FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 9 No. 5, May, 2025, pp 291 - 300
DOI: https://doi.org/10.33003/fjs-2025-0905-3428

ENHANCED PHYSICO-MECHANICAL AND THERMAL PROPERTIES OF WASTE HDPE/LDPE BLENDS REINFORCED WITH *Borassus aethiopum* FIBRES

[1]Shinggu, D. Yamta and *[2]Joseph Jacob

[1]Department of Pure and Applied Chemistry, Adamawa State University, P.M.B 25, Mubi, Adamawa State, Nigeria.
[2]Department of Chemistry, Air Force Institute of Technology, Nigerian Air Force Base, P.M.B 2104 Kaduna, Nigeria.

*Corresponding authors' email: jacobyumar@gmail.com, j.jacob@afit.edu.ng

ABSTRACT

This study evaluated the effects of *Borassus aethiopum* fibre (BAP) on waste HDPE-LDPE blends. The (*Borassus aethiopum* fibre (BAP) on waste HDPE-LDPE) materials were compounded on a Two Roll Mill and compression moulding machines. Properties such as density, water absorption, tensile strength, elastic modulus, flexural strength and hardness values were evaluated using standard procedures. The materials were further subjected to dynamic mechanical properties test in order to evaluate the influence of BAP fibre incorporation on the storage modulus, loss modulus and damping parameter of waste HDPE-LDPE blends. Optimal mechanical properties (tensile strength = 77.5 MPa, stiffness = 3.5 GPa) were achieved at 40 wt% BAP loading. This composition has corresponding minimal water absorption of 0.45 % after 240-hrs immersion period at room temperature. Similarly, dynamic mechanical properties results indicated that the storage modulus and load bearing capability of were found to be maximum (1.2 GPa) for a composite with 40 % weight of BAP fibre compared (to 400 MPa of the unreinforced) while a decrease in loss modulus was observed with increase in temperature and frequency. This indicates that incorporation of BAP fibre into waste HDPE-LDPE blends improved its physical, mechanical and dynamic mechanical properties with these properties increasing with the weight percentage of BAP incorporated up to 40 % and a sudden decrease at 50 % weight of BAP.

Keywords: *Borassus aethiopum*, Composites, Dynamic mechanical analysis, Physical and mechanical properties

INTRODUCTION

Polyethylene is recognised as one of the most common and widely used plastics in the world owing to its versatility resulting in a large volume of wastes. Effective plastic waste management strategies in form of composites development are crucial for mitigating the environmental impacts of these wastes (Jacob *et al.,* 2018). Using waste materials can assist in the fabrication of low-cost products and promote sustainability in addition to lessening the environmental impact of disposing of them (Shinggu & Jacob, 2025). It is projected that the amount of waste plastics in municipal solid garbage is increasing at a pace of two times every decade. This rise is closely linked to the rapid changes in population, urbanization, and developmental activities and lifestyle. Studies have shown that waste plastics are thought to withstand 450–500 years at Earth's surface before degrading (Thirugnanasambantham *et al.,* 2017; Shinde *et al.,* 2018; Shen *et al.,* 2019). Adopting a recycling procedure in form of composites is one approach to appropriately handle the tons of plastic garbage that need to be disposed of, and recycling also helps to maintain a cleaner environment. Due to the severe limitations controlling their disposal and the mounting environmental difficulties brought on by waste plastics, researchers are becoming more and more driven to developing new innovative products (Lendvai *et al.,* 2024).

Plastic waste poses a substantial threat to the environment classified as an emerging environmental pollutant. This pollutant has far-reaching consequences, potentially disrupting ecosystems on land and in water, underscoring the urgent need for effective management and mitigation strategies (Jacob *et al.,* 2023; Shinggu & Jacob, 2025). As industries attempt to lessen the over dependence on petroleum based products use, there is increasing need to investigate more environmental friendly and sustainable materials. Therefore, attention has been shifted to fabrication and investigation of properties of natural fibre reinforced materials The automotive and aerospace industries have both demonstrated interest in using natural fibre reinforced composites, for example, in order to reduce vehicle weight, attention had been shifted from steel to aluminium and recently from aluminium to natural fibre based composites for different applications (Mohanraj *et al.,* 2025).

The thermal characteristics of a polymer composite are quite important, particularly with regard to the production parameters and areas of application. One of the most crucial techniques for researching the thermal characteristics of polymers is dynamic mechanical analysis (DMA) (Jacob, 2023). Robust research is needed to give better performance qualities for these continuously expanding natural fibre-plastic composites so they can meet the expectations of end-user applications (Jacob & Yusuf, 2023). Researchers are also more interested in maximizing the use of renewable resources, such as natural fibers, in the production of composite due to the necessity to lessen our over-reliance on fossil fuels and synthetic fibres (Jacob & Mamza, 2021).

Numerous studies have been reported on the reinforcement of regularly used plastics to improving their morphological, creep, and physical properties (Jacob *et al.,* 2023; Jacob & Yusuf, 2023). The Physico-mechanical, and visco-elastic properties of African fan palm powder (AFPP) filled low density polyethylene composites have been reported (Shinggu & Jacob, 2025). However, much has not been done on the incorporation of BAP fibres into HDPE-LDPE blends to develop composite materials with improved properties. Examining the potential effects of adding BAP fibers into HDPE-LDPE blends on its mechanical, visco-elastic and physical properties has therefore become expedient.

MATERIALS AND METHODS

Sample Collection and Preparation

High-density and low-density polyethylene wastes were gathered from landfills. These samples underwent a full water wash, drying, and shredding into the smaller-sized particles that make up the polymer matrix. The *Borassus aethiopum* fibre utilized for reinforcement was obtained locally, sun-dried, ground, and sieved to a size of 150 µm.

Composite Production

The materials were compounded at 160 °C on a Two Roll Mill (Model number 5183, USA) according to the findings of Jacob *et al.* (2019). Table 1 shows the various weight percentage compositions of the materials. Compression of the samples was carried out at a pressure of 4 MPa for 10 minutes. The compounded and compressed samples were machined and chilled before going through characterization testing.

Table 1: % Weight compositions of the materials used in this work

BAP	rHDPE	rLDPE	TOTAL
10	45	45	100
20	40	40	100
30	35	35	100
40	30	30	100
50	25	25	100

*BAP- *Borassus aethiopum* fibre; rHDPE-recycled high-density polyethylene; rLDPE-recycled low-density polyethylene.

Mechanical Property Test

Tensile test

The ASTM D 638 (2022) standard procedure was used to determine the results of the samples' tensile strength as earlier reported (Jacob *et al.,* 2023; Jacob & Yusuf, 2023; Shinggu & Jacob, 2025).

Flexural strength

ASTM D790 (2015) standard test method was used to determine the flexural strength of the samples with the use of a universal testing machine and a three-point bending technique. The strain rate was 5 mm/min, and the spans were 40 mm apart in accordance with the work of Jacob, 2019; Jacob & Mamza, 2021).

