Comparative Studies on Physico-Mechanical Properties of Wood Plastic Composites Produced from Three Indigenous Wood Species

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Abstract: ***20 cm x 20 cm Flat boards of wood plastic composite (WPC) of thickness size of 0.5 cm was produced from three indigenous wood species (Funtumia elastica, Brachystegia kennedy and Milicia excelsa). WPCs were produced from each of selected wood species at two different wood/rHDPE mixing ratios of 1:1 and 1:1.5 at a constant nominal board density of 1g/m^3. Effect of these production variables (wood species and mixing ratio) were investigated on physical and mechanical properties of WPC boards produced. Properties such as water absorption (WA), thickness swelling (TS), abrasion (AB), modulus of elasticity (MOE), modulus of rupture (MOR) and impact bending test (IB) were all carried out on the samples. Appropriate quantities of sawdust and pulverised nylon were sieved, weighed and mixed thoroughly to produce flat WPC boards from fabricated Hot-press plate machine at 103^0 C with a constant pressure of 1.23N/mm^2 for 20 minutes. Samples were cut into specific dimensions in accordance with British Standard (B.S D373 and D1181). Results shows that flat WPC boards produced from B. kennedy and M. excelsa were relatively low in moisture uptake but lower in wood /rHDPE mixing ratio of 1:1.5. However these wood species WPC boards were stiff and strong in strength properties but stiffer and stronger with wood /rHDPE mixing ratio of 1:1, additional abrasion values was lower in both B. kennedy and M. excelsa than F. elastica. Based on the findings that increased proportion of pulverised nylon to wood in WPC boards makes the boards to be plasticized with low strength properties, but highly dimensional stable, boards in these categories could be considered for low bearing load applications in both exterior and interior engineering materials.***

Keywords: Pulverised nylon, *Funtumia elastica*, *Brachystegia. kennedy*, and *Milicia excels*

1. Introduction

Wood plastic composites (WPC) are advance technology material for structural and non-structural products, this high value products comprising wood flours as fillers and reinforcements and thermoplastic polymers as the matrices. WPCs can be made from many wood species, and mainly are formed by introducing wood flour from softwoods and hardwoods in a continuous extrusion process, presently; there is tremendous interest in understanding how wood particles and the surrounding plastic matrix behave at both the macroscopic and microscopic levels [11]. In WPCs production, the preferred method for manufacturing is compression, extrusion and injection molding, where temperatures of about 200^{0}C and high pressures are normally used [12]. There are a variety of available wood species in the inland region and other region that are potentially useful for the production of WPC, wood species such as pine, maple and oak are commonly used whereas polyethylene, polypropylene (PP), and poly (vinyl chloride) are usually used as the thermoplastics [10]. Wood species have an important influence on the properties of wood-thermoplastic composites [9], predominantly because wood structure controls the flow direction of the thermoplastic movement in the cell lumens. This complex flow process control the penetration of a thermoplastic into the wood structure, thus make it difficult to state whether one wood species is superior to another one as a filler material [11]. This is referred to as mechanical interlocking, and is an important mechanism for adhesion which could be related to the performance of composites. Wood is very hydrophilic and plastic used for many WPC are very hydrophobic, achieving a strong bond between these two materials can be challenging. Before massive production of WPC could be possible, it is necessary to understand how wood particles and surrounding plastic matrix behave at macroscopic and microscopic levels. Many studies shows significant effects related to variables such as the size and amount of fillers, coupling agents, types of thermoplastic matrix and additives [4, 5, 7 and 9]. However, there is a general reluctance amongst potential manufacturers and end-users, in the UK especially, to consider plastic recyclate as a feedstock for WPC materials [8], issues such as material consistency, security of supply, lack of material standards and product performance have all been cited as reasons for this reluctance. Wood waste from wood species would not be considered at all due to the risk of contamination, lack of traceability and quality issues. [8] reported that only wood from primary and secondary wood processing are considered being a suitable option for WPCs. Currently, the preference would be determine by polymer type and wood flour or fibre. This is however related to the high costs of WPCs in United Kingdom and the rest of Europe at the moment. The use of recyclate may become more common as market confidence in the product would increases with attempt by manufacturers to reduce production costs would highly be certain.

Due to this reports, the aims and objectives of this research work is to investigate the possibility of producing wood plastic composites from wood species grown on tropical areas and also to access recyclable thermoplastic as binder.

