Biocomposite Production from Waste Low-density Polyethylene Sachets and *Prosopis africana* Pods Biomass Residue

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ORIGINAL RESEARCH ARTICLE

Abstract- Plastic litter has become a major concern in solid waste management in recent times due to the adverse effect on the environment. In most developing countries, low-density polyethylene (LDPE) waste bags and sachets constitute a significant portion of plastic wastes that are generated daily, leading to an unnecessary environmental burden that needs to be addressed. In this study, we report the use of Prosopis africana pod particles as fillers in LDPE matrix (obtained from waste plastic sachets) for biocomposite production. Biocomposites were produced from 150μm average filler size for 10, 20, 30 wt% filler contents, using hand lay-up method. The compression, flexural, impact, and tensile strengths; water absorption and the biodegradability characteristics of the prepared biocomposites were determined using ASTM standards. In comparison with the control sample, the prepared biocomposites samples exhibited 103% improved impact strength of 34.3 J and better resistance to deformation (flexural modulus of 348.9 N/mm2; Young's modulus of 237.9 N/mm2) at 30 wt % filler content. Biocomposite sample with the 10 wt% gave the highest tensile strength of 8.3 N/mm2. Scanning Electron Microscopy (SEM) analysis of the fractured sample shows good adhesion in the matrix. Findings from this work indicate that valorisation of LDPE waste sachet and prosopis pods agricultural residues can be a value-addition, affordable waste management method for producing biocomposites towards indoor applications.

Keywords- Prosopis africana pods, biocomposites, biomass waste, low density polyethylene, plastic wastes

1 INTRODUCTION

Plastic litter is a global environmental burden (Shanmugam et al., 2021) that is cutting across both the developing and developed worlds. The global plastic wastes discarded in landfills have been predicted to reach 12,000 million tonnes by the year 2050 (Crippa et al, 2019; Shanmugam et al., 2021). Hence, it is essential to give more attention to curbing plastic pollution especially in the developing countries since about 4 million tonnes of plastics are transported mainly through African and Asian rivers to the ocean bodies, disrupting the aquatic life (Chmidt et al., 2017). China, followed by Indonesia, led the 20 top countries that generate mis-managed plastic pollutants (Crippa et al, 2019). Furthermore, it is apt to address plastic pollution in Nigeria, a country which generated between 0.13- 0.34 million tonnes per year of plastic trashes. Nigeria ranks the 9th out of the 20 countries where the plastic pollution challenge is most prevalent (Jambeck et al., 2015).

About 50% of plastics produced globally are used as packaging materials (Shanmugam et al., 2021). LDPE films have been popularly used as packaging materials in groceries shop and in the packaging of drinkable table water in quite a number of developing countries like Nigeria. The waste generated from such used water sachets constitute nuisance in these cities, clogging water ways and channels and eventually find their ways to the ocean bodies.

Circular economy concept is a major strategy for mitigating the challenge of environmental litter. Circular economy includes conversion of wastes into value added products. Recycling and inclusion of bio-based materials were recently identified as critical ways to combat the challenge and reduce the environmental footprint (Shanmugam et al., 2021).

Polyethylene is a ubiquitous plastic which is manufactured, being in excess of 100 million tonnes per year and accounting for over 33 % of the overall plastics industry (Geyer et al., 2017). It possesses density range from 0.88–0.96 kg/m3 and a melting point of 115-135 ℃ (Batra, 2014). Polyethylene is commonly used in food packaging. It is a popular synthetic polymer with huge hydrophobicity and molecular weight. Since polyethylene is not biodegradable, using it for the production of disposal or packing materials causes many problems, the main problem being environmental pollution and land shortage problems for landfills.

Prosopis africana (African mesquite or iron tree) is a popular flowering plant species that is abundant in Africa. In Nigeria, Prosopis africana seeds have been used for making "daddawa" (Barminas et al., 1998), "kpaye" (Omafuvbe et al., 1999) or "okpeye" fermented products used as food condiments (Oguntoyinbo et al., 2010). The pods are wastes usually generated through the processing of the seeds for food purposes.

