Coptotermes curvignathus effect on durability, flexural and compression strength of recycled polyethylene composites reinforced with Ceiba pentandra fibres

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Abstract

Polyethylene composites reinforced with wood dust from *Ceiba pentandra* were produced at one proportional variable of wood to polymer ratio. The polymers employed for the study were derived from recycled polyethylene embalmed dihydrogene monoxide bags. Derived homogenous particlesize of 1.00 mm of *w*ood and polyethylene particles were used for production at ascending varying percentage of 40, 50, and 60 for wood and at descending varying percentages of 60, 50, and 40 for polyethylene. The effects of *Coptotermes curvignathus* attack on weight and mechanical properties of wood polyethylene composites were investigated while the extent of damages was examined. The properties which include weight, density, flexural modulus, flexural strength, compressive strength were determined before and after field exposure. The percentage weight changes were also determined after 12 weeks of graveyard field exposure. The mechanical values obtained before and after termite attacks ranged from 781.03 Kg/cm^3 to 810.60 Kg/cm^3 for density, 1087.76 Nmm^{-2} to 4320.02 Nmm^{-2} for flexural modulus, 43.68 Nmm^{-2} to 59.14 Nmm^{-2} for flexural strength and 18.43 Nmm^{-2} to 32.55 Nmm^{-2} for compressive strength. The density of the wood polyethylene composites was found to be at peak values when the wood content was at 40% while polyethylene content was at 60%. The wood polyethylene composites made at equal percentage of 50/50 was found to be at lowest values for all properties accessed both before and after termite exposures. The proportional percentage of wood/ polyethylene significantly affects the outcome of weight, density, flexural modulus and compressive strength of the composites after exposure to graveyard under tropical climate. This study revealed that the WPC products can be classified as very durable and durable while WPC at proportional ratio of 40/60 can be adopted for house application in Nigeria.

Introduction

Plastics are products made from synthetic polymer with features such as light weight, strong and cheap. This attributes make plastic an industrial desirable material for manufacture of many products. As the daily demand continues to increase, the production also increases; this development has posed a greater risk to the environment and nature (Kumar et al., 2022). The impact of plastic wastes to ecosystem has now become a big catastrophic, causing ecological pollution to land and ocean. Many terrestrial and aquatic animals mistakenly ingest plastic firm in either micro or macro forms as food, while emissions of highly toxic gases like dioxins, furans, mercury and polychlorinated biphenyis into the air as a result of burning plastic wastes causes health effect to vegetation, humans and animal (Rinkuverma 2016; Li et al., 2016 and Burning Pit, 2016). Today, the uses of plastic products are now causing uproar in many countries of the world. Many researchers have worked on conversion of plastic waste to various polymer composites for different applications (Rehman *et al*., 2013). Researchers are tremendously working on how best to make polymer composites an environmental friendly material with less or no disaster or damage to the ecosystem. The introduction of wood to polymer composites is considered new a technology to advance composite; which involves combination of wood and polymer at specific temperature and pressure (Aina et al., 2016). Wood in polymer composite is recently 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 being tremendously used in exterior building applications for residential construction, the introduction of WPCs for decking and flooring is mainly responsible for the growth. WPCs exhibited greater durability, less maintenance, absorb less moisture and have better fungal resistance when compared to timber (Clemons, 2002). Recent findings show that WPC products are currently developed for railings, fencing, roofing and siding (Gardner et al., 2015). Slaughter, (2004) also revealed that WPC materials exhibit improved durability with respect to checking, decay, termites, and marine organisms compared to timber. As the manufacturers and interest of WPCs are growing in Europe, Japan, Taiwan and North America for architectural reasons, nothing of such are being recorded in developing countries (Kuo et al., 2009; Ticky 2004). Many wood users are mostly concerns about the durability of their products to resist biotic agents (microbes, insects and associated enzymes) found within their region. An insect such as termites are known to be ecosystem engineers that attack lignocellulosic materials and non-cellulose materials such as plastic in search of food (Kumar et al., 2020 and Kumar et al., 2022). It was recently reported that various microbial population harbour in the gut of termites helps to degrade the plastic polymer (Lopez-Naranjo *et al.*, 2013; and Yang et al., 2014). Another studies also revealed that termites have potential to degrade plastic via their mandibles (Kumar et al., 2022; Yu et al., 2015). Ahmed et al., (2018) also recorded that various types of polymers and wood plastic composites can be attack by termites.

Wood is readily abundant in Africa with many plastic wastes littering the environment in Nigeria and managing the menace has become a major problem to the country. Wood as natural lignocelluloses fibres formed a major constituent in WPCs that makes it susceptible to termite attack (Tascioglu et al., 2013). Recent studies shows that introduction of polymers to wood can improved the durability in terms of dimensional stability, water repellency, decay resistance and acid resistance compared with non polymerized wood; it has also shown to improve biodeterioration resistance (Li et al., 2016). An array of subsequent studies have clearly illustrated that wood found in many WPCs remains susceptible to biodegradation (Morrell et al., 2010; McDonald et al., 2010; Schauwecker et al., 2006, Pendleton et al., 2002; Verhey *et al.*, 2001; Khavkine et al., 2001, Laks and Verhey, 2000, Murkowski and Morrell 2000). While great improvements have been made in product formulations designed to increase durability, it's clear enough that WPCs are not completely immune to biodeterioration, but how susceptible would they be in Nigeria? Recent study shows that wood and plastic formulation in WPC has significant impact on termite resistivity (Douglas and Alejandro, 2018). Termite species (*Coptotermes acinaciformis* and *Mastotermes darwiniensis*) in Australian termites were found to damage plastic samples far more than any other species (Lenz et al., 2011; Thamil 2016). Studies also shows 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; Douglas and Alejandro 2018; Hadi et al., 2019).

As more and more researches are being carried out on durability of WPCs to biotic agents in temperate soil, less or little information are available on durability of WPCs exposed to termites in tropical soil. *Ceiba pentandra* was chosen for this investigation because it is the most vulnerable African wood to termites when in contact with the soil; it has very low durability and liable to attack by biotic agents (Insect and fungi) and also found to be good raw material for WPC production (Aina 2015). Based on this knowledge gaps, it was necessaries that this research study should be carry out to investigate the durability and mechanical properties of WPCs attack to subterranean termites using field tests. The WPCs specimens were polymerized and wood reinforced at proportion of 40/60, 50/50 and 60/40 (wood/plastic) for the purposes of comparison.

