Journal for Institute of Polymer Engineers (JIPE)
A Publication of Institute of Polymer Engineers (a division of the Nigerian Society of Engineers)

Study of the Mechanıcal Properties and Water Absorptıon of Mıcro-Sısal Fıbre Reınforced Waste Low-Densıty Polyethylene Composıte

Y. Adamu*, O. B. Ikechukwu, H. O Malik, A. S. Joji and A. D. Ado

Department of Chemical Engineering, Ahmadu Bello University, Zaria, Nigeria.

***Corresponding Author:** yusufbinadam@yahoo.com,yusufadamu@abu.edu.ng; +234(0)8034646935

Abstract

This study investigated some mechanical properties and water absorption behaviour of treated and untreated micro sisal fibre waste low-density polyethylene (wLDPE) composite. The fibres were treated with sodium hydroxide and benzoyl chloride solution to improve fibre-matrix bonding. Fourier Transform Infrared Spectroscopy (FT-IR) analyzed the effects of various treatments. The composite was produced by compression moulding technique using weight fractions 0 – 15 wt% at 5 wt% intervals of fibre in the matrix. The composite samples were characterized for tensile, flexural, impact, and water absorption properties as well as morphology. The results revealed that micro sisal particles improved the composite's tensile strength. Fibre loading of 10 wt% gave the composite's best flexural and impact strengths corresponding to 29 MPa and 4.55mJ/mm² respectively while 15 wt% gave the best tensile strength of 12.43 MPa. Generally, fibre treated with 50 ml benzoyl chloride gave better impact and flexural strengths compared to those treated with NaOH. However, fibres treated with NaOH showed improved tensile strength at all fibre loading in this study. The Scanning Electron Microscope (SEM) revealed a uniform distribution of micro-sisal fibre in the matrix. Hence, can be used for interior applications such as car seats, dashboards, and car interiors for decorative purposes or other interior parts of an automobile where high strength is not considered a critical requirement.

Keywords: *Composite, Polyethylene, Sisal fibre, Chemical treatment, Mechanical properties.*

Article History

Received: Oct 1st 2022
Reviewed: Nov 4th 2022
Accepted: December 14th 2022
Published: February 1st 2023
© Institute of Polymer Engineers, Abuja, Nigeria
www.ipe.org.ng.

1 Introduction

Natural fibres have attracted the interest of researchers, material scientists, engineers and industries, because of some beneficial properties such as low density, low cost, and reduced strength when compared to synthetic fibres. As such, providing advantages for use in commercial applications for polymer composites in the automotive industry, aerospace, building constructions and other engineering applications (Muhammed *et al*., 2020; Nisha, 2021; Naik, *et al*., 2022). However, the size, geometry and treatment of these fibres play a significant role in the properties of the resulting composites (Cho *et al*., 2020; Ahmed *et al*., 2021).

Universal market pressure requires more rapidly advanced products and reduced time to market (Patel *et al*., 2012). Consumer-driven product customization and nonstop demands for cost savings are forcing companies to look for new technologies and processes that can cope with high-volume fabrication more quickly and cheaply (Malkapuram *et al*., 2009). Many of our modern technologies require materials with unusual combinations of properties that cannot be met by conventional metal alloys, ceramics and polymeric materials (Faruk *et al*., 2012). This is especially true for materials that are needed for aerospace, underwater and shipping applications. For example, aircraft engineers are increasingly searching for structural materials that have low densities, high strength, stiffness, and high abrasion, impact and corrosion resistance. This is a rather formidable combination of properties. Frequently, strong materials are relatively dense; increasing the strength or stiffness generally decreases impact strength. Material property combinations and ranges have been and are being extended by the development of composite materials (Siddika *et al*., 2013).

Generally, a composite is produced when two or more materials are joined together to give a combination of properties that cannot be attained otherwise (Vanderfleet & Cranston, 2021). According to the principle of combined action, better property combinations are fashioned by the judicious combination of two or more distinct materials. Composites of sorts include multiphase metal alloys, ceramics and polymers. Several composites occur in nature. For example, wood consists of strong and flexible cellulose fibres surrounded and held together by a stiffer material called lignin. Bone is a composite of the strong yet soft protein collagen and the hard, brittle mineral apatite, also, as teeth and abalone shells.

