Physical and Mechanical Properties of Filler Loading on Low-Density Polyethylene/Doum Fibre Composite

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Abstract
This study investigates the physical and mechanical properties of low-density polyethylene (LDPE)/doum fibre composites with varying filler loadings. Six composite samples were fabricated using a metal mould of dimensions 120 × 120 × 3 mm, with LDPE and doum fibre mixed in ratios of 100:0, 90:10, 80:20, 70:30, 60:40, and 50:50. Processing was carried out at 120 °C for 5–10 minutes. The prepared samples were subjected to tensile tests to evaluate tensile strength, strain, percentage elongation at break, Young's modulus, and density. Results revealed that the neat LDPE sample (100:0) exhibited the highest tensile strength, strain, and elongation at break, whereas the 50:50 LDPE/doum fibre composite recorded the highest Young's modulus. The findings indicate that increasing doum fibre content, accompanied by a reduction in LDPE, decreases tensile strength, strain, and elongation at break, while enhancing the stiffness of the composite as reflected in the increased Young's modulus.

Keywords: Doum Palm Nut, Low-Density Polyethylene, High-Density Polyethylene, Sodium hydroxide, Composite

INTRODUCTION

The use of natural fibres (NFs) as reinforcement in polymer composites has attracted significant attention from researchers seeking to develop sustainable alternatives for various applications. Their growing appeal stems from their advantages over traditional fillers such as glass and carbon fibres, as well as polymer blends.

For example, polyolefin-based composites, such as high-density polyethylene (HDPE) and poly(ethylene terephthalate) reinforced with nylon-66 and polypropylene (PP), respectively, have been fabricated, and their microstructure–property relationships thoroughly investigated (Mahfuz *et al.*, 2014).

Natural fibre reinforcement offers several benefits, including low cost and density, favourable strength-to-weight ratio, non-abrasiveness, reduced health risks, lower energy consumption, recyclability, renewability, biodegradability, and local availability. Nevertheless, their use is limited by challenges such as high-water absorption and reduced mechanical performance (Pickering *et al.*, 2016).

The doum palm nut (DPN) (Plate A), which is regionally abundant, presents a promising candidate for natural fibre reinforcement in polymer composites. Its utilisation could contribute to the development of environmentally friendly and sustainable materials for construction and other applications.

However, a major drawback of NF-reinforced composites lies in poor interfacial adhesion between the fibre and the polymer matrix. This limitation arises from the inherent incompatibility between the hydrophilic nature of natural fibres and the hydrophobic nature of most polymers.

To address this challenge, surface modifications, such as chemical treatments and the incorporation of coupling agents, are commonly employed to enhance fibre–matrix compatibility and ensure effective dispersion of fibres within the polymer matrix (Alabi, 2011).

Plate A: Doum palm nut (DPN)

Low-density polyethylene (LDPE) is a widely used thermoplastic polymer and a common matrix material for wood-plastic composites (WPCs). According to Kaseem *et al.,* (2016), numerous studies have explored the reinforcement of LDPE with natural fibres to improve the performance of composite materials.

Against this backdrop, the present study focuses on the mechanical, thermal, and physical properties of LDPE composites reinforced with doum palm nut fibres, a resource that is locally available in Nigeria. Specifically, it examines the influence of doum fibre loading on the properties of LDPE-DPN composites.

The research problem addressed in this study lies in the limited utilisation of doum fibre as reinforcement in polymer composites. Despite its availability and potential, there is a dearth of information regarding its composite properties, and to date, no systematic investigations have been reported on its incorporation into polymer matrices.

Accordingly, this research aims to investigate the physical and mechanical performance of LDPE reinforced with doum fibre.

MATERIALS AND METHODS

Materials

The primary materials utilised in this study were waste low-density polyethylene (LDPE) in the form of "pure water sachets," which were collected from Amina Hall Cafeteria at Ahmadu Bello University (ABU), Zaria. In addition, doum fruits were procured from Samaru Market, located in Sabon Gari Local Government Area of Kaduna State, Nigeria.