Materials And Methods

Collection and preparation of sawdust

Ceiba pentandra of wood density ranged of 240–380 Kg/m^3 at 12% moisture content, mechanical properties ranged of 26–65 N/mm^2 and 2300–5600 N/mm^2 for modulus of rupture and modulus of elasticity were employed for production in this study. The wood has compression strength parallel to the grain of 14–26 N/mm^2 and found to be excellently good raw material for WPC and was found to be durable when exposed to weatherability (Aina et al., 2017). The particles of *Ceiba pentandra* employed for this study was collected from Sawmill section during logs conversion at 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 wire sieve mesh of size 1.00 mm to obtain fine wood powder. Discarded polythene embalmed dihydrogene monoxide bags were collected from waste dumping site of DFRIN water bottling company at Ibadan in Nigeria. The polyethylene embalmed dihydrogene monoxide packaged bags were thoroughly washed, dried and milled into plastic particles using agglomerator at 85 ^{o}C and screened with wire mesh of size 1.00 mm to obtain fine plastic powder.

Processing and production of experimental WPC samples

The homogenous fine powder of *Ceiba pentandra* and polyethylene embalmed dihydrogene monoxide bags were oven dried at 45 ^{o}C for 48 hours to remove any moisture. An appropriate quantity of polyethylene to wood was thoroughly mixed in accordance to the proportional ratio of 40/60, 50/50 and 60/40 (wood/polythene). The mixture of polyethylene to wood in respect to the ratio was fed into single screw extruder at temperature ranged of 95 to 100 ^{o}C to blend and compounded to form wood plastic composites. The ejected molten WPC materials were injected into a rectangular metal mould of dimensional size 6 cm x 6 cm x 12 cm and compressed with hydraulic cold press machine of 20 ton for 20 minutes to solidify. Specimens were dimensioned into specific size in accordance with ASTM D 790 and 638 for determination of mechanical properties (flexural and density).

Field test

Dimensioned test specimens for mechanical properties were exposed in-ground to termite feeding by subterranean termite specie of *Coptotermes curvignathus.* The *Coptotermes curvignathus* was identified on the plot by Forest Entomologist. The specimens were buried horizontally in the field soil to reduce direct exposure to sunlight. The field exposure test was carried out on timber graveyard for termite exposure located at Federal University of Technology, Akure, Nigeria, which has an average monthly rainfall of 300 to 500 mm, average daily relative humidity of 84% and average monthly temperature was about 26 to 35°C (NIMET, 2022). The WPC specimens were buried for the duration of 2 months (Plate 1), they were later exhumed (Plate 2a and 2b) and tested for properties determination. Prior to mechanical properties determination, the exhumed WPC specimens were cleaned and oven dried at 26°C for 24 hours. The lower drying temperature carried out on exhumed WPCs was to minimize the effect of soil moisture before subjected to morphological and visual ratings. The resistance of the WPCs to termites was classified according to Indonesian Standard (SNI 01-7207-2006) presented in (Table I) for graveyard test in accordance with AWPA E7 (AWPA 2007). The microstructural fracture examination of the WPC samples before and after exposure were done using Scanning electron microscope (SEM). Data collected after the period of 12 weeks of termite exposure were analysed and presented in this study. Samples identification was done for each sample on graveyard site using timber stickers (Plate 1). The visual observation of the WPC samples before and after graveyard field exposure to termite attack were presented in Plate 2 (a and b).

Properties Determination

Weight and density

The weight was determined by measuring sample 6 cm x 6 cm x 12 cm with a weighing balance. The specimens were placed on the weighing balance and readings were taken accordingly. The weight before and after exposure were used to determine the weight loss in equation. The specimens were oven dried at 65˚C for 24 hours and after cooling in the desiccators, the weight and volume of the samples before and after exposure were noted for the calculation of the density.

Weight loss = $(W_1 - W_2)/W_1 \times 100\%$ ——————————————————————————*Eq.* 1.

Where W_1 = weight of oven-dried sample prior to the test (g) and

W_2 = weight of oven-dried sample after the test (g).

The density of the samples was determined in accordance with ASTM D 792, as presented in Eq. 2, the density was obtained by dividing the mass of the test sample with its volume. Density (g/cm^3) $= Wa/Va$ ——————————————————————————*Eq. 2*

Where Wa = Air Dried weight (g);

Va = Air dried volume (cm^3)

Mechanical tests

The test samples for flexural properties was carried out in accordance with ASTM D790, with the specimen of each proportion subjected to a force on universal testing machines (UTM) of model WDW 5000 at 50 KN with 100 mm support span. Each specimen was supported with two rollers at each end and force exerted at the center. The forward movement of the machine leads to gradual increase of load until failure occurred. 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 attack.

Morphological analysis

This was done before and after exposure using SEM machine available at the University of Ibadan, Oyo State, Nigeria. This was used to examine the fracture surface of the composite fibres of wood and plastic formed. The samples were sputter coated with gold palladium and observe under SEM of model JEOL JSM-7600F operated at 15 kV. The test was carried out at various magnifications ranging from 8000x. All samples were on appropriate size that fit into the specimen chamber and are generally mounted rigidly on a specimen holder called a specimen stub. The samples were coated with platinum of electrically conducting material deposited on the sample either by low-vacuum sputter coating or by high-vacuum evaporation. The specimen was placed in a relative high-pressure chamber where the working distance is short and the electron optical column is differentially pumped to keep vacuum adequately low at the electron gun. The high-pressure region around the sample in the SEM neutralizes charge and provides an amplification of the secondary electron signal. Low-voltage SEM is typically conducted in an FEG-SEM because the field emission guns (FEG) is capable of producing high primary electron brightness and small spot size even at low accelerating potentials. Embedding in a resin with further polishing to a mirror-like finish can be used for materials specimen when imaging in backscattered electrons or when doing quantitative X-rays microanalysis.

Experimental design

The study was laid out in a 2 by 3 factorial experiments in Completely Randomized Design. Samples were subjected to two factors (exposed and unexposed) while the WPCs samples were produced at three mixing ratio (40/60, 50/50 and 60/40) polythene and wood. The data obtained were analyzed using Statistical Package for Social Sciences (SPSS) of version 20.0 at 5% level of probability. Analysis of variance was done to estimate the importance of main factors and two interaction factors on sources of variation for strength properties (density, weight, modulus of rupture, modulus of elasticity and compressive strength). Duncan Multiple Ranged Test (DMRT) was used to determine the level of significance among and between the variables in each factor. Descriptive analysis was used to obtain the mean values of data and presented in tabular form while the observed strength properties were illustrated with line graphs.