2. Methodology

Sawdust from wood species (*Milicia excelsa*, *Brachystegia Kennedy* and *Funtumia elastica*) were sourced and separately pooled together at sawmill unit in Department of Forest Products Development and Utilization, Forestry Research Institute of Nigeria (FRIN), Ibadan. Packaging nylon bag produced from packaging industries in Nigeria for packaging drinking water were collected from dumping site, these nylon bags were washed, dried and pulverised into powder form using hammer milling machine at Aleshinloye Waste-recycling Management Company, at Aleshinloye market, Ibadan. Sawdust particles of the selected wood species and granules particle of rHDPE were thoroughly sieved using wire mesh size of 35 to have homogenous powder particles and also to remove unwanted particles. The sieved sawdust was oven dried at 105^0C to attain moisture content of 8% prior to production inorder to reduce moisture in the cell lumen and allow diffusion of liquid plastic. Appropriate quantities of sieved particles was weighed and mixed thoroughly into a mould of size 200 mm by 200 mm to produce flat platen-WPC samples through the use of compounding technique at temperature of 103 - 120^0C at a constant pressure of 1.23N/mm^2 and within the period of 15 minutes.

Flat platen WPCs board was produced according to these variable factors; a constant nominal board density of 1g/m^3, with sawdust/rHDPE mixing ratio of 1:1 and 1:1.5 respectively, these were produced from all the selected wood species. Required samples to be tested were cut from each of the flat platen WPCs boards in accordance to British Standard [1 and 2] and subjected to both physical and mechanical properties test. Properties such as modulus of rupture and elasticity, impact bending, abrasion, swelling, and absorption test were all carried out on the samples produced. These properties were determined according through these given procedure and formulae stated below;

2.1. Physical properties test

Dimensional size of 50 mm x 50 mm x 6 mm was used to determine both the TS and WA respectively. Measurements such as the thickness (mm) and weight (g) were taken on the samples prior to test as initial parameters while final measurements were conducted after immersion in warm water at temperature of $20^0 \pm 1$ for the period of 24 hours. For effectiveness results, measurements were carried out using analogue calliper meter gauge and electronic sensitive weighing machine. The equation 1 and 2 below shows how both WA and TS were express as the percentage of increase in the weight/thickness of board over the initial weight/thickness.

WA (%) = $(W_1 - W_0 / W_0)$ X 100 ------------------Equation 1.
Where WA = water absorption (%), W_1 = final weight after treatment (g) and W_0 = initial weight before treatment (g).
TS (%) = $(T_1 - T_0 / T_0)$ X100-----------------------Equation 2.
Where TS = Thickness swelling (%), T_1 = Final thickness after treatment (mm) and T_0 = Initial thickness before treatment (mm)

2.2. Mechanical properties test

Following the required standard mentioned earlier (British Standard 373 of testing particleboard), test samples were dimensioned into size 6 mm (thickness) x 50 mm (width) x 194 mm (length) and subjected to a load of 125 pounds in Hounsfield tensiometer machine available at FRIN. The test specimens were supported by two rollers at both ends and loaded at the middle of the span until failure occurs. At the point of failure, the force that was exerted on the specimens that causes the specimens to crack and the point of deflection were recorded on graphs to determine both the MOR and MOE respectively. The equation 3 and 4 below shows how both MOE and MOR were express in N/mm^2.

$MOR = 3PL / 2bd^2$ ------------------Equation 3.
$MOE = PL^3 / 4bd^2H$ ----------------------Equation 4.

Where; MOR = Modulus of rupture (N/mm^2), Modulus of Elasticity (MOE), P = the ultimate failure load (N), L = the board span between the machine supports (mm), b = width of the board sample (mm), d = thickness of the board sample (mm) and H = slope from the graph.

Impact strength test conducted on the samples was done in accordance with B.S 1811, (100 mm x 100 mm x 6 mm) dimensional size was subjected to 5 kg pendulum hammer in Hatt-Turner testing machine, the test samples is arranged with a supporting frame and allow block of hemispherical mild steel to fall on the surface at successive heights in increments of 25.4 mm until failure occurs. Impact strength I_s (N/mm^2) is express as the quotient of the totally consumed dynamic energy E_t (kg.mm) to the cross-section A (mm^2) as shown in equation 5 below;

I_s (N/mm^2) = E_t / A---------------------------------Equation 5.

In abrasion resistance, samples dimension was rather small in size of 25.4 mm x 25.4 mm x 6 mm (1 in x 1 in x 0.24 in) in accordance with B.S 1811. Samples were subjected to scrubbing through steel brush in to and fro movement for 100 times. However tests of abrasion is measured as loss of weight or loss of thickness in the samples, this is expressed as the reciprocal value of the loss in weight or thickness as shown in equation 6 below;

$A = \beta \times \varrho 0 + \alpha$ --Equation 6.