A composite is a multiphase material that is artificially made, as opposed to one that occurs or forms naturally (Chandramohan & Marimuthu, 2011). In a composite, one phase is usually continuous and is known as the matrix while the other phase is known as the reinforcement which is distributed within the matrix. It may be in the form of fibrous or particulate. In addition, the constituent phases must be chemically dissimilar and separated by a distinct interface. Thus, most metallic alloys and many ceramics do not fit this definition because their multiple phases are formed as a consequence of natural phenomena. Most composites have been

created to improve combinations of mechanical characteristics such as strength, stiffness, toughness, and ambient and high temperature (Etcheverry & Barbosa, 2012).

Polymer-matrix composite (PMCs) consists of polymer resin (a high molecular weight reinforcing plastic) as the matrix with particulate as the reinforcement (Bhandari et al., 2012) The primary functions of the matrix are to transfer stress between the reinforcing fibres or particulate, act as a glue to hold the fibres together and protect them from mechanical and environmental damage (Faruk *et al*., 2012). However, natural fibres and particulate are hydrophilic, they absorb moisture. They are used in the production of composites in large quantities. These composites produced have distinct properties like improved strength and contain large amounts of coarse particles that do not block slip effectively (Adediran *et al*., 2021). Sisal plants can be used as particulate and fibre to improve the material's mechanical properties, including stiffness, strength, and hardness.

The various advantages of natural fibres over the man-made glass and carbon fibres are low cost, low density, competitive specific mechanical properties, reduced energy consumption and biodegradability (Malkapuram *et al*., 2009). The use of green plants (sisal plants) as reinforcing fillers for thermoplastics has received great attention from several researchers and manufacturers in recent years. However, polyethylene is quite an outstanding polymeric material concerning its performance, wide property spectrum, easy processability, versatility of applications and attractive combination of favourable economics and that makes it a viable option.

Previous researchers have investigated the mechanical properties of sisal fibre as functions of various alkaline treatment strategies and manufacturing parameters. Kaewkuk *et al.* (2013), reported that tensile strength and young's modulus of sisal composite increased as fibre content increased from 10 to 30 wt%. Dwivedi and Chand (2009), also reported that the use of coupling agents during the manufacturing process of sisal composite improved mechanical properties and influenced its wear resistance. According to Mylsamy and Rajendran (2011), sisal fibre/epoxy composites having a fibre length of 3 mm have better wear resistance than those with 5- and 7-mm fibre lengths. Fibre pre-treatment and fillers are reported to improve fibre tensile strength and hardness, as reported by Oladele *et al*. (2010) and Salisu *et al.* (2015). The effects of fibre modification and fibre loading on the mechanical properties, morphological and water absorption characteristics of sisal fibre/polymer composites were studied by Salisu *et al.* (2015).

This work aims to determine the mechanical properties of micro sisal particles reinforced waste low-density polyethylene composite. In this research, sisal-waste low-density polyethylene composites of various proportions and fibre treatment were tested to determine tensile, flexural, impact and water absorption properties.

2 Experimental Procedure

2.1 Materials

The materials used for this study were sisal plants (leaves) from National Research Institute For Chemical Technology (NARICT), Zaria, waste low-density polyethylene (shredded water sachet) from Ahmadu Bello University surrounding**, s**odium hydroxide (98%), benzoyl chloride (98%), distilled water, 1000 ml beaker, glass rod and 500 µm mesh.

2.2 Equipment

The equipment used for this study includes a Plastic crusher machine, a Digital weighing scale, a compression mould, a pair of scissors, an optical microscope, a Charpy impact tester, a two-roll mill machine, an Instron Tensile Testing Machine, Denison Impact testing machine and Fourier Transform Infrared Spectroscopy (FT-IR).

2.3 Preparation of Reinforcement

The reinforcement (sisal) was sourced and extracted at NARICT. The sisal fibre was extracted by first cutting off a matured sisal plant and then beating it into pulp, the bark was removed and washed with distilled water. The clean extracted fibre was sun-dried for 48 hours to remove moisture and hence various treatments were carried out.

2.4 Matrix

The matrix (waste pure water sachets) wLDPE was sourced within Ahmadu Bello University (ABU), Zaria. The matrix was first cleaned of the ink by the use of thinner and shredded for ease of compounding.

2.5 Fibre Treatment

Two types of treatment were done to the extracted sisal fibre; first, alkaline treatment, and second, double treatment (alkaline follow by benzoyl treatment).