Hardness test

According to Jacob *et al*. (2018), the relative resistance of a composite's surface to indentation by an indenter of a certain size under a given load is the basis for the hardness test of the material. Durometer Shore A was used to measure the shore hardness values of samples measuring 30 mm by 30 mm by 5 mm. The sample underwent five measurements at various locations, and the average of the results was used to determine the sample's hardness.

Physical Properties Test

Density

The density of the composites was determined by measuring mass and volume of the sample in accordance with the work of Jacob (2019).

Water Absorption Test

The water absorption test was conducted using the ASTM D570 (2010) methodology as earlier reported by Jacob & Shinggu (2021).

Thermal Properties

Dynamic Mechanical Analysis

Following ASTM D7028 (2015), DMA was performed using a DMA 242 E machine at frequencies of 2.5, 5 and 10Hz; amplititude of 60.00 μ m and at temperature of 120 ℃. Using a personal computer and the proteus software, the test parameters-storage modulus (E'), loss modulus (E"), and tangent of delta (Tan ∂)-were initially set up. The parameters of interest were then evaluated.

RESULTS AND DISCUSSION

Physical properties

Density

The density profile of the composites and unreinforced rLDPE is displayed in Figure 1. From the unreinforced (HDPE-LDPE blends) up to 40 % weight of AFPP filled rLDPE composites, a progressive decrease in material density could be observed. At 40 %, the lowest was 0.99 g/cm^3. This suggests that adding BAP fibers to waste HDPE-LDPE blends reduces the material's density. These outcomes are comparable to those of other authors' works (Khalaf, 2015; Jacob, 2019).

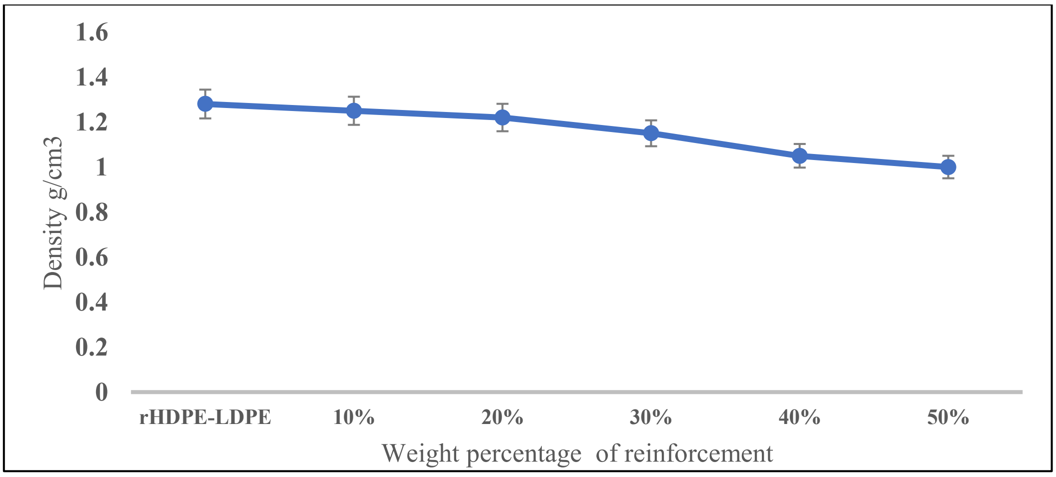

Figure 1: Effect of African fan palm powder on the density of recycled HDPE-LDPE blends

Water absorption

The rate of water absorption of BAP-filled recycled HDPE-LDPE blends is shown in Figure 2 following 240 hours of immersion at room temperature. Water absorption was shown to rise as the weight percentage of incorporated BAP fiber increased, reaching a maximum value of 6.2 % at 25 % of the weight fraction of fiber. This is to be expected since moisture uptake in polymer composites increases with the amount of hydrophilic natural fiber present. This outcome is consistent with research conducted by Abisha *et al*. (2023) and Jacob and Mamza (2020), who examined the mechanism of moisture absorption behaviour in waste HDPE composites filled with groundnut shell powder. Because recycled HDPE-LDPE sample is hydrophobic, there is little to no moisture uptake, as shown by the linearity of the chart at 0 %.

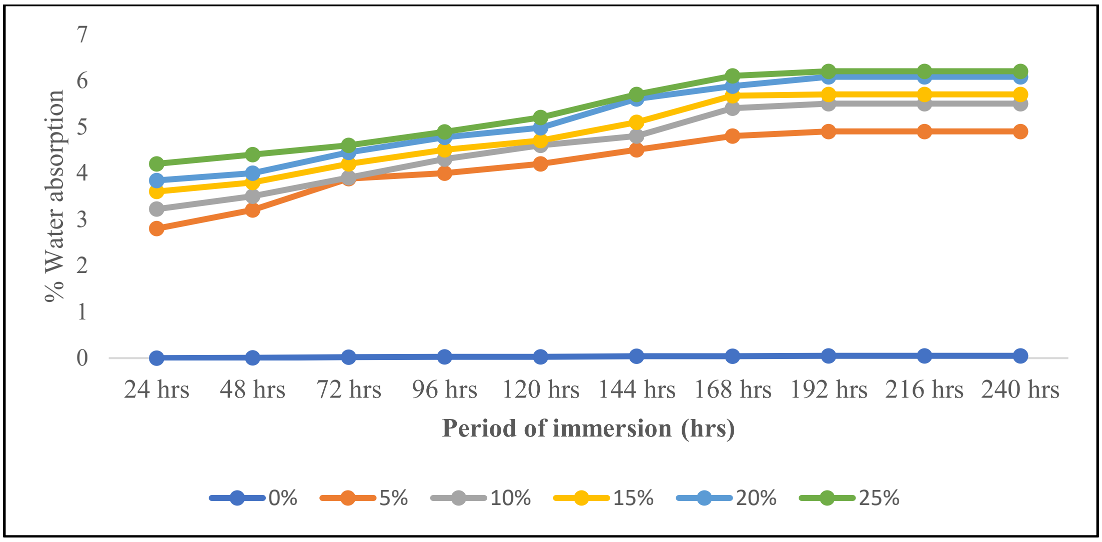

Figure 2: Percentage moisture absorption of BAP-recycled HDPE-LDPE blends at ambient temperature

Mechanical Properties

Tensile strength

Figure 3 depicts the tensile strength of BAP-rHDPE-LDPE composites with an increasing proportion of the fibres. Tensile strength improves from 10 % to 40 %, then declines at 50 %. The rise in tensile strength with the weight percentage of fibre could be attributed to the weakening of the constituent composition's interfacial attraction as the proportion of rHDPE-LDPE blends decreases with increasing weight fraction of reinforcement. Other researchers have observed similar observations (Jacob *et al.,* 2018; Jacob & Mamza, 2021).