Where A is abrasion resistance (mm^{-1}), ϱ0 is in the range of about 0.6 to 1.1 g/cm3, is the density at zero% moisture content, *β and* à are constant (for A in mm^{-1}) 356 and -186 respectively.

The data collected were statistically analysed using experimental model design of 2 x 3 factorial in Complete Randomized Design (CRD) using SPSS software of version 13.0.

3. Results and Discussion

3.1. Physical properties

At 24hrs of samples exposure to moisture immersion test, WPC samples subjected to tests, have water absorption values ranged from 6.36% to 17.25% respectively. WPC samples produced from *Brachystegia kennedyi* had the lowest WA values of 6.36% for wood/rHDPE mixing ratio of 1:1.5 and 11.99% for wood/rHDPE mixing ratio of 1:1, followed by WPC samples of *Funtumia elastica* with lower WA values of 9.44% in wood /rHDPE ratio of 1:1.5 but witnessed highest WA values of 17.25% in wood/rHDPE mixing ratio of 1:1. In WPC samples produced from *Milicia excelsa*, WA values was slightly difference to each other in wood/rHDPE mixing ratio of 1:1.5 lower in WA values with 12.10% to 12.27% in wood/rHDPE mixing ratio of 1:1 respectively, this is similar to the result of [3 and 6]. Similarly in thickness swelling test conducted on the WPC samples, the TS values ranged from 0.57% to 2.43% respectively, the relationship of moisture up taking by the samples to the thickness dimension of the boards were as follows; thickness swelling in WPCs samples from equal proportion of wood/rHDPE recorded had TS of 0.57% in *Milicia excelsa*, followed by *Brachystegia kennedyi* and *Funtumia elastica* with 0.73% and 2.43% respectively for 24 hrs of water immersion test, this observation might be as a result of chemical components and the density nature of *Funtumia elastica* but when the rHDPE proportion increased to 1.5, there is just a little different in TS value of *Milicia excelsa* (0.67%) to *Funtumia elastica* of 64%. The observation shows that as more plastic granules proportion is increasing then there is a tendency that dimensional stability of WPC boards to improve. WPC sample from *Brachystegia kennedyi* had the lowest TS in 1:1.5 but still in the range of what was reported by [3 and 6], TS and WA relationship to moisture are represented in figure 1 and 2 respectively.

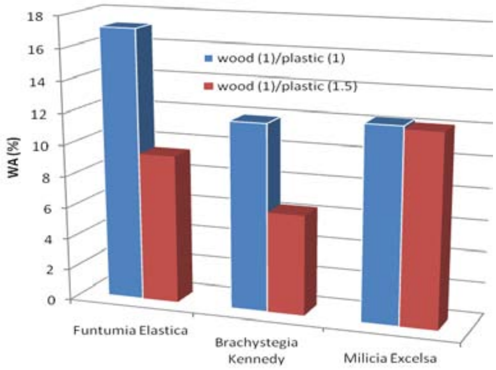

Figure 1: Effect of wood species and wood/rHDPE ratios on water absorption of WPC

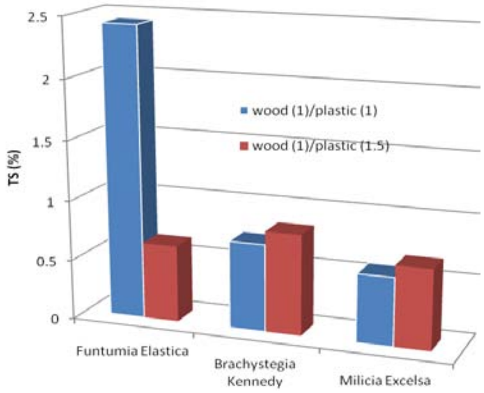

Figure 2: Effect of wood species and wood/rHDPE ratios on thickness swelling of WPC

