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COMPARATIVE STUDY ON STRENGTH PROPERTIES OF WOOD PLASTIC BONDED BOARDS PRODUCED FROM COFFEE CHAFF AND *CEIBA PENTANDRA* SAWDUST

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Abstract:
Strength properties of Wood Plastic-bonded Boards (WPBB) of 10mm in thickness were produced in this study from two lignocellulosic materials coffee and recycled low density polyethylene (rLDPE) as a binder. WPBB were produced from particles of coffee chaff and Ceiba pentandra, at three levels of mixing ratio (1:1, 2:1 and 3:1), and at three levels of board density (500, 600 and 700kgm^{-3}) given the total treatment combinations of 18 respectively. Effects of lignocelluloses particles, mixing ratio (MR) and board density (BD) on flexural strength properties of the WPBB were investigated. The flexural strength of the WPBB range from 0.25 to 4.79N/mm^2 and 891.00 to 16415.87N/mm^2 for modulus of rupture (MOR) and modulus of elasticity (MOE) respectively. The statistically results shows that the main factor and interaction factors were significantly different at P≤0.05 level of probability. It was observed in this study that as the plastic content with density increased, flexural strength of the boards increases. The study showed that WPBB made from coffee chaff particles are stiffer and stronger than WPBBs made from Ceiba pentandra particles. Based on the outcome of the results in this study, coffee chaff could as well be used as filler in the polymer industry to produce stronger biopolymer composite for structural applications. This study would form a baseline strategy for further research efforts on production of composite from agro-residues wastes.

Key words: *Ceiba pentandra; coffee chaff; flexural; wood plastic-bonded board.*

INTRODUCTION

Composites manufacture is a technology that involves binding of materials made from a combination of wood particles of various forms (shaving, flour, flake, and powder), Mastic and chemical additives together to produce panel-like products. Composite technology can simply base on breaking woody material down to some smaller parts, such as a veneer, particle, flake/strand, or fibre, then reassembling these elements using Mastic, such as resin, starch, or natural fibre–fibre hydrogen bonding, into lumber- or panel-like bio-composite products (Youngquist 1995). Wood composite technologies (plywood, particleboard, flakeboard and hardboard) have for decades been used to create value-added commodity for building and home furnishing products likes ceiling boards, floor and wall tiles.

More recently, new innovative bio-composite products on natural fibres, such as agricultural fibres or residues, or on wood–natural fibre hybrids, have also come on the market and now compete directly with traditional wood composites. Other similar new hybrid products, such as wood- or natural fibre–plastic composites, have recently become popular for decking, siding, roofing, fenestration, and millwork. Traditionally, plastic industry presently uses inorganic fillers such as talc, calcium carbonate, mica, and glass or carbon fibers to fill and to modify the performance of thermoplastic. About 3.5 mil.t: of fillers are currently used in plastic industry (Barbu and Paulitsch 2015, Caulfield *et al.* 2005, La

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Mantia *et al.* 2005, Clemons 2002). This provides rigidity and resistance to temperature (Abu-Sharkh *et al*. 2004, Mengeloglu *et al.* 2000) but costly and abrasive to the processing equipment (Mengeloglu and Matuana 2003, Matuana *et al*. 1998).

The introduction of wood in plastic industries was attributed to the properties displayed which include improved strength properties, high dimensional stability, environmental friendly and resistance to insect and fungal attack (Falk *et al*. 2002). The use of wood flour in plastic products is expected to increase due to the high demand for Wood Plastic Composite (WPC) in the construction industry for decking, siding, roofing, tiles and window frame (Eckert 2000). The interest in using plastic as binder in composite board is attributed to its properties displayed. The advantages of using organic fillers (wood and agro-residues) in thermoplastics can be attributed to its low densities, low cost and non-abrasive in nature (Sanadi *et al.* 1994, Clemons 2002, Mengeloglu and Matuana 2003, Abu-Sharkh *et al*. 2004, Caulfield *et al*. 2005). The possibility of high filling levels, low energy consumption, high specific properties, biodegradability, availability of a wide variety of fibers throughout the world, and generation of a rural/agricultural-based economy potentials could be well addressed with wood- and agro-composites (Matuana *et al*. 1998, Chen *et al*. 1998). Many researchers have reported agricultural plant as a good source of raw material for organic fillers in the production of thermoplastic composites using plant flour or fiber including hemp, flax, jute, sisal, bagasse, ramie and kapok (Gassan and Bledzki 1997, Backiel 1995). The large volume of lignocellulosic waste particles generated daily in agro- and Wood based industries of the developing countries are becoming environment menace, instead of daily burning of these wastes that resulted to climate damaging, it will be an advantage for climate change control if used for the production of valuable products. Therefore, this project aim to produce, investigate and compare the flexural properties of WPBB produce from *Ceiba pentandra* and coffee chaff waste particles.

