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Durability Performance of Polymer Composite Reinforced with *Ceiba pentandra* Wood Particles

Kehinde Sesan Aina[1], Samuel Oluyinka Olaniran[2], Babajide Charles Falemara[1*], Olayiwola Yetunde Bolarinwa[1], Temitope Olayemi Owolabi[3] and Babatola Olufemi[3]

1 Forestry Research Institute of Nigeria, P.M.B. 5054, Jericho, Ibadan, Oyo State, Nigeria.
2 University of Göttingen, Büsgenweg, Germany.
3 Federal University of Technology, Akure, Ondo State, Nigeria
* Corresponding Author: falemara.bc@frin.gov.ng

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Abstract. The study investigated the effects of *Coptotermes curvignathus* termites on the durability and strength properties of wood plastic composites produced from recycled polythene bags and *Ceiba pentandra* wood particles. The wood particles were proportionately mixed with the polyethylene powder at ratios 40/60, 50/50 and 60/40 (w /w dry basis). The composites were produced using the single screw extruder and compounding method. Some of these composites were exposed to termite attack (*Coptotermes curvignathus*) attack at a timber graveyard. The composite samples, both unexposed and exposed to termite infestation, were subjected to durability and strength assessment tests. The results revealed composite board densities ranging from 781.0 kg/m3 to 810.6 kg/m3. Strength values ranged from 1087.8 N/mm^2 to 4320.0 N/mm^2 for flexural modulus, 43.7 N/mm^2 to 59.1 N/mm^2 for flexural strength, and 18.4 N/mm^2 to 32.6 N/mm^2 for compressive strength. The wood polyethylene composite made at 50/50 ratio had the lowest values for all properties tested both before and after termite exposure. The wood/polyethylene ratio significantly influence the weight, density, flexural modulus and compressive strength of the composites after termite exposure under a tropical climate. This study concluded that wood polyethylene composite (WPC) reinforced with *Ceiba pentandra* particles are highly durable. Specifically, WPC produced at a 40/60 wood/plastic ratio is recommended for structural applications in termite-prone areas, as it met the certified standard values of < 3.52 from SNI 01-7207-2006 and ASTM D3345 for graveyard tests.

Key words: Dimensional stability, Environmental Sustainability, Polymer, Recycling, Strength & testing of materials.

1. Introduction

Plastics are products made from a synthetic polymer with features such as lightweight, strong and economical. This attribute makes plastic an industrial desirable material for the manufacture of many products. As the daily demand continues to increase, production also increases, thus posing greater risk to the environment and nature (Kumar et al., 2022). The impact of plastic waste on the ecosystem has now become a great concern to the environment as it constitutes ecological pollution to land and ocean. Unfortunately, many terrestrial and aquatic animals innocently ingest these plastic particles in micro or macro forms as food. Additionally, burning of these plastic wastes results in emissions of highly toxic gases like dioxins, furans, mercury and polychlorinated biphenyls which are injurious to human health and dangerous to the natural ecosystem (Verma et al., 2016; Li et al., 2016). Researchers have worked on the conversion of plastic waste to various polymer composites for different applications (Rahman et al., 2013) by converting it to an environmentally friendly material. Wood in polymer composite is known as wood plastic composites (WPCs) which are widely used as structural products in many construction applications; for example, decoration, roofing, furniture and home decoration.

WPCs are currently and tremendously being used in exterior buildings and other forms of applications including residential construction, decking, flooring, doors, railings, fencing, roofing and siding (Gardner et al., 2015). WPCs exhibited greater durability, less maintenance, and improved water absorption and fungal resistance when compared to timber (Clemons, 2002). Slaughter (2004) also revealed that WPC materials exhibit improved durability with respect to checking, decay, termites, and marine organisms compared to timber. There is growing interest in the manufacture of WPCs in countries like Europe, Japan, Taiwan and North America, especially for architectural reasons, while developing countries pay less attention to the development of this product (Kuo et al., 2009; Ticky, 2004). Many wood users are mostly concerned about the durability of their products to resist biotic agents (microbes, insects and associated enzymes) found within their region. Termite insects known to be ecosystem engineers attack lignocellulosic and non-cellulose materials such as plastic in search of food (Kumar et al., 2020; 2022). It was reported that various microbial populations inhabiting the gut of termites help degrade the plastic polymer (Lopez-Naranjo et al., 2013; Yang et al., 2014). Other studies have also revealed that termites have the potential to degrade plastic polymers and wood plastic composites via their mandibles (Yu et al., 2015; Ahmed et al., 2018; Kumar et al., 2022).

In Nigeria, plastic waste has become a critical environmental nuisance that requires urgent attention. Wood as a natural lignocellulosic fibre forms a major constituent in WPCs that makes it susceptible to termite attack (Tascioglu et al., 2013). Studies have shown that the introduction of polymers to wood can improve durability in terms of dimensional stability, water repellency, decay/biodeterioration resistance and acid resistance compared with non-polymerized wood (Li et al., 2016). Arrays of previous studies have demonstrated that wood found in many WPCs remains susceptible to biodegradation (Morrell et al., 2010; Fabiyi and McDonald, 2010; Schauwecker et al., 2006). Gardner and Bozo (2018) recorded that wood and plastic formulation in WPC has a significant impact on termite resistivity. Termite species (*Coptotermes acinaciformis* and *Mastotermes darwiniensis*) in Australia were found to damage plastic samples far more than any other species (Lenz et al., 2011; Thamil, 2016). Studies also show that type of polymers, polymer loadings and type of wood species used for WPCs may resist subterranean termite (*Coptotermes curvignathus*) attack than untreated wood (Nuryawan et al., 2020; Gardner and Bozo, 2018; Hadi et al., 2019).