Results And Discussion

The results obtained for analysis of variances and Duncan multiple ranged tests for weight, density, flexural strength and modulus; compressive strength of WPCs are presented in Table II and III while the effect of *Coptotermes curvignathus* on properties of WPCs at different proportions are also illustrated in Fig. 1 to 6 respectively. The reactions of *Coptotermes curvignathus* to the microstructure of WPCs were also presented in Fig. 7 to 9 respectively.

Density of WPCs before and after termite attack

The density values obtained for the WPCs after production ranged from 983.11 Kg/m^3 to 1872.11 Kg/m^3. As presented in Table IV, the density values obtained for the WPCs varies according to the different materials ratio; densities obtained were 1872.1 Kg/m^3, 967.36 Kg/m^3 and 983.11 Kg/m^3 for 40/60, 50/50 and 60/40 (wood/plastic on weight to weight respectively). These values agree with (Shakouri et al., 2009; H'ng, 2011). However, the density values obtained for the WPCs after termitarium exposure ranged from 781.03 Kg/m^3 to 810.60 Kg/m^3. Similar trend was seen in Table IV, the values obtained after exposure varied according to the materials ratio. After exposure, the density values were 810.60 Kg/m^3, 906.41 Kg/m^3 and 781.03 Kg/m^3 for 40/60, 50/50 and 60/40 (wood/plastic). It was observed in this study that variations exist among the WPC levels and also between the treatment levels (Figs. 1 and 3). As illustrated in Fig. 1, the densities reduced after termitarium exposure and this reduction cut across all the WPCs at different materials ratio. As observed in Fig. 1 also, the densities decreases as the proportion of wood content increases from 40–60% and at highest wood proportion of wood content (60%); highest variation of density difference was recorded. In Fig. 3, the difference in the densities of WPCs before and after termitarium exposure shows that at 40% wood content, WPCs reduced by 3.39 percents and this increase to 6.72 percents at 50% wood content and further increase to 25.87 percents at 60% wood content.

Weight values of WPCs before and after termite attack

The weight values obtained of WPCs before and after termitarium exposure are presented in Table IV while the percentage weight loss of WPCs at different proportion was illustrated in Figs. 2 and 3. The weight values obtained of WPCs after production ranged from 5.09 g to 7.34 g, the weight values varies according to the materials production. After production, the weight values obtained for each proportion were 6.51 g, 5.09 g and 7.34 g for WPC at 40:60, 50:50 and 60:40 respectively. But after termitarium exposure, the weight values ranged from 4.79 g to 7.02 g, similar to the pattern witnessed for unexposed WPC, the weight of WPCs exposed to termitarium varies accordingly to the materials proportion which weight values were 5.87 g, 4.79g and 7.02 g for 40:60, 50:50 and 60:40 (wood/plastic) in weight to weight basis. The same parabolic patterns was observed for both unexposed and exposed WPCs (Fig. 2), as illustrated high variation was seen among unexposed and exposed WPCs at proportion of 40/60 than the others. The difference in percentage weight loss between the unexposed and exposed WPCs was also illustrated in Fig. 3; this study observed that as the wood content is at 40%, the weight loss was 2.89 percents but when the wood content increased to 50%, the weight loss increased to 3.73 percents and at 60%, the weight loss also increased to 5.91 percents (Fig. 3). This shows that more weight loss was witnessed at WPC of proportional ratio of 60/40 (wood/plastic) than others. It implies that WPC of more wood content tends to lose weight than WPC of less wood content. This observation could be attributed to the chemistry of wood and plastic materials. Wood is hydrophilic in nature, when in contact with water, it's absorbed and desorbed moisture through its cells to swell and shrink. The movement of moisture in wood make it dimensional instability but plastic is hypophilic that doesn't allow moisture. This explanation gives the reason for the weight lost and gain in WPCs, when the quantity of plastic is more than the quantity of wood; enough plastic encapsulate the wood particles thereby preventing it from absorbing moisture. WPC at 40/60 had more plastic content and has lesser weight lost than others due to more hypophilic than hydrophilic in the compositions. The outcome of the result of analysis of variance carried out at 5% level of probability to test for significant difference in density and weight values at mixing proportions and treatment conditions (Table III). As presented in Table III, existence of significant difference occurs in variable factors for density and weight of the WPCs at 5% level of probability. This implies that both factors significantly influenced the density and weight values of the WPC. Meanwhile, since significant difference occurs, a follow up test using Duncan Multiple Ranged Test revealed that WPC made at ratio 40/60 had the highest density followed by 60/40 and 50/50 (Table IV). Also in Table IV, WPC made at 60/40 had the highest weight values followed by 40/60 and 50/50.

Mechanical properties of WPCs before and after termite attack

The values obtained for flexural strength, flexural modulus and compressive strength are presented in Table IV. As obtained in this study, the values of flexural strength, flexural and compression obtained of WPC after production ranged from 44.80 N/mm^2 to 59.14 N/mm^2, 1404.91 N/mm^2 to 4320.02 N/mm^2 and 19.49 N/mm^2 to 41.12 N/mm^2 respectively. The strength values obtained in this study were higher than the values obtained in previous study that uses *Ceiba pentandra* but at different proportional ratio by Aina et al., (2017) but the values falls within the same values obtained for WPCs by Guidigo et al., (2017). The mechanical properties values varies in proportional ratio, WPC made at proportional ratio of 40/60 (wood/plastic) had the highest values for flexural strength, flexural modulus and compressive strength (Table IV). Likewise as presented in Table IV, WPC made at ratio 50/50 (wood/plastic) had the lowest values for mechanical properties assessed. Meanwhile, the mechanical properties values obtained after the WPC was exposed to termitarium condition ranged from 1087.76 N/mm^2 to 3033.57 N/mm^2, 43.68 N/mm^2 to 51.80 N/mm^2 and 18.43 N/mm^2 to 38.21 N/mm^2 respectively. As illustrated in (Fig. 4), significant variations exist between the flexural modulus of unexposed and exposed WPC at 40/60. Further illustration was seen in Fig. 7, WPC made at 40/60 (wood/plastic) had the least variation of 0.34% difference after termitarium exposure. Meanwhile, when the proportion of wood content increased to 50 percents and 60 percents, the variation gradually increased to 29.16% and 45.72% difference after termitarium exposure (Fig. 7). Also as illustrated in (Figs. 5 and 6) for flexural strength and compression that significant variations exist between the unexposed and exposed WPC and the same pattern of variations was seen for both flexural strength and compressive strength. As illustrated in (Fig. 7), high variations of 17.39% and 21.01% difference were observed between unexposed and exposed WPC at 40/60 (wood/plastic) for flexural strength and compressive strength respectively. But when the wood content increased to 50 percents and 60 percents in the composition, least variation values of (2.56%, 5.64%) and (7.28%, 7.62%) was obtained between the unexposed and exposed WPC for flexural strength and compressive strength (Fig. 7). The results of analysis of variance carried out at 0.05% level of probability to test for significant difference among the WPCs at different proportion and treatments for mechanical properties are presented in (Table III). As presented in (Table III), the two factors and interaction were significant at 5% level of probability for flexural modulus. This implies that both the mixing proportion and treatments have influence on the modulus of WPCs. The results were different in flexural strength and compressive strength, (Table III) revealed that only treatments was not significant in flexural strength while treatment and interaction were seen not to be significant for compressive strength at 5% level of probability. This significantly implies that the treatment doesn't really affect the strength and compression while mixing proportion affects all the mechanical properties. The outcome of the analysis of variance allows a follow up test to be carried out for mean values comparison. As presented in (Table IV), the mean values of each level in factors were alphabetical graded. WPC made at 60/40 had the highest mean values and with letter (a) attached for flexural modulus, flexural strength and compressive strength was best performed formulation for WPC in this study (Table IV). It was followed by WPC made at 40/60 and 50/50 (Table IV). Also in (Table IV), unexposed WPC performed better than exposed WPC for flexural modulus but remains insignificant for flexural strength and compressive strength for the period of 12 weeks.