MATERIAL AND METHOD

Coffee chaff waste was collected from coffee production milling industry at Ikare -Akoko, Ondo State, while *Ceiba pentandra* sawdust was collected from the saw mill section of Forest Products Development and Utilization Department, Forestry Research Institute of Nigeria, Ibadan, Oyo State. The particles were thoroughly sieved with wire mesh of size 250µm to select only the fine powder. The particles were oven dried at 103^0C for 24 hours to attain 4% moisture content; this was to prevent bubbles formation inside the resulting boards. The rLDPE employed in this study was collected from dumping site of plastic packaging industry (Primos packaging industry at Akure, Ondo–State). Plastic waste from packaged sachets were thoroughly washed in cold water to remove stains, air-dried and milled into powder particle using 50 ton pulverize hammer mill machine available at Aleshinloye recycling plant, Ibadan, Oyo State, the plastic particles was thoroughly sieved with wire mesh of size 250µm to get equal sized particles with the lignocelluloses particles employed. Appropriate quantity of lignocellulosic and rLDPE particles were weighed accordingly to the varied plastic/fibre mixing ratio of 1:1, 2:1, and 3:1 (w/w). The pre-determined and nominal board densities of the boards were based on 500, 600 and 700kg/m^{-3} respectively.

Composite board formation

Particles were thoroughly hand mixed together and fed into a locally fabricated single screw extruder machine constructed by Alex Engineering Company, Ibadan, and Oyo State. The machine consists of screw diameter and length of 63 and 1090mm, while the extruder consists of four compartmental zones which include the feeding hopper (Fig. 1) as zone 1, coolant chamber (Fig. 2) as zone 2, the heater and mixer (Fig. 3) as zone 3 and lastly is the square shape die (mould) (Fig. 4). The mixed particles was fed through the feeding hopper, mixed and blended thoroughly in zone 2 and 3 and passes through the coolant chamber un-melted to zone 3 for proper mixing under specific temperature and pressure of 185 – 200^0C and 175N to produce compounded strand, the stranded materials were conditions under water bath at temperature of 26^0C before pelleted using a fabricated polymer pelletizer. The pellet materials were oven dried at 65^0C for 24h and uniformly spread inside aluminium mould of size of 300x300x10mm and platen pressed with 30 ton capacity hot press machine at temperature of 170^0C for 45 minutes with exerted pressure of 230N. WPBB produced was removed 65^0C and stacked under a controlled room condition at temperature of 26 ± 2^0C and relative humidity of 65 ± 2% prior to properties determination.

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Fig. 1.
Feeding hopper

Fig. 2.
Coolant

Fig. 3.
Heaters

Fig. 4.
Die (moulder)

Strength properties

Test specimen of 10mm (thickness) × 50mm (width) × 195mm (length) was subjected to Hounsfield tensiometer machine available at Timber Mechanics Unit of Forest Products Development & Utilization Department to test for flexural strength of the boards in accordance with British Standard D373 (1989). The three-point bending method at a load cell of 125 pounds and load frame of 100mm was applied to the specimen until failure occurred. MOR and MOE data were calculated based on these formulas below:

$$\text{MOR (N/mm}^2\text{)} = \frac{3\rho L}{2bh^2} \tag{1}$$

where: MOR = Modulus of rupture (N/mm^2), P = the ultimate failure load (N), L= the board span between the machine supports (mm), b = width of the board sample (mm), h = thickness of the board sample (mm).

The modulus of elasticity was determined from the bending test performed on each specimen and MOE was calculated using the formula:

$$\text{MOE (N/mm}^2\text{)} = \frac{\rho L^3}{4\Delta bd^3} \tag{2}$$

where: MOE = modulus of elasticity (N/mm^2), P = Load (N), L= the span of board sample between the machine supports (mm), b = width of the board sample (mm), d = thickness of the board sample (mm), Δ = gradient from the slope.

Data analysis

A 2x3x3 completely randomized design factorial experiments was conducted to investigate the effects of lignocellulosic particles (*Ceiba pentandra* and coffee chaff), plastic/wood mixing proportions (1:1, 2:1 and 3:1) and nominal densities (500, 600 and 700kgm^{-3}) on tensile strength of the WPBBs. Based on the factorial experiment, a two way analysis of variance (ANOVA) was conducted to determine the effects of main and interaction factors. The separation of mean values for board samples were compared using Duncan Multiple Range test (DMRT) at 5% level of probability.

