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EVALUATION OF MECHANICAL AND PHYSICAL PROPERTIES OF BAMBOO LEAF NANO SILICA FILLED WITH RECYCLED LOW DENSITY POLYETHYLNE COMPOSITE

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ABSTRACT

This study investigates the influence of bamboo leaf nano-silica (BLNS) filler on the mechanical and physical properties of recycled low-density polyethylene (RLDPE). RLDPE composites were fabricated using a two-roll mill at 150°C, followed by compression moulding. A comprehensive evaluation of the composites was conducted, encompassing tensile, impact, flexural tests, water absorption, modulus of elasticity, and hardness measurements. Results demonstrated that the incorporation of BLNS significantly enhanced the hardness of RLDPE composites. However, an increase in filler loading led to decreased tensile strength and increased water absorption. Interestingly, impact strength exhibited an improvement with increasing BLNS content. These RLDPE/BLNS composites with enhanced mechanical properties hold promise in various applications, including automotive components, construction materials, packaging, and consumer goods.

Keywords: *Recycle low-density polyethylene, Bamboo Leaf, Tensile Strength, Flexural, Hardness.*

INTRODUCTION

Driven by the imperative to mitigate environmental pollution caused by plastic waste and foster sustainable development, there has been a surge in research exploring the utilization of biomass-based materials for packaging applications (Gajender and Narula, 2010). Composites, defined as materials comprising two or more distinct phases with a well-defined interface (Mariana and Silvia, 2012), offer a compelling solution. By judiciously combining these phases, composites exhibit superior structural and functional properties unattainable by their individual constituents (Mariana and Silvia, 2012). These "wonder materials" are increasingly vital in modern materials science due to their advantageous characteristics, including low weight, corrosion resistance, high fatigue strength, and ease of assembly (Ipilakyaa *et al.,* 2017).

Natural fibers, such as cotton, coconut fibers, and bamboo, represent a promising class of materials for composite reinforcement. Their abundance, renewability, and low density make them suitable candidates for sustainable composite production (Han-Seung *et al.,* 2004). Among these, bamboo has garnered significant attention owing to its exceptional sustainability, renewability, and biodegradability (Junsik, 2021). This perennial woody grass, belonging to the Poaceae family and Bambusoideae subfamily, is a rapidly growing, evergreen monocotyledonous plant widely distributed globally, with China being a major producer (Uzochukwu *et al.,* 2020).

In this study, we focus on addressing the environmental challenge posed by the widespread accumulation of recycled low-density polyethylene (RLDPE), commonly found in the form of discarded water sachets. These non-biodegradable plastics contribute significantly to environmental pollution. Incineration, a common disposal method, exacerbates the problem by releasing harmful pollutants into the atmosphere and depleting the ozone layer. To mitigate this issue, we propose the utilization of readily available bamboo leaf waste as a bio-filler for RLDPE. The primary objective of this research is to investigate the influence of bamboo leaf silica nanoparticles on the mechanical and physical properties of RLDPE composites.

MATERIALS, EQUIPMENT AND METHOD

Waste low-density polyethylene (LDPE) was sourced from Samaru, while bamboo leaves were obtained from Okene, Kogi State.

Equipment

The research utilized a two-roll mill (model 5185) from Reliable Rubber & Plastic Machinery,

sourced from the Polymer Workshop at NILEST, for material processing. A Carver Inc. compression machine (model 3851-0) was also obtained from the Polymer Workshop at NILEST for sample preparation.

For material characterization, the study employed an impact tester (model 6957) from Ceast, a weighing balance (model HR-200-BC) from A and D Instrument, and a Vickers hardness tester (model MV1-PC) from the Mechanical Engineering Department at ABU. Additionally, a Transcell Technology tensiometer (model TM 2101) was utilized from the Polymer and Textile Engineering Department at ABU, along with a JEOL furnace (model JSM-7600F) from the Polymer Laboratory at NILEST.

Finally, a Universal Material Tester (Cat-Nr-261) was sourced from the Polymer and Textile Engineering Department at ABU for comprehensive mechanical property analysis.

