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Tensile Properties of Recycled Low-Density Polyethylene Composites with Sawdust and Natural Rubber

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ABSTRACT

The increasing generation of plastic and wood-processing wastes presents environmental and economic challenges, particularly in developing nations. This research explores how the addition of sawdust and natural rubber (NR) influences the tensile properties of composites made from recycled low-density polyethylene (rLDPE). Composite samples were prepared by varying sawdust content (0–50 wt %) and rLDPE content (50–100 wt %) with fixed NR proportions, while stearic acid, sulphur, and zinc oxide served as additives. The composites were processed via two-roll milling and compression moulding. Tensile properties were assessed according to ASTM D-638. Results showed that tensile strength improved in samples with moderate sawdust loading (Samples B and C), reaching a peak of 25.34 MPa in Sample C (20% sawdust, 80% rLDPE, 10% NR), outperforming both controls A (24.34 MPa) and G (20.60 MPa). As the percentage of sawdust was increased in Samples D to F, tensile strength reduced, though elongation was larger than Control A. The sample D having 70 g rLDPE, 30 g sawdust, and 10 g natural rubber exhibited the most favorable rigidity-flexibility balance. The research discloses that a properly calibrated blend of natural rubber and sawdust possesses the capability to enhance tensile performance and allow the fabrication of green composites for thermal insulation.

Keywords: *Recycled polyethylene, sawdust, natural rubber, composites, tensile properties, waste management*

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INTRODUCTION

Plastic and wood-processing wastes are major environmental concerns worldwide (Khan et al., 2021). The most common solid waste experienced in Nigeria are rLDPE, which is mostly derived from rejected sachet water wrappers, and sawdust from forestry sector (Ogunniyi et al., 2021). Open burning and illegal dumping into waste disposal sites greatly enhance environmental pollution, while environmentally friendly reuse and recycling procedures are left untouched (Al-Wabel et al., 2022). By combining polymer bases with natural additives, composite technology provides an eco-friendly alternative. Sawdust is a cheap, renewable material that is locally sourced, while natural rubber adds elasticity and absorptive energy (Bledzki & Gassan, 1999). When the mixtures include the use of waste disposal materials like recycled LDPE as a component, sawdust and natural rubber, the resultant composites become higher-performance materials.

The utilization of natural fillers in polymer composites has been extensively reported. Findings from the study indicate that the addition of natural fillers can greatly enhance the mechanical performance of polymer composites (Hayajneh et al., 2022; Pęśko & Masek, 2025; Senthil et al., 2020). It was reported that hybrid composites containing both rigid and elastic fillers exhibit synergistic effects, improving tensile strength and ductility (Ogunleye et al., 2022). Since it is composed of fibers, the sawdust increases the tensile modulus, though the elongation at break may be lowered by an excess amount (Godard et al., 2009). Conversely, natural rubber increases elongation and toughness but can reduce stiffness if not balanced properly (Nian et al., 2025). It is challenging to balance the filler content to attain good mechanical attributes with efficient processing conditions and environmental viability (Akinlabi et al., 2021).

Experiments conducted on wood fiber composites derived from polyethylene indicate that the best filler content levels enhance tensile strength up to a level beyond which the mechanical properties begin to decline (Khalid et al., 2008). By the incorporation of recyclable polymer materials and lignocellulosic filler materials, there is promising evidence toward the production of low-cost, environmentally friendly composite materials (Ogbomo et al., 2020). There is little evidence on the Nigerian situation regarding the synergistic effect of rLDPE, sawdust, and natural rubber, thus inspiring the research conducted in this present work. This study focuses on evaluating tensile performance to identify optimal formulations for structural and insulation applications.

MATERIALS AND METHODS

Materials

This study uses inexpensive materials from environmental waste:

(i) Recycled Low Density Polyethylene (rLDPE) to serve as the binding matrix
(ii) Sawdust as organic filler
(iii) Natural rubber latex as the extender to increase the wetted surface area
(iv) Additives include sulphur, stearic acid and zinc oxide.

