UNIZIK JOURNAL OF ENGINEERING AND APPLIED SCIENCES (UJEAS)

Research Article

The Potentials of using Neem Bark Flour in Polymer Composite Production for Refrigerator Components

Government R. M., Agu O. S.

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

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

Edited by
Chinonso Hubert Achebe PhD.
Christian Emeka Okafor PhD.

UJEAS

UNIZIK JOURNAL OF ENGINEERING AND APPLIED SCIENCES

UNIZIK Journal of Engineering and Applied Sciences 3(3), September (2024), 910-918
Journal homepage: https://journals.unizik.edu.ng/index.php/ujeas
PRINT ISSN: 2992-4383 || ONLINE ISSN: 2992-4391

The Potentials of using Neem Bark Flour in Polymer Composite Production for Refrigerator Components

Government R. M. [1] and Agu O. S.[2]
[1] Department of Chemical Engineering, Federal University Wukari, Taraba State, Nigeria
[2]Department of Chemical Engineering, Federal University of Technology, Owerri, Nigeria
[*]Corresponding Author's E-mail: govt_4real@yahoo.com

Abstract
The particle variation and content of neem bark flour (NBF) on the mechanical properties of neem bark flour-high density polyethylene (NBF-HDPE) composite were examined. The HDPE and NBF were thoroughly mixed at 10-40 wt.% and particles of 10(2000 µm), 20 (850 µm), 40 mesh (425 µm); compounded with aid of an injection moulding machine, respectively. The NBF-HDPE composite sample produced was passed through micro-mechanical testing to ascertain the ultimate tensile strength (UTST), elongation (EL), elastic modulus (EMO), impact strength (IST) and Brinell hardness. (BHA), respectively. Scanning electron microscopic (SEM) and Fourier transform infrared (FTIR) was performed for HDPE, NB, and NBF-HDPE composite, respectively. The outcome from this research indicated that the NBF-HDPE composite UTST and EL lowered than the fresh HDPE with 10 mesh particles (2000 µm) of the NBF in HDPE matrix yield better values of 18.91 MPa and 7.5 %, respectively. However, EMO, IST and BHA of NBF-HDPE composite were greater than new HDPE maintaining an optimum value of 0.53 GPa, 95.77 KJ/m^2 and 452.2 BHN at 40 mesh, 10 mesh and 20 mesh particles of NBF in the matrix of HDPE, respectively. The valued emanated confirmed that NBF-HDPE composite can be alternatively utilized for refrigerator parts.

Keywords: Neem bark flour; neem bark flour-high density polyethylene composite, mechanical properties, production; potentials

1. Introduction

The abundance of large forest in Africa has led to the generation of too many plant fibers that have not been tapped for manufacturing agenda. Therefore, the needs of these fibers in human activities have improved, specifically in the field of composite technology for household and commercial utilization (Azeez et al., 2018; Azeez et al., 2019; Dungani et al., 2016; Obasi, 2015; Azizah et al., 2020; Government et al., 2022). Presently, researches have been focus on the reduction of metals and heavy alloys for composite production in making parts and other accessory in automobile productions, domestic and industrial material (Government et al., 2022; Government & Ngabea, 2023 (a-c); Government & Okeke, 2023; Government & Okeke, 2024; Obasi, 2015). The simple reason may be in conjunction with cheap material and lighter weight end-product that can generate good properties which are comparable to the conventional material (Rajak et al., 2019; Government & Okeke, 2024; Obasi, 2015).

One of the conversant constituents which makes the composite to derive these properties is the non-edible fiber. New discovery has been geared to the manufacturing of many new natural filler-based composites due to large vegetation which in turn yield abundant filler sourcing at minimal cost(Government et al., 2022; Government & Ngabea, 2023 (a-c); Government & Okeke, 2023; Government & Okeke, 2024; Obasi, 2015). Moreover, the amalgamation of different materials gives enviable properties defer from the sole components said to be called composite (Rashid et al., 2016). Polymer composites have the composition; polymer resin as the matrix, with fibers as the reinforcement medium (Government & Okeke, 2024). Meaningful attention has been created in the fabrication of composites due to their distinctive properties, and minimization of production cost (Government & Okeke, 2024).

The operational use of wood-based particles and fibers as flour for composites needs a necessary knowledge of the structural and chemical qualities of wood (Obasi, 2015; Government & Okeke, 2024)). This in engineering is applicable to aggravate the qualities and dimensional strength of polymeric-natural-fibers-based composites (Government and Ngabea, 2023(a, b)). High fiber content is often applied to obtain reasonable mechanical characteristics. However, it seriously alters the polymer component and can form agglomerates, which induce stress concentration and decreases or increases the tensile strength, modulus and ductility of the material based on the fiber characteristics (Rashid et al., 2016; Government et al., 2022; Homkhiew et al., 2014; Rostamiyan et al., 2015). So the practical relevance of mechanical properties of polymer composites is enormous (Government et al., 2022; Turku et al., 2018; Rostamiyan et al., 2014(a,b); Laadila et al., 2017).