METHODS

SILICA EXTRACTION

Bamboo leaves were subjected to calcination at 500°C for a duration of two hours within a furnace. Subsequently, the resulting ash was carefully extracted and allowed to cool to ambient temperature. To achieve the desired nano-sized particles, the cooled ash was subjected to a rigorous ball milling process for a period of four hours, ultimately yielding a fine, powdered form.

FILLER CHARACTERIZATION

Determination of Density

The filler's bulk density was determined following the protocol outlined in BS-EN-5669. Precisely weighed samples were carefully introduced into a uniform cylinder characterized by a consistent cross-sectional area. Subsequently, the filled cylinder was subjected to repeated tapping until no further reduction in the occupied volume was observed. This stabilized volume was then recorded, enabling the calculation of the bulk density.

Moisture content

This is for informational purposes only. For medical advice or diagnosis, consult a professional.

The moisture content of each filler was determined using the standard method outlined in BS-EN-120-92 at 125°C. This method involves drying the sample to a constant weight to ascertain the percentage of water present. The initial weight of the moist sample was recorded. Subsequently, the sample was dried to a constant weight within an oven maintained at a temperature of 125°C. Upon cooling, the sample was reweighed, and the final weight was recorded.

Moisture Content (%) =

$$\frac{\textit{Initial weight} - \textit{final weight}}{\textit{Initial weight}} \text{ x } 100$$

PARTICLE SIZE DETERMINATION

The most common method for particle size determination is sieving. It is the simplest way to assess particle size determination. Test sieves provide a simple cost-effective mechanical method of distributing granules into particle size classes preparing them for further analysis as each sieve in a stack has a progressively smaller mesh size.

Table 1: Formulation Table

Ingredient	Sample A	Sample B	Sample C	Sample D	Sample E	Sample F
RLDPE	100g	95g	90g	85g	80g	75g
NANO SILICA	0g	5g	10g	15g	20g	25g

Sample Formulation, Mixing and Preparation of Composite Samples

Composite samples were prepared by incorporating varying volume fractions of bamboo leaf ash nanoparticles into the RLDPE matrix. The RLDPE was introduced into a two-roll mill operating at 120°C. Subsequently, bamboo leaf ash nanoparticles were added according to the predetermined formulation, and the mixture was thoroughly blended until a homogeneous dispersion was achieved. The resulting mixture was then transferred to a compression molding machine, where it was subjected to compression for 10 minutes within a mold. Finally, the compressed composite sheets were carefully extracted.

TESTING OF SAMPLE

Tensile Strength Test

Tensile strength tests were conducted in accordance with ASTM standard D638 utilizing a Hounsfield Monsanto tensometer operated at a crosshead speed of 10 mm/min. Dumbbell-shaped specimens were subjected to uniaxial tensile loading. The resulting stress-strain data were analyzed to determine key tensile properties, including tensile strength, strain at break, and Young's modulus. Three replicate tests were performed for each condition, and the average values were recorded.

Hardness test

Hardness testing was conducted in accordance with ASTM D 785-08 using a Vickers Hardness Tester (model MV1-PC, serial no. 07/2012-1329) on the Shore D scale. The sample was positioned on the mounting stage, and the dial gauge was zeroed. The hand lever was then used to bring the indenter into contact with the sample surface, applying the specified force. Three indentations were made at distinct locations on the sample, and the corresponding hardness values were recorded. The average hardness value was subsequently calculated.

$$\text{Average Hardness} = \frac{\mathbf{1st + 2nd + 3rd\ readings}}{\mathbf{3}}$$

Impact Strength

Impact tests were conducted in accordance with ISO 179 and ASTM D-156. Specimens with dimensions of 50 mm x 10 mm x 7 mm were prepared from each composite sample. An Izod impact tester was employed to determine the impact energy. The specimens were clamped vertically in the machine's jaws. A pendulum hammer with a weight of 1500 N was released from a 150° inclination angle. The impact energy absorbed by each specimen was measured and recorded. Subsequently, the impact strength was calculated and recorded accordingly.

$$\text{Impact Strength} = \frac{Impact\ energy}{Thickness\ of\ Sample}\ (J/mm)$$

Flexural Strength

Flexural testing was conducted using a Universal Testing Machine in accordance with ASTM D790 standard. This involved a three-point bending method. The test was performed at a crosshead speed of 5 mm/min. Flexural strength and modulus were subsequently determined.