Sample collection and preparation

The locally sourced recycled Low-Density Polyethylene (rLDPE) used was obtained from waste pure water sachets in Samaru town, Sabon Gari Local Government Area of Kaduna State, Nigeria (Figure 1). The sachets were washed properly, sun-dried, and mechanically shredded to obtain 1 mm diameter fibers. Sawdust utilized here was obtained from a sawmill at Okpanam Road, Asaba, Delta State, Nigeria (Figure 2). It was sorted properly to remove adulterants like pieces of metal, stone, shreds of paper, grass, etc. Clean sawdust was spread on a clean surface and sun-dried for seven consecutive days on an average five hours a day to reduce moisture content that may cause complications like low bonding or void formation upon compounding. The powder form upon drying was sifted through a 500 µm sieve to get equal particle size for even distribution within the rLDPE polymer matrix. The Natural rubber latex was sourced from Aviara community located within the Isoko South Local Government Area of Delta State, Nigeria. The latex was allowed to coagulate after which it was dried under the atmosphere for two weeks. Later additives such as stearic acid, sulphur, and zinc oxide were added (Figure 3).

Equipment

Equipment used in this analysis is briefly described in (Table 1).

Compounding

The materials employed include rLDPE, natural rubber, and sawdust (Table 2). A digital balance (Model AE200) was used to weigh the materials accurately. Seven composite samples were formulated with a total weight of about 100g each. The percentage content of the sawdust varied from 0 to 50 wt %, whereas the content of the natural rubber was maintained constant in the materials at 10g. The compositions in full details appear in (Table 2).
The mixture was prepared by using a two-roll mill (Model 5183) at Nigerian Institute of Leather and Science Technology, Zaria, Nigeria. The polymer was initially introduced into the mill whose rolls were rotated counterclockwise for 5 minutes at 170 °C. While maintaining a stable band and bank on the front roll, pre-treated fillers (sawdust and natural rubber) were added slowly in small portions, well-cross-mixed, mixed for an additional 3 minutes to have uniform distribution. The last sheets of the composite were produced and identified accordingly.

Compression moulding

Composite mixture was filled into a 120 mm × 100 mm × 3.2 mm-sized metallic mould and subjected to compression moulding machine for hydraulic hot press (Model 0557) at a temperature of 150 °C and 2.5 MPa pressure for 5 min.

Table 1: Equipment used for this research work.

EQUIPMENT	MANUFACTURER/MODEL NO.	SOURCE
Two-Roll Mill	North Bergen, U.S.A (Model: 5183)	NILEST, Zaria
Compression Moulding Machine	Wenzhou Zhiguang Machine Ltd, China (Model: 0557)	NILEST, Zaria
Universal Material Testing Machine	Norwood Instruments Ltd, (Cat. Nr. 261)	ABU, Zaria
Digital Weighing Balance	Mettler Instruments Ltd (Model no: AE200)	NILEST, Zaria
Plastic Shredder		NILEST, Zaria

Table 2: Composite formulations

Sample	rLDPE (g)	Sawdust (g)	NR (g)	Sulfur (g)	Stearic Acid (g)	ZnO (g)
A	100	-	10	2	2	2
B	90	10	10	2	2	2
C	80	20	10	2	2	2
D	70	30	10	2	2	2
E	60	40	10	2	2	2
F	50	50	10	2	2	2
G	100	-	-	-	-	-

Figure 1: Recycled low density polyethylene **(rLDPE).**

Figure 2: Sawdu

Figure 3: Natural rubber latex

Figure 4: Visual representation of the composite sample formed through the combination of rLDPE, sawdust, natural rubber and other additives.

