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Mechanical Properties of Rattan Cane (*Calamus Longipinna*)-Filled Low Density Polyethylene (LDPE) Composite

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Abstract: This study explored the mechanical properties of both treated and untreated rattan cane (*Calamus longippina*) integrated with low-density polyethylene (LDPE) composite. The composite was produced by mixing different amounts (5-40 g) of rattan powder, under 180 microns in size, into 40 g of LDPE. The mechanical properties of the treated and untreated composites were analyzed. The tensile strength of LDPE was reduced by 59.36% for untreated composites and 62.56% for treated ones with the addition of rattan cane filler. The elongation at break decreased by 70.82% for untreated and 69.5% for treated composites. The Young's modulus increased by 68.85% for untreated and 69.70% for treated composites as the filler content increased. Impact strength declined with higher filler content by 68.96% for untreated and 69.36% for treated composites. Hardness improved with higher filler content by 57.04% for untreated and 57.36% for treated composites. Flexural strength dropped by 59.33% for untreated and 60.69% for treated composites as filler content increased. The composite's weight loss increased with more filler, reaching a maximum of 3.7% in soil burial tests at 40% filler content. Water absorption rose with more filler, peaking at 13.18% for the 40% filler content. Adding rattan powder enhanced the mechanical properties initially, but further additions led to a decline as LDPE could not effectively transfer the load between fibers. Overall, treated composites showed better mechanical properties compared to untreated ones.

Keywords: Rattan cane, Low Density Polyethylene, Mechanical properties, Filler weight, Treated, Untreated

I. Introduction

Polymers, whether natural or synthetic, are integral to human existence and industry. Synthetic polymers are widely used in industrial equipment and household appliances, particularly in electrical and electronic devices due to their hydrophobic and insulating properties. These materials provide protection and waterproofing. Over time, synthetic polymers have significantly benefited the global economy. However, their non-biodegradability has led to an accumulation of synthetic plastic waste, posing a threat to environmental sustainability if not regulated. Low-density polyethylene (LDPE) has been extensively studied due to its flexibility compared to high-density polyethylene (HDPE). LDPE can be easily modified by adding other materials to its polymer matrix, creating composite materials for various applications.

The introduction of matrix additives does not significantly alter the molecular structure of polymers (Answari et al., 2016). Rattan cane (*Calamus longipinna*) is a non-wood forest plant traditionally used for binding materials and various household items (Weinstock, 1983). It is widely utilized in the furniture industry, resulting in substantial waste from discarded rattan poles. The disposal of this waste is a concern due to its potential environmental impact, contributing to landfill space and causing pollution through open burning. Given the high strength and flexibility of rattan cane pole waste, there is significant interest in using it as a filler for plastic composites (Ismail et al., 2012; Muniandy et al., 2012). However, there is limited research on LDPE and rattan cane filler composites. This study aims to examine some of the mechanical properties of these composites to provide valuable information for further use.

II. Materials and Methods

Materials: Low-density polyethylene (LDPE 20FS0I0) was sourced from Indorama Eleme Petrochemicals Limited, Port Harcourt, Nigeria. Bio-filler (Rattan cane) was obtained from Swali market, Yenagoa, Bayelsa State, Nigeria. A mild steel mold (100 x 50 x 15 mm) was locally fabricated. Potassium hydroxide (KOH) was purchased from Molychem, India. A Universal Testing Machine was provided by the Mechanical Engineering Laboratory, Niger Delta University.

Bio-filler Preparation: Rattan canes were cleaned and chopped into smaller pieces. Fifty percent (50%) of the chopped canes were treated with a potassium hydroxide (KOH) solution using the method outlined by Oladele and Okoro (2015) to increase the adhesive properties of the cane. This treatment also helped preserve the particles and reduce contamination when incorporated into the matrix. The treated canes were then washed with distilled water and sun-dried to remove moisture. Both treated and untreated rattan cane pieces were ground into powder and sieved to an average mesh size below 180 microns using a standard test sieve. The treated and untreated rattan cane powder was then oven-dried at 80°C for 24 hours to eliminate excess moisture.

Composite Sample Preparation: The composite sample was created by melt-mixing the polymer matrix and the bio-filler at 114°C for 7 minutes. The homogenized mixture was then transferred into a mild steel mold for shaping and sizing.

