
[7] Cao, F., Wang, L., Zheng, R., Guo, L., Chen, V. & Qian, X. (2022). Research and progress of chemical depolymerisation of waste PET and high-value application of its depolymerisation products. RSC Adv., 12(1), 31564-31576. doi: 10.1039/D2RA06499E.
[8] Dauletbek. A., Xue, X., Shen, X., Li, H., Feng, Z., Lorenzo, R., Liu, K., Escamilla, E.Z., Yao, L. & Zheng, X. (2021). Lightweight bamboo-structures-report on 2021 international collaboration on bamboo construction. Sustainable structures, 3(1),1-14. doi: 10.54113/j.sust.2023.000025.
[9] Wei, X., Wang, G., Smith, L.M., Chen, X. & Jiang, H. (2021). Effects of gradient distribution and aggregate structure of fibers on the flexibility and flexural toughness of moso bamboo (Phyllostachys edulis). Journal of materials research and technology, 16(1), 853-863. doi: 10.1016/j.jmrt.2021.12.071.
[10] Khajouei-Nezhad, M., Semple, K., Nasir, V., Hu, Y., Marggraf, G., Hauptman, J., & Dai, C. (2023). Advances in engineered bamboo processing: Material conversion and structure. Advances in bamboo science, 5(1), 1-15. doi: 10.1016/j.bamboo.2023.100045.
[11] Pramudi, G., Raharjo, W.W., Ariawan, D. & Arifin, Z. (2021). Utilization of bamboo fiber in the development of environmentally friendly composite - A review. IOP conference series: Materials science and engineering, 1096(1), 1-14. doi: 10.1088/1757-899X/1096/1/012038.
[12] Siswanto, J., Latifah, K., Supriyadi, B., Rochim, A. & Alzami, F. (2020). The relation of compressive strength and tensile strength of bamboo fiber for soil stabilization. Journal of physics conference series, 1517(1), 1-6. doi: 10.1088/1742-6596/1517/1/012075.
[13] Hassan, K.M.F., Al Hassan, K.M.N., Ahmed, T., Gyorgy, S., Pervez, M.N., Bejo, L., Sandor, B. & Alpar, T. (2023). Sustainable bamboo fiber reinforced polymeric composites for structural applications: A mini review of recent advances and future prospects. Environmental engineering, 8(1), 1-16. doi: 10.1016/j.cscee.2023.100362.
[14] Sanjita, W., Surbhi, K., Pritesh, Y., Halil, T., Soydan, O. & Uday, V. (2022). Bamboo fiber reinforced polypropylene composites for transportation applications. Frontiers in materials, 9(1), 1-14. doi: 10.3389/fmats.2022.967512.
[15] Ojetoye, A.A., Abu, R. & Adewole, N.A. (2023). Assessment of automobile user’s perception of viability of producing spare parts from biomaterial composites in Nigeria. Conference proceedings, 1st faculty of engineering and technology conference (FETiCON). Jun. 5-7, 724-728.
[16] Bharat, N., & Bose, P.S.C. (2021). An overview on the effect of reinforcement and wear behavior of metal matrix composites. Materials today: Proceedings, 46, 1-7. doi: 10.1016/j.matpr.2020.12.084.
[17] Ilori, O.O., Soji-Adekunle, A.R., Adedokun, O.P., Umama, T.O., Olagunju, C.B. & Olasunkanmi, A.U. (2021). Production of automobile brake pads from bagasse, banana peels and periwinkle shell. Adeleke university journal of engineering and technology, 4 (2), 1-6.

[18] Ilori, O.O., Ojetoye, A.A., Adedokun, O.P., Umama, T.O., Olagunju, C.B. & Olasunkanmi, A.U. (2022). Effect of mechanical and physical properties on brake pads produced from bagasse, banana peels and periwinkle shell. LAUTECH journal of engineering and technology, 16 (1), 100-105.
[19] Djonga, P.N.D., Tom, A., Valery, H.G. & Nkeng, G.E. (2022). Mechanical properties and chemical stability of bathroom wall composites manufactured from recycled polyethylene terephthalate (PET) mixed with cocoa hull powder. Journal of advanced chemical science, 7(4), 751-754. doi: 10.5772/intechopen.102457.