Notwithstanding, composite researchers had labored on numerous fibers; date palm wood (Atuanya et al., 2014; Government & Okeke. 2023), avocado wood (Government & Okeke, 2024; Government & Ngabea, 2023(a,b)), paulownia wood (Tisserat et al., 2014), groundnut shell (Obasi, 2015; Government et al., 2022; Government & Ngabea, 2023(c)), to be introduced in polymeric based composite for commercialization. Therefore, the use of minimal cost material, NBF, is sparse in the literal work on the analysis of thermoplastic composite for mass-production in engineering applications. This work is aim at studying the size distribution and weight of flour effects on the mechanical properties, morphology and chemical structure of the polymer composite produced from high density polyethylene matrix, reinforced with NBF for refrigerator component.

2.0 Material and methods

2.1 Preparation of NBF.

The Neem bark (NB) was gotten from New G.R.A in Trans-Ekulu Enugu State. The NB was sun-dried for 18 hours. The crushing and grinding processes were executed at Kenyetta Timber market, Enugu. The NBF was sieved using mesh particle sizes of 10, 20 and 40 mesh sizes, respectively.

2.2 Purchasing of HDPE.

The HDPE used in this research was acquired from Indorama Petrochemical Company Limited, Eleme, Rivers State, Nigeria. It has a melt flow index (MFI) of 2.16 g × 10 min^{-1}, and density of 0.946 g × cm^{-3}

2.3 Compounding process for composite production and properties determination

NBF of varied weight percent were compounded with HDPE. Then, they were compounded together into a composite at mesh particle sizes of 10-40 mesh and filler loading of 10-40 wt. % to explore its mechanical properties. The HDPE was melted and compounded homogeneously with the NBF in an injection moulding machine model HUICHON/5SON10/500×1000 no.6241 produced in 1990/6 and the resultant composites were produced at Ekenedilichukwu workshop, Onitsha. The compounded composites attain normal environmental condition before mechanical analysis was carried out. The following mechanical properties of the composite arising from differences in particle size and filler content formulation was analyzed using universal tensile machine (model no 8889) for UTST, EL, EMO with ASTM D638 (3.2mm x 19mm x 160mm), and BHA for ASTM E103 (3.2 mm × 19mm ×19mm), respectively (Government et al., 2022; Government & Ngabea, 2023 (a-c); Government & Okeke, 2023; Government & Okeke, 2024; Obasi, 2015). The IST was made of Charpy impact tester machine model no.17562/1963 at specification of ASTM E103 at sample size of 3.2 mm × 19mm ×19mm. The UTST, EL, EMO, BHA and IST were tabulated using Eq (1), Eq (2), Eq (3), Eq (4) and Eq (5), respectively.

$$. \mathrm{UTST} = \frac{f_m}{A_1} \tag{1}$$

$$\mathrm{EL} = \frac{L_2 - L_1}{L_1} \times \frac{100}{1} \tag{2}$$

$$\mathrm{EMO} = \frac{\Delta\sigma}{\Delta\varepsilon} \tag{3}$$

$$\mathrm{BHA} = \frac{2f}{\pi D\left[D - \sqrt{D^2 - d^2}\right]} \tag{4}$$

$$\mathrm{IST} = \frac{E}{A_1} \tag{5}$$

Where $f_{m,}$ $A_{1,}$ L1, L2,, Δσ, Δε, f, D, d and E were proportional to force at ultimate strength, area at cross-section, final length, initial length, variation in stress, difference in strain. Force at indentation, diameter of steel ball and Energy at impact., respectively.

2.4 FTIR analysis

The FTIR was performed using Shimazdu Model 8400S. Each specimen of 1.5 mg HDPE, NBF and NPF-HDPE composite with 0.5 mg KCl was homogenously intermixed, respectively. The unified products from each of the the mixture injected in FTIR equipment within a period of 5 seconds. The graph of spectrum which involved peaks and transmittance was displayed after the said time from the equipment.

2.5 SEM verification

The SEM endorsed for this examination was Model PHENOM ProX. Each of HDPE and NBF-HDPE composite of 1g specimen was combined with platinum to attain homogeneity, respectively. The output mixture was passed into SEM device. The mixture was verified in the system till variant magnification was obtained..

