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Investigation on the Mechanical Properties of Luffa (*Luffa cylindrica*) and Banana (*Musa acuminata*) Fibre Reinforced Recycled Low-Density Polyethylene (rLDPE)

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Abstract

In response to the environmental concerns posed by low-density polyethylene (LDPE) pollution, this study explores the potential of natural fibers—specifically banana and luffa fibers—as reinforcements in recycled LDPE composites. Composites were fabricated by blending post-consumer rLDPE with banana and luffa fibers at weight ratios 10, 20, and 30%. Mechanical properties: tensile strength, flexural strength, elongation at break, and impact resistance tests were evaluated. Results showed that banana fiber composites exhibited an increase in tensile strength from 12.4 to 13.99 MPa with increasing fiber content (10–30%). Flexural strength decreases from 125.9 MPa at 10%, 105 MPa, at 20% and 92.74 MPa at 30%, elongation at break increases from 14.51% at 10% to 35.31% at 30% fiber loading. However, both flexural strength and impact resistance decreased with increased banana fiber loading. Optimal performance for banana-reinforced composites was observed at 30% fiber content for tensile strength, at 10% for flexural strength, impact resistance, and elongation at break. In contrast, luffa fiber composites showed a decrease in tensile strength from 11.84 to 10.07 MPa as fiber content increased, attributed to weak interfacial adhesion. Flexural strength increased from 10 MPa at 10% to 57.78 MPa at 20% fiber loading. Elongation decreased from 10 - 20% fiber content (44.62-25%), but slightly increased between 20% and 30% fibre loading (25-28%) due to poor adhesion. Overall, banana fiber demonstrated consistent and favorable mechanical performance than luffa, particularly in tensile properties, highlighting its potential as a sustainable reinforcement material in rLDPE composites to mitigate plastic waste and reduce environmental impact.

Keywords: Composite, fibre, pollution, recycled-polyethylene, waste

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Introduction

Natural fibres are now attracting attention as good reinforcements for polymer matrices for many applications, a lot of work have been published in this regard [1–3]. This observation is because of developments in science and technology in search for materials with excellent properties, eco-friendliness, light weight and low cost. Researches on fibre modified polymer composites as well as their production have served as one of the most promising approaches to meet up with this demand [4–6]. The use of natural fibres such as sisal, bamboo, hemp, kenaf, flax, palm, and jute, as reinforcements for both engineering and commodity plastics in certain applications, is particularly attractive. This is attributed to their; biodegradable, non-toxic, low densities, and cost effectiveness characteristics [7, 8]. Similarly, thermoplastics are in high demand for both engineering and commodity plastics. For instance, polystyrene PS has excellent transparency, high electrical insulation ability as well as fluidity [9]. Furthermore, this polymer has been reinforced with natural fibres to enhance and increase its applicability [10, 11]. Polystyrene polymers are hydrophobic in nature; hence lack compatibility with natural fibres, which are hydrophilic. One way to improve the fibre association with polymer matrix is to subject it to chemical treatment. This increases the fibre surface roughness as a result of the removal of some waxy and gummy hydrophilic cells [12]. Good interaction between the polymer and the fibre can also be achieved by graft-copolymerising of hydrophobic polymer to the surface of the fibre. This approach gives the best fibre-polymer adhesion [13].

Luffa cylindrica (LC) also known as sponge gourd, is a plant from the cucumber family grown for its multipurpose use. It has an architectural structure that is highly complex with compositions such as; cellulose (60%), hemicelluloses (30%) and lignin (10%) [14, 15]. Recently, many reports such as Oboh *et al*. [16], Asim *et al*. [17], Kumar *et al*. [18] have shown the use of luffa fibre as reinforcement for different polymer matrices. Its complex microstructure confers excellent mechanical performance with potential in vibration and shock isolation, as well as thermal insulation, and acoustic absorption [19]. The combination of Luffa fiber and Banana with recycled polyethylene to create a reinforced composite can offer enhanced mechanical properties while reducing environmental waste [20]. This research is essential in addressing the growing concern over plastic waste and the need for sustainable materials in various industries. The combination of the characteristics of the polymer and properties of fiber bring about a superior performance. With higher mechanical strength and physical behavior of the fiber, the resulting composite material produces superior behavior capability. Through the blend, weaknesses of the separate constituents of the composite materials give way to a product which have excellent structural and physical properties. The reinforcement in composites enables composite materials to endure high load and have good bending abilities. Natural fibers obtained from renewable resources also provide environmental benefits that include reduction in petroleum-based products [21].