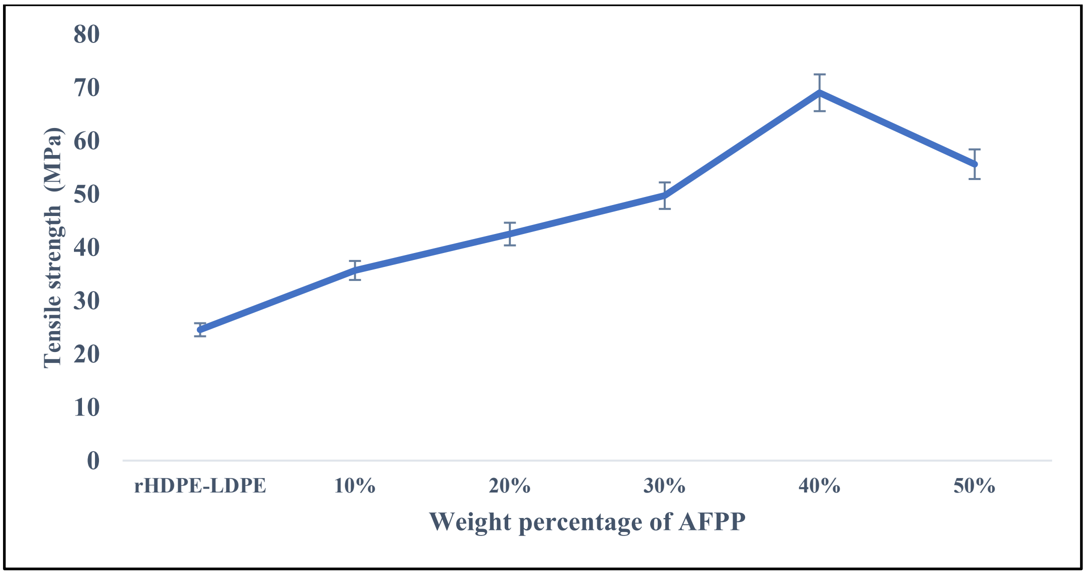

Figure 3: Effect of BAP on the tensile strength of recycled HDPE-LDPE blends

Elastic modulus

Figure 3 shows the elastic modulus (stiffness) of the BAP filled rHDPE-LDPE composite as a function of reinforcement weight. A comparable rise in stiffness with weight percentage of rHDPE-LDPE was observed. The composites' elastic modulus increases from 0.99 GPa (rHDPE-LDPE) to 1.69 GPa (at 40 % BAP). This could be attributed to improved interaction between rHDPE-LDPE and the integrated BAP fiber. These findings are consistent with those of other researchers (Khalaf, 2015; Jacob *et al.,* 2019; Jacob & Mamza, 2021).

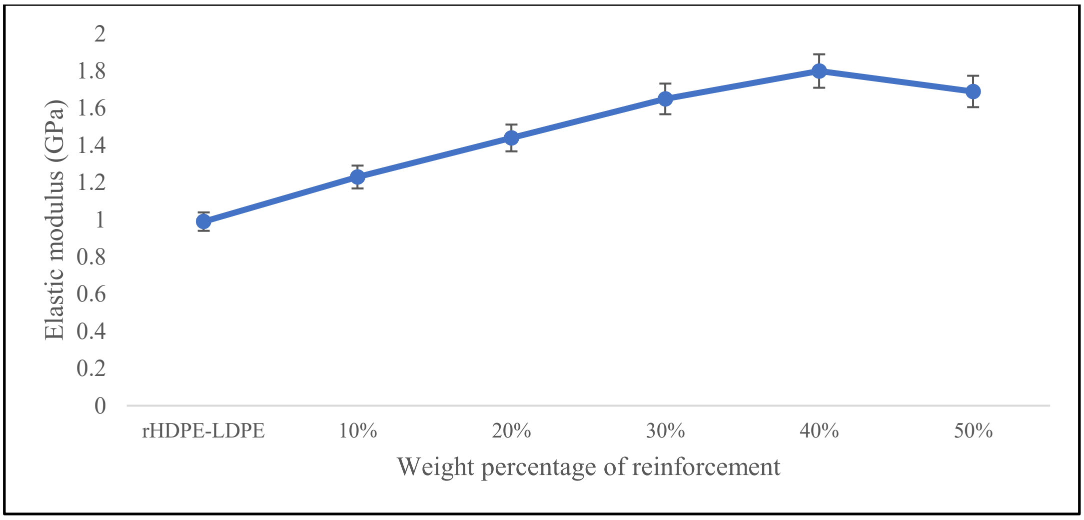

Figure 4: Effect of BAP on the elastic modulus of recycled HDPE-LDPE blends

Flexural strength

Figure 3 depicts the composites' flexural strength in relation to their weight percentage of BAP fibres. The flexural strength of *Borassus aethiopum* powder reinforced rHDPE-LDPE composites increases with the weight fraction of reinforcement and thereafter drops, reaching 68 MPa at 50 % wt reinforcement. This indicates better contact and stress transfer between the wHDPE-LDPE and BAP particles. It was discovered that increasing the weight fraction of reinforcement (at 50 %) reduces the flexural strength value due to poor fibre-matrix adhesion (Jacob & Shinggu, 2021).