Biocomposites are simply composites in which at least one of the components is of biomass origin. They comprise of mixture of fibre and a matrix which yields a material of more desirable characteristics than any of the original materials. Some of the advantages which have been attracting research interests are strength and biodegradability (Odetoye and Ashaolu, 2020; Odetoye et al., 2020; Baffor-Awuah et al., 2021; Fazeli et al., 2019;

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Section D- MATERIALS/ CHEMICAL ENGINEERING & RELATED SCIENCES
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Burmawi et al., 2018). Attempts have been made to utilize various biomasses as fillers in LDPE biocomposite production. Some of the work include the use of paddy (Faris et al., 2018), palm kernel fibres (Panigrahi et al., 2011), sisal fibre (Joseph et al. 2002), rice starch and cotton fibre (Prachayawarakorn et al., 2010), rice husk (Majeed et al., 2014), kenaf and roselle fibres (Alabi, 2011) among others. The improvement of mechanical properties and dimensional stability by using treated short sisal fibre reinforcement in low density polyethylene has been reported (Joseph et al. 2002).

Prachayawarakorn et al. (2010) used thermoplastic rice starch (TPRS) that had been plasticized with glycerol to create a biodegradable polymer and improved the tensile properties by the addition of the cotton fibre and LDPE into the TPRS matrix. Enhancement of tensile and tear properties of LDPE/Rice husk (Rice Husk) composite with the addition of MMT has been reported (Majeed et al., 2014). The utilization of kenaf and roselle fibres as filler materials in biocomposites in fresh and recycled LDPE matrices have been suggested for applications in packaging industries, though these fibres were reported to increase moisture absorption of samples while the tensile strength decreases (Alabi, 2011). Although, extensive works are available on the use of various biomasses as fillers in LDPE biocomposite, we report for the first time, the application of Prosopis africana pod in LDPE biocomposite preparation. This work is aimed at investigating the production of LDPE- Prosopis africana biocomposites as a value-added product from wastes.

2 MATERIALS AND METHODS

2.1 MATERIALS

Prosopis africana pods and the low-density polyethylene (LDPE) were materials obtained locally within the vicinity of University of Ilorin, Ilorin, Nigeria. The Prosopis africana pods (Figure 1) were collected from prosopis trees on the University of Ilorin campus while the waste low-density polyethylene water sachets were sourced from Water packaging factory from the same source.

2.2 METHODS

2.2.1 Preparation of Filler and Matrix Materials

1 kg Prosopis africana pods was washed with water and sun-dried for two days; the dry pods were then crushed with a mortar and pestle for size reduction. The seeds were removed, and the already crushed pods were blended with an electric blender to fine homogeneous particles and screened to maximum size of 150µm. The discarded water sachets were washed with running water to remove dust and dirt from them. They were sundried for two days after washing and cut into smaller pieces with a pair of scissors in preparation for the melting stage.

Fig. 1: Prosopis africana pods

2.2.2 Preparation of Prosopis africana particle-LDPE Biocomposite

For the first run, 270g of LDPE was melted in a stainless-steel pan for about 10 minutes. Then 30g Prosopis africana particles was charged into the melted LDPE and mixed thoroughly with the wooden stirrer to facilitate even dispersal of the particles in the matrix. Afterwards, the mixture was transferred into the metal moulds (of sizes 50x50x50mm3, 200x20x10mm3, 40x10x10mm3 and, 200x25x15mm3) as shown in Figure 2, initially coated with the lube oil. A ramming stick was used to compact the melts in the moulds so as to remove air voids. The solidified biocomposite samples were removed from the moulds after a period of 2 hours (Figure 3). The same procedures were followed for the 0% (control), 20% and 30% filler contents. Each sample was produced in duplicates to enable the determination of average value during the tests for the samples.

Fig. 2: Metal moulds for moulding the biocomposites

2.2.4 Characterization of the Produced Biocomposites

2.2.4.1 Tensile Strength

Tensile test was carried out with a Testometric Universal Testing Machine (TUTM) model FS50AT (Testometric Co Ltd., UK) according to the ASTM D638 standard. Duplicate samples of dimension (200 x 20 x 10mm3) were utilized to find average values for force at peak, elongation at break, Young's modulus and stress at peak (Zaaba et al., 2013).

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2.2.4.2 Compression Strength

Tests for the compressive strength of the samples were done using a Testomeric universal testing machine. Samples of size 50mm x 50mm x 50mm were cut from the mould to get average values during the compressive strength tests. Average values of two samples were also calculated.