Equipment

The experimental procedures employed various equipment, including a Jaw Crusher (Retsch, Masch Nr. 70992), a Ball Mill Grinding Machine (Kera B.V., 057748), and a Standard Sieve (Sieve-Tronic, ISO 3310-1:2000, BS 410-1:2000).

Processing of the composite materials was carried out using a Two-Roll Mill (CP 5183, North Bergen, U.S.A.) and a Compression Moulding Machine (DT 8679-7585, Wenzhou Zhingang, China).

Mechanical characterisation was performed with a Tensile Properties Tester (TM 2101-T7).

Additional instruments included an Analytical Weighing Balance (HR-200), Vernier Calliper, and a Super Dumbbell Cutter Machine (TZ-8108).

EXPERIMENTAL METHODS

Extraction of Doum fibre

The Doum fruit for the study was sourced and purchased from Samaru market, Sabon Gari, Zaria Kaduna state. The edible part of the fruit and the seed were removed, and the shell was washed and sundried for hours to remove residual moisture from it.

The dry Doum fruit shell was crushed into smaller pieces with the aid of a jaw crusher, ground to powder with a ball mill grinding machine, and sieved using a standard sieve of 100 μm in order to ensure equal distribution of the fibres. The fibre obtained (Plate B) was used as the reinforcement for the composite.

Plate B: Doum fruit particulate

Matrix preparation

The matrix material used was the waste LDPE pure water sachets which were collected immediately after usage from students at the Amina Hall cafeteria in ABU Zaria, Kaduna State Nigeria. The sachets were sorted, cleaned, washed, and sundried for a few hours. The waste LDPE (pure water sachets) was shredded into flake form for easy melting in the two-roll mill machine at 120^0c.

Compounding and Compression Moulding

The waste polymer in flakes form (LDPE) was compounded and mixed with Doum fruit particles (DFP) in a two-roll mill machine in accordance with ASTM D15-627.

The two-roll mill machine was preheated to a temperature of 120°C for 30 minutes, which is the melting temperature of low-density polyethylene. At the end of this period, 90 wt% of LDPE (pure water sachet) was poured into the preheated two-roll mill to melt the LDPE for about 5 minutes, followed by the gradual pouring of 10 wt% Doum fruit particles (100 µm) used as reinforcement into the melted LDPE until a complete mixing of the fibre reinforcement with the matrix was achieved.

Finally, the compounded Doum particles/LDPE were scraped from the mill to form a sheet.

The resulting compounded sheet was placed in a metal mould 120 x 120 x 3 (mm) in length, width, and thickness, respectively, to which silicon oil has been initially applied on the surface of the metal mould for easy removal of the sample.

The compounded sheet in the metal mould was then pressed on a compression moulding machine for five minutes (5min), which was also preheated at a set temperature of 120℃ for thirty minutes (30min).

Thereafter, the samples were removed from the press and allowed to cool down before removing the composite sample from the mould and then each sample was labelled using masking tape.

The procedure was repeated for 20 wt%, 30 wt%, 40 wt% and 50 wt% of Doum particles with the corresponding 80 wt%, 70 wt%, 60 wt% and 50 wt% matrices of low-density polyethylene. A sample with 100% LDPE was also thermoformed and used as a control.

Composite sheets were thereafter cut into various dimensions with a Super dump bell cutter machine, according to ASTM (American Society for Testing Materials), for characterisation

Characterization

The physical and mechanical analyses of the composites were performed in accordance with standard ASTM procedures. The physical property evaluated was density, which was determined following the guidelines of ASTM D792, a standard method for measuring the density and specific gravity of plastics.

This parameter provides valuable insight into the material's compactness and structural integrity.

The mechanical characterisation included tests for tensile strength, percentage elongation at break, and tensile modulus (Young's modulus). These were conducted in compliance with ASTM D638, which specifies the standard test method for tensile properties of plastics.