Water Absorption Test

The water absorption of the samples was determined in accordance with ASTM D750-95. The samples were cut into uniform dimensions of 10 mm x 3 mm and weighed. Subsequently, they were immersed in water for a period of 24 hours. After this period, the samples were removed, their final weights were recorded, and the weight gain due to water absorption was calculated.

$$\text{M} = \frac{W2-W1}{W1} X\ 100$$

where:
M- Percentage water absorption
W_1- Initial Weight of sample before immersion
W_2- final weight sample after immersion

RESULTS AND DISCUSSION

Filler Characterization of particle size and percentage of silica

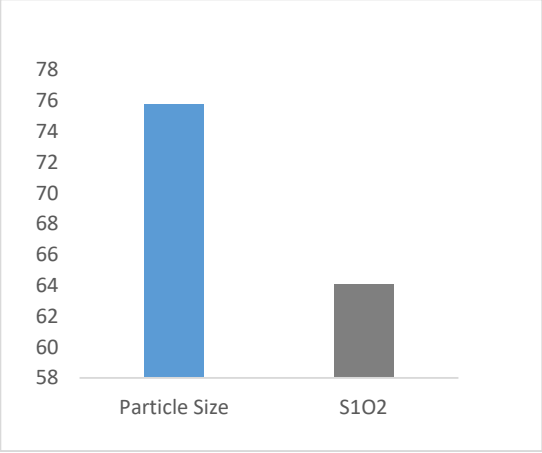

Figure 1: composition of particle size (d.nm) and component of silica (S_1O_2)(wt%) of the bamboo leaf.

Figure 1, represent the graph of the particle size and percentage of silica of the filler. The particle size was determined by Malvern instrument, at 25 ºC. The particle size distribution of the Silica nano particles samples by volume shown in Figure 1 the results shows that the Silica nano particles have three peaks with the first peak having 85.5% of particles size of 104.3(d.nm), the second peak having 13.3 % of particle between the size of 1-13.90 (d.nm) while the last peak having 1.2 % of the particle between the size 1-4634 (d.nm), the volumetric quantity of nano-silica particles between 1nm and 100 nm is 85.5% indicating that the ball mill Silica

falls between the acceptable nano-standard of 100 nm according to (Uzochukwu *et al.,* 2020).

Filler Characterization of density and moisture content

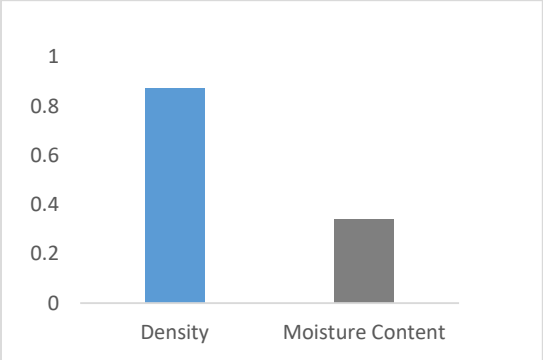

Figure 2: composition of density (g/cm^3) and moisture content (%) of the bamboo leaf

This Figure 2, presents the measured density and moisture content of the silica filler. The density was determined to be 0.37 g/cm³, indicating a relatively low value. A low density can be advantageous in composite materials as it can help to minimize the overall weight of the final product while maintaining desired mechanical properties.

The moisture content of the filler was measured at 0.34%. Low moisture content is crucial for several reasons. Firstly, it minimizes the potential for degradation of the filler material due to moisture-induced reactions. Secondly, it reduces the risk of adverse effects on the processing and curing of the polymer matrix, which can be sensitive to moisture. The low moisture content of the silica filler suggests that it is well-suited for incorporation into the polymer matrix without significant processing challenges.