Firstly, the sisal fibre was treated with 5wt% sodium hydroxide (NaOH) solution for 1 hour at a temperature of 40 ^{0}C after which it was washed with distilled water until neutral pH was achieved. The washed fibre was sun-dried for 12 hours and then placed in an oven at 80 ^{0}C for 72 hours.

Secondly, for benzoylation, part of the treated sisal fibre obtained from the NaOH treatment was further treated using 50ml benzoyl chloride for 15 minutes. The isolated fibre was soaked in ethanol for 1 hour and washed with distilled water until a neutral pH was achieved. The washed fibre was sun-dried for 12 hours and then placed in an oven at 80 ^{0}C for 72 hours (Salisu *et al.*, 2015).

2.6 Preparation of the micro sisal fibre composite

A grinding machine was used to crush both the treated and untreated fibre into a powdery form, the crushed fibre was then passed through a mesh having a size range of 0 – 500µm. Various micro fibre loading of 5 – 15 wt% at intervals of 5 wt% consisting of both treated and untreated sisal fibre was measured so also as 85 – 95 wt% at intervals of 5 wt% of the wLDPE measured using the analytical weighing balance. The treated and untreated sisal fibre were compounded with the wLDPE using a two-roll mill set at a temperature of 70 ^{0}C. The mixture obtained was placed in a metallic mould of dimensions 100 mm × 100 mm × 10 mm and 120 mm × 120 mm × 3 mm and was cured in a heavy-duty compression machine at a temperature of 140 ^{0}C at 13.80 MPa for 5 minutes, based on ASTM in Table 1.

Table 1. ASTM standards used for the tests An example table.

Test	ASTM standard	Test method (if applicable)	Specimen type/specifications (if applicable)	Deviations from ASTM standard
Tensile ASTM Standard D638 (2014)	D638-14, standard test method for tensile properties of plastics		Type I	No extensometer was used. The nest speed is 10 mm/min. No toe compensation was made.
Flexural ASTM Standard D7264 (2007)	D7264/D7264M-07, Standard Test Method for flexural properties of polymer matrix composite materials	Type A	Ratio: 32:1	Crosshead displacement was issued as an extension.
Impact ASTM Standard D256 (2002)	D256-02, standard Test methods for determining the Izod pendulum impact resistance of plastics	Test method A		
Water absorption ASTM standard D570-98 (2002)	D570-98 Standard Test method for water absorption of polymer composite.	Type A		

2.7 Composite characterization

The fabricated micro sisal fibre reinforced with waste low-density polyethylene composites was tested for mechanical, physical and morphological properties.

2.7.1 Tensile strength test

A tensile test of the composite samples was performed using a Monsanto Tensometer type 'w' serial number 9875. Tests were conducted as per ASTM D638, using a sample of dimension 100 mm × 15 mm × 3 mm. Three (3) specimens of each composite were tested and average values are reported, the tensile strength is calculated using Equation 1.

$$Tensile\ strength = \frac{Breaking\ load\ (N)}{Cross\ sectional\ area\ (cm2)} \quad (1)$$

2.7.2 Flexural strength test

The flexural strength of the composite was determined using a Universal Materials Testing machine, cat. Nr. 261 D. The dimension of the sample used for the flexural test was 100 mm × 25 mm × 10 mm following the ASTM D790 standards. The flexural strength was calculated using Equation 2.

$$Flexural\ strength = \frac{3FL\ (N)}{2bd^2\ (mm^2)} \quad (2)$$

2.7.3 Impact strength test

The impact property is concerned with the behaviour of the composite to a dynamic or shock wave loading condition. It was determined using a Charpy impact testing machine with serial number 412-07-15269C with an energy capacity of 15J and 25J. The dimension of the sample used was 100 mm × 10 mm × 10 mm, with a notch thickness of 2 mm, as per ASTM D 256-78 and Equation 3 was used to determine the values.

$$Impact\ strength = \frac{Energy\ Absorbed\ (J)}{Cross\ Sectional\ Area\ (mm^2)} \quad (3)$$

2.7.4 Water absorption test

The water absorption test was conducted based on ASTM D570-98. The samples were machined to dimensions (25 mm × 25 mm × 10 mm). The initial weight of the sample was recorded before it was immersed in a beaker containing water for 48 hours. Percentage water absorption by a sample was calculated using Equation 4

$$Water\ absorption\ (\%) = \frac{C2-C1}{C1} X100 \quad (4)$$

Where;

C1- the weight of the sample before immersion in water

C2- the weight of the sample after immersion in water

2.7.5 Fourier Transform Infrared Spectroscopy (FTIR)

The functional groups of both the treated and untreated sisal fibres were determined using a Shimadzu machine (model: FTIR-84005) FT-IR spectrometer. The samples were dried in an oven at 60ºC to remove the moisture. About 0.5 mg of the specimens were placed on a KBr plate and inserted into the infrared barrel. The infrared spectra of these samples were measured in the transmission of a wavelength number range between 4000 and 500 cm^{-1}.