The tensile strength assesses the maximum load-bearing capacity of the composites before failure, the percentage elongation at break measures their ductility, while the tensile modulus reflects the stiffness and resistance of the composites to elastic deformation under stress.

Physical Properties: These are the properties that can be measured or observed without changing the chemical nature of the substance and are called physical properties. These properties are used to observe and describe matter. Typical examples are: density, water absorption, moisture content, etc. The density property measurement was the only physical property analysis carried out for this research.

Density Measurement: The cut sample of pure LDPE and Doum fiber reinforced LDPE of different percentage

composition was weighed using an analytical weighing balance and the mass of each sample was determined and recorded. The length, width and height of the samples were also obtained using a Vanier calliper to determine the volume of each of the samples by multiplying the length by the width and also the height.

The density was calculated using equation (1).

$$Density = \frac{Mass\ (g)}{Volume\ (mm)^3} \text{ ……...(1)}$$

Mechanical Properties

The characteristics that indicate the elastic or inelastic behaviour of a material, such as a polymer under pressure (force), such as tensile, flexural, and impact strength, elongation at break, tensile modulus, flexural modulus, and hardness (HV).

The response to applied forces and deformation of polymeric materials contributes immensely to the behaviour of polymers in processing. The mechanical properties over a large number of factors, all of which combine to determine the particular character of the polymer.

For this research, the only analysis carried out for mechanical properties was; tensile test analysis.

Tensile Test (ASTM D638)

The tensile test was conducted according to ASTM D638 using the tensile properties tester (TM 2101-T7). The dimensions, gauge length, and cross-head speeds are chosen according to the ASTM D638 standard. The samples were cut into dumbbell strips with a super dumbbell machine and the dimensions were 100 x 15 x 3 (mm) in length, width, and thickness, respectively. A cross-head speed of 2mm/min was used.

The test specimens were held in the grips of the testing machine and tightened evenly and firmly to prevent any slippage as the test commenced. The resistance and elongation of the specimens were detected and recorded by the load cell until a failure or rupture occurred.

Three readings were obtained for each sample and the average was taken. From the test, tensile parameters (tensile strength, elongation at break, and tensile modulus) were determined and recorded.

The tensile strength was calculated by dividing the maximum load by the cross-sectional area of the sample, as shown in equation (2).

$$Tensile\ strenght = FA \text{ ……(2)}$$

where F = force acquired to break the material, A = cross-sectional area of the material, Area = thickness x width

The modulus of elasticity was expressed as the ratio of the applied stress to the resulting strain, as shown in equation (3).

$$E = \sigma\epsilon \text{ …….. (3)}$$

where E = Young's modulus of elasticity, σ = stress, ε = strain

while the percentage elongation at break was expressed as the percentage of change of the original length for each specimen between grips at the break, as shown in equations (4) and (5)

$$\epsilon = \Delta xx \text{ …….. (4)}$$

ε = Strain

Δx = change in dimension, X = original dimension,

Elongation (%) = strain (ε) x 100 …….. (5)

The same procedure was followed for all the samples.

RESULTS AND DISCUSSION

Table 1: Mechanical properties of LDPE/Doum fibre particulate composite

S/N	SAMPLECOMPOSITION LDPE: DOUM (%)	TENSILE STRENGTH (Mpa)	STRAIN	ELONGATION AT BREAK (%)	TENSILE MODULUS (Mpa)
1	100-0	11.098	5.3095	530.948	2.090
2	90-10	8.958	0.776	77.576	11.545
3	80-20	8.304	0.859	85.861	9.672
4	70-30	8.317	0.477	47.691	17.437
5	60-40	9.170	0.182	18.186	50.423
6	50-50	7.984	0.151	15.093	52.905