3.2. Mechanical properties

In modulus of rupture, the values ranged from 1.72N/mm^2 to 24.42 N/mm^2 respectively. As illustrated in Figure 3, sawdust/rHDPE mixing ratio of 1:1.5, MOR values are high in both *Brachystegia kennedyi* and *Milicia excelsa* with 6.34N/mm^2 and 6.20N/mm^2 respectively, while the value was low in WPC produced from *Funtumia elastica* with 1.72N/mm^2. In equal quantity of wood/rHDPE mixing ratio of 1:1, *Milicia excelsa* had the highest MOR value of 24.42N/mm^2 followed by *Brachystegia kennedyi* with MOR value of 16.40N/mm^2, while WPC produced from Funtumia *elastica* was low in MOR values compared to the others with 13.94N/mm^2 respectively. As illustrated in Figure 4, MOE values ranged from 5,372N/mm^2 to 15,717N/mm^2 respectively. MOE in sawdust/rHDPE mixing ratio of 1:1.5, *Funtumia elastica* had the highest MOE value of 1235.2N/mm^2 followed by *Milicia excelsa* with MOE value of 8888.8N/mm^2, the lowest MOE value among the samples was the MOE derived from *Brachystegia Kennedy* with 5,372N/mm^2 respectively. In equal proportion of sawdust/rHDPE of 1:1, *Milicia excelsa* with the value of 15,717N/mm^2 had the highest MOE value, followed by the MOE value of 13,326N/mm^2 from *Funtumia elastica* while the lowest MOE value is from *Brachystegia kennedy* with 12,482N/mm^2 respectively.

The report of IB test is presented in figure 5 below, the ranged of IB test values ranged from 8.47N/mm^2 to 21.00N/mm^2 respectively. In sawdust/rHDPE mixing ratio of 1:1.5, *Milicia excelsa* had the highest IB strength value of 21.00N/mm^2, followed by *Brachystegia kennedy* with IB strength value of 15.17N/mm^2, the least IB strength among the tested samples is from *Funtumia elastica* with IB strength value of 13.00N/mm^2 respectively. In the equal proportion of sawdust /rHDPE mixing ratio of 1:1, WPC from *Milicia excelsa* had the highest IB strength value of 17.43N/mm^2, followed by *Funtumia elastica* with IB strength of 12.07N/mm^2, WPC from *Brachystegia kennedy* had the lowest IB strength of 8.47N/mm^2 respectively. Wearing resistance test conducted on the WPCs, figure 6 shows the response of WPC to wearing resistance, in such that abrasion values ranged from 0.91^{-}mm to 4.93 $^{-}$mm. Abrasion resistance was very high in WPC produced sawdust/rHDPE mixing ratio of 1:1.5 in *Milicia excelsa* with 2.47^{-}mm, followed by *Funtumia elastica* with value of 2.36^{-} mm and the lowest is from *Brachystegia kennedyi* with value of 2.20 $^{-}$mm. in equal proportion of mixing ratio of 1:1 of sawdust/rHDPE, *Funtumia elastica* had the highest wearing resistance value of 4.93 $^{-}$mm followed by *Milicia excelsa* with value of 1.29 $^{-}$mm and least with *Brachystegia kennedy* with 0.91 $^{-}$mm respectively.

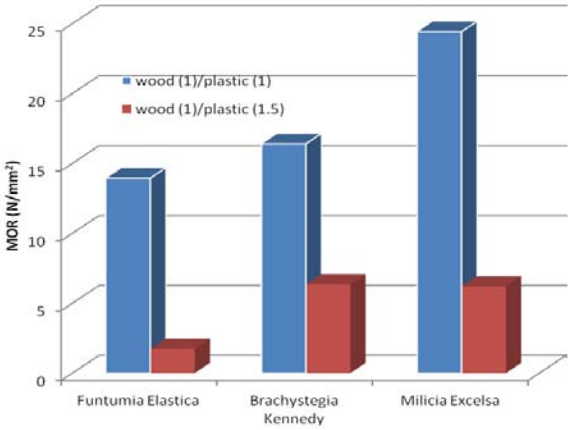

Figure 3: Effect of wood species and wood plastic ratios on modulus of rupture examined on WPC

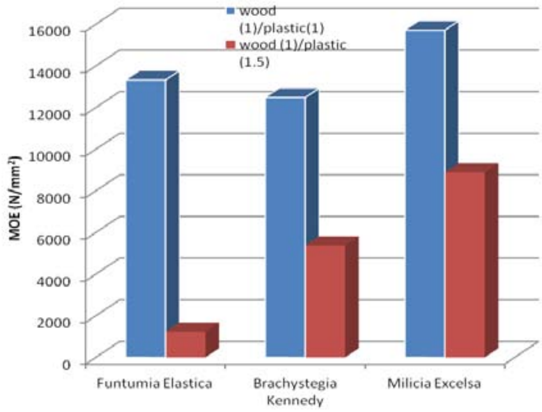

Figure 4: Effect of wood species and wood/plastic ratios on modulus of elasticity examined on WPCs