2.7.6 Scanning Electron Microscope (SEM)

The morphology of the composites was studied using a Zeiss EVO 15 scanning electron microscope with an acceleration voltage of 15 kV. The surface of selected composite samples was coated with a thin layer of gold to ensure adequate conduction and prevent surface overcharging.

3 Results and Discussion

3.1 Fourier Transform Infrared (FTIR) Spectroscopy

Fourier Transform Infrared Spectroscopy (FTIR) was carried out on both treated and untreated sisal fibre and the results are shown in Figure 1.

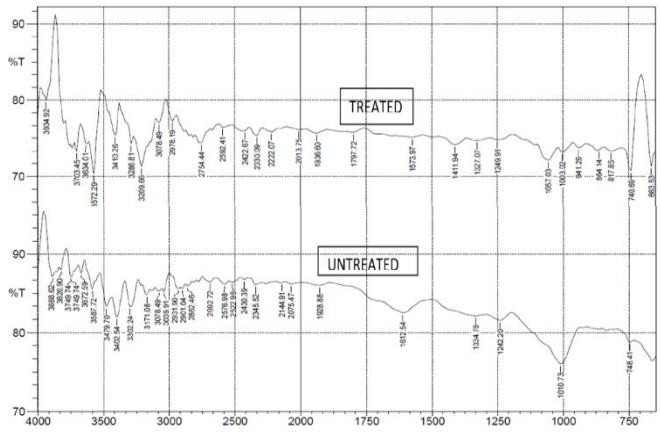


Figure 1: FT-IR Spectra of Untreated and Treated Sisal Fibre

Figure 1, shows a well-defined band at 3479.70 cm^{-1} of the untreated sisal which corresponds to the intermolecular bonding of O-H groups in cellulose and hemicellulose. However, this band reduced to a lower wave number of 3410.26 cm^{-1} after treatment. This is an indication of the breakage of the hydrogen bonds in O-H groups of cellulose (Durowaye *et al*., 2014). Peaks around 2931.90 cm^{-1} and 2692.72 cm^{-1} (Figure 1) are specific peaks for C-H stretching vibrations and these peaks were decreased to low wave number 2916.47 cm^{-1} and high wave number 2916.47 cm^{-1} as seen in Figure 1. This observed change could be due to the modification of sisal fibre orientation. Table 2 shows the functional groups assigned to cellulosic fibre using FTIR spectra.

Table 2. Assignments of FTIR absorption bands for treated and untreated sisal fibre

Assignment	**Wavenumber (cm^{-1})**	
	Untreated sisal	Treated sisal
-OH alcohol	3479.70	3410.26
-OH stretching	3302.24	3218.24
–C–H	2931.90	Nil
CH_2 symmetric stretching	2862.46	2754.44
Carbonyl stretching	Nil	1797.72
C=O stretching	1334.78	1327.07
C–O stretching	1242.20	1249.91
C=C alkanes	Nil	941.29
Typical structure of cellulose	748.41	740.69

3.2 Scanning electron microscope (SEM)

SEM analysis of composite treated with 50 ml benzoyl chloride, as it gave the highest values in terms of mechanical properties (Figure 2).

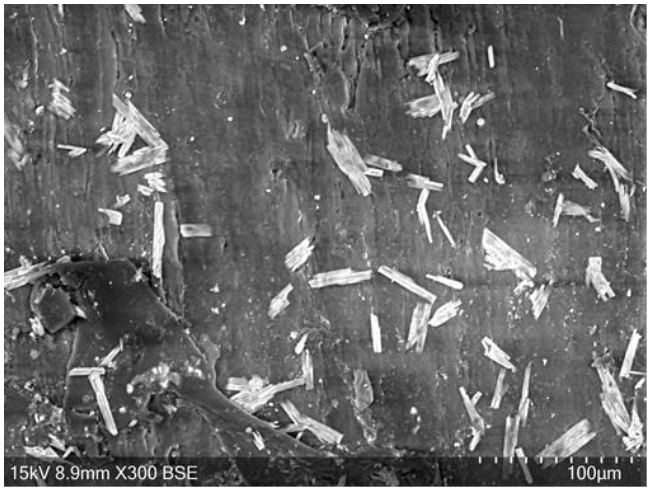


Figure 2: SEM image of micro-sisal fibre composite treated with 50 ml benzoyl chloride