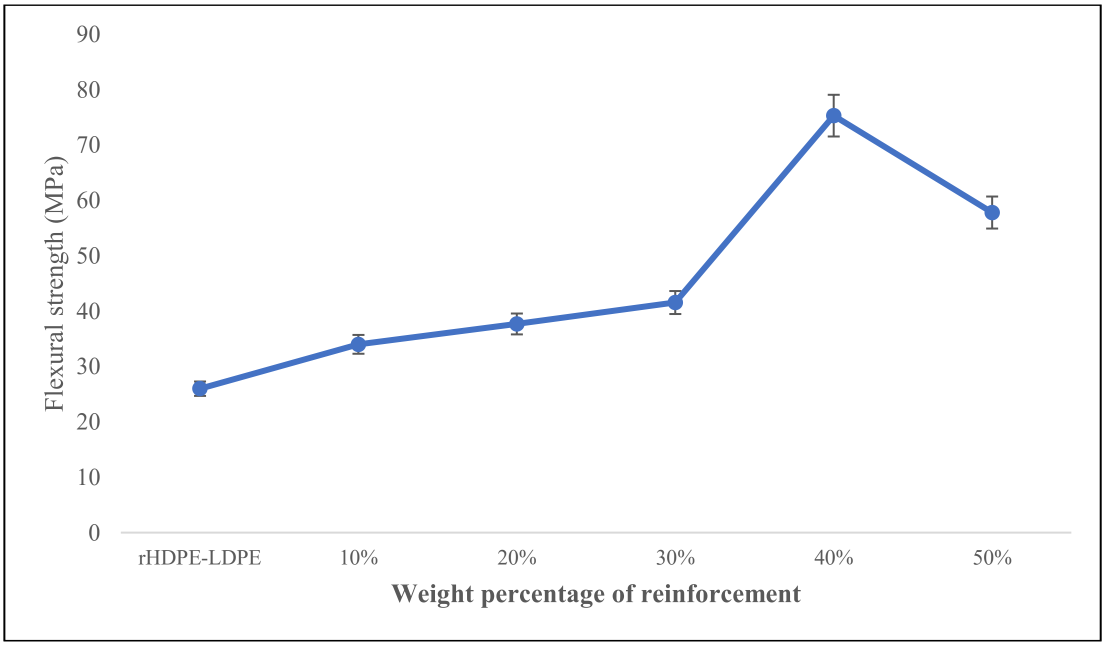

Figure 5: Effect of BAP on the flexural strength of recycled HDPE-LDPE blends

Hardness

Composite hardness testing is based on the surface's relative resistance to indentation by an indenter of specified dimensions under a specified load (Jacob *et al.,* 2018). The hardness of the composites was observed to increased gradually with weight of TSHP incorporated from

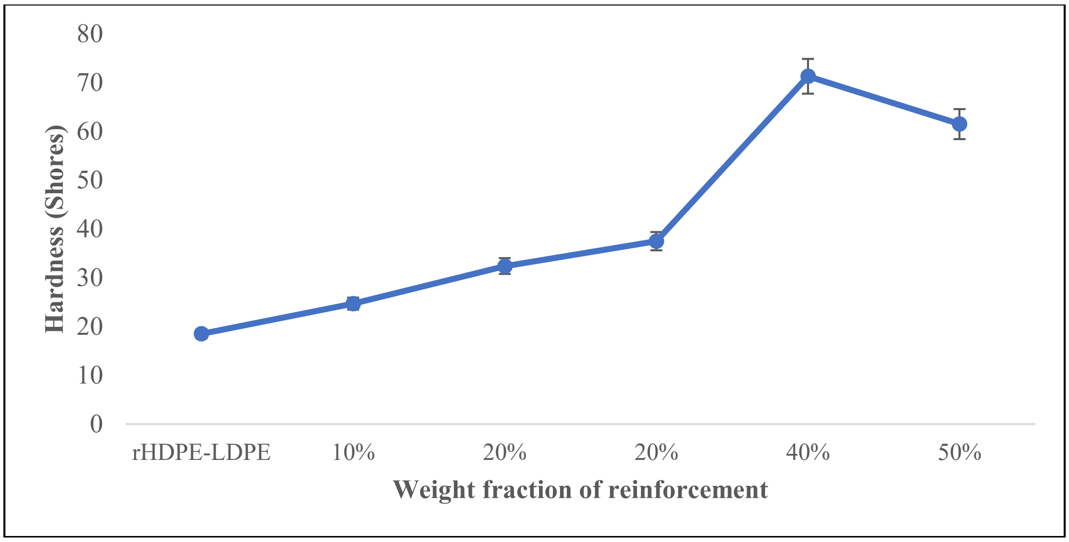

Figure 6: Effect of BAP powder on the hardness of recycled HDPE-LDPE blends

Thermal Properties

The storage modulus of unreinforced waste HDPE-LDPE composites

The stiffness and energy storage capacity of a material is described by its storage modulus (Jacob *et al.,* 2018). Figure 6 shows the storage modulus of unfilled HDPE-LDPE (control) at frequencies of 2.5, 5, and 10 Hz. The graph shows that the material is unstable at temperatures under 40 °C, with a maximum rigidity of 0.038 GPa. The finding is consistent with the work of Palanivel *et al.* (2017) who investigated the dynamic mechanical properties of natural fibre-filled composites and the results revealed that the storage modulus (E') and damping peaks (Tan ∂) values were found to be reduced with increasing matrix loading and temperature and that made by Jacob *et al.* (2019), who studied the thermomechanical properties of plantain peel particle reinforced waste HDPE-LDPE as composite wall tiles and that made by Jacob (2023).

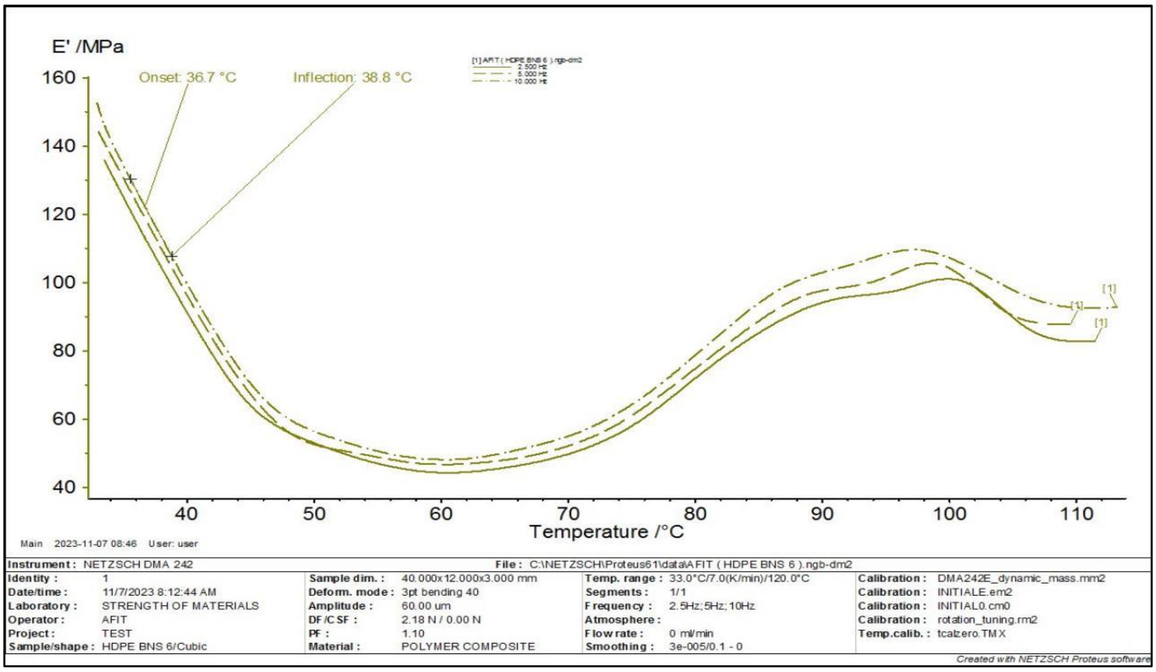

Figure 7: Storage modulus of unfilled recycled HDPE-LDPE blends

The Storage modulus of BAP waste HDPE-LDPE composites at different compositions

Figures 7, 8, and 9 show the storage modulus of 30, 40, and 50 % BAP waste HDPE-LDPE composites at 2, 5, and 10 Hz, respectively. These results show that the addition of BAP fibre into HDPE-LDPE increased the material's stiffness and energy storage capability. This is because HDPE-LDPE's maximum stiffness stability increased from 0.42 GPa (control) to 0.50 GPa at 30 % weight of BAP (Figure 8), 1.25 GPa at 40 % weight of BAP (Figure 9), and 0.34 GPa at 50 % (Figure 10). The obvious evidence of an increase in storage modulus from 30 wt % to 50 % weight percentage of BAP fibres could be attributed to the composites' strong fiber-matrix interaction (Jacob *et al.,* 2019). The precipitous decrease in stiffness stability to 0.34 GPa at 50 % weight fraction of PA fibre could be attributed to a weakening of the constituent composition's interfacial attraction as the percentage of waste HDPE-LDPE decreases with increasing weight fraction of BAP fibre (Gupta, 2018; Jacob, 2023). The results of an increase in storage modulus with a weight percentage of BAP fibres incorporated are also at par with the mechanical properties results.