While research on the durability of wood-plastic composites (WPCs) against biotic agents in temperate soils has progressed, limited information is available on the durability of WPCs exposed to termites in tropical soils. *Ceiba pentandra* was selected for this study because research has shown that it is one of the most vulnerable tropical wood species to termite attack when in soil contact. This is attributed to its low durability and susceptibility to biotic agents such as insects and fungi. These knowledge gaps necessitated this research study, which aims to investigate the durability and mechanical properties of WPCs exposed to subterranean termites through field tests.

2. Materials and Methods

2.1. Collection and preparation of materials

Ceiba pentandra wood was used for this study. This species has a density range of 240–380 kg/m^3 at 12% moisture content (Reyes et al., 1992; Falemara et al., 2012), a modulus of rupture between 26–61 N/mm^2, and a modulus of elasticity ranging from 2300–5600 N/mm^2. Additional properties include compression parallel to grain of 14–26 N/mm^2, shear strength of 2–4 N/mm^2, cleavage of 4–13 N/mm, Janka side hardness of 1060–1110 N, and Janka end hardness of 1820–1960 N (Duvall, 2011). The particles of *Ceiba pentandra* employed for this study were collected from the Sawmill section during logs conversion at the Department of Forest Products Development and Utilization, in Forestry Research Institute of Nigeria (FRIN), Ibadan, Oyo State, Nigeria. The *Ceiba pentandra* particles were thoroughly screened using a sieve mesh of size 1.00

mm to obtain fine wood powder. Discarded low-density polyethylene (LPDE) satchet bags of density range of 915–940 kg/m^3, melting temp of 105–115 °C, and melting index rate (g/10 min) of 0.1–150 (Egbuhuzor et al., 2022) were collected from waste dumping site of DFRIN water processing and packaging factory at FRIN, Headquarters, Ibadan in Nigeria. Low-density The recycled low density polyethylene (rLPDE) satchet bags were thoroughly washed, dried, shredded and milled into plastic particles using an agglomerator at 85 ^{0}C and screened with wire mesh of size 1.00 mm to obtain fine plastic powder.

2.2. Production of experimental WPC samples

The *Ceiba pentandra* wood particles were oven-dried at 103±2 °C for 24 hours to reduce moisture content, while the low density polyethylene packaged bags were washed, and oven-dried at 45 0C for 48 hours to remove moisture before milling into powder. The polyethylene powder was proportionately mixed with the wood particles at ratios 40/60, 50/50 and 60/40 (wood/polyethelene) and fed into the single screw extruder at a controlled temperature of 95 ± 5 ^{0}C. The blended molten mix after compounding into a ribbon, was ejected into a rectangular mould (6 x 6 x 12 cm^3) and compressed in a hydraulic cold press (20 tons) for 20 mins to solidify. Specimens were dimensioned into specific sizes in accordance with ASTM D790 and ASTM D 638 standards for the determination of flexural properties.

2.3. Timber Graveyard Field test

Test specimens were exposed to the subterranean termite species *Coptotermes curvignathus*, as identified by a forest entomologist in the field. The specimens were buried horizontally in the soil to minimize direct sunlight exposure. The field exposure test was conducted at the experimental timber graveyard of the Federal University of Technology, Akure, Ondo State, Nigeria. The site has an average monthly rainfall of 300–500 mm, a daily relative humidity of 84%, and a monthly temperature range of 26–35 °C. The WPC specimens remained buried for 12 weeks. After this period, the exposed specimens were exhumed, cleaned of soil debris, and oven-dried at 60 °C for 24 hours before morphological and visual assessments (Plates 1 to 2). The resistance of the WPCs to termites was classified according to the Indonesian SNI 01-7207, (2006) and ASTM D3345, (2008) standards for graveyard tests (Tables 1 and 2). Table 1 shows how materials are graded and classified for termite resistance during field exposure. The weight of each sample before and after termite exposure was calculated using Equation 1, and the resulting values are recorded in Table 2. These values were compared with the standard values in Table 1 to classify WPC termite resistance. Microstructural fracture examination of the WPC samples before and after exposure was conducted using a scanning electron microscope (SEM), along with visual observations of the WPC samples before and after field exposure to termite attack.

Table 1. Classification of the resistance class to termite activities

Class	Weight loss (%)	Category of resistance	Scale	Rating
I	< 3.52	Very durable	Surface nibbles permitted	10
II	3.52 - 7.50	Durable	Light attack	9
III	7.50 – 10.96	Moderate	Moderate attack, penetration	7
IV	10.96 – 18.94	Poor	Heavy	4
V	18.94 – 31.89	Very poor	Failure	0
Source	SNI 01–7207 (2006)		ASTM, D3345	

Table 2. Resistance of WPCs to termite attack at timber graveyard

Mixing Ratio (Wood Polyethylene)	Mean weight loss (%)	Class of resistance	Rating/Scale
40/60	2.89	Very durable	10-Surface nibble
50/50	3.73	Durable	9- light attack
60/40	5.91	Durable	9- light attack

Plate 1: WPCs samples buried in Timber graveyard

(a) **(b)**

Plate 2: WPCs samples (a) before and (b) after exposure to timber graveyard

2.4. Properties Determination

2.4.1. Weight and density

The weight loss of the test sample before and after field exposure were determined according to equation 1, while the density of the samples was determined in accordance with ASTM D 638-90 as shown in equation 2:

$$Weight\ loss\ (\%) = \frac{W_1 - W_2}{W_1} x\ 100 \qquad \text{Eq 1}$$

Where W_1 = Oven-dried weight of the sample before the field exposure test (g) and W_2 = Oven-dried weight of sample after the field exposure test (g).

$$Density\ (g/cm^3) = \frac{W_a}{V_a} \qquad \text{Eq 2}$$

Where W_a = Air Dried weight (g); and V_a = Air dried volume (cm^3)

2.4.2. Mechanical tests

The flexural strength properties were carried out in accordance with ASTM, D790 using universal testing machines (UTM), model WDW 5000 with a load of 50KN, a span of 100 mm and a speed of 2.8 mm/min for three-point bending flexural tests. Each specimen was supported with two rollers at each end and force exerted at the centre. At the point of failure, the force exerted on the specimen was recorded to determine the strength and modulus of each specimen before and after termite field exposure.