The Scanning electron microscope (SEM) revealed good interaction between the fibre/matrix interface (wettability). And also, shows an even distribution of micro-sisal fibre treated with 50 ml benzoyl chloride in the composite, which translated to high mechanical properties recorded at that composition.

3.3 Tensile Strength

Figure 3, shows the effect of micro sisal loading and treatment on the tensile strength of the resulting composite. From the Figure, the tensile strength of the resulting reinforced composite was found to increase steadily as the percentage fibre loading increased from 5 to 15 wt% compared to the control sample (0 wt% fibre-reinforced composites).

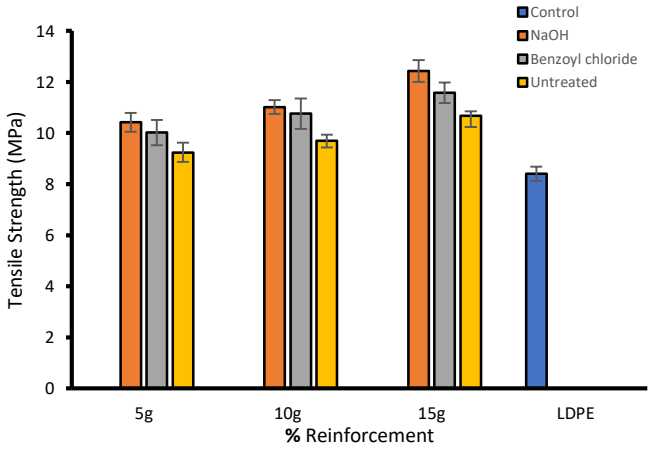


Figure 3: Effect of fibre loading and treatment on the tensile strength of micro-sisal composite

The trend is in agreement with Wambua *et al*. (2003) who worked on the "microstructure and mechanical properties of sisal particles reinforced polypropylene composite" and reported that the tensile strength increased with fibre loading. The 15wt% reinforced composite recorded the highest tensile strength for both treated and untreated fibre composite.

Also, in Figure 3, the treated fibre composite showed better tensile strength than the untreated fibre composite. The increase in tensile strength was attributed to an increase in surface compatibility between the micro-sisal and waste low-density polyethylene, as a result of the removal of impurities and the creation of rough surfaces from the fibre (Chandramohan & Marimuthu, 2011). 15 wt% sodium hydroxide treatment recorded the highest tensile strength of 12.85 MPa more than the benzoyl-treated fibre having a strength of 11.58 MPa and the untreated composite of 10.67 MPa.

3.4 Flexural Strength

Figure 4, shows the effect of fibre loading and treatment on the flexural strength of the resulting composites. From the result, it can be seen that flexural strength increased with an increase in fibre loading.

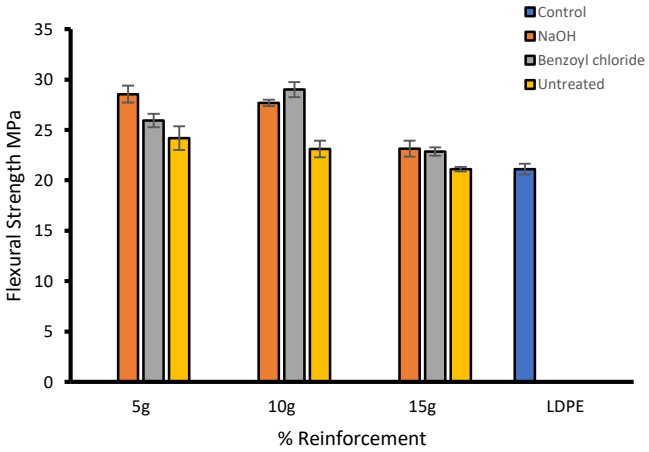


Figure 4: Effect of fibre loading and treatment on the composite flexural strength

From Figure 4, the flexural strength of unreinforced waste low-density polyethylene (wLDPE) gave the least flexural strength of 21.1 MPa compared to the reinforced and treated fibres reinforced wLDPE composite. From the result, it can also be seen that 10 wt% fibre reinforcement gave the best flexural strength while at 15 wt%, there was a decrease which might be a result of unfavourable entanglement of the polymer chain due to weak fibre-matrix adhesion with increasing fibre content.