2.2.4.3 IZOD Impact Test

Izod impact test was used to test for the impact strength of materials which is a measure of the impact resistance of materials. The tests were done using the Avery Denison 150J Impact testing machine (Odetoye et al., 2020). The test was done using a notched rectangular sample based on ASTM D256 with a 4.0 J hammer. Samples of size 40mm x 10mm x 10mm were cut from the mould to obtain average values for the impact strength. Average values of results from duplicate samples were calculated (Obasi, 2015).

2.2.4.4 Flexural Test

Tensile test was carried out with a Testometric Universal On the same universal testing machine, flexural test was done based on ASTM D790-17 method (2017), using a speed of 2mm/min to evaluate the flexural strength and modulus under a load cell of 1kN. Average values of two samples (200 x 25 x 15mm3) were calculated

2.2.4.5 Water absorption

The test was done by drying and immersing the samples in distilled water and weighed every day for five days to determine the difference in weight. The percentage water absorption was then calculated (Odetoye et al, 2020; Obasi, 2015).

2.2.4.6 Morphology Evaluation

The observation was achieved through a scanning electron microscope (SEM) model ZEISS Supra 35 VP. The surface of the sample X30% was observed to indicate the morphology of the samples The image results were analysed to observe the distribution of natural fillers in the polymeric matrix and their interactions (Zaaba et al., 2013).

2.2.4.7 Biodegradability Test

The tests were done according to ASTMD5988 method. After weighing the samples, they were buried inside the natural soil and removed after seven days. The exhumed samples were replaced into the soil after washing, drying and weighing them. The test was repeated for five weeks. The initial and the final sample weights after burying in the soil were noted. The degradation studies of samples were done by observing the effects on sample weights.

3 Results and Discussions

3.1 Biocomposite Characterization

3.1.1 Tensile strength of samples

From Figure 4 it can be observed that tensile strengths of the biocomposite samples were lower than that of the control sample which was 9.8 N/mm2. Tensile strength reduced with increase in filler content as a result of increasing filler-fillers interactions (Obasi, 2015; Faris et al., 2018). More so, it can be inferred that the biocomposite with the least percentage weight of the filler had the highest (8.3 N/mm2) average stress at peak while the sample with the highest composition of the filler had the least.