The curves also show that the composites are stable under dynamic loading with increasing temperature up to 43.3 ℃ before its point of inflection at 48.2 ℃ (Figure 8); 57.6 ℃ (Figure 9); and 51.8 ℃ (Figure 10), which are taken as the glass transition temperatures for the composites with 30, 40, and 50 % weight of BAP fibre, respectively. According to Palanivel *et al.* (2017), Jacob *et al.* (2019) and Jacob &Yusuf (2023), Similar results of the increase in storage modulus with a weight percentage of reinforcement were observed for composites with 10 w % and 20 w % of BAP (plots not shown). These materials are suitable for the development of materials that can withstand temperatures up to 50 ℃.

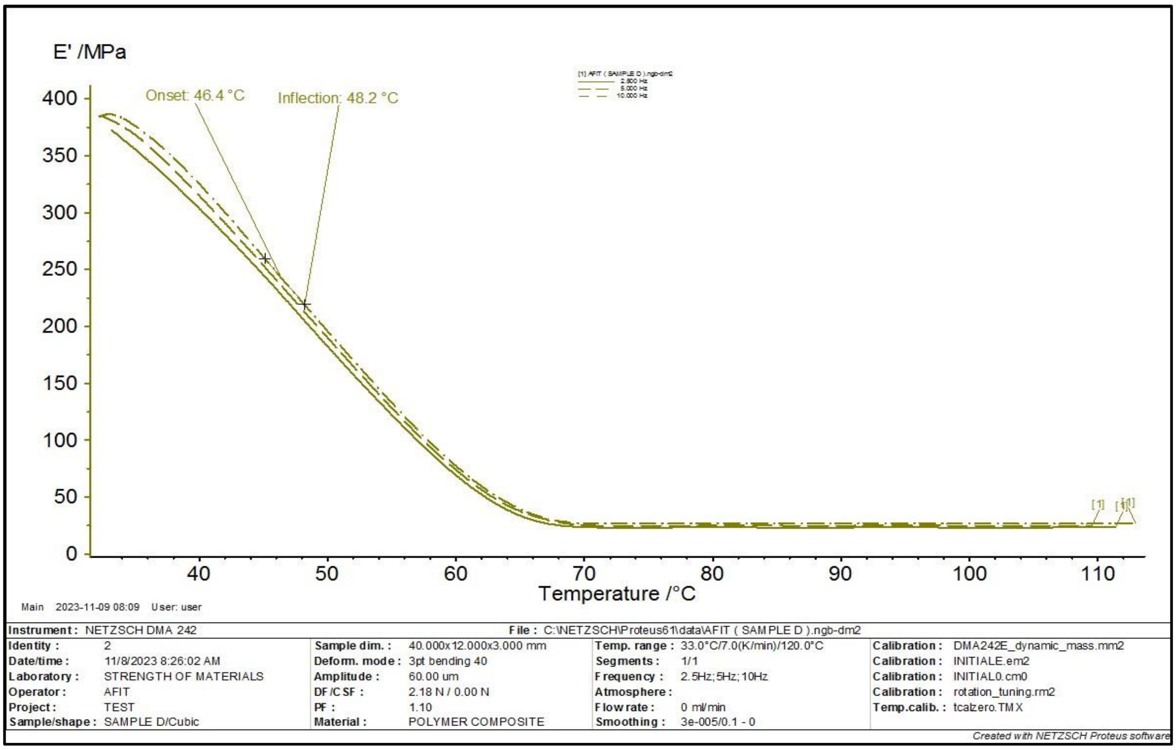

Figure 8: Storage modulus of 30 % BAP filled HDPE-LDPE blends

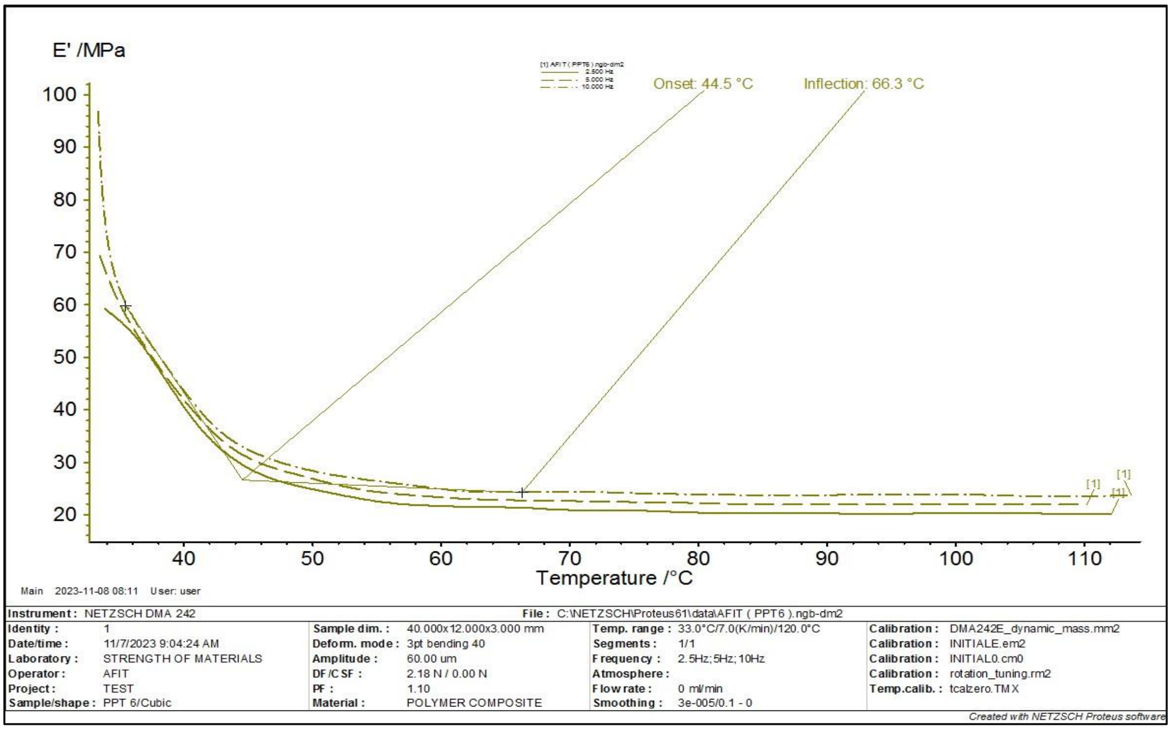

Figure 9: Storage modulus of 40 % BAP powder filled recycled HDPE-LDPE blends

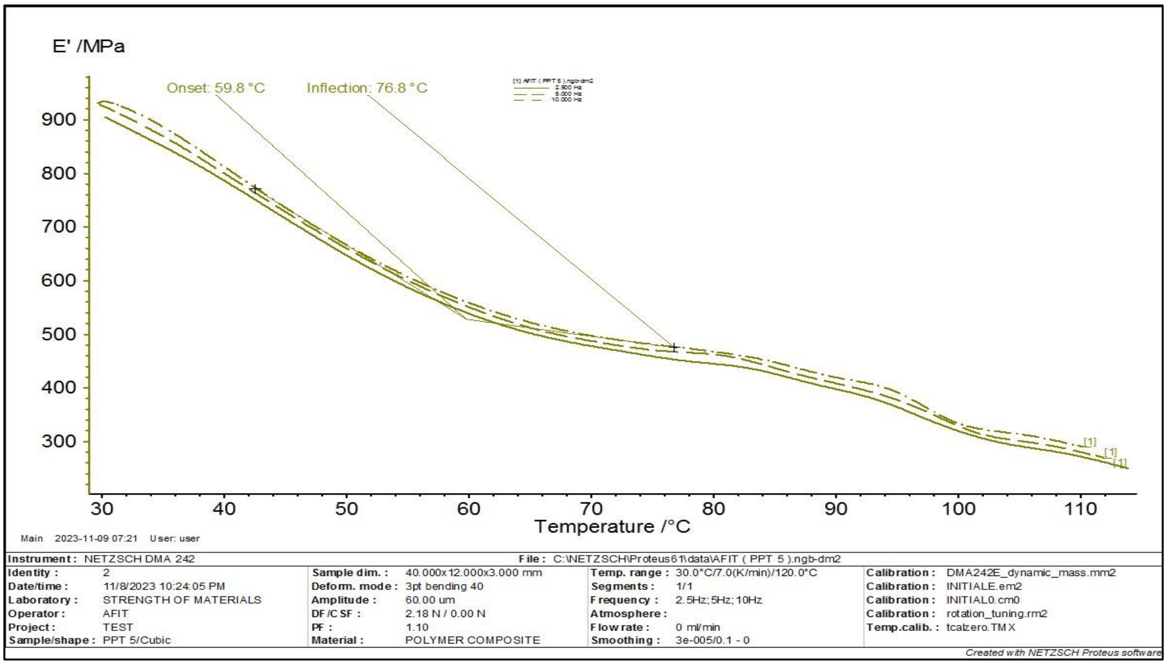

Figure 10: Storage modulus of 50 % BAP filled HDPE-LDPE blends

Damping parameter of BAP reinforced waste HDPE-LDPE composites at different compositions

Damping (Tan delta) is defined as the loss modulus divided by storage modulus. It is also known as the loss factor and is typically stated as a dimensionless number (Gupta, 2018; Jacob *et al.,* 2019; Rajesh *et al.,* 2021). Figure 11 depicts the damping