It was also observed that flexural strength decreased from 28.55 to 23.13 MPa for the sodium hydroxide treatment, while there was an unusual trend in the benzoyl chloride treatment as the strength increased from 25.93 to 29 MPa before decreasing to 22.85 MPa and the flexural strength of untreated composite decreased from 24.2 to 21.1 MPa. At 10 wt% fibre loading, benzoyl chloride-treated reinforced composite recorded the highest flexural strength of 29.0 MPa. The increased flexural strength with alkaline and benzoyl chloride treatment could be due to improved bonding of the fibre with the wLDPE matrix.

3.5 Impact Strength

The result of impact strength of the resulting composite is shown in Figure 5.

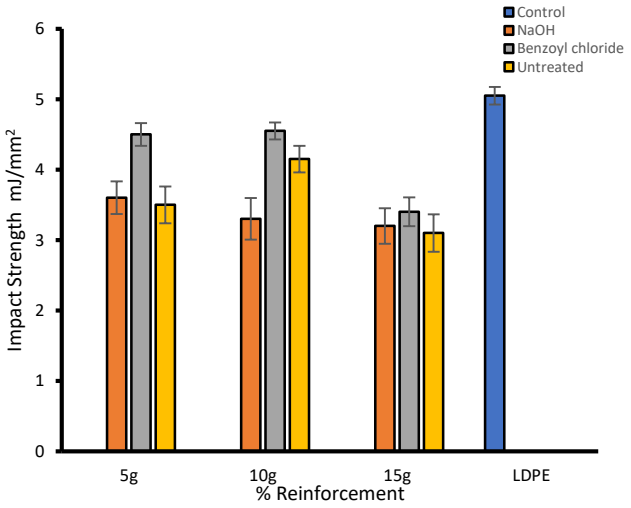


Figure 5: Effect of fibre loading and treatment on the impact strength of the composite

From the Figure, it was observed that the waste low density-polyethene (wLDPE) gave the utmost impact strength of 6.05 mJ/mm^2. The impact strength of the reinforced low-density polyethylene composite showed that as the fibre weight fraction increased, the impact strength decreased. The drastic decrease in the strength of both the treated and untreated composite as shown in the figure might be due to agglomeration during compounding which creates more pores. More so, an increase in the concentration of filler reduces the ability of the matrix to absorb energy and thereby reduced toughness.

Furthermore, various treatments carried out on the reinforced fibre composite helped enhanced the impact strength as compared to the untreated fibre-reinforced composite. This could be attributed to the increase in surface roughness and dispersion as a result of single and double treatment, resulting in good mechanical interlocking and the increased amount of cellulose exposed on the fibre surface. Hence, increase the active site for interaction. Benzoyl chloride treatment of the reinforced fibre composite recorded the best impact strength of 4.55 mJ/mm^2 at a fibre loading of 10 wt. % more than that of the untreated and sodium hydroxide-treated one.

3.6 Water Absorption

The effect of micro-sisal content on the moisture absorption characteristic of the wLDPE/micro-sisal composite is shown in Figure 6.

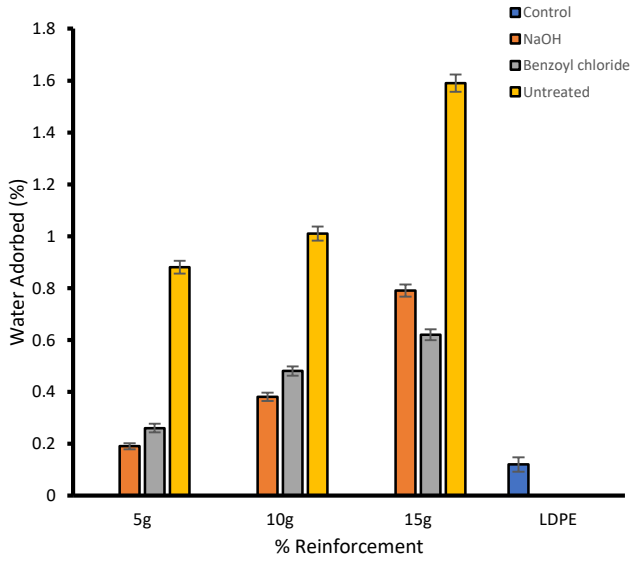


Figure 6: Effect of fibre loading and treatment on the water absorption capacity of the composite.