Percentage Water Absorption

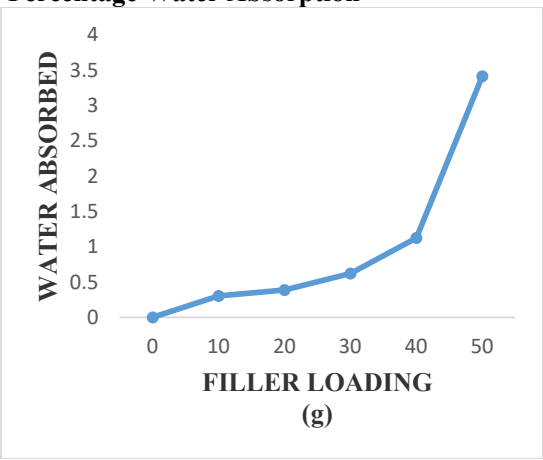

Figure 3: Effect of Nano Silica on the Water Absorption of the composite

This figure depicts the water absorption behavior of the composites as a function of filler loading. The results demonstrate a clear trend: water absorption increases gradually with increasing filler loading from 10 g to 25 g. This observation can be attributed to the hydrophilic nature of the bamboo leaf-derived silica filler.

Hydrophilic materials have a strong affinity for water molecules. As the filler loading increases, the presence of more hydrophilic silica particles within the polymer matrix creates more sites for water molecules to interact and become absorbed. This leads to an overall increase in the water absorption capacity of the composite.

Tensile Strength

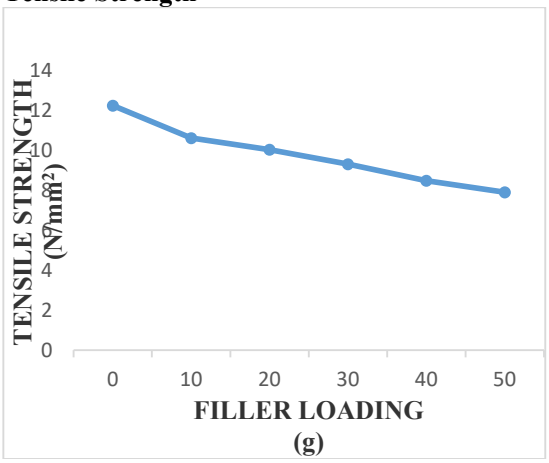

Figure 4: Effect of Nano Silica on the Tensile Strength of the Composite

This Figure 4, illustrates the tensile strength of the composites as a function of filler loading. A significant observation is a decreasing trend in tensile strength with increasing filler loading. This decline can be attributed to several factors:

Decreased Wettability: Increased filler loading may lead to a decrease in the interfacial wettability between the filler particles and the polymer matrix. Poor wettability can hinder effective load transfer between the filler and the matrix, resulting in a weaker composite.

Filler-Filler Interactions: As filler loading increases, the probability of filler-filler interactions also increases. These interactions can create agglomerations or weak zones within the composite, disrupting the continuous polymer matrix and compromising its tensile strength.

Improper Filler Distribution: Non-uniform dispersion of filler particles within the matrix can create localized areas of high filler concentration,

leading to stress concentrations and potential failure sites.

These factors can collectively contribute to the observed decrease in tensile strength with increasing filler loading, consistent with findings reported in the literature (Hamanshu and Niranjan, 2015).

Tensile Modulus

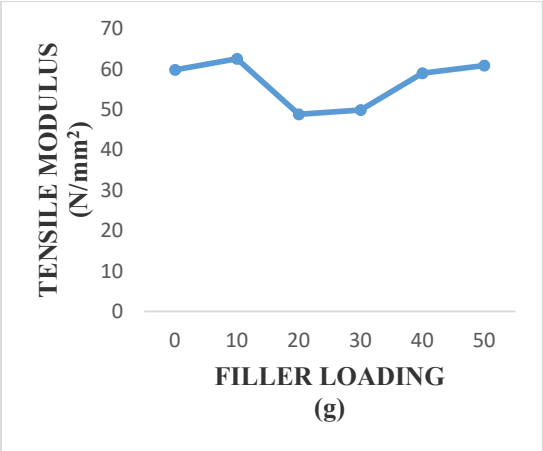

Figure 5: Effect of Nano Silica on the Tensile Modulus of the Composite

Figure 5 presents the tensile modulus of the composites, a measure of their stiffness. The results demonstrate a non-monotonic trend with increasing filler loading. Initially, the tensile modulus decreases from 10 g to 20 g of filler loading. However, it subsequently increases from 20 g to 50 g. The highest tensile modulus is observed at 10 g of nano-silica loading. This behavior can be attributed to a complex interplay of factors, including:

Interfacial Adhesion: Poor interfacial adhesion between the filler and the matrix can hinder effective stress transfer, leading to a decrease in tensile modulus. This may be particularly pronounced at lower filler loadings.