3.0 Results and Discussions

SEM analysis was carried out to determine the morphology or surface chemistry of the pure HDPE and HDPE-NBF composite base on difference in filler content at a particle size of 40 mesh from 0 to 40 wt.% filler content as was displayed in Figure 1-2. As can be noticed, there are two distinct areas, the white dotted areas reflect the NBF. While the grey areas show HDPE. Generally speaking, one of the conditions which determine the durability of a polymer composite in terms of mechanical properties is dependent on the level and degree of the dispersive homogeneity of the fillers in the polymer matrix. The SEM analysis of the virgin HDPE shows that it is has a neat uniform surface having few curve lines with minimal defects to show for. But the SEM analysis of the NBF–HDPE composite shows agglomeration of some NBF particle filler in form of patches at different locations in varying sizes. The ease of the tendency of agglomeration of the filler particle might be as a result of its lower particle size which is 40 mesh. The presence of cavities and pulled-out fibers confirmed that the polymer matrix was poor and weak because of filler involvement in the phase. Also, the localised bunch of fibers and patches indicated the poor dispersion of fillers within the HDPE matrix. Thus, the surface of the composite appeared to be dominated by pull-out damage. A similar fracture surface was reported in composites containing mineral fillers [20]. This observed phenomenon increased and became more noticeable as the filler content in the polymer matrix increases from 0% to 40% as shown in the Figure 1-2. This may arise due to improper dispersion between the HDPE matrix and NBF as earlier mentioned. It is expected that that the dispersion of fillers within the polymer matrix should be evenly distributed. Close results were attributed by existing authors (Government et al., 2022; Government & Ngabea, 2023 (a-c); Government & Okeke, 2023; Government & Okeke, 2024; Obasi, 2015; Oushabi et al., 2017).

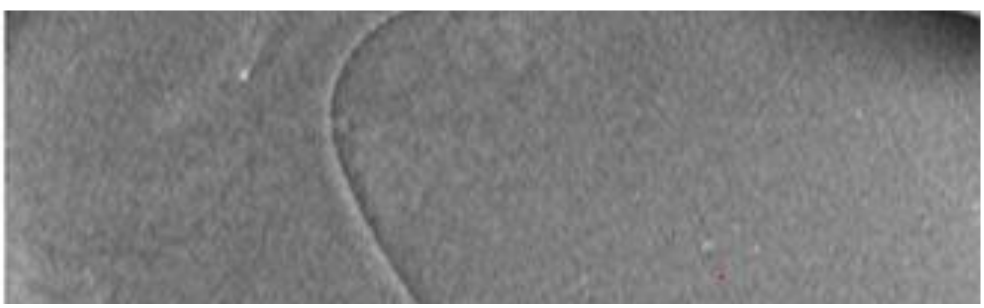


Figure 1: Pure virgin HDPE with 0 wt.% NBF

Figure 2: 40 wt. % filler content at 40mesh size of NBF-HDPE composite

The FTIR result for pure HDPE, NBF and NBF- HDPE composite is presented on Figure 3, 4 and 5, respectively. The result for pure HDPE shows that it has a transmittance of 14% and is dominated by concentrations of OH stretching bonds with peaks ranging from 3164.65 to 3889.83 cm^{-1} on one side. We also have concentrations of C=O carbonyl stretching vibrations, C=C aromatic symmetrical stretching, HCH and OCH in –plane bending vibrations. There are also few C-H symmetrical stretching bonds within 2953.34cm^{-1} and 2340.03 cm^{-1}. The least of all is the skeletal number of out of plane bending of C=CH in 729.49 to 965.05 cm^{-1}. The FTIR result for NBF shows that it has a transmittance of 22% which is a little bit higher than that of pure HDPE. The outcome further shows that the bonds present in it are almost evenly distributed within the band wave length range of 3897.53 to 423.15 cm^{-1}. Furthermore, result from the NBF-HDPE composite shows a transmittance of 9% with a shift and high concentration of the bonds within the band wavelength of 1738.33 to 405.78 cm^{-1}. This deviation in the peaks and transmittance is further indication of the introduction of NBF in HDPE matrix for the manufacturing of NBF-HDPE composite capable for fridge spare parts. These have been reported in recent time (Government et al., 2022; Government & Ngabea, 2023 (a-c); Government & Okeke, 2023; Government & Okeke, 2024; Obasi, 2015; Oushabi et al., 2017; Ikramullah et al., 2018).