From Figure 6, it can be observed that the waste low-density polyethylene (wLDPE) showed a lower percentage of water absorption of 0.12% due to its hydrophobic nature. The water absorption capacities of the reinforced composites showed a steady increase as fibre loading increased as compared to the control sample. This is also in agreement with the work on the effect of particle size and alkali treatment of sugar cane bagasse on the thermal, mechanical and morphological properties of PVC-Bagasse composite (Ramkumar & Saravanan, 2020; Abd El-Baky et al., 2021; Jaiswal & Devnani, 2022). The increment was attributed to the fact that Sisal fibre was hydrophilic and increased fibre content also lead to an increase in cellulose content.

Also, from Figure 6, the water absorption capacity decreased with fibre treatment, as the untreated composite gave the highest percentage of water absorption at 1.59%. The expected result was due to the reaction of the hydroxyl group present in the fibre with chemicals used for treatment. The best treatment concentration is 5% NaOH because it gave lower water absorption not exceeding 0.19% after 2 days of soaking.

4 Conclusions

Micro sisal particles improved the tensile, impact and flexural strength of the waste low-density polyethylene composite**.** The highest impact energy of 4.55 mJ/mm^2 was recorded for a sample with 10 wt% fibre treated with benzoyl, while the sample treated with NaOH recorded 4.0 mJ/mm^2. Generally, the elasticity of the composites improved significantly compared to the unfilled or control sample but decreased with an increase in fibre loading for all treatments. The tensile strength was found to increase with an increase in fibre loading for both treatment types. This indicates that shock absorption reduces with increasing reinforcement. 5 wt% micro sisal loading with NaOH treatment absorbed minimal water. While the SEM image shows good interaction between the fibre and matrix. Thus, making it suitable for interior applications in automobiles such as car seats, dashboards, and car interiors for decorative purposes or other interior parts of an automobile where high strength is not considered a critical requirement. Hence, waste low-density polyethylene matrix composite reinforced with micro sisal particles is a good material for engineering applications.

5 Acknowledgements

The authors like to acknowledge Ahmadu Bello University, the National Research Institute for Chemical Technology and the Nigerian Institute of Leather and Science Technology for their support throughout the entire work.

Conflict of interest statement

The authors declare no conflict of interest

6 References

1. Nisha, S. S. (2021). *Ionic-Liquid Extracted Lignin for Development of Novel Composites Materials* (Doctoral dissertation, Swinburne University of Technology Melbourne, Australia).
2. Muhammed, H. C., Joseph, M. A., & Prasad, V. (2020). Recent developments in flax fibre reinforced composites and their applications. *Emerging Technologies for Sustainability*, 623-630.
3. Naik, N., Shivamurthy, B., Thimmappa, B. H. S., Gupta, A., Guo, J. Z., & Seok, I. (2022). A review of processing methods and characterization techniques of green composites. *Engineered Science*, *20*, 80-99.
4. Cho, K., Sul, J. H., Stenzel, M. H., Farrar, P., & Prusty, B. G. (2020). Experimental cum computational investigation on the interfacial and mechanical behaviour of short glass fibre reinforced dental composites. *Composites Part B: Engineering*, *200*, 108294.
5. Ahmed, M. M., Dhakal, H. N., Zhang, Z. Y., Barouni, A., & Zahari, R. (2021). Enhancement of impact toughness and damage behaviour of natural fibre reinforced composites and their hybrids through novel improvement techniques: A critical review. *Composite Structures*, *259*, 113496.
6. Patel, B. C., Acharya, S. K., & Mishra, D. (2012). Environmental effect of water absorption and flexural strength of red mud-filled jute fibre/polymer composite. *International Journal of Engineering, Science and Technology*, *4*(4), 49-59.
7. Malkapuram, R., Kumar, V., & Negi, Y. S. (2009). Recent development in natural fibre-reinforced polypropylene composites. *Journal of reinforced plastics and composites*, *28*(10), 1169-1189.
8. Faruk, O., Bledzki, A. K., Fink, H. P., & Sain, M. (2012). Biocomposites reinforced with natural fibres: 2000–2010. *Progress in polymer science*, *37*(11), 1552-1596.
9. Siddika, S., Mansura, F., & Hasan, M. (2013). Physico-mechanical properties of jute-coir fibre reinforced hybrid polypropylene composites. *Engineering and Technology*, *73*, 1145-1149.
10. Vanderfleet, O. M., & Cranston, E. D. (2021). Production routes to tailor the performance of cellulose nanocrystals. *Nature Reviews Materials*, *6*(2), 124-144.