[20] Atunaya, C.U., Olaitan, S.A., Azeez, T.O., Akagu, C.C., Onukwuli, O.D., & Mentikit, M.C. (2013). Effects of rice husk filler on mechanical properties of polyethylene matrix composites. International journal of current research review, 5(15), 58-65.
[21] Ilori, O.O., Idowu, I.A. & Adeleke, K.M. (2018). Comparing the effect of fillers on the mechanical properties of recycled low density polyethylene composites under non-weathered and weathered conditions. European journal of engineering research and science, 3 (5), 17-20.
[22] Idowu, I.A. & Ilori, O.O. (2020). Effect of fillers on mechanical properties of recycled low density polyethylene composites under weathered condition. Nigeria journal of technological research, 15 (3), 44-49.
[23] Awolusi, T., Taiwo, A., Aladegboye, O., Oguntayo, D. & Akinkurolere, O. (2022). Optimisation of quinary blended supplementary cementitious material for eco-friendly paving unit using taguchi orthogonal array design. Materials Today: Proceedings, 65(3), 2221-2227, doi: 10.1016/j.matpr.2022.06.263.
[24] Oyewo, A.T., Adefajo, A.A., Adeleke, K.M., Oyerinde, A.Y. & Ojetoye, A.A. (2024). Taguchi optimization prediction to evaluate the synergetic impact of coconut shell ash particles on the tensile strength of banana pseudo stem fiber composites. *Journal of Engineering and Technology, xx(x), 1-11.*
[25] Benjamin, M.A.Z, Ng, S.Y, Saikim, F.H. & Rusdi, N.A. (2022). The effects of drying techniques on phytochemical contents and biological activities on selected bamboo leaves. Molecules, 27(19), 1-23.
[26] Jabłońska, B., Kiełbasa, P., Korenko, M. & Dróżdż, T. (2019). Physical and chemical properties of waste from pet bottles washing as a component of solid fuels. Energies, 12(1),1-17. doi: 10.3390/en12112197.
[27] Nyantakyi, E., Obiri-Yeboah, A., Ghadafi, A., Domfeh, M. & Obeng-Ahenkora, N. (2020). Partial replacement of cement with glass bottle waste powder in concrete for sustainable waste management: A case study of Kumasi metropolitan assembly, Ashanti region, Ghana. Journal of civil engineering research. 10(1), 29-38. doi: 10.5923/j.jce.20201002.01.
[28] Tao, Y., Hadigheh, S.A. & Wei, Y. (2023). Recycling of glass fibre reinforced polymer (GFRP) composite wastes in concrete: A critical review and cost benefit analysis. Structures, 53(1), 1540-1556.
[29] Enache, A.C., Grecu, I., & Samoila, P. (2024). Polyethylene terephthalate (PET) recycled by catalytic glycolysis: A bridge toward circular economy principles. *Materials*, *17*(12), 1-33. doi: 10.3390/ma17122991 Akhator, E., Bazuaye, L., Ewere, A. & Oshiokhai, O. (2023). Production and characterisation of solid waste-derived ffuel briquettes from mixed wood wastes and waste pet bottles. Heliyon 9(1), 1-11.
[30] Akhator, P.E., Bazuaye, L., Ewere, A., & Oshiokhai, O. (2023). Production and characterisation of solid waste-derived fuel briquettes from mixed wood wastes and waste pet bottles. Heliyon, 9(11), 1-11. doi: 10.1016/j.heliyon.2023.e21432.
[31] Zawawi, E.Z.E, Amirrudin, M., Kamarun, D., Bonnia, N.N. & Rozana, M.D. (2019). Characterizations of poly-lactic acid/polypropylene filled with bamboo charcoal powder. Journal of physics: Conference series, 1349:1-8.
[32] Mariyam, S., Parthasarathy, P., Pradhan, S., AlAnsari, T. & McKay, G. (2024) Co-pyrolysis of biomass and binary single-use plastics: synergy, kinetics, and thermodynamics. International journal of sustainable energy, 43(1), 1-23. doi: 10.1080/14786451.2023.2168003.
[33] Lim, J., Kim, S.Y., Yeo, D., Shin, H., Jeong, D. (2018). Effects of ZrO2 addition on mechanical strength and thermal shock resistance of cordierite-mullite ceramics. Korean journal of materials research. 28(1), 719-724.