Morphological properties

The interfacial adhesion between the wood and plastic were examined in this study. The micrographs of the unexposed and exposed WPC sample were demonstrated in (Figs. 7, 8 and 9). For more inspection, the pores, density and surface appearance were visually carried out (Plate 2). Formation of porosities and voids in structure of WPC was seen and it's somehow inevitable. Numerous presences of void can be seen in WPC made at proportion of 60/40, which could be attributed to the materials vapour during production process due to wood moisture and polymer content (Shakouri et al., 2009). The imperfect adhesion between the wood component and polymeric matrix led to the existence of pores that might have weakened the stress concentration that decrease the density and flexural modulus after exposed to termitarium. WPC at 60/40 had the highest percentage decrease of 45.72 (Fig. 3) and 25.87 (Fig. 7) for flexural modulus and density after exposed to termitarium. The differences in the density and flexural modulus of exposed WPC at 60/40 show clearly that termites attack was more dominant due to the wood content in composition. The porous structures of WPC at 40/60 collapsed more than 50/50, its make the composites to be compact, and stronger after exposure, its density and weight slight decrease by 3.39 and 2.89 after exposure. Weight loss of 2.89 is lesser than 3.52 of resistance class to termite and this make the products at 40/60 to be very durable (Table II). Macroscopically, color was altered both in WPCs exposed (Plate 2). After being buried in the soil, voids were visible in the WPCs, particularly on the WPC at 60/40 (60% of wood filler content) (Lukmandaru, 2009). The WPC color changed from brown to lightened gray after 12 weeks of exposure. This phenomenon of lightening color could originate from weathering factors such as relative humidity (RH) in the soil and lignin degradation of wood filler from the WPC (Chen et al., 2014; Aydemir et al., 2019 and Chen et al., 2016).

Effect of Termite attack on density and weight loss of WPCs

The densities of the WPCs before and after termitarium exposure were 1274.20 Kg/cm^3 and 832.69 Kg/cm^3. The densities obtained in this study for WPCs before and after termite attacks met the standard density required that ranged between 400 to 900 Kg/cm^3 (JIS A 5908, 2003) and the density after termite attack still fell below target. The density of WPCs decreases as the wood content increases from 40–60%, this agrees with (Nuryawan et al., 2020; Yu et al., 2015). After termite attack, the density of WPC decreased with increase in wood filler. The drops in the density can be related to voids and cracks found on the surface of the exposed WPCs; this could have been a favour for termite attacks in WPC. The imperfect encapsulation of the wood fibres by the polymeric make ways for possible termite attacks which created pores that allows moisture when contact with soil. It was reported that apart from termite attacks, the activities of microorganisms in the soil do also degrades the WPC, soil factors such as moisture or relative humidity, high temperatures originating from exposure to sunlight as indicated in discoloration (Douglas and Alejandro 2018; Yu et al., 2015). The weight loss between the unexposed and exposed WPC sample buried in the soil for 12 weeks falls between 2.85 percents to 5.91 percents, this makes the products to be classified as very durable and durable (Table II). This is an evidence that WPC can be consumed by termites and are more significant when the wood content are more than the plastic (as seen in Fig. 3 for 60/40).

Effect of termite attack on mechanical properties of WPCs

The mechanical properties behaviours of WPC samples at different mixing proportion of wood to plastic exposed to graveyard for 12 weeks shows reduction in flexural modulus, it decreased by (0.34, 29.16 and 45.72) percents for 40/60, 50/50 and 60/40. It was seen in (Fig. 4) that 60/40 attain highest flexural modulus while 50/50 attain the lowest flexural modulus after production but the rate of reduction was very high (45.72%) when compared to others after graveyard treatment. This observation agrees with the finding by Douglas and Alejandro (2010). The stress concentration of the exposed WPC was weakened after graveyard exposure; this is an evidence of termite attack on WPC and it was severe for the proportion of 60/40 than others. This might be attributed to the much wood fibers pull out of the matrix, this create access for termites and assisted by other factors such as moisture, relative humidity and temperature in the soil (Gulitah and Liew, 2019; Douglas and Alejandro 2018; Yu et al., 2015). Meanwhile for flexural strength and compression, the proportion of 50/50 still maintained the lowest values both after production and after graveyard treatment (Figs. 5 and 6). The percentage changes in flexural strength and compressive strength of unexposed and exposed WPC were very minimal at 50/50, this implies that less attacked occurred in 50/50 than others. After graveyard treatment, WPC at 40/60 was seen to have slight reduction of 17.39 percents in strength and 21.01 percents in compression than others. This is an observation that WPC can be attack by termites when in contact with the soil. This agrees with findings of (Lopez et al., 2020; Nuryawan et al., 2020). This clearly shows that when WPC come in contact with soil, the relative humidity and moisture invites termites for destruction. This agrees with recent report by Kumar et al., (2022) that termites need moisture for degrading wood in plastic. It was also reported that the appearance of cracks and voids on the WPCs surface provides entrance route for termite mandibles to change the physical and mechanical properties of WPCs (Kumar et al., 2022; Yang et al., 2021; Lopez-Naranjo *et al*., 2013; Stephan and Plarre 2008).