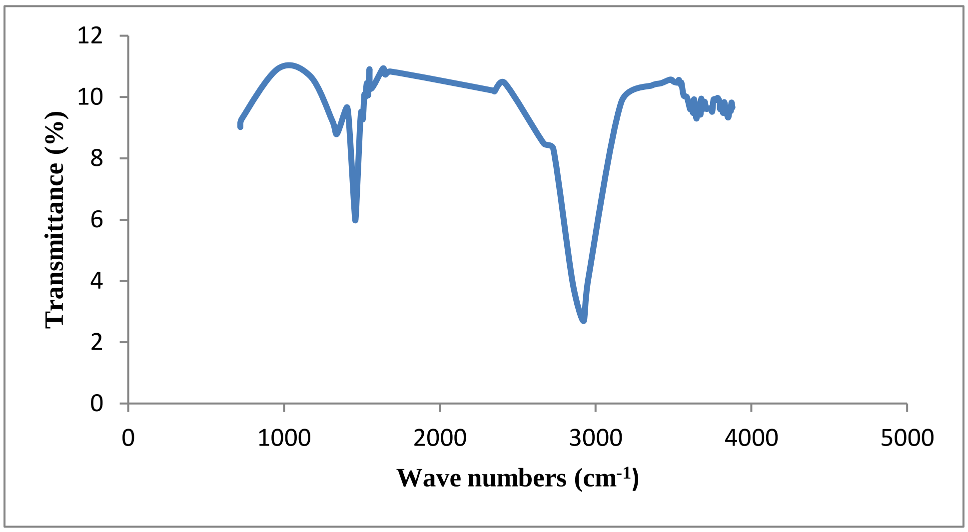


Figure 3: FTIR of pure HDPE.

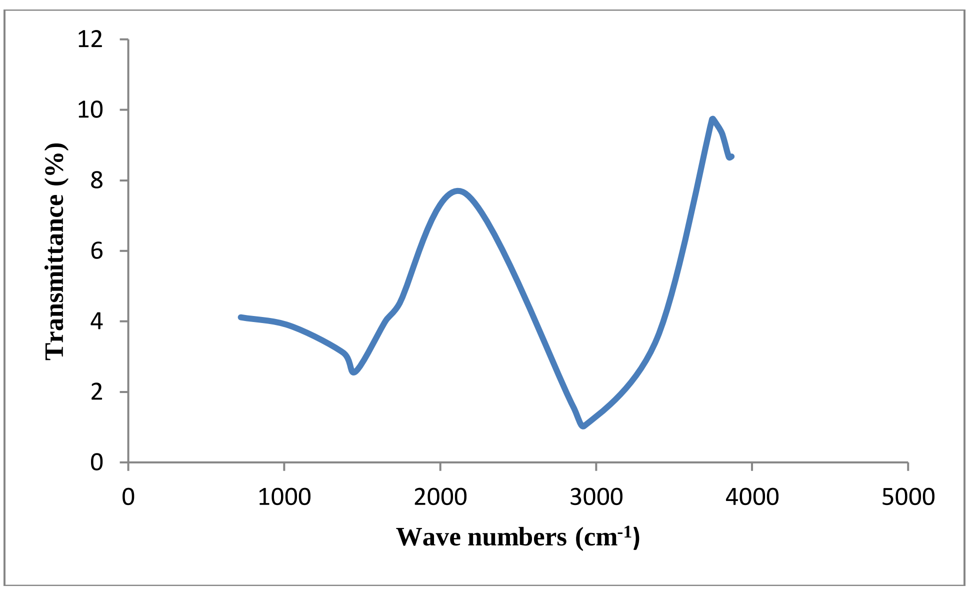


Figure 4: FTIR of NBF

.