2.4.3. Morphological analysis

The fracture surface of the WPC produced was examined using Scanning Electron Microscopy model JEOL JSM-7600F operated at 15 kV. The samples were sputter-coated with gold-palladium and observed at different magnifications under the SEM.

2.5. Experimental design

The study was laid out in a 2 by 3 factorial experiments in Completely Randomized Design, replicated five times. Samples were subjected to two factors (exposed and unexposed) while the WPC samples were produced at three mixing ratios 40/60, 50/50 and 60/40 (wood/polyethelene). The data obtained were subjected to a two-way analysis of variance (ANOVA) and further to the Duncan Multiple Ranged Test (DMRT) to determine the levels of significance among and between the variables.

3. Results and discussion

3.1. Effect of Termite attack on density and weight loss of WPCs

The mean density values for unexposed WPCs ranged from 781.03 g/cm^3 to 1872.11 g/cm^3 (Table 3). Variations exist in the mean density values of unexposed and exposed WPCs across the different wood/polythene production ratios. The densities for unexposed WPCs were 1872.1 g/cm^3, 967.36 g/cm^3, and 983.11 g/cm^3 for the 40/60, 50/50, and 60/40 (wood/polythene) ratios, respectively, aligning with previous findings (Shakouri et al., 2009; H'ng, 2011). However, after exposure to *Coptotermes curvignathus* termites, the densities decreased across the mixing ratios with decreasing polyethylene content (Table 3). Figures 1 and 3 clearly illustrate these density variations among exposed WPC samples, with a noticeable density reduction across all ratios following termite attack (Figure 1, Table 3). Densities decreased as wood content in the composite increased from 40% to 60%, with a particularly high variation at 60% wood content when compared with composites containing 50% and 40% wood. Wood content significantly influences composite strength and serves as a food source for termites. Figure 3 highlights the percentage change in WPC density before and after termite exposure, showing a decrease of 3.39% for WPCs with 40% wood content, an increase to 6.72% at 50% wood content, and a further increase to 25.87% at 60% wood content. This indicates that WPCs with 60% wood content experienced a significantly higher density change than those with lower wood content when exposed to termite attack.

The weight loss of the composites generally ranged from 4.79 g to 7.34 g (Table 3). For the unexposed composites, the measured weights were 6.51 g, 5.09 g, and 7.34 g at 40:60, 50:50, and 60:40 (wood/plastic) mixing ratio, respectively. Similarly, the weight of WPCs exposed to termites varied according to the material ratios, with values of 5.87 g, 4.79 g, and 7.02 g for the 40:60, 50:50, and 60:40 mixing ratios (Table 3). A similar parabolic pattern was observed for both unexposed and exposed WPCs (Figure 2), with significant variation at the 40/60 proportion (Figure 3). The study results revealed a mean weight loss of 2.89 % at 40% wood content, 3.73% at 50%, and an increased weight loss of 5.91% at 60% wood content. The greater weight loss at the 60/40 wood/plastic ratio suggests that WPCs with higher wood content are more prone to termite infestation and consequent mass loss. This can be attributed to the hydrophilic nature of wood, which absorbs and desorbs moisture, causing dimensional instability. In contrast, plastic is hydrophobic and does not absorb water; thus, at lower wood and higher plastic proportions (40/60), more plastic encapsulates the wood particles, limiting water absorption and hindering termites' activities.

The analysis of variance (ANOVA) indicated a significant difference in the density and weight of the WPCs produced (5% level of probability) across the mixing ratios. Composites with a 60/40 wood/plastic ratio showed the highest percentage weight loss, followed by 40/60 and 50/50 ratios (Tables 2, 4). Consistent with findings by Yu et al. (2015), Oladejo and Omoniyi (2019), and Nuryawan et al. (2020), density decreases in unexposed composites with higher wood content (60/40) compared to those with lower wood content (40/60). However, this result contrasts with Migneault et al. (2008), Flores-Hernández et al. (2017), and Bhaskar et al. (2020), who reported an increase in WPC density with higher wood content. This discrepancy may be due to the higher density of the LPDE (915–940 kg/m^3) compared to *Ceiba pentandra* wood with density range of 230–398.47 kg/m^3 (Egbuhuzor et al., 2022; Reyes et al., 1992; Falemara et al., 2012).

After termite exposure, a similar density decrease was observed with increased wood content and reduced plastic content (Table 3). This can be attributed to the higher wood ratio, which provides more material for termites, resulting in greater mass loss and lower density. Higher density in 40/60 composites after exposure is likely due to better adhesion and encapsulation between wood particles and plastic, which reduces termite activity. Lower density in higher wood-content composites can be explained by weak adhesion between wood and plastic, leading to cracks and voids (Zimmermann et al., 2014), which increase termite access (Yu et al., 2015; Gardner and Bozo, 2018; Delviawan et al., 2019). According to Martinez-Lopez et al. (2020), the encapsulation of wood particles by plastic in thermoplastics plays a critical role in enhancing its physical and mechanical properties.