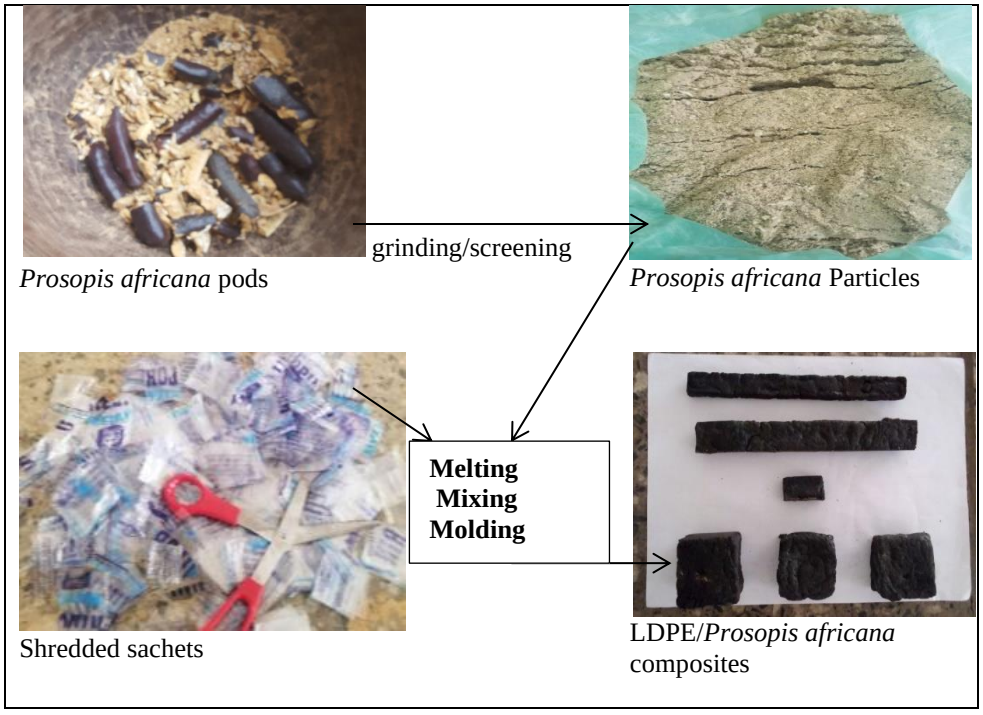

Fig. 3: LDPE/*Prosopis africana* composite preparation

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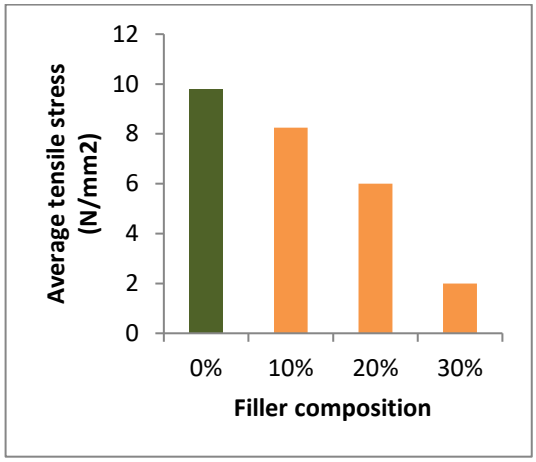

Fig. 4: Tensile strength performances of the samples

This is also true for elongation at peak because, as the loading increases, the percentage humidity of the matrix decreases, thus causing the decrease in the elongation and stress at peak. This reduction could be as a result of increasing filler-filler interaction, compared to filler-matrix interactions. In addition, it is attributable to poor adhesion owing to difference in polarity between the filler and the matrix that can promote spots for failure (Obasi, 2015). On the contrary, in Figure 5, the Young's modulus and force at peak values increased as the percentage weight of the filler increased. It can be inferred that as filler loading increases both Young's modulus and the average force at peak increase in value with X30% having the highest values of 237.9 N/mm2 and respectively.

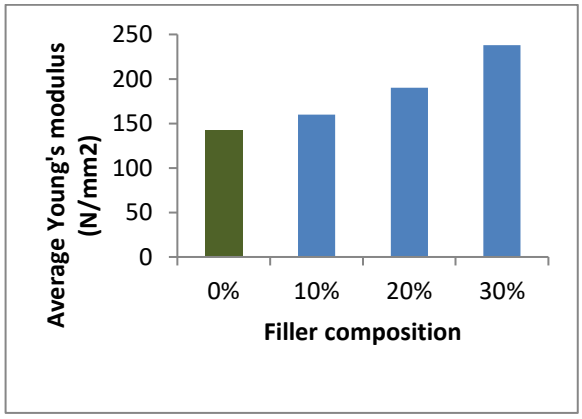

Fig. 5: Young's modulus variation with filler contents

The stress-strain curve in Figure 6 shows that sample X10% exhibited higher brittleness compared to sample X20% and X30% which have higher filler content. Hence, X20% and X30% showed higher ductility compared to X10%.

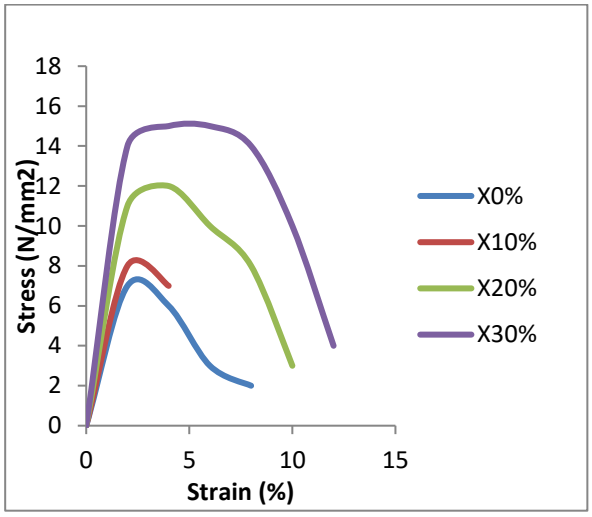

Fig. 6: Stress-strain properties of the biocomposite samples

3.1.2 Flexural Strength

Biocomposites that will be applied as structural material need to possess a certain amount of flexural property. Figure 8 shows an increasing trend in the bending modulus with addition of more filler, the value increased from 256 N/mm2 in control sample to highest value of 348.9 N/mm2 in X30%. This trend is linked to the enhanced interfacial bonding between the filler particles and LDPE matrix. The characteristics of the filler material, filler content, and the uniformity of the filler dispersion have been found to influence composites stiffness (Canigueral et al., 2009). The prosopis pod particles tend to obstruct dislocation because the load is being transferred from the matrix to the particulate reinforcements (Oladele et al., 2020). Hence, the presence of prosopis filler has imparted more flexural modulus property.