parameter of unfilled recycled HDPE-LDPE whereas Figures 12-14 depict the damping parameters of BAP-filled composites at 30, 40, and 50 %, respectively. These results show that the damping of the composites reduces with the weight fraction of reinforcement from 30 to 50 %. This suggests that the sample with 40 % BAP has the best load bearing capability of all the composites. This could be due to improved interfacial interaction between the waste HDPE-LDPE and BAP fibres. Other authors have shown similar decreases in damping with weight percentage of reinforcement (Rana *et al.,* 2017; Gupta, 2018; and Jacob *et al.,* 2019). The figures also show the glass transition temperature (the temperature at which an amorphous solid material changes from a hard, brittle state to a softer, more pliable state) of unfilled waste HDPE-LDPE and composites. Figure 14 shows that the unfilled HDPE-LDPE sample has a glass transition temperature of 50.7 °C, which increases to 61.4 °C with 30 % BAP (Figure 15), 77.1 °C with 40 % weight percentage of fibre, and drops to 68.6 °C with 50 % weight percentage of fibre. This suggests that incorporating BAP fibre into recycled HDPE-LDPE increases stiffness stability (Jacob, 2023; Jacob & Yusuf, 2023).

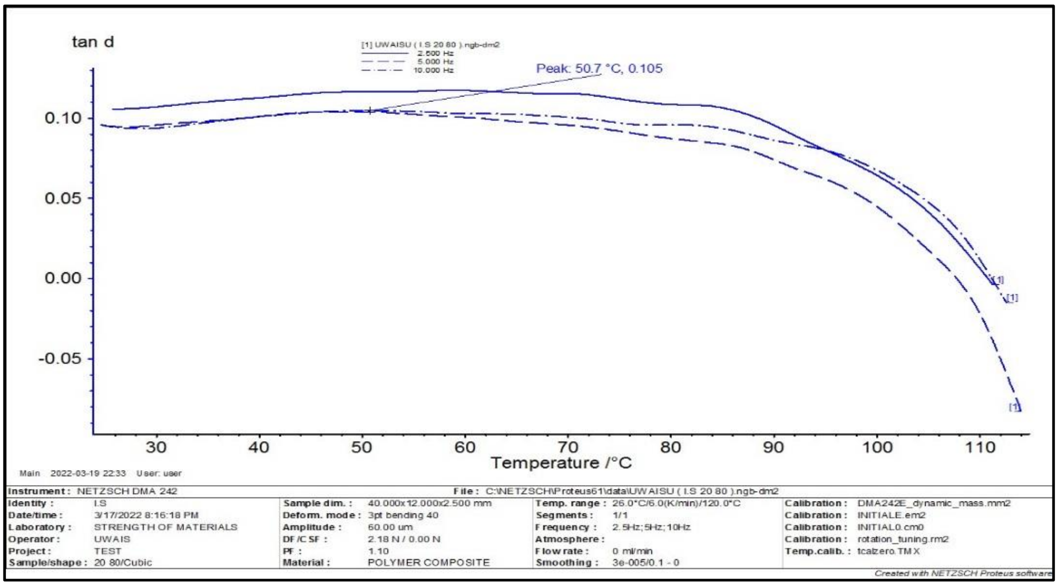

Figure 11: Damping parameter of unreinforced recycled HDPE-LDPE blends at 2, 5 and 10 Hz