Table 3. Mean values obtained for WPCs before and after termitarium exposure

Mixing Ratio (Wood Polyethylene)	Density (g/cm^3)		Weight (g)	
	Unexposed	**Exposed**	**Unexposed**	**Exposed**
40/60	1872.11±74.41	1810.60±44.96	6.51±079	5.87±0.55
50/50	967.36±11.79	906.41± 20.14	5.09±1.04	4.79±0.90
60/40	983.11±38.44	781.03±22.48	7.34±0.13	7.02±0.41

Each value represents mean of 5 replicates

Table 4. Duncan multiple range test (DMRT) separation of mixing ratio and termite activities

Variables	Levels	Density (g/cm^3)	Weight (g)
Mixing ratio (Wood/Polyethylene)	50/50	882.08^c	4.94^a
	40/60	936.89^b	6.18^b
	60/40	1341.36^a	7.02^c
Termite	Unexposed	1274.20^a	6.31^a
	Exposed	832.69^b	5.78^b

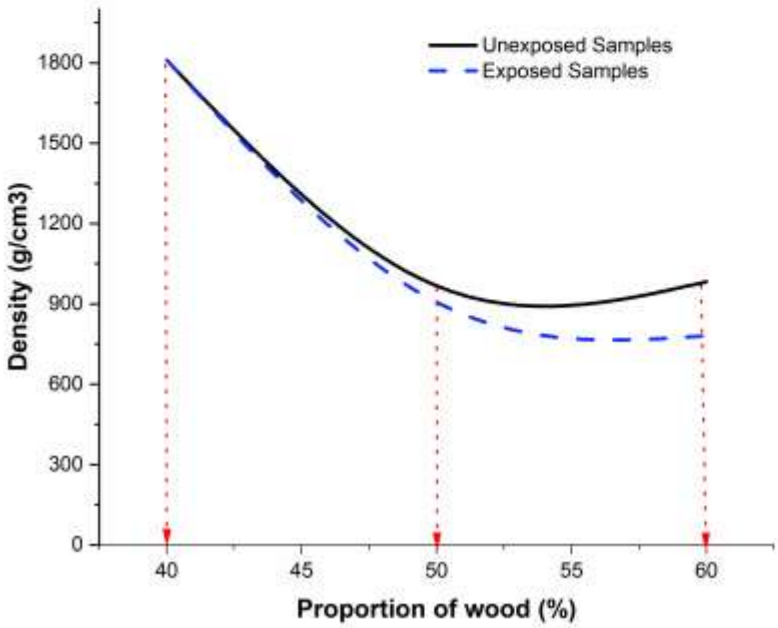


Fig 1. Density of exposed and unexposed WPCs

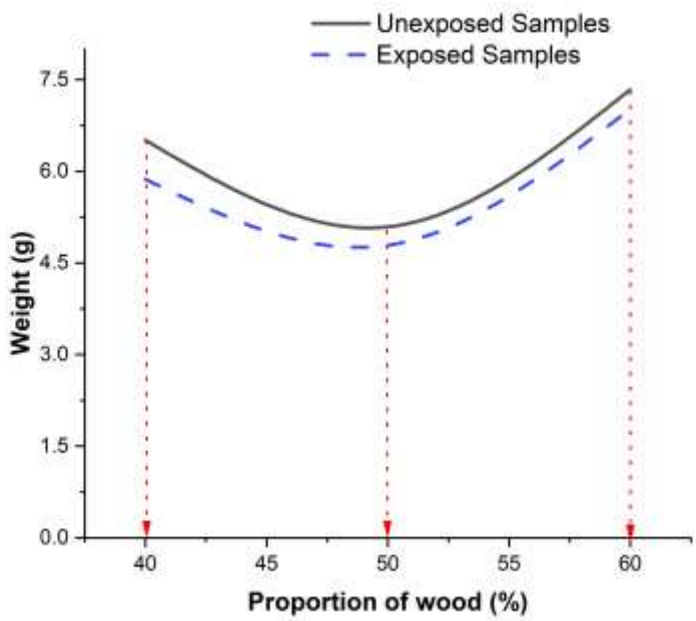


Fig 2. Weight of exposed and unexposed WPCs

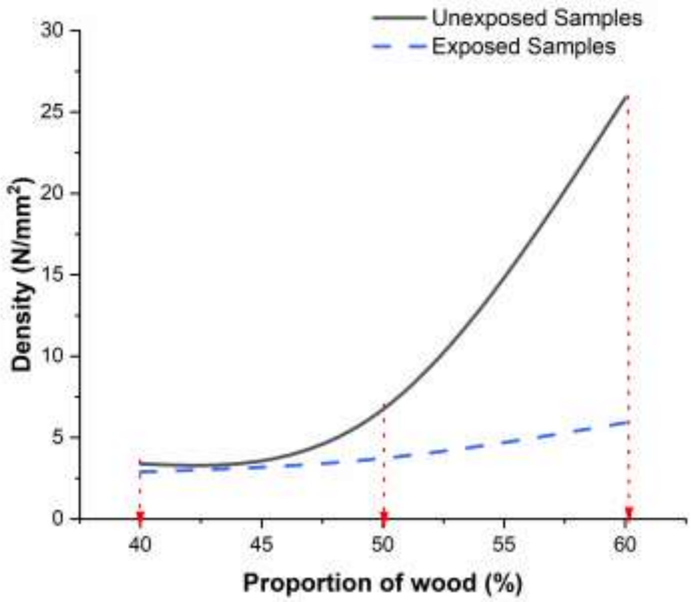


Fig 3. Changes (%) in density between unexposed and termite exposed WPCs

3.2. Effect of termite attack on mechanical properties of WPCs

The flexural modulus (MOE) of the WPCs is detailed in Tables 5 and 6. WPCs produced at the 60/40 wood/polyethylene mixing ratio exhibited the highest flexural modulus among unexposed composites, while the 40/60 composite mix showed the highest flexural modulus among the exposed samples (Figure 4). Statistical analysis (Table 5) further revealed that the flexural modulus of composites produced at the 60/40 wood/polyethylene mixing ratio (3597.37 N/mm^2) is significantly ($p<0.05$) different from and higher than those of 40/60 (3028.37 N/mm^2) and 50/50 (1246.23 N/mm^2) mixing ratios. The variations in flexural modulus, though higher than values obtained in previous studies (Atuanya et al., 2014; Gulitah and Liew, 2019; Nuryawan et al., 2020) were attributed to the mismatch between the hydrophobic low-density polyethylene and the hydrophilic *Ceiba pentandra* wood species particles (Gao et al., 2018; Gulitah and Liew, 2019; Nuryawan et al., 2020). This disparity could result in poor interfacial adhesion between the plastic and wood components, resulting in the variation in the overall flexural modulus properties. The high glutinous nature of recycled polyethylene during WPCs formation, combined with the polarity of the wood particles intended to bind them together, may have led to a lack of uniform distribution of the wood particles. Rather than being uniformly dispersed within the plastic matrix, the wood particles tend to cluster randomly, resulting in poor uniformity of the wood plastic composites (Atuanya et al., 2014; Gulitah and Liew, 2019), particularly at higher plastic content of 50/50 and 40/60 wood/polyethylene mixing ratio, without the addition of a coupling agent or compatibilizer (Gulitah and Liew, 2019).

As shown in Table 5, the flexural strength (MOR) of the WPCs was highest in composites produced at the 40/60 wood/polyethylene mixing ratio, for both unexposed and exposed samples subjected to termite activity (Figure 5). Statistical analysis (Table 5) indicated that the flexural strength of composites produced at the 60/40 wood/polyethylene ratio (54.07 N/mm^2) is significantly ($p<0.05$) different from and higher than flexural strength of composites produced at the 40/60 (50.09 N/mm^2) and 50/50 (44.24 N/mm^2) mixing ratios. The variation in flexural modulus of the composites with change in wood content is consistent with the report of Gulitah and Liew (2019). They noted that addition of wood filler up to 10% did not make any significant effect on the composites, whereas, a significant weak change was observed in MOR when wood filler was increased to 15%. This was attributed to the heterogenous nature and incompatibility between the wood particle and polyethylene matrix materials resulting in non-uniform distribution of the wood filler in the polyethylene composite mix such that stress was not evenly transferred and distributed across the WPC system. During the mixing process, even dispersion prevents wood particles from clustering into large assemblies, which would otherwise have hindered efficient stress transfer to the recycled plastic matrix (Rahman et al., 2013; Gulitah and Liew, 2019; Borysiuk et al., 2020; Nuryawan et al., 2020).