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Property Testing: Tensile, flexural, and hardness tests were conducted using a universal testing machine (Instron 3366) following ASTM D-638 standards. An impact pendulum tester (Zwick) was utilized for impact tests under a 7.5 J load. Soil burial and water absorption tests were performed based on methods by Obasi and Onuegbu (2013) and ASTM D-1037-99 standards, respectively. Nine specimens were used to obtain average values for tensile strength, elongation-at-break, and Young's modulus.

Tensile Strength: The tensile strength at break was calculated using the equation provided in 1

$$\text{Tensile strength} = \frac{\text{Breaking force in (N)}}{\text{Original cross sectional Area in } m^2} \quad \text{---------- (1)}$$

Flexural Strength : The flexural strength was determined using equation 2;

$$\delta F = \frac{3FfL^3}{2bd^2} = \quad \text{---------- (2)}$$

Where, Ff is the load of fracture, L is the distance between support points, d is the height of the specimen and b is the specimen's width.

Hardness: Hardness was determined by measuring the permanent depth of the indentation.

Equation 3 was used to calculated the hardness value.

$$HV = \frac{Force}{Surface\ Area} = \frac{2F\sin\left(\frac{\alpha}{2}\right)}{d^2} = \frac{1.854}{d^2} \quad \text{---------- (3)}$$

Where, HV = Hardness Value

F = Test Force (N)

α =Indenter face contact angle = 136°

d = Average diagonal length (m)

Soil Burial Test: Samples were weighed and buried in soil-filled boxes with tiny apertures. Following previously adopted methods, the soil was maintained at around 20% moisture content by mass, and the samples were buried at a depth of 15 cm (Obasi and Onuegbu, 2013). Once a week, the samples were retrieved from the soil, washed with distilled water, dried, and measured to obtain new results before being reburied. The percentage weight loss was calculated using Equation 4.

$$Weight\ Loss(percentage) = \left[\frac{(M_o - M_d)}{M_o}\right] \times 100 \quad \text{----------(4)}$$

where M_o is the composite sample's initial mass before burial and M_d is the degradation mass at each week. The average of eight samples were used to calculate the % weight reduction

Water Absorption Study: The water absorption tests were conducted using the standard method ASTM D-1037-99. To estimate the amount of water absorbed, a 15 x 15 x 3 mm composite sample was soaked in distilled water for 8 weeks at a constant temperature of 25°C. The weight increase was measured weekly. The sample's water absorption at ambient temperature was calculated using Equation 5.

$$M_t\,(\text{percent}) = \frac{W_t - W_0}{W_t} \times 100 \quad \text{---------- (5)}$$

The amount of water absorbed at time t is denoted by M_t.

W_t is the sample's weight at time, t.

W_o is the composite sample beginning weight.

Young's Modulus: Young's modulus is a material's mechanical property to withstand compression or elongation relative to its original length. It was calculated using Equation 6.

$$E = \frac{\sigma}{\varepsilon} = \frac{F/A}{\Delta L/L} \quad \text{---------- (6)}$$

Where E = Young's modulus

σ = stress in Pascals (Pa)

ε = Strain

F = Force applied in newton (N)

A = Area in square metre (m^2)

L = Initial length in metre (m)

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ΔL = Change in length

Elongation at Break: Elongation at break is the percentage of elongation relative to the initial size when breakage occurs. It was calculated using Equation 7.

$$\text{Elongation} = \Sigma = (\Delta L / L) \times 100 \quad \text{---------- (7)}$$

Where ΔL = final length

L = Initial length

III. Results and Discussion

This section presents the mechanical properties of pure LDPE and LDPE-rattan fiber composites for treated and untreated samples. The effects of adding rattan fibers to the polymer matrix and varying rattan composition in the composites are discussed.

Tensile Properties

A biodegradable polymer must endure normal stress during its application. Tensile tests were conducted to investigate the tensile properties of pure LDPE and rattan-filled LDPE for treated and untreated composite samples. Figures 3.1 to 3.8 illustrate the effects of filler concentration on the tensile strength,Young's modulus, elongation at break, and other properties of the composite films.

Tensile Strength

From the plot in Figure 3.1, it is observed that adding rattan powder reduced the polymer's tensile strength from 38 MPa to 12 MPa for the untreated and from 20 MPa to 7.5 MPa for the treated, representing about a 62.5% decrease. Similarly, rattan cane powder reduced the tensile strength of LDPE by approximately 59.36% for untreated and 62.56% for treated composites. Similar findings were reported by other researchers (Demir et al., 2006; Yang et al., 2004) who also used natural fillers in polymer matrices. Rattan is known to be hydrophilic (Wahab et al., 2016), causing poor compatibility with hydrophobic LDPE. The introduction of rattan powder creates an interface between the LDPE matrix and rattan powder that cannot efficiently transfer stress.