Filler-Matrix Interactions: At higher filler loadings, improved filler-matrix interactions, such as stronger interfacial bonding, can contribute to an increase in tensile modulus.

Filler Distribution and Agglomeration: Non-uniform filler distribution and the formation of agglomerations can negatively impact the tensile modulus.

The observed trend suggests an optimal filler loading range where a balance between these factors is achieved, resulting in the highest tensile modulus. The findings align with those reported in Mariana and Silvia, 2012, which also observed non-monotonic behavior in the tensile modulus of polymer composites with varying filler loadings.

Hardness

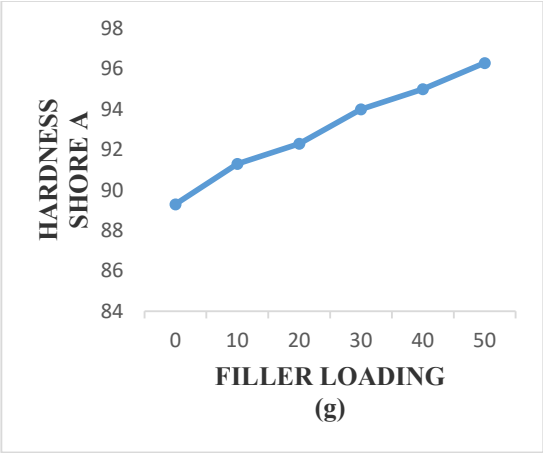

Figure 6: Effect of Nano silica on the Hardness property of the composite

Figure 6, illustrates the hardness of the composites, a measure of their resistance to indentation. The results demonstrate a clear positive correlation between filler loading and hardness. The presence of the silica nanoparticles within the polymer matrix enhances its hardness. This can be attributed to several factors:

Increased Stiffness: The incorporation of rigid silica nanoparticles increases the overall stiffness of the composite material, making it more resistant to indentation.

Surface Resistance: The presence of the filler particles can enhance the surface resistance of the matrix to indentation, providing a more robust barrier against penetration.

Filler-Matrix Interactions: Strong interfacial bonding between the filler and the matrix can effectively transfer loads, further increasing the hardness of the composite.

However, it is important to note that excessive filler loading may lead to the formation of agglomerations, which can disrupt the uniform distribution of filler particles and potentially reduce the overall hardness. The observed increase in hardness with increasing filler content aligns with findings reported in Zani, 1997, which also demonstrated an enhancement in hardness with the addition of reinforcing fillers to polymer matrices.

Impact Strength

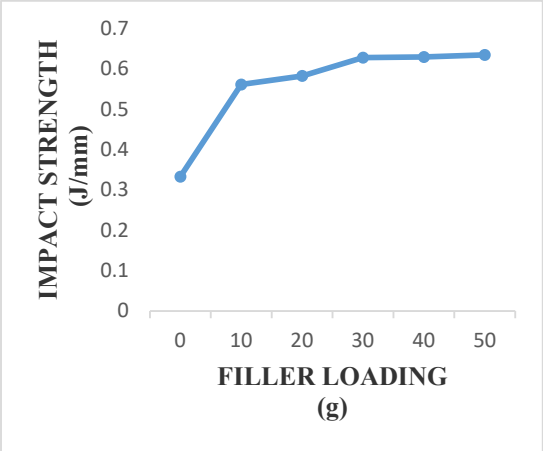

Figure 7: Effect of Nano Silica the Impact Strength of the Composite

Figure 7 illustrates the impact strength of the composites, a measure of their ability to resist sudden, localized loads. The results demonstrate a consistent increase in impact strength with increasing filler loading from 0 g to 50 g.

This enhancement in impact strength can be attributed to several factors:

Stress Distribution
The presence of the silica nanoparticles can effectively distribute stresses within the matrix, preventing the formation of localized stress concentrations that can lead to crack initiation and propagation.

Crack Deflection
The nanoparticles can act as crack deflectors, hindering the propagation of cracks through the matrix. This can significantly improve the impact resistance of the composite.