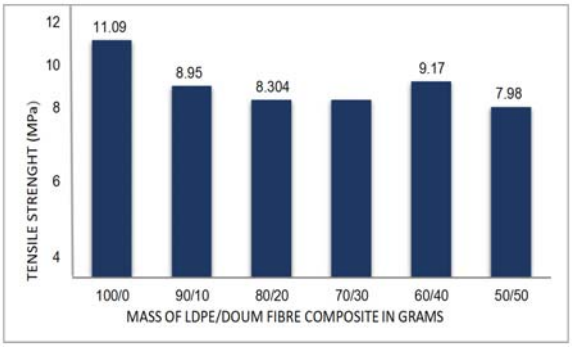

Fig. 1: Effect of an increase in the mass of Doum fibre on the tensile strength of the LDPE/Doum fibre composite

The tensile properties of the LDPE (matrix) and Doum fibre (reinforcement) composites are shown in Table 1 and Figure 1. It can be seen from the table that 100g/0g of LDPE (unreinforced LDPE) has the highest tensile strength value and the composite of 50g/50g LDPE/Doum fibre (reinforced LDPE) has the lowest tensile strength value. The decrease in the tensile strength value between the unreinforced and reinforced LDPE might be due to the weak compatibility between the natural fibre and the polymer matrix.

However, 40 wt% Doum fibre-reinforced LDPE had the highest average tensile strength value among the reinforced LDPE composites.

Tensile strength decreases with an increase in the weight percentage of Doum fibre, but showed a slight increase in the percentage composition of (LDPE/Doum fibre 70:30), then a further increase in the percentage composition of (LDPE/Doum fibre 60:40), followed by a decrease in the percentage composition of (LDPE/Doum fibre 50/50).

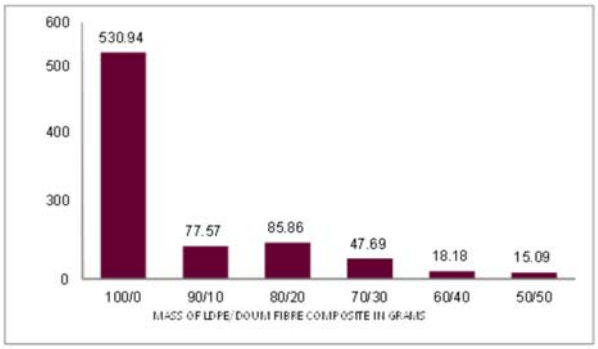

Fig. 2.; Effect of increase in mass of Doum fibre on the % elongation of the LDPE/Doum fibre composite

The elongation at break of the unreinforced composites (100% LDPE) was higher than any of the reinforced Doum fibre composites. As indicated in Figure 2, elongation at break drastically decreased on the initial addition of 10% Doum fibre to 90% LDPE, but there was an increase in % elongation at break on the addition of 20% Doum fibre to 80% LDPE. Followed by a further decrease on increase in the percentage composition of Doum fibre. This indicates that the elastic nature of the LDPE decreases with the addition of the Doum fibre.

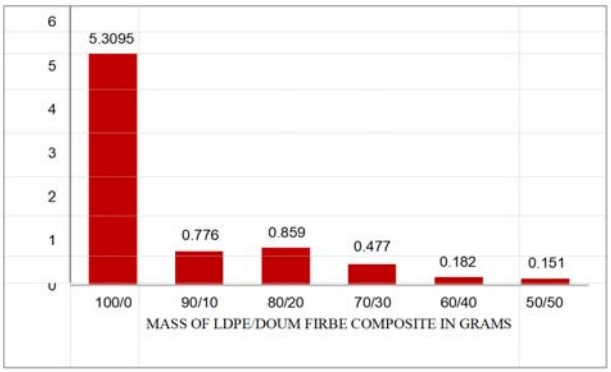

Fig. 3: Effect of an increase in mass of Doum fibre on the strain of the LDPE/Doum fibre

The strain of the LDPE/Doum fibre composite decreases with an increase in fibre loading. The strain in Figure 3 above drastically decreased after 10% doum fibre was added to 90% LDPE, but the strain also increased after 20% doum fibre was used, followed by a continuous decrease in the strain as the percentage composition of the doum fibre was increased.