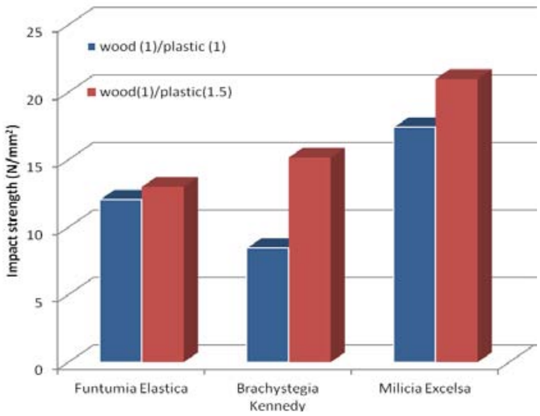

Figure 5: Effect of wood species and wood/plastic ratios on Impact bending strength examined on WPCs

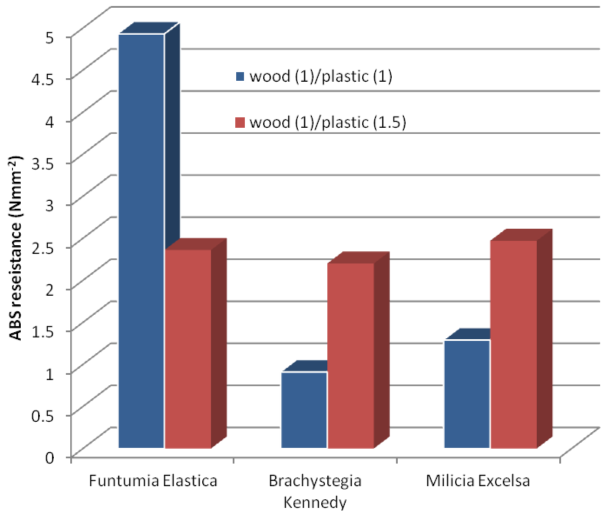

Figure 6: Effect of wood species and wood/plastic ratios on wear resistance examined on WPCs

Statistical analysis conducted on the main factor and interaction factors shows that there are significant difference at 5% level of probability in the main factors (wood species and wood/rHDPE) and effect of two factors interactions of all properties except wear resistance (Abrasion). This study shows that there are significant influence on the properties assessed on the different WPCs produced from all the wood species, factors such as the wood species have influence on the properties as well as the sawdust/rHDPE mixing ratios. In two factors interaction, between the wood species and sawdust/rHDPE mixing ratio, all excerpt Abrasion are significantly different at 5% level of probability. This implies that different wood species with sawdust/rHDPE mixing ratios will definitely have impact on the properties of WPC produced.

4. Conclusion

This study was successfully carried out to investigate the effect of three indigenous wood species at two sawdust/rHDPE mixing ratios for WPC utilization potentials. *Brachystegia kennedyi* and *Milicia excelsa* were both outstanding after exposure to moisture content, they were dimensionally stable than the WPC produced from *Funtumia elastica.* But the sawdust/rHDPE mixing ratio of 1:1.5 were more resistance to water uptake than the equal proportion of sawdust/rHDPE mixing ratios, which might be due to the high percentage of polymer in the composition, the fiber were properly encapsulated with polymer which is water repellent material. In strength properties accessed also, both wood species and sawdust /rHDPE had impact in the strength of WPCs, *Brachystegia kennedyi* and *Milicia excelsa* were stiffer and stronger than the *Funtumia elastica,* but the strength drastically reduced in sawdust /rHDPE proportion of 1:1.5, more of polymer in these proportion turns the WPCs to behave more of elastic in nature, so it was able to have low elastic limit. This is also observed in the Impact bending strength, *Milicia excelsa* and *Funtumia elastica* more impacted in strength than *Brachystegia kennedy* while the sawdust/rHDPE mixing ratios of more polymer was more impacted in IB strength then the equal proportion of sawdust and polymer. In wear resistance test, *Funtumia elastica* was the least tolerance to wearing test than the others, while both the *Brachystegia kennedy* and *Milicia excelsa* are more resistance to wearing test, but more resistance in equal proportion of sawdust to polymer in both wood species.

Based on the findings of this research work, consideration must be giving to type of wood species to be used, while the mixing proportion must be also base on the application uses of the WPC before embarking on mass manufacturing of WPC to the consumers. More research should still be conducted on indigenous wood species from different region to different continent, in order to ascertain the suitability of their wood species for WPC production.

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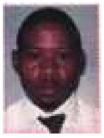

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