Similarly, the compression strength of the WPCs (Table 5) was highest in composites produced at the 40/60 wood/polyethylene mixing ratio, for both unexposed and termite exposed samples (Figure 6). Statistical analysis (Table 6) showed that the compression strength of WPCs produced at the 60/40 wood/polyethylene ratio (39.67 N/mm^2) had the highest significant effect ($p<0.05$), followed by composites produced at 40/60 wood/polyethylene mixing ratio (35.49 N/mm^2), while the 50/50 wood/polyethylene mixing ratio (18.96 N/mm^2) had the lowest significant effect on the compression strength. The reduced flexural modulus, flexural strength and compression strength at higher polyethylene content could be explained by the lower elastic properties of the polyethylene in the matrix compared to the wood filler (Seachtling and Woebcken, 1995; Falk, 1999; Sellers, 2000). The observed decrease in flexural modulus, flexural strength and compression strength with decrease in wood content aligns with the findings of Stark and Berger (1997), Błędzki and Faruk (2004) and Cui *et al.* (2008). The strength values obtained in this study were higher than the values obtained in the study of Aina et al. (2017) on *Ceiba pentandra* composite but in consonance with the values reported by Guidigo et al. (2017).

In general, the flexural modulus of unexposed composites was significantly higher than that of termite exposed WPCs, a pattern similarly observed in the flexural and compression strengths of the WPCs produced (Table 6). WPCs produced at 40/60 (wood/polyethylene) had the least significant variation of 0.3 % (Figure 7) after termitarium exposure. This could be attributed to absorption of moisture in the composite and considerable activities of termites when the WPCs were buried underground. According to Turku et al. (2018), moisture absorption weakens the interfacial bonding within the composite, diminishing stress transfer and thereby reducing its strength properties. The hydrophilic nature of wood causes it to absorb water, resulting in swelling, which induces stress in the matrix and leads to the formation of microcracks. These microcracks further promote water penetration into the composite upon subsequent exposure. The impact of water is typically irreversible, with the material's properties remaining compromised even after drying.

Increase in the wood content from 50% to 60% resulted in increased gradual variation of flexural modulus (%) between 29.2% and 45.7% after termitarium exposure (Figure 7). Similar trend was observed for flexural strength and compression properties of the unexposed and exposed WPC (Figures 5, 6 and 7) such that least significant variation values of (2.6 %, 5.6 %) and (7.3 %, 7.6 %) were obtained when the wood content increased from 50 % and 60 % in the composition (Figure 6). At 50% wood, the mixture shows the lowest strength due to the very poor interfacial adhesion between the wood and the polyethylene (without compatibilizing agent). At lower wood content (40%), the strength is better since polyethylene is dominant and creates a continuous phase. At higher wood content (60%), the strength is better, since the wood particles mainly are in contact with each other. This occurrence can be attributed to the much wood particle pull out of the matrix, thus creating access to termites and other environmental factors including soil moisture, relative humidity and temperature (Gulitah and Liew, 2019; Gardner and Bozo 2018; Yu et al., 2015).

On the other hand, high significant variations (17.4 % and 21.0 %) were observed between unexposed and exposed WPC at 40/60 (wood/plastic) for flexural strength and compressive strength respectively (Figure 7). This confirms the assertion that termites attack WPCs when in contact with the soil as corroborated by similar studies (Lopez et al., 2020; Nuryawan et al., 2020; Kumar et al., 2022). Appearance of cracks and voids on WPCs surface have been reported to create an avenue for termite activities in WPCs thus affecting the physical and strength properties of the composites (Kumar et al., 2022; Yang et al., 2021; Lopez-Naranjo et al., 2013; Stephan and Plarre, 2008).