Conclusion

From the research carried out on wood plastic composites produced from wood-flour and recycled polyethylene at proportional ratio of 40/60, 50/50 and 60/40 (wood/plastic); these following conclusions were made;

1. It was found in this study that proportional ratio of (wood /plastic) significantly affects all the properties assessed in this study.
2. It was also found that termite attacks significantly affects weight, density and flexural modulus of WPC exposed to graveyard located at tropical climate
3. WPC at 60/40 had the highest percentage decrease for flexural modulus and density after exposure; this was a clear evidence of termites attack to be more dominant due to higher wood content in composition.
4. The interrelationships are complicated because of the very fine capillaries in the structure that play a role. Due to the porosity structure of the WPC at 40/60 which collapsed more than 50/50, make the composites to be compact, and stronger after exposure, its density and weight slight decrease by 3.39 and 2.89 after exposure.
5. The weight loss between the unexposed and exposed WPC sample buried in the soil for 12 weeks falls and this makes the products to be classified as very durable and durable.

RECOMMENDATION

Based on the above conclusions, it is recommended that WPC of 40/60 can be adopted for house application in Nigeria.

Declarations

Declaration of competing interest

This research has not been financially supported by any research funding organisation or grant

giving foundation. Thus, there is no conflict of interest.

Author's contribution

Aina k. S and Owolabi T.O were in charged of project conception and design. Olanira S.O, Olufemi B did the drafting of the paper and revised the intellectual content of the project while Olayiwola Y.B did the analysis and interpretation of the data

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Tables

Table I. Classification of the resistance class to termite assay

Class	Weight loss (%)	Class of resistance
I	< 3.52	Very durable
II	3.52 - 7.50	Durable
III	7.50 – 10.96	Moderate
IV	10.96 – 18.94	Poor
V	18.94 – 31.89	Very poor

Source: SNI 01–7207 (2006)

Table II: Resistance of WPCs to termite attack at timber graveyard

Type	Wood (wt)	Plastic (wt)	Mean weight loss (%)	Class of resistance
WPC-1	40	60	2.89	Very durable
WPC-2	50	50	3.73	Durable
WPC-3	60	40	5.91	Durable

Table III: Analysis of variances

Properties	Weight (g)		Density (Kg/cm^3)		Flexural modulus (Nmm^{-2})		Flexural strength (Nmm^{-2})		Compressive strength (Nmm^{-2})	
Source of variation	F-Cal	P-Sig.	F-Cal	P-Sig.	F-Cal	P-Sig.	F-Cal	P-Sig.	F-Cal	P-Sig.
Treatment (A)	6.258	0.00*	8.685	0.01*	8.852	0.01*	1.200	0.29^{ns}	0.632	0.44^{ns}
Proportion (B)	0.031	0.00*	3.738	0.05*	64.648	0.00*	11.227	0.00*	55.953	0.00*
A and B	0.130	0.00*	4.355	0.03*	4.714	0.03*	6.042	0.01*	2.258	0.14^{ns}

*significant at (P<0.05) probability level; ns= not significant at (P>0.05) probability level

Table IV: Duncan Multiple Range Test separation of Mixing Ratio for weight

Variables	levels	Weight	Density	MOE	MOR	Compressive
Wood Proportion	50	4.94^a	882.08^c	1246.23^c	44.24^c	18.96^c
	40	6.18^b	936.89^b	3028.39^b	50.09^b	35.49^b
	60	7.02^c	1341.36^a	3597.37^a	54.07^a	39.67^a
Treatment	unexposed	6.31^a	1274.20^a	2886.05^a	50.40^a	32.04^a
	exposed	5.78^b	832.69^b	2361.95^b	48.53^a	30.70^a

Plates

Plates I and II available in the Supplementary Files section.