This study aims to characterize Banana and Luffa fibres as a reinforcement agent in recycled polyethylene and assess the mechanical properties of the resulting composite material, including tensile strength, impact resistance, flexural strength, hardness, and elongation at the break.

Materials and Methods

Materials

Luffa fruit was collected from a local source in Keffi town. The Luffa fruit was then immersed in water (retting) for 14days. This retting procedure improves the fiber's strength, length, uniformity, composite properties and makes the fibers easier to be separated. After the 14 days the back of the Luffa fruit was peeled off. The fibers were air dried at room temperature until there was no moisture and chopped into smaller sizes. A500 g of post-consumed Polyethylene waste was collected around Keffi town in Nasarawa State, cleaned properly using #11 nitrocellulose thinner to remove the branded write up and other impurities that may affect the effectiveness of the result and rinsed with running tap water then allowed to air dry and shredded into smaller sizes with the aid of scissors.

After weighing the recycled low-density polyethylene (rLDPE) and the chopped luffa fibers in the ratios of 10:90, 20:80, 30:70, and were taken to a two roll mill machine for compounding where the shredded polyethylene was first fed to the machine to compress and shear at a temperature of 190°C with the two rollers rotating in opposite direction at different speeds, the back roller rotating at a constant speed of 2.24 rpm and the front roller at the speed of 5.48 rpm for 40 sec, before adding the chopped luffa fibers to the mill machine for mixing with the rLDPE and it was allowed to mix for 1:40 sec to produce a uniform blended sheet. Banana trunks was collected from a local source in Keffi town by using washed Cutlass to cut down the banana tree so as to reduce impurities that might affect the results. The banana trunks were washed thoroughly with water, and then cut into manageable size for easy handling. After separation, the layers of banana trunks were rolled to loosen them for fiber separation. Impurities in the rolled layers of banana trunks such as broken fiber and coating of cellulose were removed manually; the banana layers were packaged inside Polyethylene bag for transportation. The banana layers were then immersed in water (retting) for 14 days. This retting procedure improves the fiber's strength, length, uniformity, composite properties and makes the fibers easier to be separated. After the 14 days comb was used to extract the fibers manually and washed thoroughly to remove lignin, hemi cellulose, pectin 16 and other impurities that may affect the properties of the banana fiber. The fibers were sun dried until there was no moisture and chopped into smaller sizes. Waste of post-consumed polyethylene (340 g) was collected around Angwan Lambu phase 1, Keffi town in Nasarawa State, cleaned properly using one liter of 11 nitrocellulose thinner to remove the branded write up and other impurities that may affect the effectiveness of the result and rinse with running tap water then allowed to air dry and shredded into smaller sizes with the aid of scissors. After weighing the rLDPE and the chopped banana fibers in the ratios of 10:90, 20:80, 30:70, and were taken to a two roll mill machine for compounding where the shredded Polyethylene was first fed to the machine to compress and shear at a temperature of 190°C with the two rollers rotating in opposite direction at different speeds, the back roller rotating at a constant speed of 2.24 rpm and the front roller at the speed of 5.48 rpm for 40 sec. before adding the chopped banana fibers for mixing with the rLDPE and it was allowed to mix for 1:40 sec to produce a uniform viscous blended sheet, lubricant was applied on the sheet and mold to enable easy removal of the sample when cured. The viscous melt was transferred to a mold shape of 3 mm thickness, 120 mm length and 180 mm width and another sheet was placed on top of the mold. The mold was transferred to the compression molding machine at a pressure of 2.5 Pa and a temperature of 150°C at the duration of 5 min for the sample to be properly cured. After curing, it was cut into different samples for mechanical properties: tensile strength, flexural strength, elongation at break, and impact resistance evaluation. Baikie *et al.* [22].