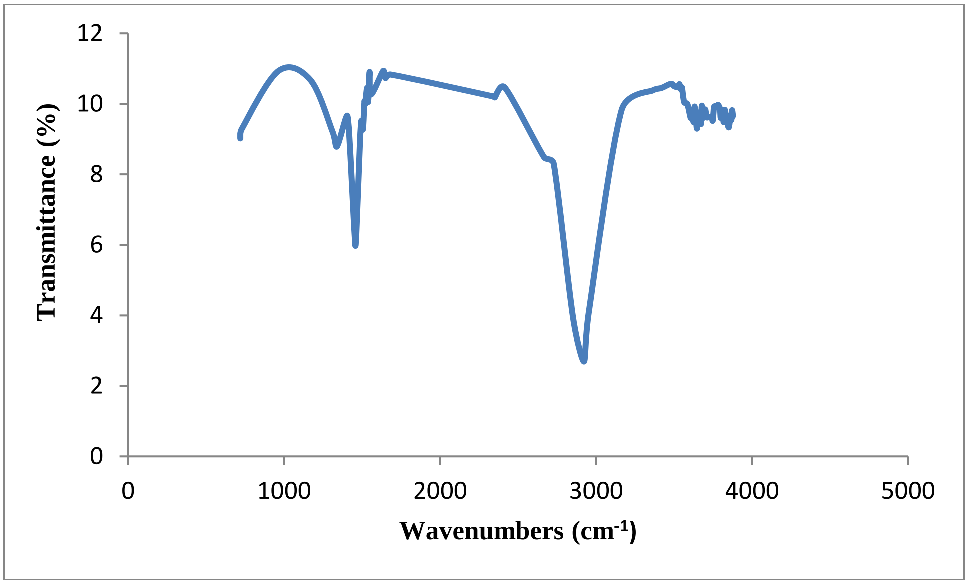


Figure 5: FTIR for NBF–HDPE composite

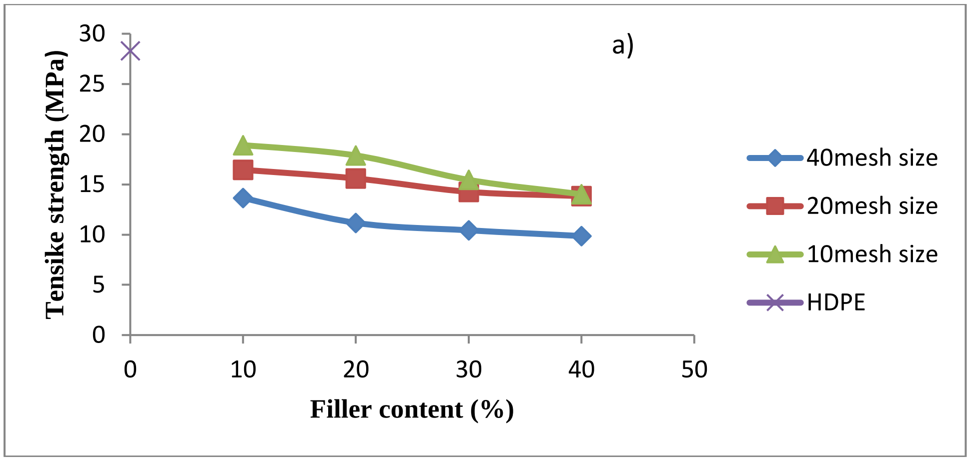
Fig. 6 (a) presents the NBF effect on the tensile strength of pure HDPE as the reference point which is 28.3MPa. Fig. 6(a) depicts that increase in filler content from 10 wt.% , 20 wt.%, 30 wt.% and 40 wt.% leads to corresponding decrease in UTST, while increase in particle size from 40, 20 and 10 mesh gave a positive result on their strength. According to past research [24], the decrease in UTST may be the product of deprived mixing of the filler-matrix and the settlement of filler particles within the HDPE polymer matrix. The least UTST was observed at 9.86 MPa with 40 wt.% filler content and 40 mesh particle size. This trend is similar to result reported previously (Government et al., 2022; Government & Ngabea, 2023 (a-c); Government & Okeke, 2023; Government & Okeke, 2024; Obasi, 2015; Turku et al., 2018; Rostamiyan et al., 2014(a,b); Laadila et al., 2017).

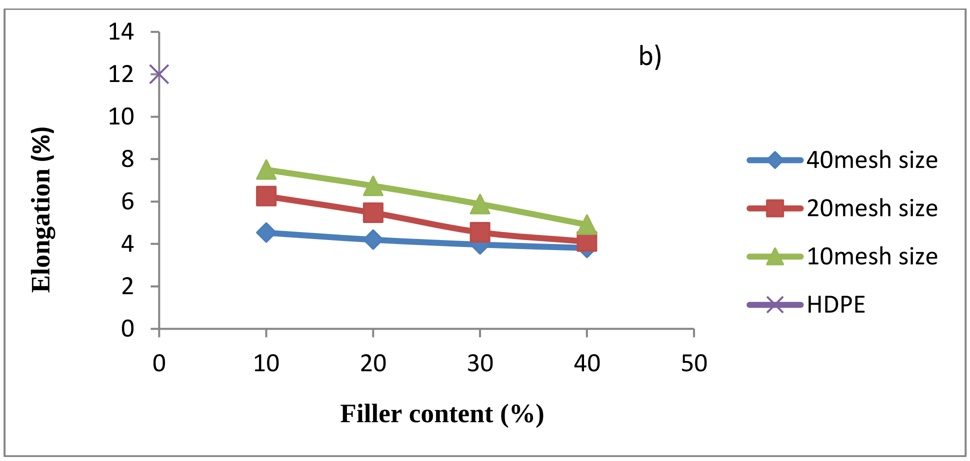
Figure 6 (b) captures the significant of filler content on the elongation of NBF-HDPE composite. The plot shows that the EL of HDPE composites lessened as NBF contents and particle size increase. With growing filler content, the stiffness of the HDPE composite is gradually enhanced, with proportional diminution in the EL. This is to say, with the improvement in rigidity, the ductility of composites declines, consequently the composites break at lower EL. Fillers reinforcement that reflects poor interfacial adhesion with polymer matrices generally appears to cause disruption in the alignment of the polymer chains. This is synonymous with the study of past authors (Government et al., 2022; Government & Ngabea, 2023 (a-c); Government & Okeke, 2023; Government & Okeke, 2024; Obasi, 2015; Turku et al., 2018; Rostamiyan et al., 2014(a,b); Laadila et al., 2017). However, the lowest EL traced was 3.81%, also at 40 wt.% filler content and 40 mesh particle size as compared with the EL of pure HDPE which was 12 %.