[34] Musa, D.E., Mariette, O.L., Osilama, A.J. & Sotonye, W.A. (2023). Preparation of acid-base indicators using extract from petals of pride of barbados (caesalpinia pulcherrima) flowers. Nigerian research journal of chemical sciences, 11(1), 127-137.
[35] Celebrezze, J.V., Boving, I. & Moritz, M.A. (2023). Tissue-level flammability testing: a review of existing methods and a comparison of a novel hot plate design to an epiradiator design. *Fire*, 6(4), 1-22. doi: 10.3390/fire6040149.
[36] Adeleke, K.M., Fadara, T.G., Ojetoye, A.A., Oyerinde, A.Y. & Soji-Adekunle, A.R. (2024). Mechanical properties of boron-doped-zinc oxide thin films using spray pyrolysis technique. Journal of engineering sciences and design, 12(2), 265-276. doi: 10.21923/jesd.1304303.
[37] Harish, M., Whitaker, F., Daniel, G., Mohan, R. & Mini, K M. (2021). Performance assessment of recycled LDPE with sand fillers. Materials Today: Proceedings. 42. doi: 10.1016/j.matpr.2021.02.285.
[38] Adegbola. J.O., Alli, O.D., Akingbade, T.O., Ojetoye, A.A., Sanni, J. & Ajala, O.M. (2024). Development of a graphene-carbon composite: an alternative to metals and plastics used in the production of pyramidal satellite horn antenna. *Nigerian research journal of engineering and environmental sciences 9(1), 298-303.*
[39] Ilori, O., Idowu, I. & Adeleke, Kehinde. (2018). Comparing the effect of fillers on the mechanical properties of recycled low density polyethylene composites under non-weathered and weathered conditions. European journal of engineering research and science, 3(5), 17-20. doi: 10.24018/ejers.2018.3.5.707.

[40] Azeez, T.M., Mudashiru, L.O. & Ojetoye, A.A. (2022). Assessment of Microstructure and Mechanical Properties of As-cast Magnesium Alloys Reinforced with Organically Extracted Zinc and Calcium. *Advances in ManufacturingTechnologies and Production Engineering*, 1, 45-55. doi: 10.2174/9789815039771122010009.
[41] Abdullah, A.H.D., Karlina, N., Rahmatiya, W., Mudaim, S. & Fajrin, A.R. (2017). Physical and mechanical properties of five indonesian bamboos. *IOP Conf. Ser. Earth Environ. Sci. 60*, 1-6.
[42] Christine, A.T., Panti, 1,, Christy, S.C., Althea, R.N., Kerby, D.R., Lessandro, E.O., Garciano, 1, & Luis, F.L. (2024). Establishing the characteristic compressive strength parallel to fiber of four local philippine bamboo species. Sustainability, 16(9), 1-21. doi: 10.3390/su16093845.
[43] Adedipe, O., Abdullahi, A., Ogunwole, O. & Sadiq, I. (2013). Investigation of some mechanical properties of 'Agaraba' - A native nigerian bamboo. AU journal of technology. 16(1), 181-186.
[44] Awalluddin, D., Ariffin, M.A., Osman, M., Hussin, M., Ismail, M., Lee, H., & Abdul, S.L.& Nor, H. (2017). Mechanical properties of different bamboo species. MATEC Web of Conferences. 138, 1-9. doi: 10.1051/matecconf/201713801024.
[45] Djamil, S., Suardana, N.P.G., Irawan, A.P., Sugita, I.K.G., Lubis, S.Y. & Dicky T. (2020). Bamboo composite compressive strength with three-layer configuration. Conference series: Materials science Engineering, 1007(1), 1-6.
[46] Odiakaose, C., Hassan, M. A., & Raji, A. (2023). Tensile strength and hardness of polypropylene-bamboo/kenaf hybrid composite after optimization of production process. *Open journal of engineering science*, *4*(2), 14-34.
[47] Banga, H., Singh, V., & Choudhary, S. (2015). Fabrication and study of mechanical properties of bamboo fibre reinforced bio-composites. International institute of science technology & education, 6(1), 30-38.