Figures

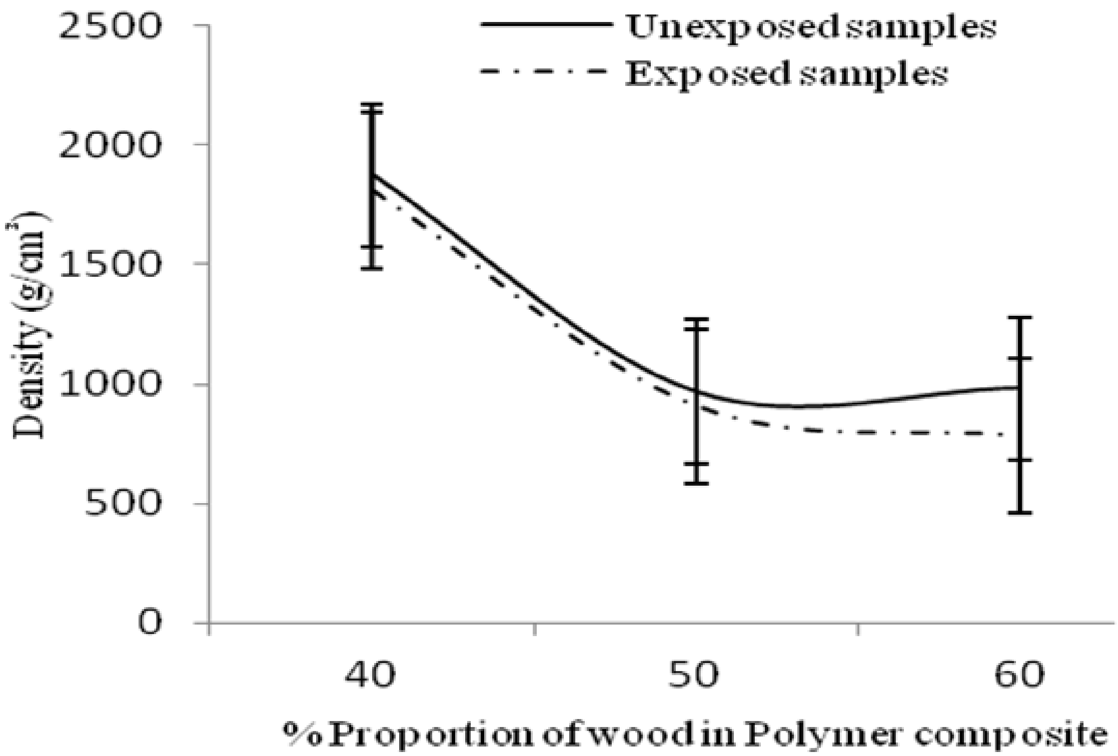

Figure 1

Density of exposed and unexposed WPCs

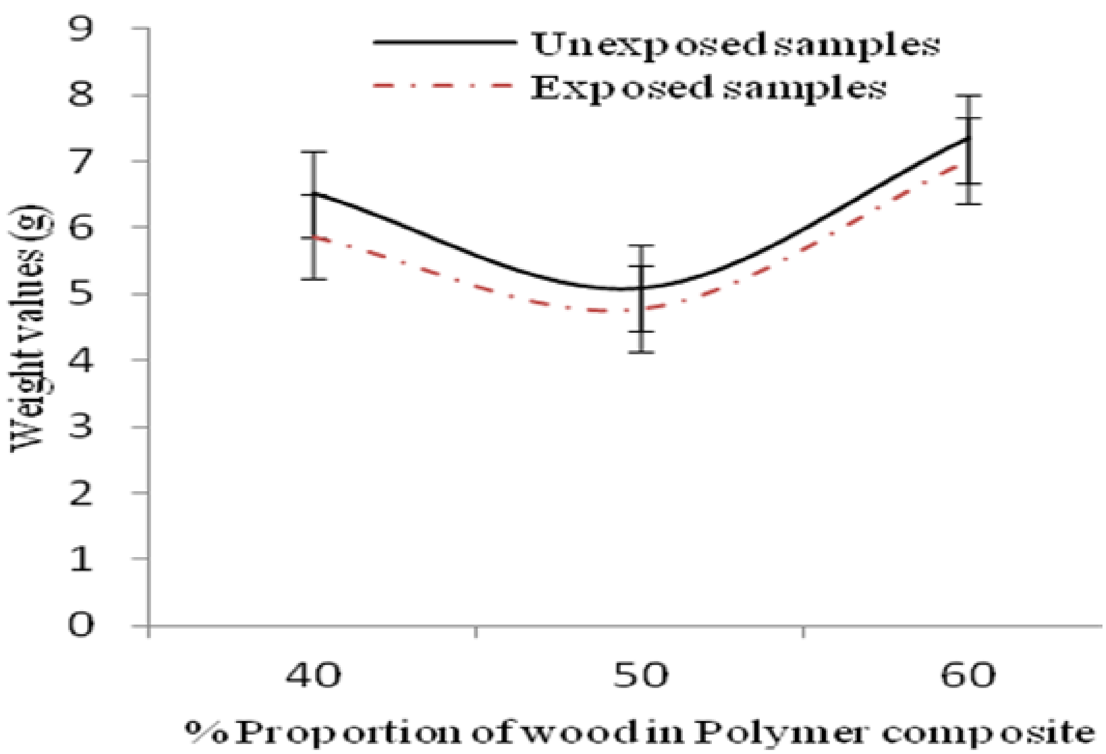

Figure 2

Weight of exposed and unexposed WPCs

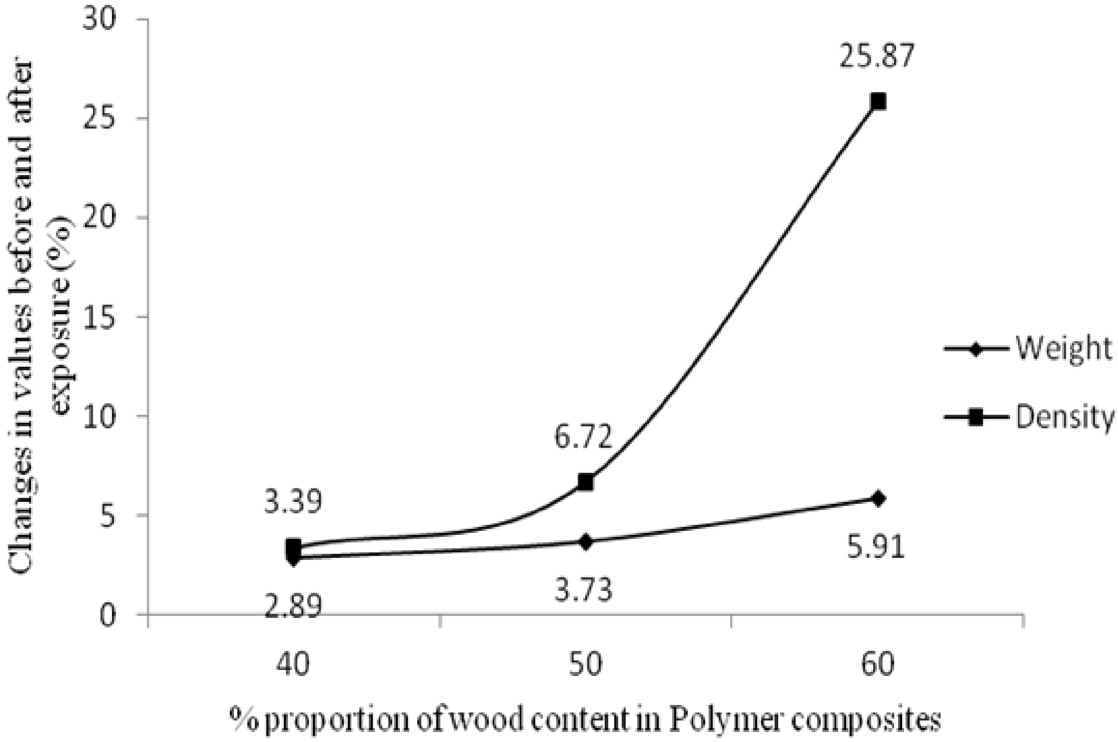

Figure 3