Table 5. Mean values obtained for WPCs before and after termitarium exposure

Mixing Ratio (Wood Polyethylene)	Flexural modulus -MOE (N/mm²)		Flexural strength -MOR (N/mm²)		Compression (N/mm²)	
	Unexposed	Exposed	Unexposed	Exposed	Unexposed	Exposed
40/60	3033.57±226.40	3023.22±402.55	59.14±2.46	49.00±3.15	38.21±4.17	32.55±2.79
50/50	1404.91±245.31	1087.76±310.66	44.8±1.82	43.68±2.45	19.49±0.27	18.43±1.28
60/40	4320.02±738.93	2964.70±223.50	51.8±2.02	48.38±7.12	41.12±9.88	38.21±2.35

Each value represents mean of 5 replicates

Table 6. Duncan multiple range test (DMRT) separation of mixing ratio and termite activities

Variables	Levels	MOE (N/mm²)	MOR (N/mm²)	Compressive (N/mm²)
Mixing ratio (Wood/Polyethylene)	50/50	1246.23ᶜ	44.24ᶜ	18.96ᶜ
	40/60	3028.39ᵇ	50.09ᵇ	35.49ᵇ
	60/40	3597.37ᵃ	54.07ᵃ	39.67ᵃ
Termite	Unexposed	2886.05ᵃ	50.40ᵃ	32.04ᵃ
	Exposed	2361.95ᵇ	48.53ᵃ	30.70ᵃ