The tensile strength for both treated and untreated composites decreased steadily with increasing filler loading. According to Mwaikambo and Ansell (2012), more filler leads to more filler-filler interactions. These increased interactions could result in rattan filler aggregation within the LDPE matrix. The authors noted that rattan fibers contain hydroxyl groups in their amorphous regions, which could hinder the ability of rattan powder to develop adhesion with non-polar polymer materials.

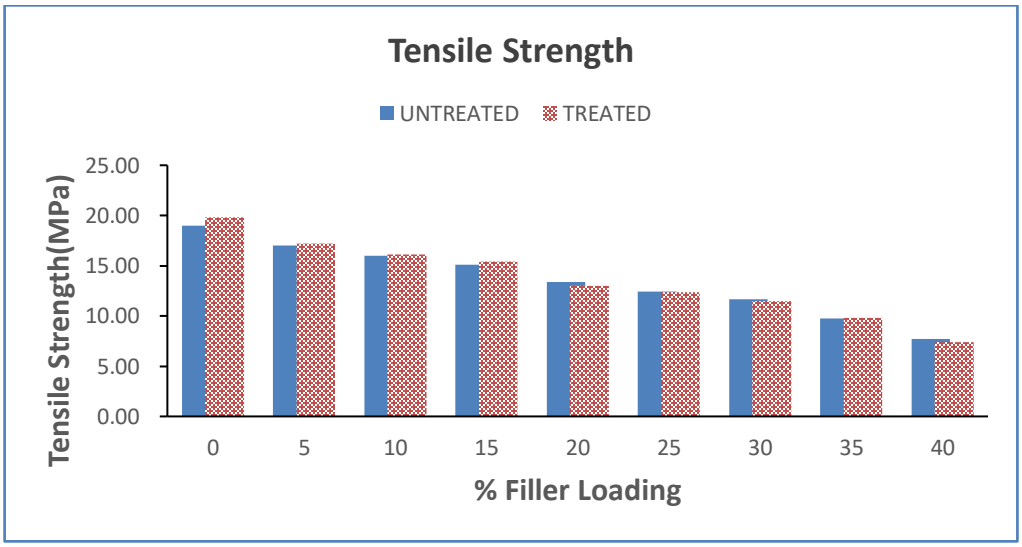

Figure 3.1. Effect of filler loading on tensile strength of treated and untreated LDPE-rattan composites.

Young's Modulus

The Young's tensile modulus for LDPE composites with varying amounts of rattan for treated and untreated samples is shown in Figure 3.2. Young's modulus, which measures a solid material's stiffness, increased for both treated and untreated composites with rising % filler loading, from 45 MPa to 155 MPa—about a 70.96% increase. Specifically, Young's modulus rose by 68.88% for untreated and 69.07% for treated composites. Fillers contributed to this increase by inhibiting polymer chain mobility, thus adding rigidity to the composite. John and Thomas (2008) attributed this stiffness to the cellulosic nature of the rattan filler.

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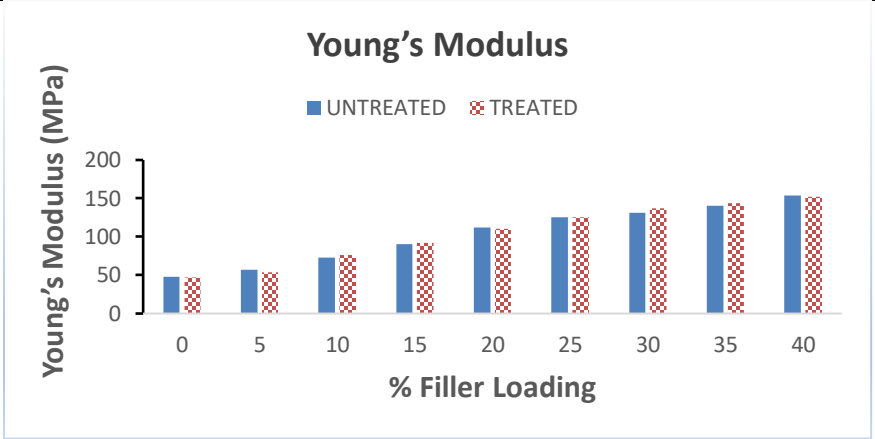

Figure 3.2. Effect of filler loading on Young's Moduli treated and untreated LDPE-rattan composites.