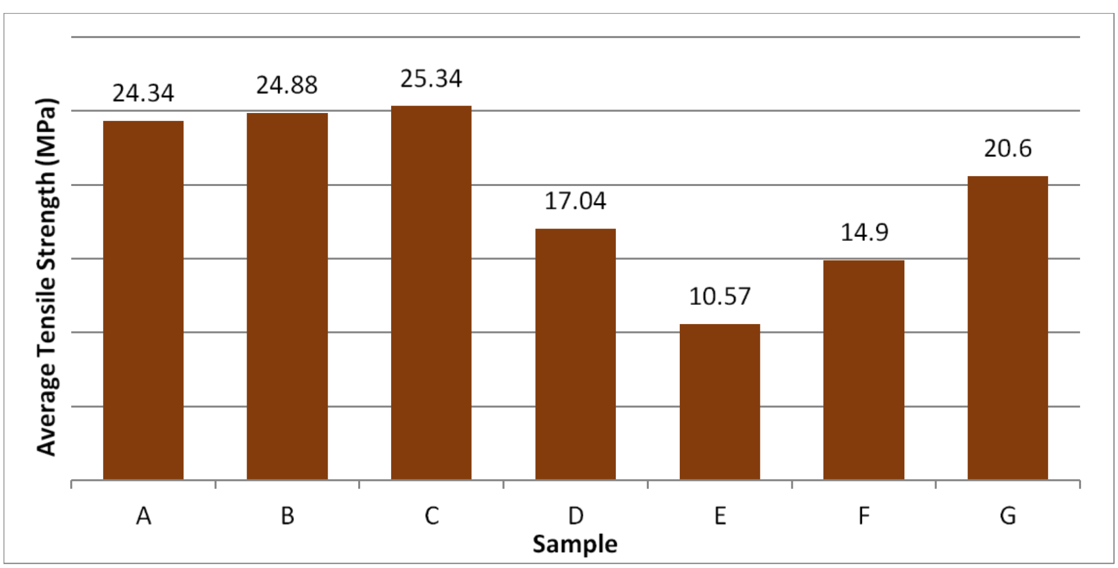

Figure 5: Average tensile strength of rLDPE-sawdust composites.

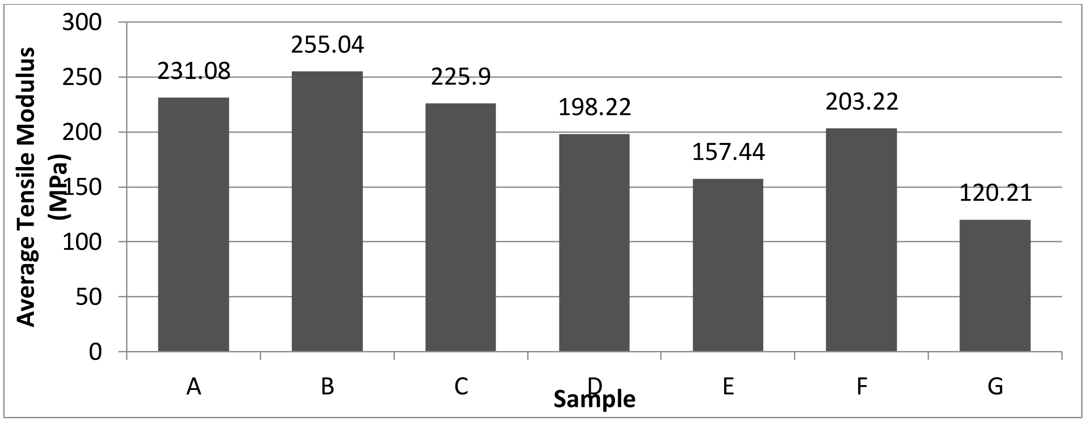

Figure 6: Average tensile modulus of rLDPE-sawdust composites.

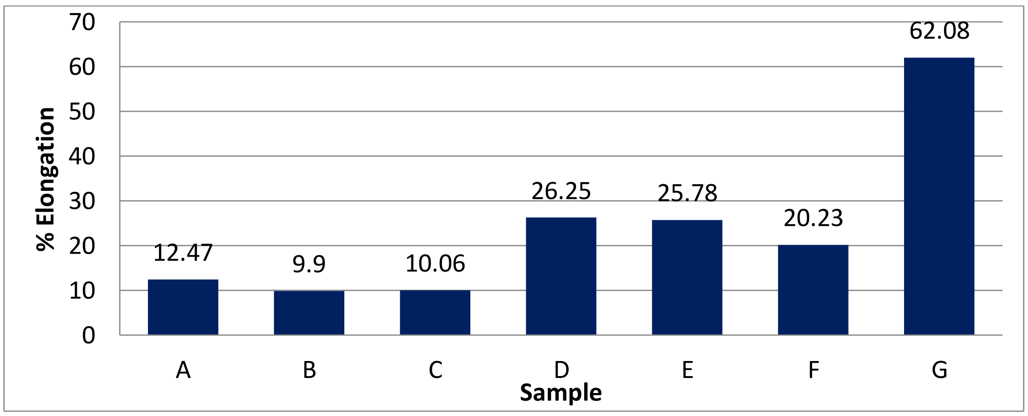

Figure 7: Average elongation at break of rLDPE/sawdust composites.

The samples were cut into the shape of dumbbell under ASTM D638 conditions. The samples were then placed in the cold press plate with the same settings of pressure and maintained for 5 min. After which they were removed and labeled.