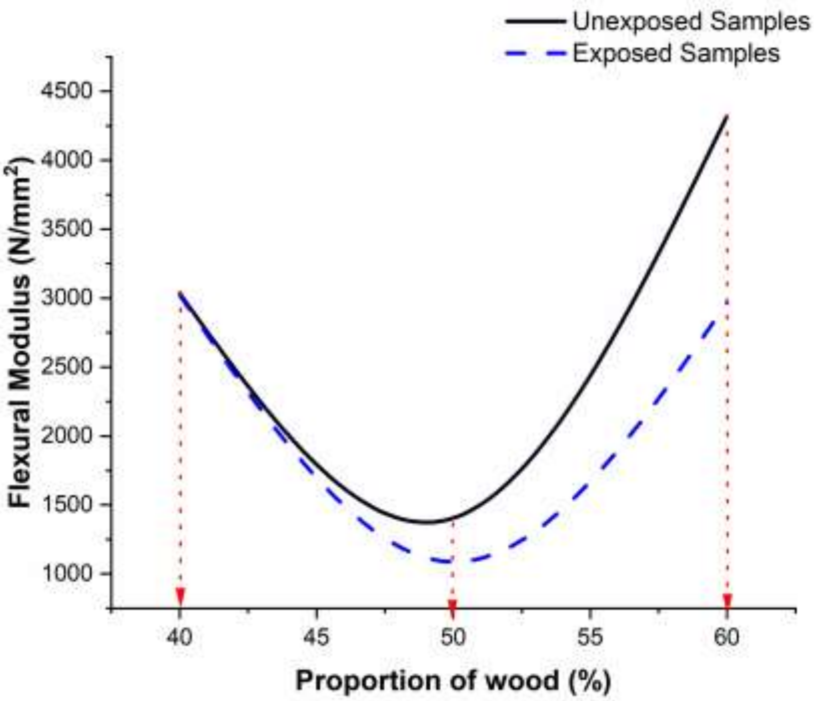


Fig 4. Changes in flexural modulus of unexposed and termite exposed WPCs

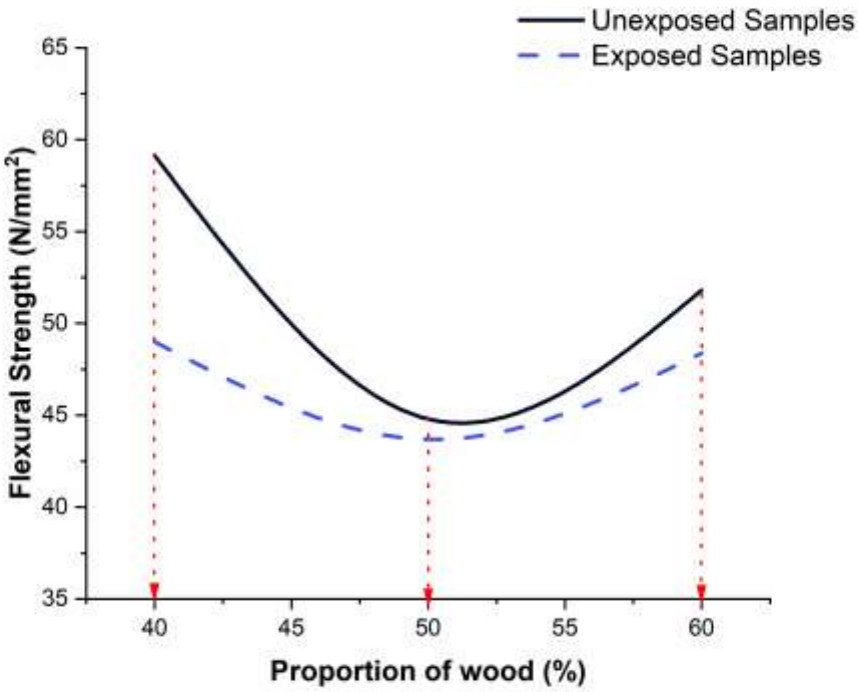


Fig 5. Changes in flexural strength of unexposed and termite exposed WPCs

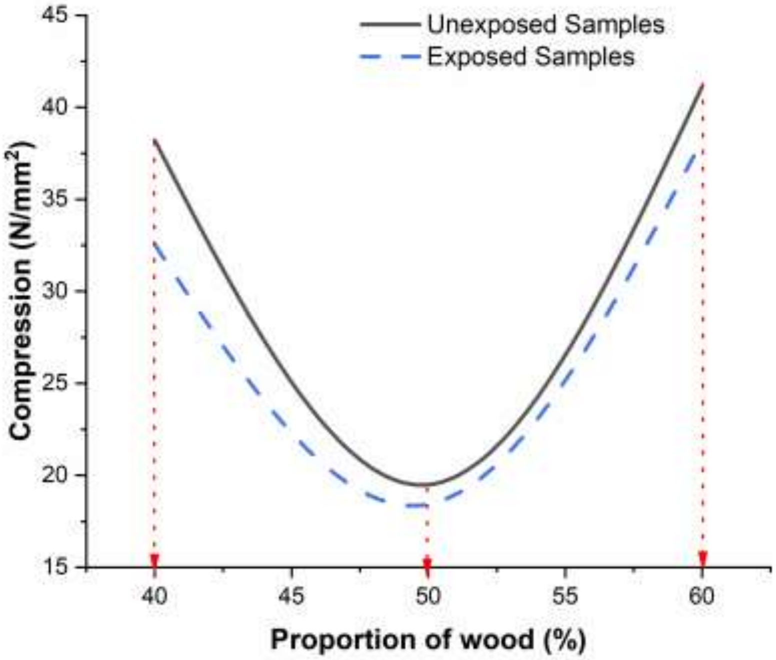


Fig 6. Changes in compression strength of unexposed and termite exposed WPCs

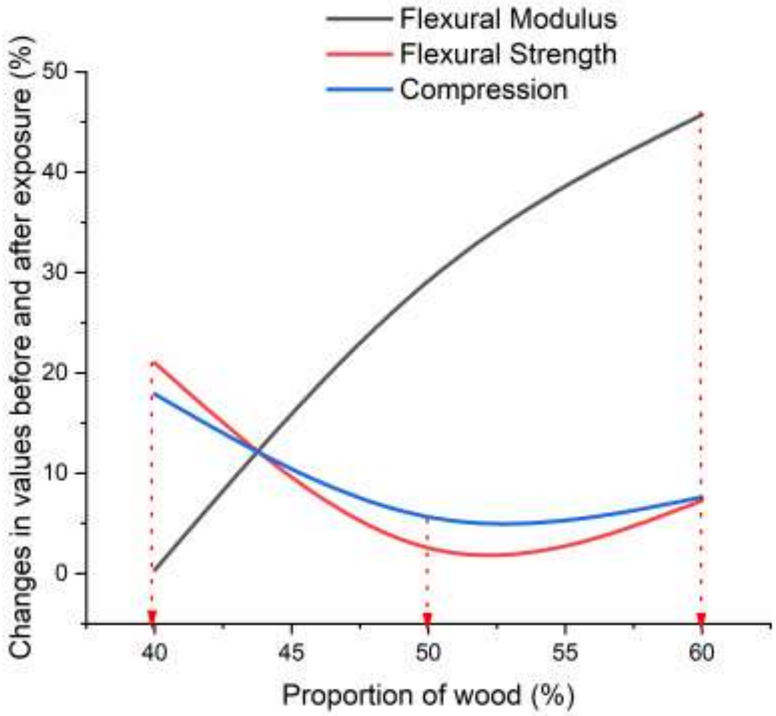
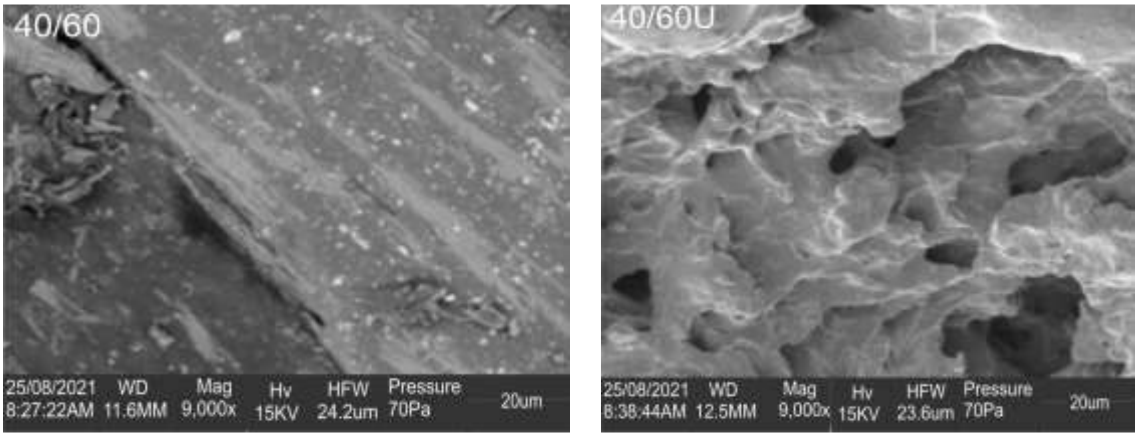


Fig 7. Changes (%) in strength properties between unexposed and termite exposed WPCs