Elongation at Break

The effect of filler addition on the elongation at break for both treated and untreated composites is illustrated in Figure 3.3. As filler loading increases, the tendency for filler-filler agglomeration also rises, forming stress-concentrated areas that can lead to composite failure. These areas may also create voids (Ansari and Ismail, 2009). Poor stress transfer from rattan agglomerates can result in brittle behavior, reducing elongation at break, as shown in Figure 3.3. Similar observations were made by Zaini et al., (1996) and Tajvidi and Ebrahimi (2003). For both treated and untreated samples, percent elongation at break decreased with rising filler loading, from 37% to 12%, with untreated composites reducing by 70.82% and treated by 69.5%.

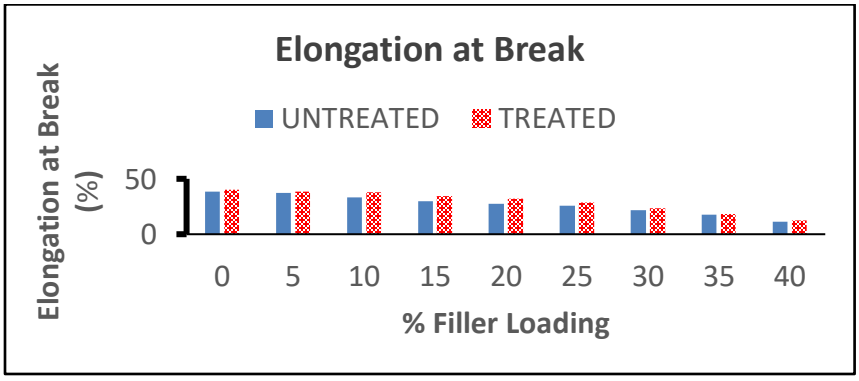

Figure 3.3: Effect of filler loading on elongation-at-break of treated and untreated LDPE-rattan composites.

Soil Burial Test

The biodegradability of pure LDPE and LDPE-rattan composites was studied through a soil burial test, calculated using Equation 4. The percentage weight loss, shown in Figure 3.4, increased with higher bio-filler content. Pure LDPE showed negligible weight loss after 6 weeks (0.002%), indicating its resistance to microbial attack. However, composites displayed steady weight loss with rising filler content, reaching 6.29% at 40% filler content. This rapid initial loss, slowing after two weeks, is attributed to microorganisms consuming the filler and creating pores in the polymer matrix (Obasi and Onuegbu, 2013). The high water absorptivity of rattan fibres also contributed to biodegradability.

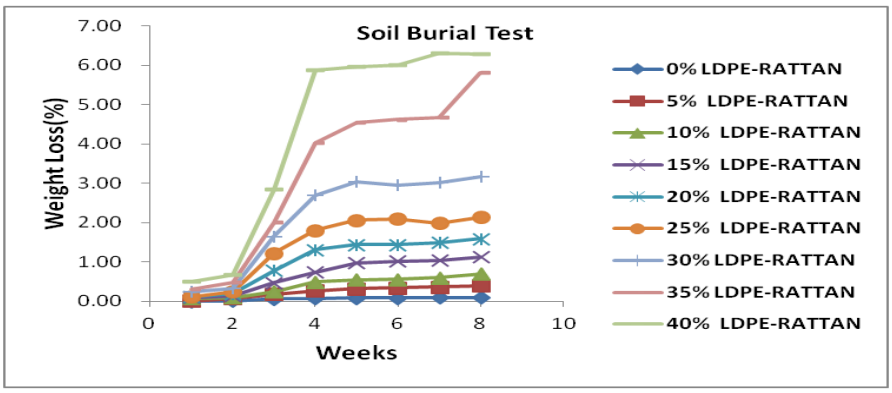

Figure 3.4. Effect of filler loading on Biodegradability susceptibility(% weight loss) of LDPE-rattan composites.

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Water Absorption

The water absorptivity of the LDPE matrix and composites, expressed as percentage water absorption over time, is depicted in Figure 3.5. Water absorption increased with filler content due to the hydrophilic nature of rattan powder. Similar findings were reported by Obasi and Onuegbu (2013) and Bikiaris and Panayiotou (1998). The highest water absorption, 31.89%, was recorded at 40% filler content.