Results and Discussion

The results of the mechanical properties of the banana fibre were presented in blue figures below: Figs 1 and 2 shows tensile strength and flexural strength while elongation at break and impact strength were presented in Figs 3 and 4. For the mechanical properties of lufah in green Figures shows tensile strength, flexural strength and elongation at break in Figs 5, 6 and 7 respectively while impact strength was presented in Fig. 8.

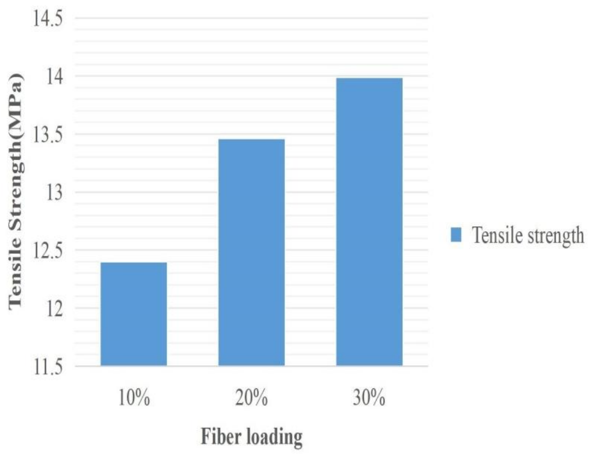

Figure 1: Plot of tensile strength against fiber loading

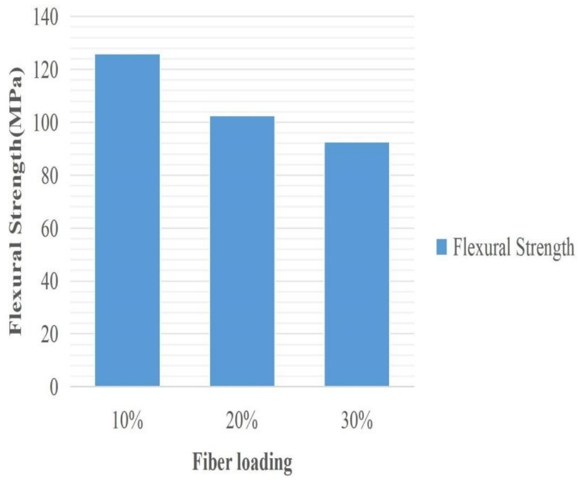

Figure 2: Plot of flexural strength against fiber loading

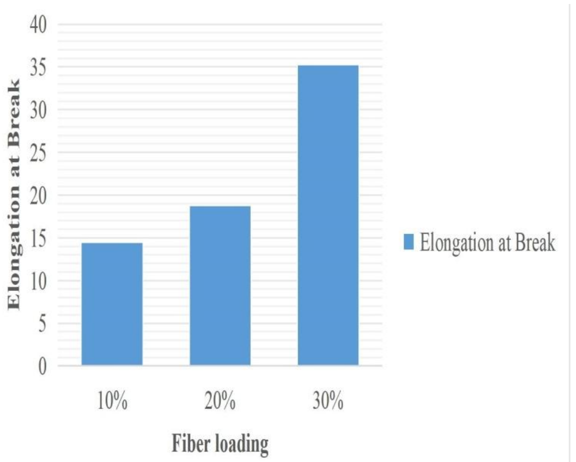

Figure 3: Plot of elongation at break against fiber loading

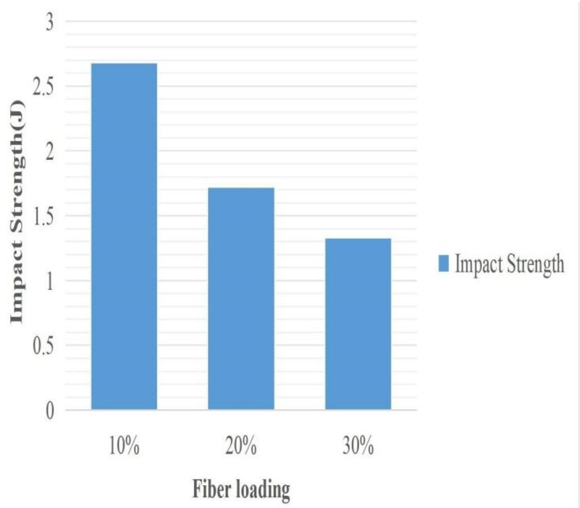

Figure 4: Plot of impact strength against fiber loading

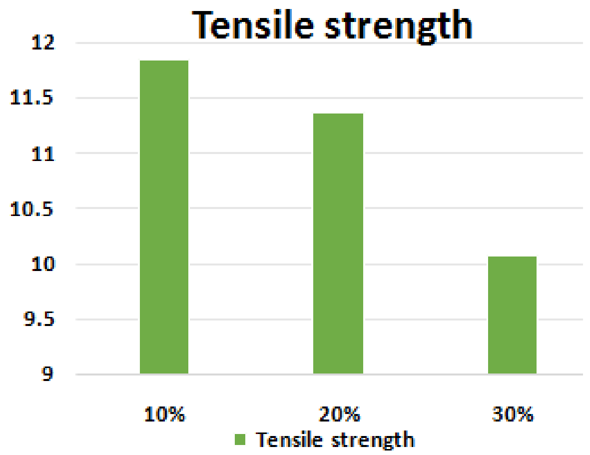

Figure 5: Plot of tensile strength against fiber loading

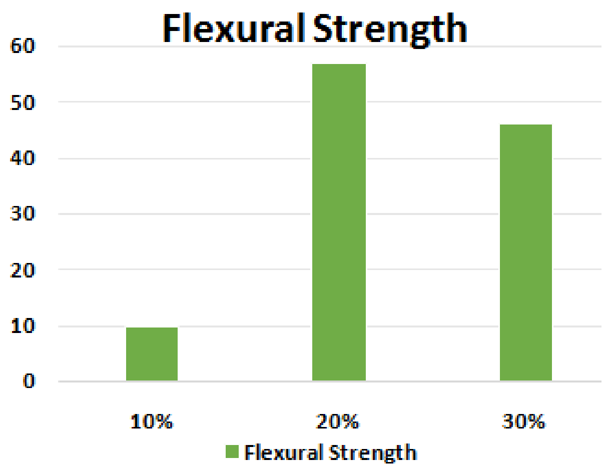