11. Chandramohan, D., & Marimuthu, K. (2011). Drilling of natural fibre particle reinforced polymer composite material. *International Journal of Advanced Engineering Research and Studies*, *1*(1), 134-145.

12. Etcheverry, M., & Barbosa, S. E. (2012). Glass fibre reinforced polypropylene mechanical properties enhancement by adhesion improvement. *Materials*, *5*(6), 1084-1113.

13. Bhandari, N. L., Thomas, S., Das, C. K., & Adhikari, R. (2012). Analysis of morphological and mechanical behaviours of bamboo flour reinforced polypropylene composites. *Nepal Journal of Science and Technology*, *13*(1), 95-100.

14. Adediran, A. A., Balogun, O. A., Akinwande, A. A., Mwema, F. M., Adesina, O. S., & Olayanju, A. (2021). Effect of surface modification on the properties of polypropylene matrix reinforced with coir fibre and yam peel particulate. *The Scientific World Journal*, *2021*, 1-12.

15. Kaewkuk, S., Sutapun, W., & Jarukumjorn, K. (2013). Effects of interfacial modification and fibre content on physical properties of sisal fibre/polypropylene composites. *Composites Part B: Engineering*, *45*(1), 544-549.

16. Dwivedi, U. K., & Chand, N. (2009). Influence of MA-g-PP on abrasive wear behaviour of chopped sisal fibre reinforced polypropylene composites. *Journal of Materials Processing Technology*, *209*(12-13), 5371-5375.

17. Mylsamy, K., & Rajendran, I. (2011). Influence of fibre length on the wear behaviour of chopped agave americana fibre reinforced epoxy composites. *Tribology Letters*, *44*, 75-80.

18. Oladele, I. O., Omotoyinbo, J. A., & Adewara, J. O. T. (2010). Investigating the effect of chemical treatment on the constituents and tensile properties of sisal fibre. *Journal of Minerals and Materials Characterization and Engineering*, *9*(06), 569.

19. Salisu, A. A., Musa, H., Yakasai, M. Y. And Aujara, K. M. (2015). Effects of Chemical Surface Treatment on Mechanical Properties of Sisal Fibre Unsaturated Polyester Reinforced Composites. 6(2), 8–13.

20. ASTM Standard D638 (2014) Standard test method for tensile properties of plastics. ASTM International, West Conshohocken, PA.

21. ASTM Standard D7264 (2007) Standard test method for flexural properties of polymer matrix composite materials. ASTM International, West Conshohocken, PA.

22. ASTM Standard D256 (2002) Standard test methods for determining the Izod pendulum impact resistance of plastics. ASTM International, West Conshohocken, PA.

23. ASTM standard D570-98 standard test methods for determination of water absorption of polymer composites. ASTM International, West Conshohocken, PA.

24. Durowaye, S. I., Lawal, G. I., & Olagbaju, O. I. (2014). Microstructure and mechanical properties of sisal particles reinforced polypropylene composite. *International Journal of Composite Materials*, *4*(4), 190-195.

25. Wambua P, Ivens J, Verpoest I (2003) Natural fibres: can they replace glass in fibre-reinforced plastics? *Compos Sci Technol* 63: 1259–1264.

26. Ramkumar, R., & Saravanan, P. (2020). Assessment of composites using waste sugarcane bagasse fibre and wood dust powder. *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, *9*(5), 2126-2131.

27. Jaiswal, D., & Devnani, G. L. (2022). Bagasse fibres, their composites and applications. In *Plant Fibers, their Composites, and Applications* (pp. 111-130). Woodhead Publishing.

28. Abd El-Baky, M. A., Megahed, M., El-Saqqa, H. H., & Alshorbagy, A. E. (2021). Mechanical properties evaluation of sugarcane bagasse-glass/polyester composites. *Journal of Natural Fibers*, *18*(8), 1163-1180.