Tensile testing

Two trials of tensile test were done using a universal test machine at a crosshead speed of 50 mm/min (ASTM. 2021). The principal mechanical properties such as tensile strength, modulus, and elongation at break were found and the average result of the two tests was used to calculate the individual characteristics of performance of each specimen (Davis, 2004).

RESULTS AND DISCUSSION

The sawdust, natural rubber, and additive-reinforced rLDPE-based composites exhibited typical tensile behavior. The graphical illustration of the composite is shown as (Figure 4). Based on the composition laid out in (Table 2), samples A and G were set to be the “Control” samples of the study. Sample A is composed of 100g rLDPE filled with additives consisting of 10g natural rubber, 2g sulphur, 2g stearic acid, and 2g zinc oxide but without reinforcement material like sawdust. On the other hand, Sample G is composed of 100g rLDPE without any additives or reinforcements. Table 3 shows the result of the tensile test conducted on each of the seven samples.

Tensile strength is the ultimate pulling force a material is able to withstand before rupture (Callister & Rethwisch, 2020). As stated by Davis (2004), plastics and polymers with ultimate tensile values ranging between 10 to 100 MPa should be adequate for normal lightweight or non-demanding structural applications.

In the current research study, control Sample A (rLDPE-based additives) average tensile strength was 24.34 MPa, while that of pure rLDPE control Sample G was 20.60 MPa. As depicted in (Table 3), tensile strength kept increasing for Samples B and C, then decreased for Samples D, E, and F, the former being weakest at 10.57 MPa. Interestingly, the maximum tensile strength was recorded for Sample C (25.34 MPa) whose formulation ratio was 80g rLDPE, 20g sawdust and additives, as depicted in (Figure 5). Tensile modulus or Young's modulus show material stiffness when stretching is applied. Material with a higher value of modulus would be rigid and less deformable, while materials with low modulus would be flexible and deform when load is introduced (Callister & Rethwisch, 2020). Figure 6 indicates that control Sample A (the additive-rich rLDPE) possessed a relatively high tensile modulus of 231.08 MPa, while Sample B with 90g rLDPE and 10g sawdust plus additives had a higher modulus of 255.04 MPa. To provide a point of comparison, Control Sample G (untreated rLDPE) had a much lower modulus of 120.21 MPa.

Elongation is a measure which shows the amount the material is able to deform or stretch before it will fail (rupture). Elongation values which are high refer to ductility, characteristic of polymers and soft metals. Low elongation values refer to brittleness, typical of ceramics and glass (ASTM, 2021**;** Davis, 2004; Callister & Rethwisch, 2020**)**.

As can be seen from (Figure 7), control Sample A (additives containing rLDPE) had an average elongation level of 12.47%, while control Sample G (pure rLDPE) had an elongation level considerably greater than A as 62.08%. However, Sample D consisting 70g rLDPE, 30g sawdust and additives had a comparatively high elongation value of 26.25%.

Conclusion

The introduction of additives improved tensile strength and modulus of control Sample A when compared to the untreated control Sample G. The introduction of the sawdust was beneficial to the mechanical properties by raising the strength as well as the elasticity. Mechanical properties were reduced when the volume content of added sawdust was higher than a threshold value resulting in low interfacial bonding or disruption within the polymer matrix. Control Sample A had good mechanical strength but poor flexibility, while Control Sample G had great flexibility but poor rigidity. Optimum stiffness was exhibited on Sample B, optimum tensile strength on Sample C, and optimum strength-elongation balance on Sample D. Samples E and F, however, had sub-standard performances because there was excess inclusion of sawdust. Samples B and C were the most mechanically efficient, having the highest modulus and tensile strength, a sign of good measures of stress distribution between rLDPE matrix material and reinforcement by the sawdust. Elevated content levels of the sawdust (≥40%) sacrificed strength on the other hand but increased ductility, the former varying depending on functional requirements, e.g., load-carrying capability or flexibility. This current study focuses on the potential of upgrading recycled LDPE through hybrid reinforcement using sawdust and natural rubber. The highest tensile strength value was observed by Sample C (80 g rLDPE, 20 g sawdust, 10 g NR) among the entire set of samples, and the sample with the finest mechanical profile was Sample D (70 g rLDPE, 30 g sawdust, 10 g NR). The findings confirm the potential role of natural fillers towards the development of sustainable polymer composites in the field of engineering.

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