Figure 6: Plot of flexural strength against fiber loading

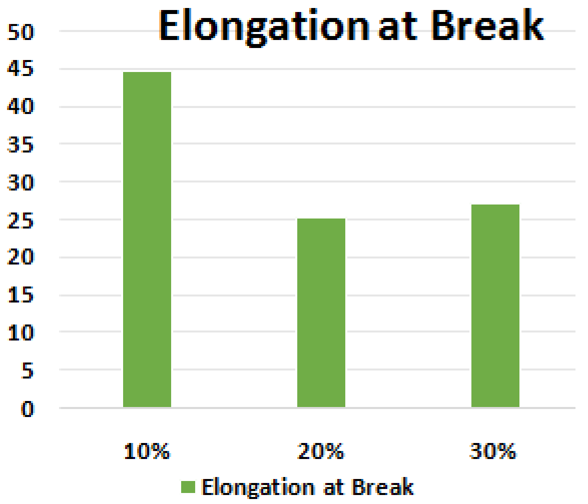

Figure 7: Plot of elongation at break against fiber loading

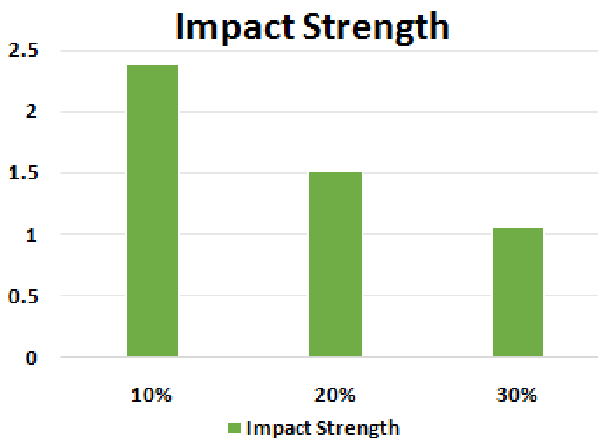

Figure 8: Plot of impact strength against fiber loading

From the results analyzed, Fig. 1 indicates that as the fiber loading increases, the tensile strength increases from 12.40 MPa at 10% BF to 13.99 MPa at 30% as shown in Fig. 1. The result was in agreement with the one reported by [22] in the Journal of Biobased Materials and Bioenergy. The flexural strength decreases from 125.9 MPa at 10% fibre to 105 MPa at 20% loading, further fiber loading led to decrease 92.74 MPa at 30% as shown in Fig. 2. The result was not in agreement with the one reported by [23] in the Journal of Biobased Materials and Bioenergy. The elongation increased from 14.51% at 10 to 35.31% at 30% fiber loading as shown in Fig. 3. The result was not in agreement with the one reported by [23] in the Journal of Biobased Materials and Bioenergy.