Energy Absorption
The nanoparticles may absorb some of the impact energy, reducing the amount of energy transmitted to the polymer matrix and mitigating the severity of damage. These factors, collectively, contribute to the observed increase in impact strength with increasing filler loading. The findings align with those reported in [8], which also demonstrated an improvement in impact strength with the addition of nanoparticles to polymer matrices.

Flexural Strength

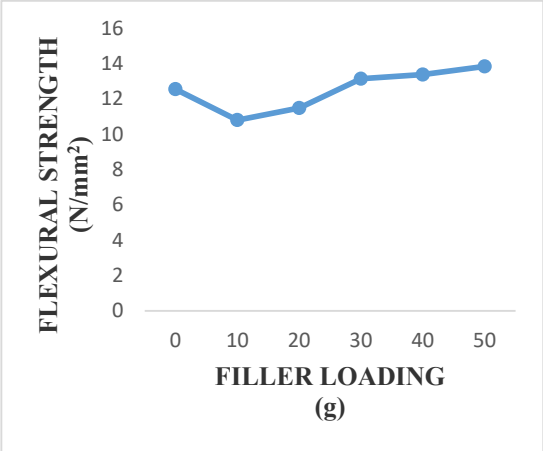

Figure 8: Effect of Nano Silica the Flexural Strength of the Composite

Figure 8 illustrates the flexural strength of the composites, a measure of their resistance to bending. The results show an increasing trend in flexural strength with increasing filler loading from 10 g to 50 g. This enhancement in flexural strength can be attributed to several factors:

Improved Filler-Matrix Interactions: Improved interfacial bonding between the filler and the matrix can effectively transfer loads during bending, leading to increased flexural strength.

Reduced Material Rigidity: The presence of the filler particles can disrupt the continuous polymer matrix, reducing its overall rigidity and enhancing its ability to deform under bending loads.

Filler Particle Size and Distribution: The size and distribution of the filler particles can significantly influence flexural strength. Smaller, uniformly distributed particles can effectively reinforce the matrix and improve its flexural properties.

The increase in flexural modulus with increasing filler loading can be attributed to a decrease in the contact area between larger filler particles and the matrix. This reduced contact area can restrict the mobility of the polymer chains, leading to increased stiffness, as reported in George *et al.,* 1997.

Modulus of Elasticity

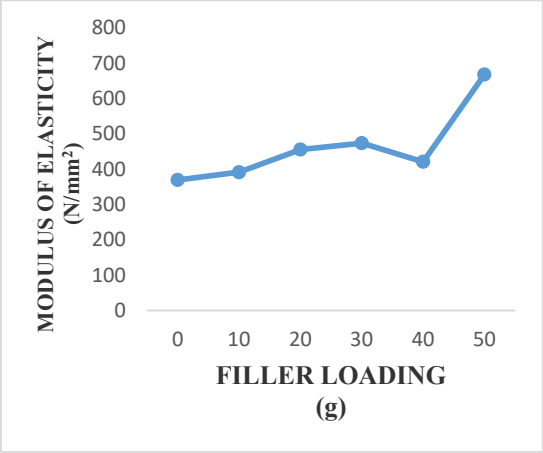

Figure 9: Effect of Nano Silica the Modulus of elasticity of the Composite

Figure 9 illustrates the modulus of elasticity of the composites, a measure of their stiffness or resistance to elastic deformation. The modulus of elasticity exhibits a similar trend to that observed for flexural strength, with a slight decrease at 40 g of filler loading.

The sample with 50 g of filler loading demonstrated the highest modulus of elasticity, suggesting the most effective reinforcement and improved overall composite performance. This indicates that the addition of 50 g of filler effectively enhances the stiffness of the composite material.

CONCLUSIONS

This study successfully investigated the influence of bamboo leaf nano-silica as a filler material on the mechanical and physical properties of recycled low-density polyethylene (RLDPE). A comprehensive evaluation was conducted, encompassing hardness, water absorption, flexural strength, tensile strength, and impact strength. The results demonstrated a notable increase in hardness with increasing filler loading. Conversely, an increase in filler content resulted in an increase in water absorption and a decrease in tensile strength. Interestingly, an enhancement in impact strength was observed with the addition of the filler. Based on the observed mechanical properties, the developed RLDPE/bamboo leaf nano-silica composites exhibit potential for applications where moderate mechanical performance is required.

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