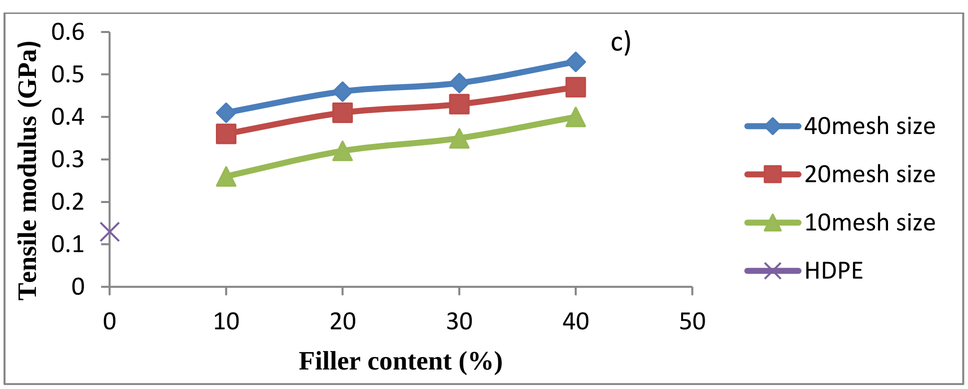
Figure 6 (c) depicts the variation of filler content on the tensile modulus of NBF-HDPE composite with pure HDPE having a value 0.13 GPa. In this case, the EMO increases with corresponding increase in both filler content and particle size. The maximum value recorded was 0.57 GPa at 40 wt.% filler content and 40 mesh particle size. It can be deduced from this experimental survey that toughness of the composite is stiffened on further adding more content of NBF. The possible outcomes obtained in this study toe the line of findings by later scholars (Government et al., 2022; Government & Ngabea, 2023 (a-c); Government & Okeke, 2023; Government & Okeke, 2024; Obasi, 2015; Turku et al., 2018; Rostamiyan et al., 2014(a,b); Laadila et al., 2017).

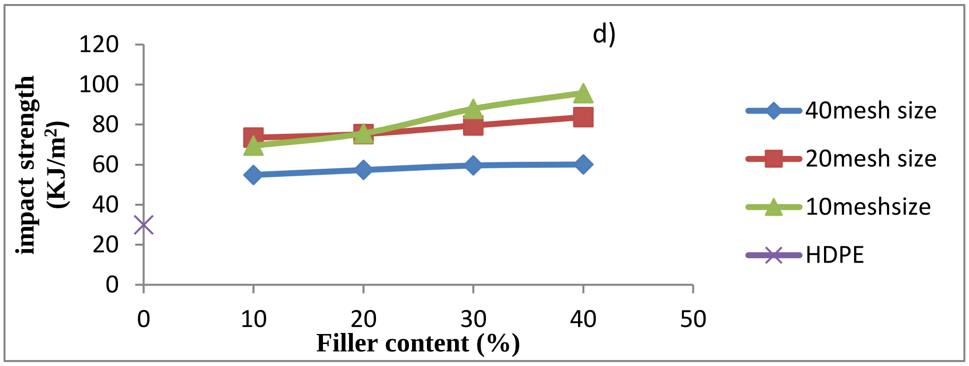
Fig.6 (d) depicts the effect of NBF content on the impact energy of NBF-HDPE composite. Pure HDPE gave a value of 30 KJ/m^2 while the highest IST was 95.77 KJ/m^2 at 10 mesh particle size and filler content of 40 wt.%. The addition of NBF augmented the stiffness of the HDPE steadily in the sizes of particle used. With inclusion of NBF into the HDPE, the IST increases as a consequent of the energy to initialize cracking grows. These were also reported by previous workers in this area of study(Government et al., 2022; Government & Ngabea, 2023 (a-c); Government & Okeke, 2023; Government & Okeke, 2024; Obasi, 2015; Turku et al., 2018; Rostamiyan et al., 2014(a,b); Laadila et al., 2017).

Figure 6(e), displays the BHA of NBF-HDPE composite on the content of NBF. The plot shows that the BHA increased steadily with increase in contents of NBF at the particle sizes measured. The highest BHA recorded .452.2 Pa at 20 mesh size of NBF-HDPE composite as against that of pure HDPE which is 40 Pa. From this upshot, it was established that NBF in a HDPE matrix discloses progress in the BHA of the composite. This may be ascribed to the fact that the addition of NBF in HDPE polymeric material stiffened and enhanced the surface inhibition for indentation. This is also in line with that recorded by existing researchers in the field of study (Government et al., 2022; Government & Ngabea, 2023 (a-c); Government & Okeke, 2023; Government & Okeke, 2024; Obasi, 2015; Turku et al., 2018; Rostamiyan et al., 2014(a,b); Laadila et al., 2017).