Percentage changes in physical properties between unexposed and exposed WPCs

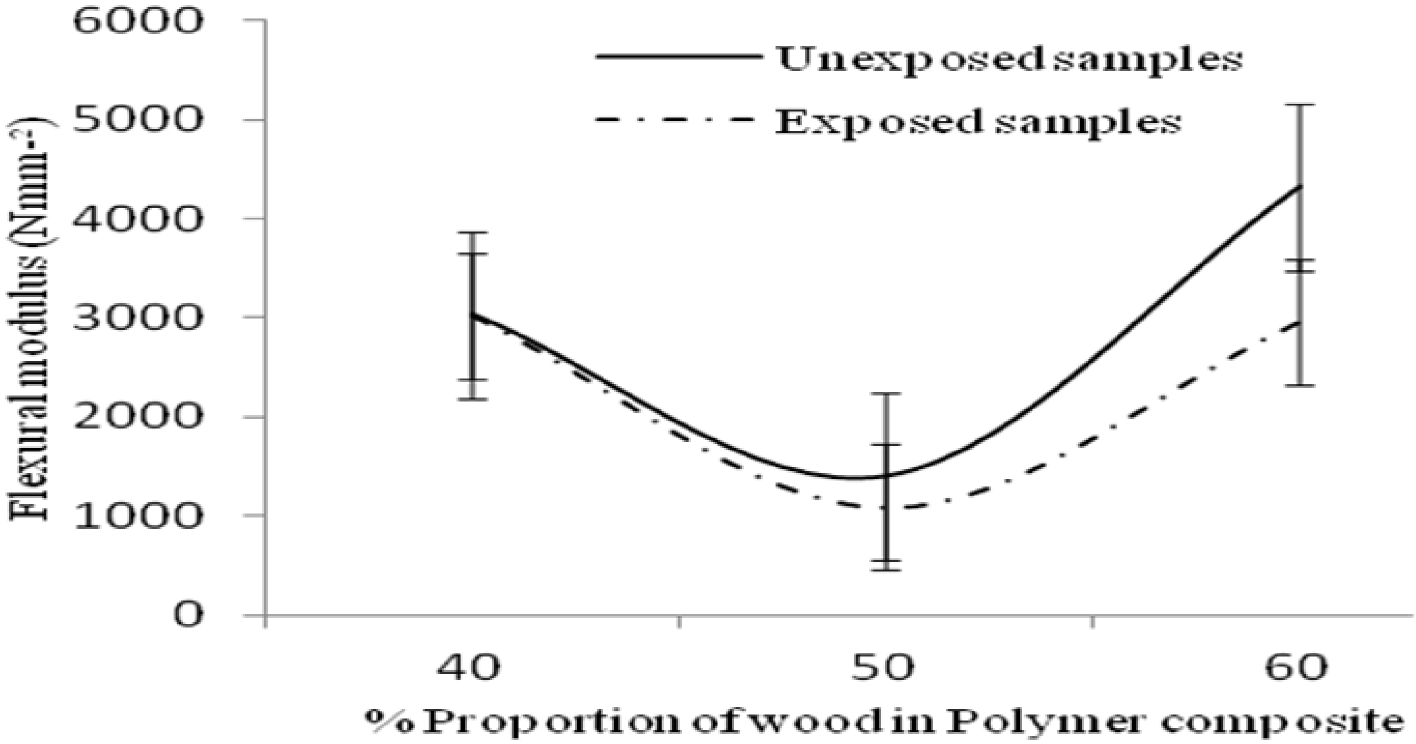

Figure 4

Flexural modulus of exposed and unexposed WPCs

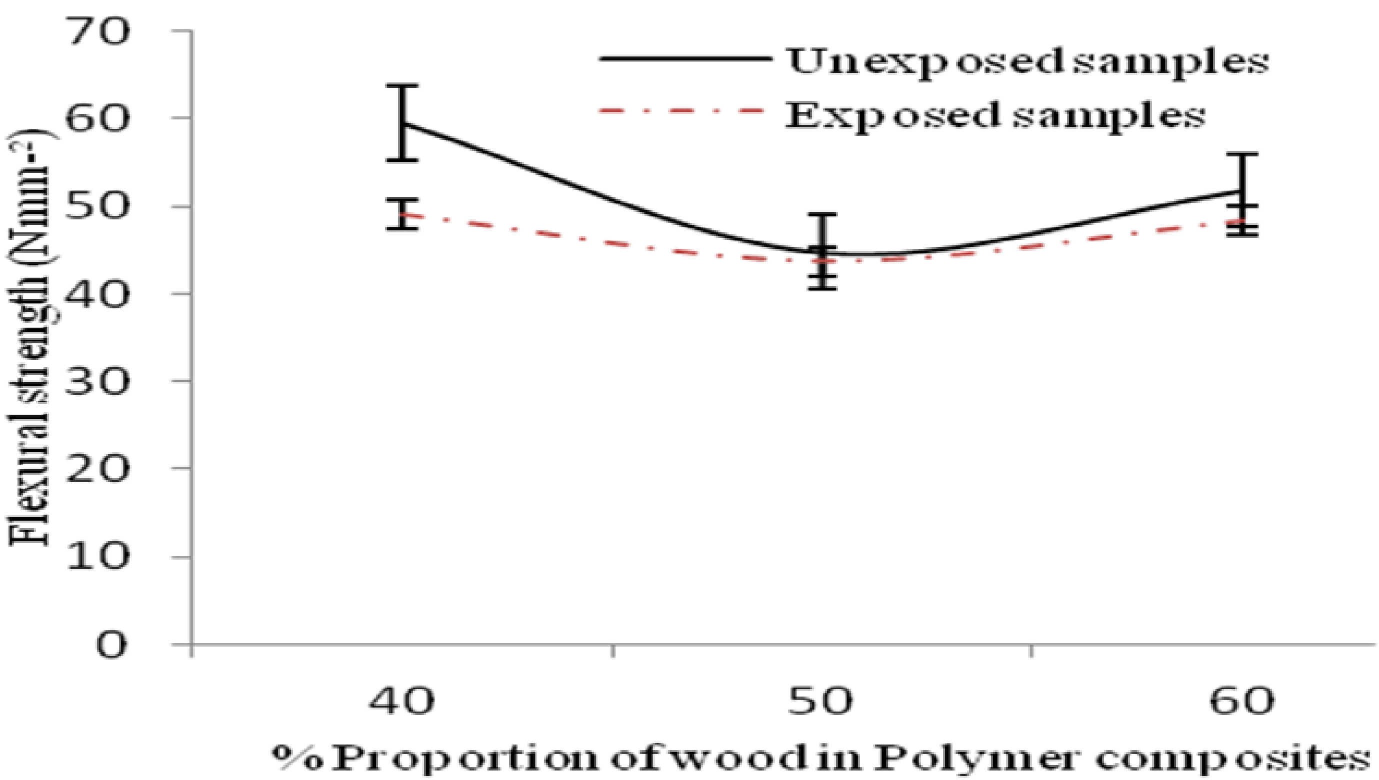

Figure 5

Flexural strength of exposed and unexposed WPCs

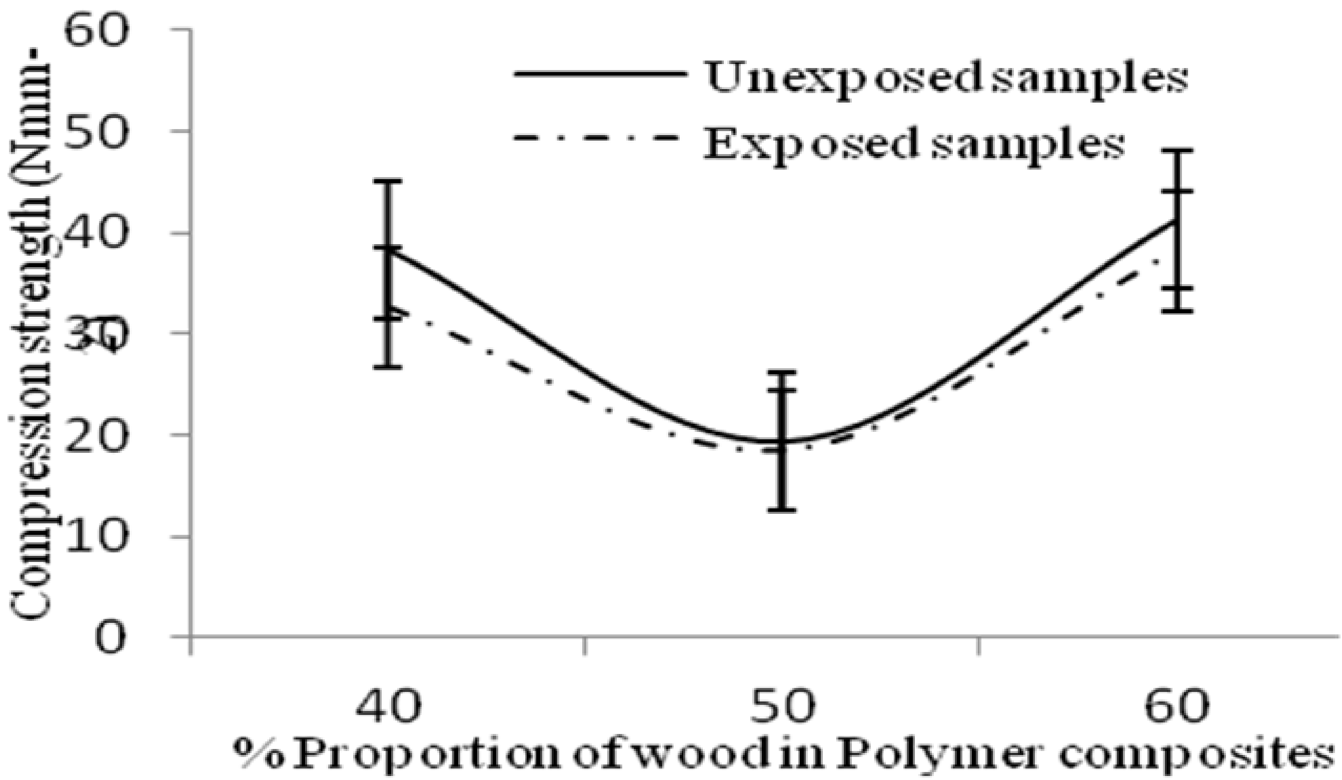