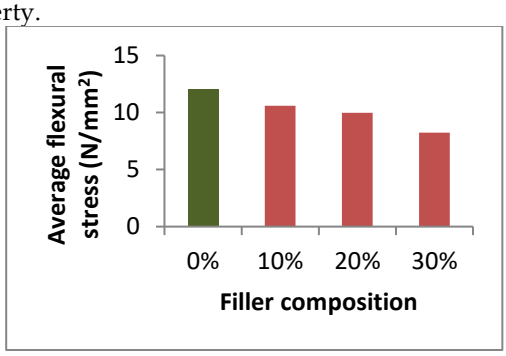

Fig. 7: Flexural strength performances of the biocomposites

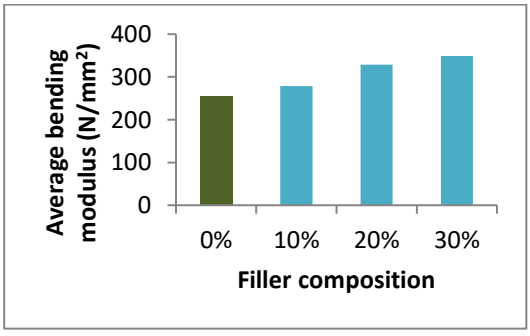

Fig. 8: Bending modulus variation

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3.1.3 Impact strength

Figure 9 shows increasing trend of impact strength as filler content increased, with the control sample (0% filler content) having the least impact strength of 16.9 J and 30% filler content sample exhibiting impact strength of 34.3 J, indicating a percentage impact strength increase of 103%. This shows higher impact strength owing to increase in the filler-matrix interfacial bonding. This result agrees with those of earlier works which states that high filler content leads to high filler agglomeration, resulting in regions of stress concentration which require more energy for crack propagation (Pardhan et al., 2009). Hence, the presence of prosopis has imparted desirable impact strength on the biocomposite samples.

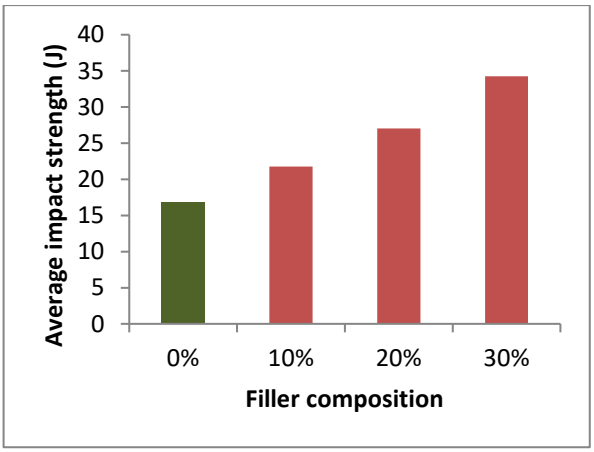

Fig. 9: Impact strength performance of the prosopis/LDPE biocomposites

3.1.4 Compressive strength

Compressive strength test can be a measure of the ability of biocomposite materials to accept vertical loading to cross-section of the object (Burmawi et al., 2018). The produced biocomposite were tested for each filler percentage weight composition and it was found out that the produced biocomposite exhibited good compressive strength as there were no cracks or fracture seen after continuous loading from the testing machine at maximum load of 13.972N/mm2. However, the samples compressed and increased in density upon each loading. This shows that the produced samples are not suitable for high compressive strengths applications (Odetoye et al, 2020)

3.1.5 Water absorption test

The amount of water absorbed by the biocomposite depends on the temperature, amount of filler, permeability of the filler, hydrophilicity of individual components, surface area exposed among others. The composite with 0% filler absorbed the least water and the little amount of water absorbed is due to the presence of voids in the sample. From the values for the water absorption test in Table 1, it is clearly shown that the biocomposite samples absorbed water after five-day (Odetoye et al., 2020) water immersion procedure. This hydrophilic nature is characteristic of lignocellulosic materials. The presence of voids in the samples might also have contributed to the amount of water absorbed. The biocomposites produced can be suitable for indoor purposes where wooden (hydrophilic) furniture can be applicable.