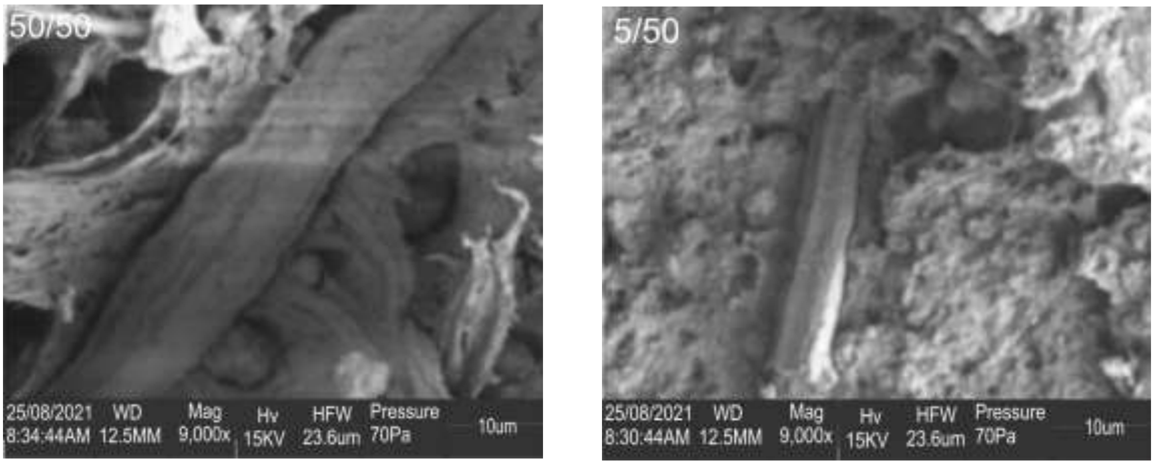
3.3. Morphological properties

An inevitable formation of porosities and voids were observed in the micrograph structures of the WPCs (Figures 8-10). Numerous presences of void were observed in WPC made at 60/40 mixing proportion (Figure 8) with lower plastic content. This could be explained by the fact that some of the wood fillers were not completely covered by the polyethylene matrix (Gulitah and Liew, 2018; Petchwattana, 2018; Gulitah and Liew, 2019). This consequently resulted in weak interfacial adhesion between the wood particle filler and the polyethylene material. The imperfect adhesion between the wood component and polymeric matrix led to the existence of pores that might have weakened the stress concentration resulting in decreased density and flexural modulus after exposed to termitarium. WPC at 60/40 had the highest percentage decrease of 45.72% (Figure 3) and 25.87% (Figure 7) for flexural modulus and density after exposed to termitarium. The differences in the density and flexural modulus of exposed WPC at 60/40 clearly showcased the activities of termite attack on the WPCs. As observed in the micrographs, the porous structures of WPC at 40/60 (Figure 10) collapsed more than 50/50 (Figure 9), resulting in well compacted and stronger composites. The weight loss (2.89%) observed for WPCs produced at 40/60 (wood/plastic) mixing proportion falls within the very standard durable class (Tables 1 and 2). The lightening changed in colour of the WPCs from brown to lightened gray after field exposure could be attributed to weathering factors including relative humidity (RH) in the soil and lignin degradation of wood filler from the WPC (Chen et al., 2016; Aydemir et al., 2019).



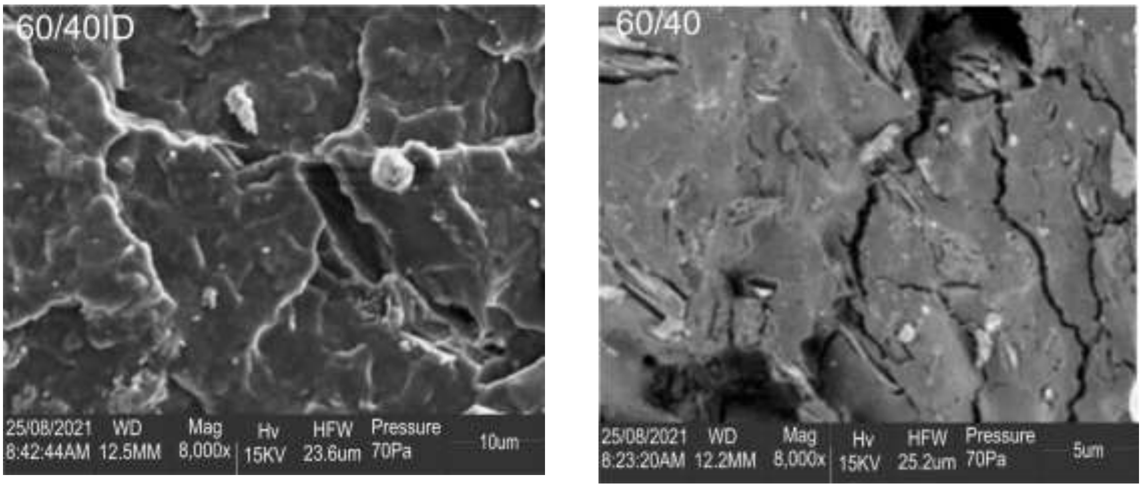
(a) **(b)**

Fig 8. Micrographs of 40/60 WPCs (a) exposed (b) unexposed



(a) **(b)**

Fig 9. Micrographs of 50/50 WPCs (a) exposed (b) unexposed



(a) **(b)**

Fig 10. Micrographs of 60/40 WPCs (a) exposed (b) unexposed

4. Conclusions

The investigation of the durability performance of polymer composite reinforced with *Ceiba pentandra* wood particles revealed the following submissions;

- Proportional ratio of (wood/polyethylene) significantly affects all the properties in terms of density, weight, flexural modulus, flexural strength, and compression strength.
- The density and weight slightly decreased by 3.39 % and 2.89 % after termitarium exposure.
- Based on weight loss values WPC products can be classified as very durable for the ratio of 40/60 and durable for 60/40 and 50/50 (wood/plastic).
- *Coptotermes curvignathus* termite attacks have effects on the weight, density and flexural modulus of WPC
- WPCs at a ratio of 60/40 decreases more than others in flexural modulus and density after termitarium exposure.
- The WPCs at 40/60 mixing ratio is more dimensionally stable than composites produced at 50/50 wood/polyethylene mixing ratio
- The scanning electron microscopy indicated the presence of voids as the polyethylene content of the matrix decreased.

Based on the above conclusions, it is recommended that WPCs produced at lower wood content and higher polyethylene content (40/60) can be adopted for structural applications.

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