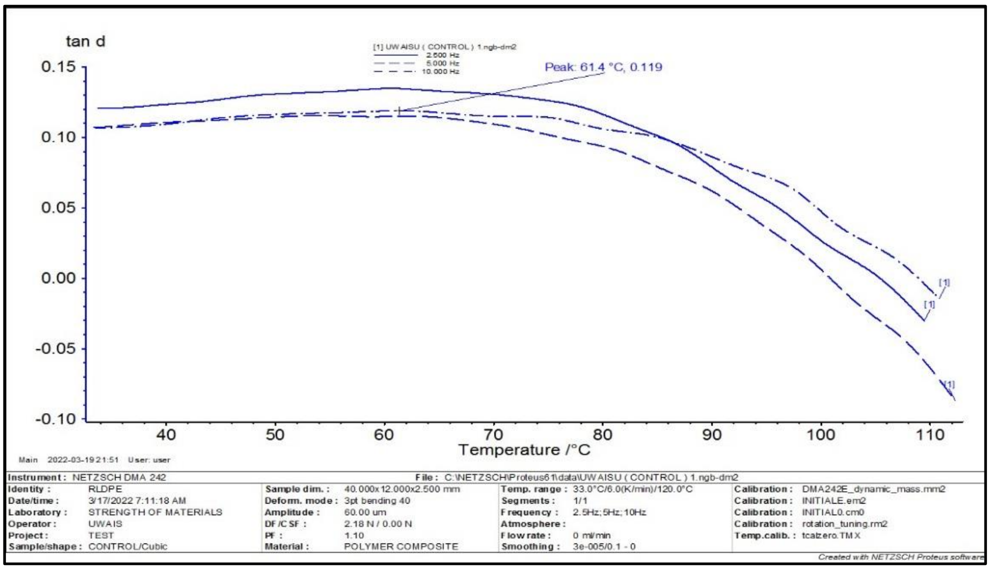

Figure 12: Damping parameter of 30 % AFPP reinforced HDPE composites at 2, 5 and 10 Hz

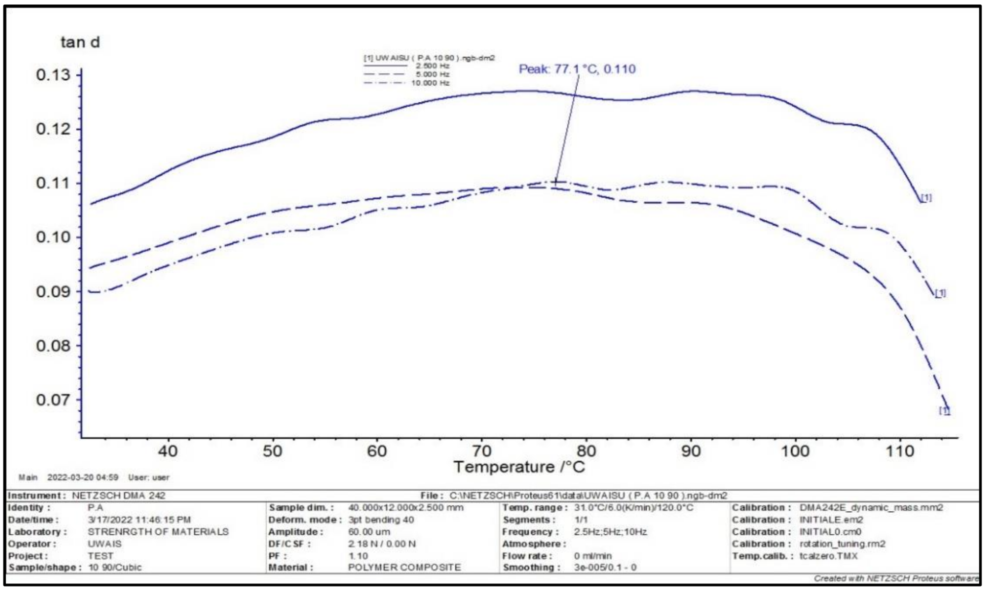

Figure 13: Damping parameter of 40 % AFPP reinforced HDPE composites at 2, 5 and 10 Hz

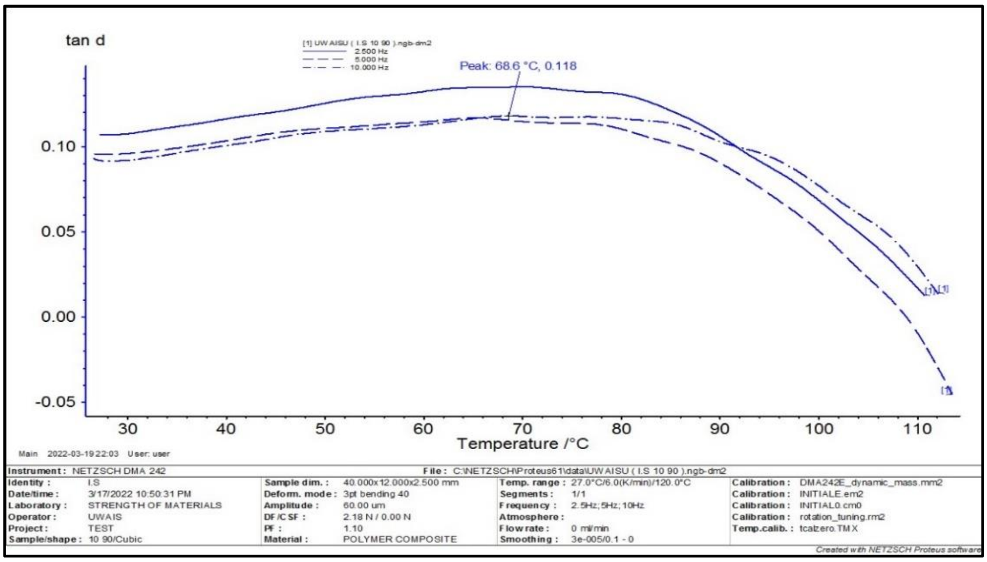

Figure 14: Damping parameter of 50 % BAP filled recycled HDPE-LDPE composites at 2, 5 and 10 Hz

CONCLUSION

The effects of BAP powder addition on the mechanical and dynamic mechanical characteristics of recycled HDPE-LDPE composites were studied. The results obtained lead to the following conclusions:

Incorporating *Borassus aethiopum* powder into waste HDPE-LDPE improved its physical, mechanical and visco-elastic properties. The density decreased with weight percentage of BAP fibres, with a minimum of 0.88 g/cm^3 compared to 1.98 g/cm^3 of unreinforced recycled HDPE-LDPE. At 40 % weight fraction, water absorption was minimal at 6.08 %. Tensile strength of 58.5 MPa, stiffness of 2.05 GPa, flexural strength of 68.8 MPa, and hardness value of 70 Shores were achieved with 40 % weight fraction of reinforcement. Dynamic mechanical properties showed that a composite with 40 % reinforcement also had the highest storage modulus and load bearing capability (0.95 GPa) compared to 0.15 GPa of unreinforced HDPE-LDPE. However, loss modulus was observed to decrease with increasing temperature and frequency. Future studies should focus on the chemical treatment of BAP in order to improve its compatibility with the HDPE-LDPE fibres.