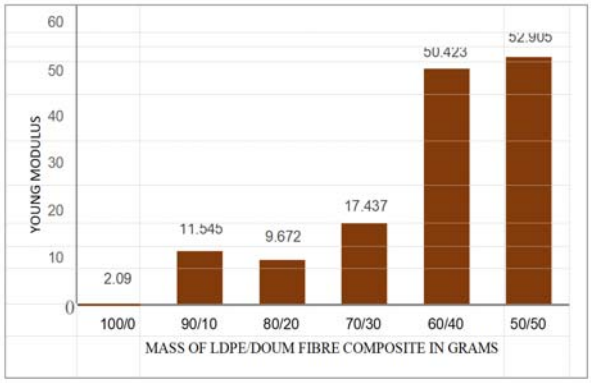

Fig. 4: Effect of an increase in mass of Doum fibre on the tensile modulus of the LDPE/Doum fibre composite.

The 50 wt% fibre loading exhibited the highest young

modulus of 52.905 MPa as shown in Figure 4. This suggests that the 50 wt% fibre loading composite exhibits a higher degree of stiffness within the fibre loadings investigated.

The observed increase in Young's modulus with an increase in fibre loading is consistent with Nara *et al*. (2012), where it was reported that the tensile modulus, which is an indication of load-bearing capacity, increases with fibre weight fraction.

At this fibre content, the stiffer component of the fibre in the composite was observed; resistance towards deformation increases with an increase in fibre content, which is expectedly to increase the stiffness of the composite.

However, the drop in Young's modulus after 20 wt% fibre loading might be attributed to poor dispersion of fibre in the matrix at higher loading, in addition to poor fibre-matrix interaction.

Density Test

The density of the LDPE/Doum fibre composite (Figure 5) noticeably increased with an increase in filler loading. The pure LDPE sample had the lowest density value, while the composite with 50 wt.% had the highest density value, but on the addition of 30 wt.% Doum fibre to the composite, the density value dropped from 0.860 g/cm^3 to a value of 0.845 g/cm^3. This may be due to poor distribution of the filler in the composite.

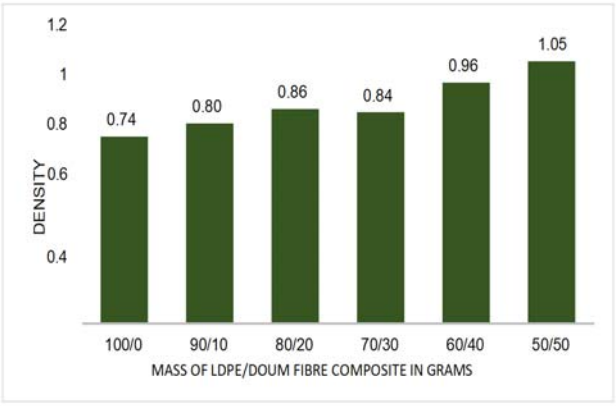

Fig. 5 Effect of increase in mass of Doum fibre on the density of the LDPE/Doum fibre composite.

CONCLUSION

This study investigated the effect of doum fibre reinforcement on the physical and mechanical properties of low-density polyethylene (LDPE) composites. Results showed that fibre loading significantly influenced composite performance. At 40 wt.% loading, the composites exhibited the best tensile strength, while 40–50 wt.% yielded the highest Young's modulus values (50.432–52.905 MPa). The best strain and elongation at break were recorded at 20 wt.% (0.859 and 85.861%, respectively), although neat LDPE displayed the highest values (5.306 strain and 530.948% elongation), confirming that elasticity decreased with increasing fibre content. Overall, doum fibre was not found to be an excellent reinforcement for LDPE, as it reduced tensile strength, load-carrying capacity, and stiffness, while increasing density. Nonetheless, the composites met ASTM D638 standards for tensile properties, making them suitable for applications such as deck boards and guardrail systems. It is recommended that future work should include chemical treatments (e.g., alkaline, silane, or peroxide) to improve fibre–matrix compatibility and explore hybridisation with other natural or synthetic fibres.

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