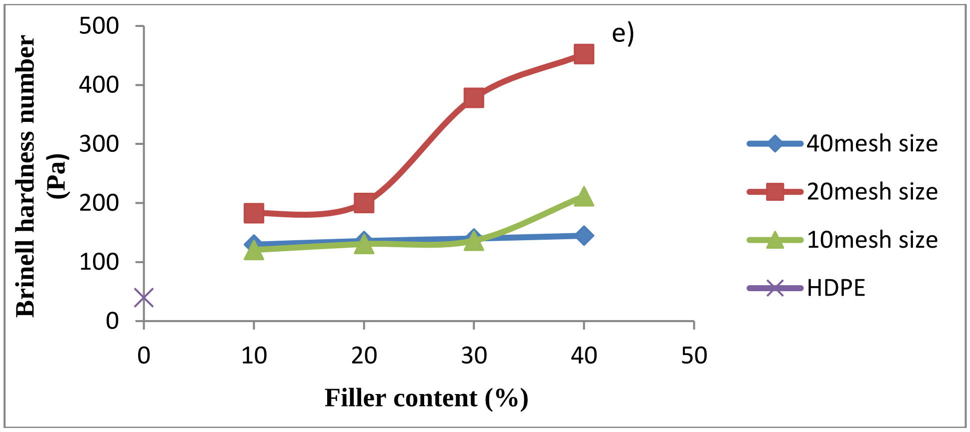


Figure 6: Variation of filler content on the a) tensile strength b) elongation c) tensile modulus d) impact strength e) Brinell hardness of NBF-HDPE composite.

4.0. Conclusion

The significant of investigating novel NBF by considering factors like filler content and fiber size of the features of NBF-HDPE composite for engineering material parts had been studied. The variables are influential in determining properties of NBF-HDPE composite. The reinforcement of the pure HDPE by NBF has positive significant influence on the particle size and flour content for the mechanical properties of the produced NBF-HDPE composite. The SEM analysis shows that there is relatively fair interfacial adhesion between the HDPE matrix and the NBF. Result from the FTIR of the HDPE, NBF and NBF-HDPE composite showed dominating shift and concentration of bonds within the band wavelengths which were evidence of change in characteristics of inputs and output after production of the end product. High particle of NBF favoured the UTST, BHA and IST. Lower particles improved EMO and EL of NBF-HDPF composite.

5.0 Recommendation

The NBF-HDPE composite at this optimum particle size and fiber content can be recommended for refrigerator manufacturing parts as result of characteristics displayed by NBF-HDPE composite.

References

Atuanya, C. U., Government, M. R., Nwobi-Okoye, C. C., & Onukwuli, O. D. 2014. Predicting the mechanical properties of date palm wood fibre-recycled low density polyethylene composite using artificial neural network. *International Journal of Mechanical and Materials Engineering*, *9*(1), 1–20. https://doi.org/10.1186/s40712-014-0007-6

Azeez, T. O. 2019. Thermoplastic recycling: properties, modifications, and applications. in *polymer recycling* (pp. 1–19). Rijeka, Croatia: InTech Open. https://doi.org/http://dx.doi.org/10.5772/intechopen.81614

Azeez, T. O., Onukwuli, O. D., Walter, P. E., & Menkiti, M. C. 2018. Influence of chemical surface modifications on mechanical properties of combretum dolichopetalum fiber-high density polyethylene (HDPE) composites. Pakistan Journal of Scientific and Industrial Research Series A: Physical Sciences, 61A(1), 28–34.

Azizah, A. B., Rozman, H. D., Azniwati, A. A., & Tay, G. S. 2020. The effect of filler loading and silane treatment on kenaf core reinforced polyurethane composites: mechanical and thermal properties. *Journal of Polymers and the Environment*, *28*(2), 517–531. https://doi.org/10.1007/s10924-019-01623-8

Dungani, R., Karina, M., Subyakto, Sulaeman, A., Hermawan, D., & Hadiyane, A. 2016. Agricultural waste fibers towards sustainability and advanced utilization: A review. *Asian Journal of Plant Sciences*, *15*(1–2), 42–55. https://doi.org/10.3923/ajps.2016.42.55

Government, R. M., Okeke, E. T., Ibrahim, I. A., & Onukwuli, O. D. 2022. Modeling and simulation of tensile properties of r-LDPE/GSF composite using the response surface methododology. *Materialpruefung/Materials Testing*, 64(3), 446–454 https://doi.org/10.1515/mt-2021-2109.

Government, R. M. & Okeke, E.T. 2023. Elastic-characteristics of recycled low-density-polyethylene-date palmwood composite by response surface methodology optimization process for structural application. *UNIZIK Journal of Engineering and Applied Sciences*, 2(2), 358-368.