ACKNOWLEDGEMENT

The authors appreciates and acknowledges funding of this research from the Tertiary Education Trust Fund under the Institutional Based Research Intervention with the Grant allocation number: TEFT/DR & D/UNI/MUBI/RG/2023/VOL. 1.

REFERENCES

Abisha, M., Priya, R.K., Arunachalam, K.P., Avudaiappan, S., Saavedra-Flores, E.I and Parra, P.F (2023). Biodegradable Green Composites: Effects of Potassium Permanganate Treatment on the Thermal, Mechanical and Morphological Behaviour of Butea Parviflora (BP) Fibres. *Polymers,* 15, 2197. https://doi.org/10.3390/polym15092197.

ASTM D570 -98 (2010). Standard test method for water absorption properties of polymer matrix composite materials, ASTM International, West Conshohocken, PA.

ASTM D638 (2014). Standard test method for the tensile properties of polymer matrix composite, American Society for Testing and Materials, International West Conshohocken, PA.

ASTM D7028 (2015). Standard test method for glass transition temperature (DMA, Tg) of polymer matrix composites by dynamic mechanical analysis (DMA), American Society for Testing and Materials International West Conshohocken.

ASTM D790 (2015). Standard test method for flexural properties of polymer composites, American Society for Testing and Materials, International West Conshohocken, PA West Conshohocken.

Gupta, M.K (2018). Effects of Variation in Frequencies on Dynamic Mechanical Properties of jute fibre reinforced Epoxy Composites, *Journal of Materials and Environmental Sciences* 9:100-106. http://doi.org/10.26872/jmes.2018.9.1.12.

Jacob, J. (2019). Physico-mechanical, Thermal and Sorption Properties of Groundnut shell Powder and Plantain Peel Reinforced Polyethylene Composites, Doctoral Thesis Department of Chemistry, Ahmadu Bello University, Zaria. https://kubanni.abu.edu.ng.

Jacob, J. (2023). Effect of Variation in Frequencies on Dynamic Mechanical Properties of Plantain Peel Particulate Reinforced Recycled Polypropylene Composites. *Journal of Materials and Environmental Science.* 14(3):317-325.

Jacob, J. and Mamza, P.A.P (2021). Mechanical and Thermal Behaviour of Plantain Peel Powder Filled Recycled Polyethylene Composites. *Ovidius University Annals of Chemistry.* 32 (2): 114-119. https://doi.org/10.2478/auoc.2021-0017.

Jacob, J. and Yusuf, U. (2023). Dynamic Mechanical and Morphological Characterization of Treated *Prosopis africana* Wood Fibre Reinforced Polyvinyl Chloride Composites. *ChemSearch Journal* 14(1): 39 – 44. ISSN: 2276 – 707X.

Jacob, J. Mamza, P.A.P (2020). Mechanism of water absorption in Groundnut shell powder filled waste HDPE Composites, *Communication in Physical Sciences* 6: 793-802. https://journalcps.com/index.php/volumes.

Jacob, J. Mamza, P.A.P. Ahmed, A.S. and Yaro, S.A (2018). Effect of benzoyl chloride treatment on the mechanical and Visco-elastic properties of Plantain Peel Powder-reinforced Polyethylene Composites, *Science World Journal*, 13:25-29.

Jacob, J. Mamza, P.A.P. Ahmed, A.S. and Yaro, S.A (2019). Thermo-mechanical Characterization of Plantain Particulate Reinforced Waste HDPE as Composite Wall Tiles, *Nigerian Research Journal of Chemical Sciences* 7:124-136.

Jacob, J., Dauda, K. and Muhammad, K.M. (2023). Chemical Treatment of Fibres and their Effects on the Physico-Mechanical Properties of African Fan Palm Powder Reinforced Waste Polypropylene Composites. *Journal of Materials and Environmental Sceiences*, 14 (6):689-701.

Khalaf, M.N. (2015). Mechanical Properties of Filled high Density Polyethylene, *Journal of Saudi Chemical Society* (19): 88-91.

Lendvai, L; Singh, T and Ronkay, F. (2024). Thermal, thermomechanical and structural properties of recycled polyethylene terephthalate (rPET/waste marble dust composites. *Heliyon, Science direct*. 10:e25015.

Mohanraj, C.M., Rameshkumar, R., Mariappan, M., Mohankumar, A., Rajendran, B., Senthamaraikannan, P., Suyambulingam, I. and Kumar, R. (2025). Recent Progress in Fibre Reinforced Polymer Hybrid Composites and Its Challneges-A Comprehensive Review. *Journal of Natural Fibres,* 22(1):2495911. https://doi.org/10.1080/15440478.2495911.

Palanivel A., Veerabathiran, A., Duruvasalu R., Iyyanar, S., Velumayil R., (2017) Dynamic mechanical analysis and crystalline analysis of hemp fibre reinforced cellulose filled epoxy composite" *Polimeros* 27 (4), 309-319.

Rajesh, C., Divia, P; Dinooplal, S., Unnikrishnan, G., and Purushothaman, E. (2021). Dynamic Mechanical Analysis of Nylon 6 Fibre-reinforced Acrylonitrile Butadiene Rubber Composites, *Sage Journals-Polymers and Polymer*

Composites, 29, 1328-1339. https://doi.org/10.1177/0967391121104144.

Rana, S.S, Gupta, M.K and Srivastava R.K (2017). Effect of variation in frequencies on dynamic mechanical properties of short sisal fibre reinforced Polyester Composite. *Materials Today: Proceedings* 4 (Part A):3387-3396.

Shen, Y., Tan, J., Fernandes, L., Qu, Z and Li, Y. (2019). Dynamic Mechanical Anaysis on Delaminated Flax Fibre Reinforced Composites, *MDPI-Materials*, 12 (16): 2559. https://doi.org/10.3390/ma12162559.

Shinde, N. S; Wadekar, R; Wadekar, H; Deshmukh, M and Bhute, S. (2018). Development and Analysis of Brick made from Waste Plastic bags. *International Journal of Engineering Research and Advanced Technology,* 4(3):19-26.

Shinggu, D.Y and Jacob, J. (2025). Utilization of Indigenous Sourced Borassus aethiopum Fruit Cap Fibre in Enhancing the Physical, Mechanical and Thermal Properties of Waste LDPE Composites. *Journal of Materials and Environmental Sciences*, 16 (1):145-162.

Thirugnanasambantham, N; Kumar, P.T. Sujithra, R; Selvaraman, R; and Bharathi, P. (2017). Manufacturing and Testing of Plastic sand Bricks. *International Journal of Science and Engineering Research,* 5(4):150-1155.