Figure 6

Compression strength of exposed and unexposed WPCs

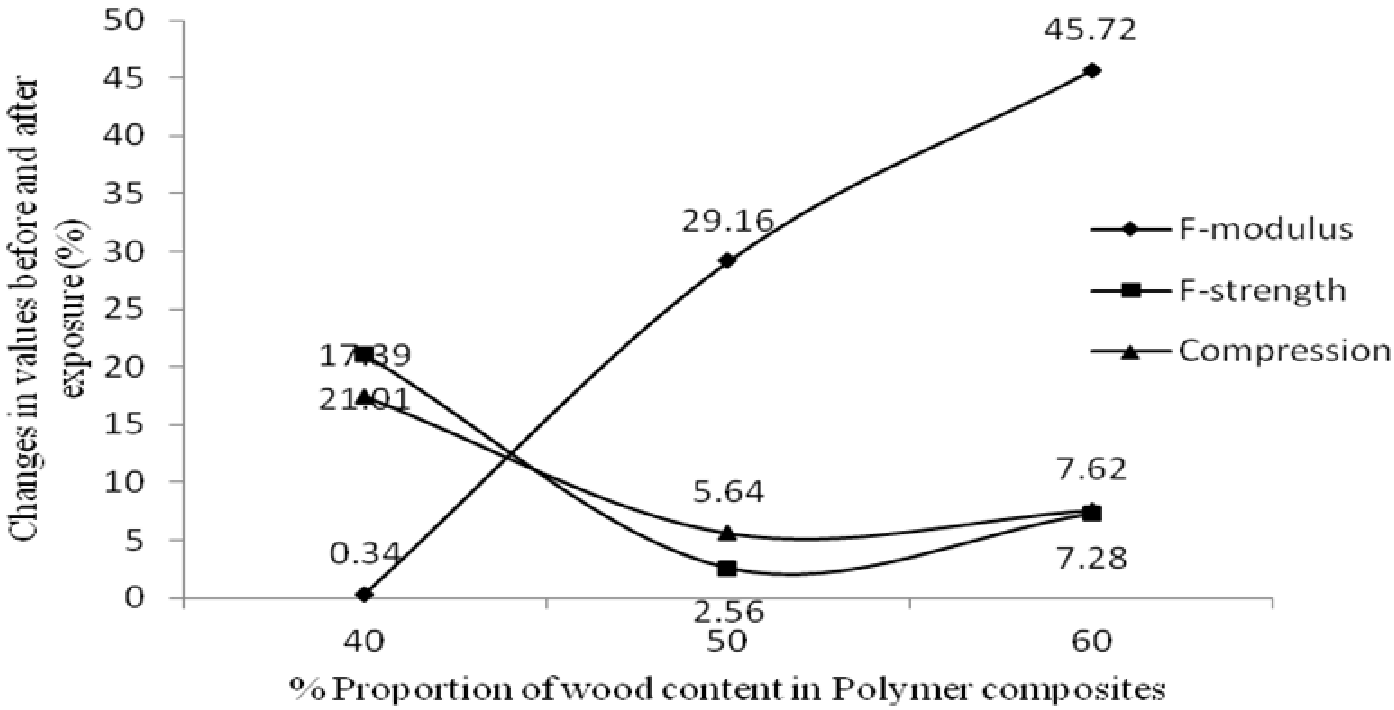

Figure 7

% changes in mechanical properties between unexposed and exposed WPCs

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- PlateItoIII.doc