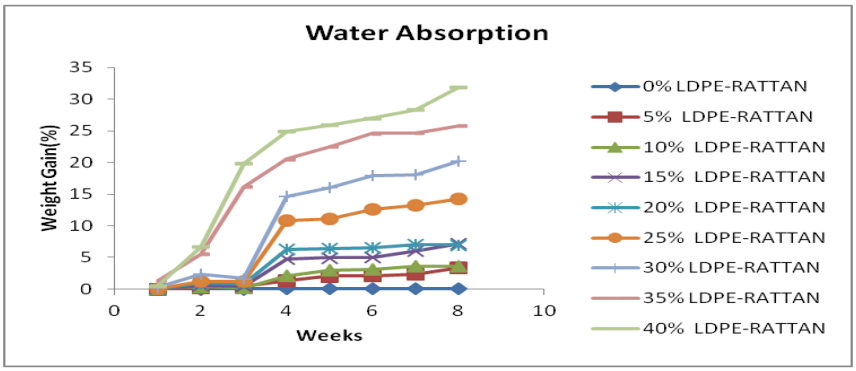

Figure 3.5. Effect of filler loading on water absorptivity of LDPE-rattan composites.

Impact Test

Figure 3.6 shows the effect of filler loading on the impact behavior of pure LDPE and LDPE-rattan composites (treated and untreated). Impact strength decreased with increasing filler content by 68.96% for untreated and 69.36% for treated composites. This reduction indicates insufficient matrix to transmit stress after impact. High filler content led to agglomeration, creating stress concentration zones that required less energy to propagate cracks.

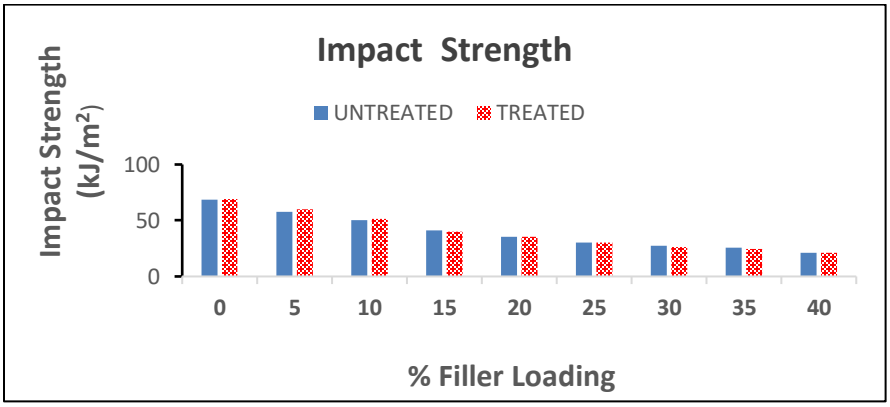

Figure 3.6. Effect of filler loading on impact strength of untreated and treated LDPE-rattan composites.

Hardness

The hardness of pure LDPE and LDPE-rattan composites (treated and untreated) is shown in Figure 3.7. Hardness increased with rising filler content, by 57.04% for untreated and 57.36% for treated composites, due to the rigidity imparted by cellulosic rattan powder. However, this increase in hardness resulted in greater brittleness due to poor interfacial bonding between components.

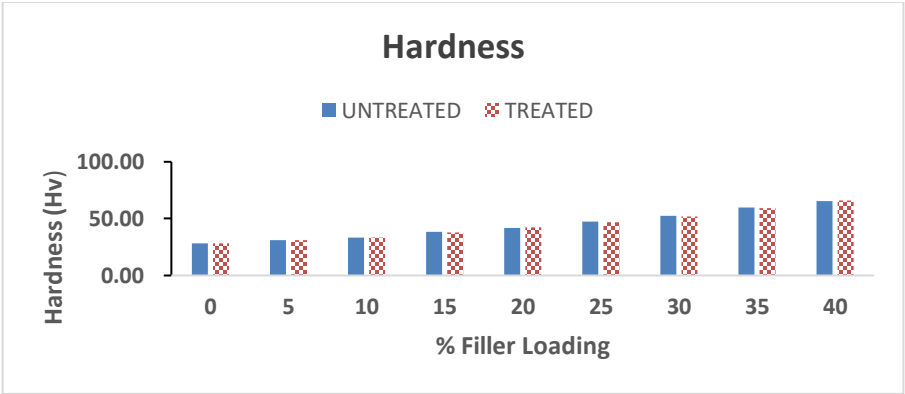

Figure 3.7. Effect of filler loading on hardness value of LDPE-rattan composites.