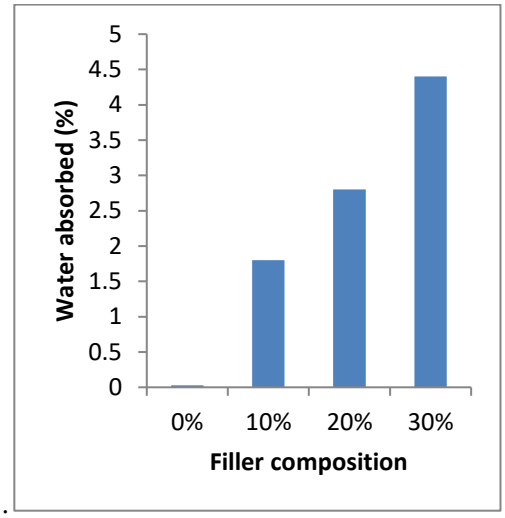

Fig. 10: Water absorption variation

3.1.6 Biodegradability test

From the results presented in Table 1, it can be shown that the reduction of weight is a function of the amount of filler present. The weight reduction increased with increase in amount of filler present with the 30% sample showing the highest decrease in percentage due to availability of more material for decomposition. The composite with 0% filler is non-biodegradable due to absence of biomass filler for decomposition. The inclusion of prosopis filler has imparted environmentally friendliness into the biocomposite samples.

Table 1. Biodegradability of biocomposite samples

Samples	Week 1	Week 5	% Weight reduced
$X_{0\%}$	39.478	39.474	0.01
$X_{10\%}$	42.564	42.432	0.31
$X_{20\%}$	40.174	40.004	0.42
$X_{30\%}$	43.223	42.933	0.67

3.1.7 Surface Morphology

X30% exhibited the overall most favourable desirable properties in comparison with the other samples. Large pores are obviously noticeable in the SEM micrograph of the X30% sample as shown in Figure 11. The rising trend in water absorption may be due to an increase in void content, which allows water to seep into the materials. Water enters the biocomposites through the pores, which could explain the higher water absorption rate. When the fibre content of biocomposites is increased, it is pertinent to control water absorption tendencies through the moulding temperature and time (Alimuzzaman et al., 2016).

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Fig. 11: SEM micrographs of the X30% sample (200µm and display mag 250) or (100X)

Since a higher fibre content is required to attain desirable mechanical properties in biocomposites, controlling the moulding temperature and time is critical to reducing water absorption (Alimuzzaman et al., 2016). The micrograph shows that the filler particles in the X30% matrix are distributed almost uniformly across the matrix of prosopis/LDPE composite.

Table 2. Elemental composition of the X30% biocomposite sample

Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
7	N	Nitrogen	8.94	4.67
6	C	Carbon	42.22	15.78
14	Si	Silicon	2.25	3.67
19	K	Potassium	3.82	12.09
17	Cl	Chlorine	9.86	8.37
20	Ca	Calcium	0.31	3.56
13	Al	Aluminium	4.43	5.75
16	S	Sulphur	3.89	7.67
11	Na	Sodium	5.30	2.52
15	P	Phosphorus	7.67	4.56
12	Mg	Magnesium	4.87	4.36
8	O	Oxygen	5.23	4.69
26	Fe	Iron	7.05	8.21
22	Ti	Titanium	0.71	5.66

The uniformity of particle distribution contributed to the ease with which stress can be transferred across the biocomposite sample, resulting in higher tensile stress, flexural strength and Young's modulus. The composition of the biocomposites is as shown in Table 2 Table 2. Elemental composition of the X30%biocomposite sample.

4 Conclusion

The production of biocomposite material from waste LDPE and *Prosopis africana* particles was successfully done. The evaluated characteristics of the Prosopis africana particle filled-LDPE biocomposite showed improved Young's modulus, impact strength and biodegradability of the biocomposite which increased desirably as the filler particles increased. The water absorptivity and compressive strengths suggest application for indoor applications and where enormous compressive strengths are not needed. Findings from this work indicate that production of biocomposites from LDPE waste sachet and prosopis pods agricultural residues is a potential a value-addition, waste management method which can be harnessed for cleaner environment and wealth creation benefits.

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