Government, R. M. & Okeke, E. T. .2024. Effect of particle size on the properties of avocado pear wood fiber / low-density polyethylene composite enhanced by pretreatment. *Materials Testing*, 66(1), pp. 22–35.

Government, R. M. & Ngabea, S. A. 2023(a). Effect of particle size and filler content on mechanical properties of avocado wood flour-low density polyethylene composite. *Journal of Applied Science, Environment and Management*, 27 (10), 2303-2313.

Government, R. M. & Ngabea, S. A. 2023(b). Optimization of tensile, hardness and water absorption characteristics of pre-treated APWF-LDPE composite using central composite design. *Journal of Engineering for Development*, 15(3), 36-55.

Government, R. M. & Ngabea, S. A. 2023(c). Optimization of process parameters on the flexural and impact properties of GSF-R-LDPE composite for television appliance parts. *Journal of Engineering for Development*, 15(3), 56-74.

Homkhiew, C., Ratanawilai, T., & Thongruang, W. 2014. Optimizing the formulation of polypropylene and rubberwood flour composites for moisture resistance by mixture design. *Journal of Reinforced Plastics and Composites*, 33(9), 810–823. https://doi.org/10.1177/0731684413518362

Ikramullah, Rizal, S., Thalib, S., & Huzni, S. 2018. Hemicellulose and lignin removal on typha fiber by alkali treatment. *IOP Conference Series: Materials Science and Engineering*. 352(1), 1-7.. https://doi.org/10.1088/1757-899X/352/1/012019

Laadila, M. A., Hegde, K., Rouissi, T., Brar, S. K., Galvez, R., Sorelli, L., Cheikh, R. B., Paiva, M., Abokitse, K. 2017. Green synthesis of novel biocomposites from treated cellulosic fibers and recycled bio-plastic polylactic acid. *Journal of Cleaner Production*, 164, 575–586. https://doi.org/10.1016/j.jclepro.2017.06.235

Obasi, H. C. 2015. Peanut Husk Filled Polyethylene Composites: Effects of filler content and compatibilizer on properties. *Journal of Polymers*, 2015, 1–9. https://doi.org/10.1155/2015/189289

Oushabi, A., Sair, S., Oudrhiri Hassani, F., Abboud, Y., Tanane, O., & El Bouari, A. 2017. The effect of alkali treatment on mechanical, morphological and thermal properties of date palm fibers (DPFs): Study of the interface of DPF–Polyurethane composite. *South African Journal of Chemical Engineering*, 23, 116–123. https://doi.org/10.1016/j.sajce.2017.04.005

Rajak, D. K., Pagar, D. D., Menezes, P. L., & Linul, E. 2019. Fiber-reinforced polymer composites: Manufacturing, properties, and applications. *Polymers*, *11*(10), 1-37. https://doi.org/10.3390/polym11101667

Rashid, B., Leman, Z., Jawaid, M., Ghazali, M. J., & Ishak, M. R. 2016. The mechanical performance of sugar palm fibres (ijuk) reinforced phenolic composites. *International Journal of Precision Engineering and Manufacturing*, *17*(8), 1001–1008. https://doi.org/10.1007/s12541-016-0122-9

Rostamiyan, Y., Hamed Mashhadzadeh, A., & SalmanKhani, A. 2014(a). Optimization of mechanical properties of epoxy-based hybrid nanocomposite: Effect of using nano silica and high-impact polystyrene by mixture design approach. *Materials and Design*, *56*, 1068–1077. https://doi.org/10.1016/j.matdes.2013.11.060

Rostamiyan, Y, Fereidoon, A., Ghalebahman, A. G., Mashhadzadeh, A. H., & Salmankhani, A. 2014(b). Experimental study and optimization of damping properties of epoxy-based nanocomposite : Effect of using nanosilica and high-impact polystyrene by mixture design approach. *Journal of Materials&Design*. https://doi.org/10.1016/j.matdes.2014.10.022

Rostamiyan, Yasser, Fereidoon, A., Mashhadzadeh, A. H., Ashtiyani, M. R., & Salmankhani, A. 2015. Using response surface methodology for modeling and optimizing tensile and impact strength properties of fiber orientated quaternary hybrid nano composite. *Composites Part B: Engineering*, *69*, 304–316. https://doi.org/10.1016/j.compositesb.2014.09.031

Tisserat, B., Reifschneider, L., Grewell, D., & Srinivasan, G. 2014. Effect of particle size, coupling agent and DDGS additions on Paulownia wood polypropylene composites. *Journal of Reinforced Plastics and Composites*, *33*(14), 1279–1293. https://doi.org/10.1177/0731684414521886

Turku, I., Kärki, T., & Puurtinen, A. 2018. Durability of wood plastic composites manufactured from recycled plastic. Heliyon, 4(3), 1–20. https://doi.org/10.1016/j.heliyon.2018.e00559