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Flexural Strength

Flexural strength, obtained through flexural testing using a Universal Testing Machine, is shown in Figure 3.8. Increasing filler content decreased the flexural strength of composites, by 59.33% for untreated and 60.69% for treated samples. The results corroborate the hardness tests, where increased filler content led to greater brittleness, reducing flexural strength due to poor bonding between the polymer matrix and rattan powder.

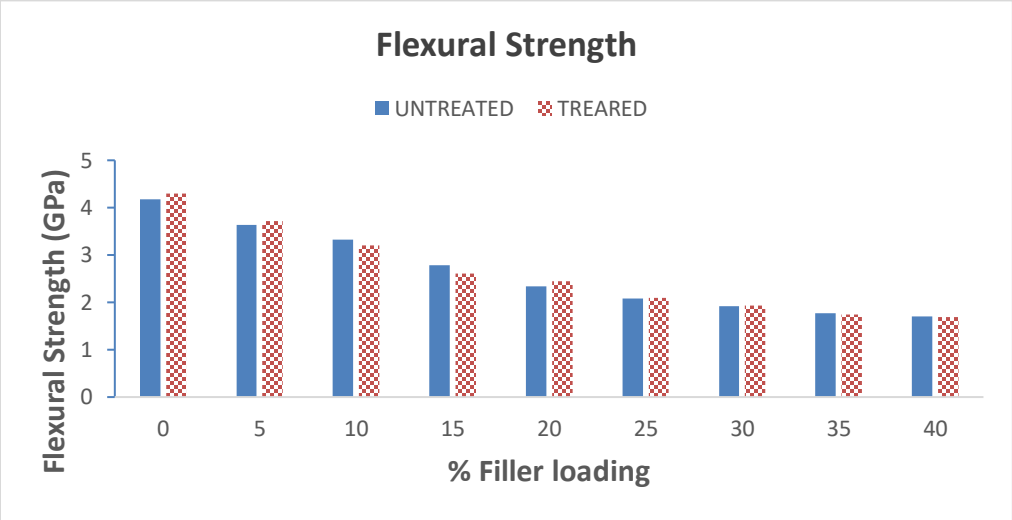

Figure 3.8. Effect of filler loading on the flexural strength of LDPE-rattan composites.

Performance Contrast between Untreated and Treated Composites

The treated composite exhibited greater improvements in mechanical properties compared to the untreated, except for elongation at break, where the untreated composite showed a higher percent decrease. Addition of rattan powder improved properties like Young's modulus and hardness, but other properties decreased as LDPE could not effectively transfer the load between fibres. Treatment likely enhanced matrix adhesion and filler loading, increasing Young's modulus and hardness. Alkaline treatment is known to enhance cellulosic H-bonding OH groups, imparting greater strength through strong intermolecular interactions (Boey et al., 2022).

The relationship between untreated and treated samples' data sets was analyzed using Pearson correlation coefficient (r) in Microsoft Excel. The correlation coefficients for various properties are presented in Table 1. All values of the correlation coefficient (r) are close to 1, indicating a very strong positive linear relationship, meaning that as the properties of untreated composites increase, so do those of treated composites, almost linearly with filler weight.

Table 1: Pearson Correlation coefficient values of the mechanical properties of the untreated and treated rattan - filled LDPE composites

Composite Mechanical Property (Untreated & Treated)	**Pearson Correlation Coefficent (r)**
Tensile strength	0.9982
Flexural strength	0.9942
Elongation at break	0.9893
Young's modulus	0.9971
Impact test	0.9989
Hardness	0.9993

IV. Conclusion

The mechanical properties of both untreated and treated LDPE-rattan filler composites were studied. An increase in filler loading led to reductions in tensile strength, flexural strength, impact strength, and elongation at break for both types of composites. This decline is likely due to weak interfacial bonding between the polymer matrix and rattan filler. However, Young's modulus and hardness increased with higher filler loading, by over 65% and 55% respectively for both untreated and treated composites. Higher filler content also resulted in greater weight loss and water absorption, with the highest weight loss of 6.29% and water absorption of 31.89% observed at 40% filler content.

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Rattan cane (*Calamus longippina*), a natural fiber, can be combined with an LDPE polymer matrix to modify mechanical properties in both untreated and treated forms. Treated composites exhibited superior mechanical properties compared to untreated ones. The strong positive correlation between the datasets suggests that the properties of untreated and treated composites are closely related and increase almost in sync with rising filler weight.

Conflict of interest

The authors do not have any form of conflict of interest in this work.

Acknowledgement

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