The increase in elongation with fiber addition indicates that the composite has poor elongation at break due to poor interfacial locking between the fiber and the matrix.

The impact strength decreased from 2.98J at 10% to 1.33J at 30%. The result was not in agreement with the one reported by [23] in the Journal of Biobased Materials and Bioenergy, due to uneven fiber distribution or poor interfacial adhesion between the fiber and rLDPE matrix Adding fibers reduces the impact strength, suggesting that the fibers do not absorb impact energy as effectively as the pure rPE matrix. This might be due to poor energy transfer between the fibers and the matrix during impact loading.

For lufah, tensile strength in Fig. 5, decreased with increase in fibre loading, and this was as a result of poor interfacial adhesion at fiber / matrix interface.

This result agrees with [24] who found out that the tensile strength of hemp fiber- reinforced poly propylene composites decreased as filler loading increased despite an increase in stiffness. The authors noted that as fiber content increased, the material became stiffer, but poor fiber – matrix interaction at higher loadings reduced the composite's ability to resist tensile stress. Flexural strength as shown in Fig. 6, increased from 10 MPa at 10% of fiber loading to 57.78 MPa at 20% fiber loading then fell to 48 MPa at 30% of fiber loading. This agreed with [25] who reported that the tensile and flexural properties of hybrid natural fiber composites declined with increased fiber content, mainly due to inadequate interfacial bonding between the fibers and matrix. The study highlighted that poor adhesion led to ineffective stress transfer resulting in mechanical weakness at higher filler loadings. Elongation at break decreased as the fiber loading increased as observed in Fig. 7. This was due to polymer chain mobility and increase in stiffness. This result was in agreement with the one reported by [26]. Impact strength decreased with increase in fiber loading as indicated in Fig. 8. This was due to weak bonding between polymer matrix and the fiber. Dhakal *et al.* [27] concluded that at higher fiber content, poor interfacial bonding leads to stress concentrations and micro – cracks, which reduce the material's ability to absorb impact energy. This behavior is particularly noted in both natural and synthetic fiber composites, where inefficient load transfer at the matrix- fiber interface weakens overall impact resistance.

Conclusion

This study demonstrated that reinforcing recycled low-density polyethylene with banana and luffa fibers improves its mechanical properties, offering a promising approach for enhancing the performance of recycled plastics. The tensile strength and flexibility of the composites were notably higher than that of pure recycled LDPE, suggesting that banana and luffa fibers can effectively offset the loss of strength typically seen in recycled plastics.

Moreover, the use of natural fibers aligns with the growing demand for sustainable materials, contributing to the reduction of both plastic waste and the reliance on virgin resources. The results indicated that both banana and luffa fiber-reinforced recycled LDPE has potential applications in various industries where strength and sustainability are prioritized. This study explored the potential of luffa fiber as a natural reinforcement in recycled low-density polyethylene (rLDPE) composites, focusing on its mechanical performance and sustainability. The findings indicated

that both banana and luffa fibers significantly enhance the mechanical properties of rLDPE, making it a viable option for applications demanding lightweight, eco-friendly, and cost-effective materials. Testing across varied fiber contents showed notable improvements in tensile strength, fleural strength, and impact resistance, with optimal performance observed at (20%) fiber loadings. The improvement in mechanical properties is attributed to the inherent strength of banana and luffa fibers and their porous structures, which facilitates mechanical interlocking with the rLDPE matrix.
Further research is recommended to investigate and optimize the composites derived from the two blended fibers and investigate long-term performance under varying environmental conditions to fully realize the potential of these bio-composites.

Conflict of interest: Authors collectively declare that they have no conflict of interest related to this work.

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