RESULTS AND DISCUSSION

Bending strength

The MOR average values are presented in Table 1 and the mean values range from 1.39 to 4.79N/mm^2 in WPBB made from coffee chaff particle. The mean values for MOR range from 1.39 to 2.24N/mm^2 for rLDPE/agro ratio of 1:1, 2.01 to 4.05N/mm^2 for ratio 2:1 and 2.35 to 4.79N/mm^2 for ratio 3:1. Meanwhile, the mean values for the MOR of WPBBs produced from *Ceiba pentandra* sawdust range from 0.25 to 0.54N/mm^2 for rLDPE/wood ratio of 1:1, 0.38 to 0.55N/mm^2 for ratio 2:1 and 0.46 to 0.71N/mm^2 for ratio 3:1 respectively. The MOR of the boards increase with increased in the plastic/particle proportion as illustrated in Fig. 5. Similarly, the mean values for the MOR of board densities range from 1.39 to 4.79N/mm^2 for WPBBs made from coffee chaff while for *Ceiba pentandra,* the mean values for MOR from densities range from 0.25 to 0.71N/mm^2 respectively. Fig. 5 shows that irrespective of the lignocellulosic material, MOR values increased with increase in plastic content. This observation might be as a result interactions between the agro- particle and plastic particle, there was higher compatibility force between the plastic and agro particle than the wood particle, the weigh per weight interaction bond between the plastic and agro-particle might have resulted into the higher MOR values obtained for boards made from coffee chaff than the *Ceiba pentandra.* The mechanical and chemical characteristics of each lignocellulosic particle with polymer might also be other advantages, the bulk weight of coffee chaff made it to be heavier than the wood employed. The values obtained in this study are within the range of values reported in previous findings by (Aina *et al*. 2013, Aina and Fuwape 2008, Aina *et al.* 2008, Terry *et al.* 2000, Stark *et al*. 2003). The boards made from rLDPE/lignocellulosic particles of 3:1 were stronger while the boards at 700kgm^{-3} were better in terms of strength than lowest densities of 500kgm^{-3}. The MOR values of coffee chaff plastic bonded composite increased in MOR by 2.45% to 1.84% of WPBBs made from *Ceiba pentandra.* This shows that the structure-like nature and weight exhibited in each particle has significant influence on the bending force assessed, the higher the plastic proportion and density in the matrices the stronger the board. These observations agree with (Ajayi 2006). Each lignocellulosic particle mixed with polymer leads to strong reinforcement in the matrices thereby creates more compacted WPBB which resulted in increased load to applied stresses.

Stiffness in bending

The MOE average values are presented in Table 1 and the mean values range from 4833.6 to 16415.87N/mm^2 in WPBB made from coffee chaff particle while the mean values range from 4833.6 to 8514.3N/mm^2 for rLDPE/agro ratio of 1:1, 6599.7 to 15247.4N/mm^2 for ratio 2:1 and 13225.9 to 16415.9N/mm^2 for ratio 3:1. Similarly, the mean values for MOE of WPBBs made from *Ceiba pentandra* sawdust range from 891.0 to 1102.5N/mm^2 for rLDPE/wood ratio of 1:1, 954.2 to 1438.9N/mm^2 for ratio of 2:1 and 1867.9 to 2512.40N/mm^2 for ratio 3:1 respectively. The mean values of MOE of board made from density of 500 to 700kgm^{-3} range from 4833.6 to 16415.9N/mm^2 for coffee chaff while for *Ceiba pentandra*, it range from 891.0 to 2512.4N/mm^2 (Fig. 6). It was observed that MOE increase with increased in the plastic/lignocellulosic proportion and density as illustrated in Fig. 6. WPBB made from rLDPE/lignocellulosic proportion of 3:1 (polymer/lignocellulosic particles) and board density of 700kgm^{-3} are stiffer than the WPBB made from low rLDPE/lignocellulosic proportion of (1:1) and board density of 500kgm^{-3}. It was observed in this study that MOE of WPBB produced from *Ceiba pentandra* were lower to the MOE of WPBB made from coffee chaff respectively. The MOE values of the WPBB from coffee chaff increased by 2.39% to 1.82% of WPBB made from *Ceiba pentandra.* As illustrated in Fig. 6, MOE values increase with increased in polymer/particle ratio and board density. This observation is similar to the previous findings (Stark *et al*. 2003, Terry *et al*. 2000, Rodrinquez 1996). However the values are higher in coffee chaff than the results obtained from previous studies by these authors but there values were almost similar to the values obtained from *Ceiba pentandra* particle. These authors revealed that factor such as mechanical properties of both the wood and plastic should be considered. So also the anatomical and chemical interaction between the wood and plastic tends to affect the strength properties of composite. This might be as a result of bulk weight of the agreement residue employed in this study. The compatibility bonding force between the plastic and the particle might have enhance better interrelation force that allows uniform stress transfer and distribution in the board structure. The density displayed by each of particle could also contribute to the variability in MOE displayed by each WPBB investigated.

The result of analysis of variance is presented in Table 2, the results of analysis of variance shows that all the main factors, two and three interaction factors assessed were significantly different at 5% level of probability. This implies that the density, rLDPE/wood ratio and particle significantly influenced the flexural strength of the WPBB, the two and three interaction factors also influenced the flexural strength of the boards. Following the result of follow up test using Duncan Multiple Ranged Test at 5 % level of probability, the bending strength of the WPBB for coffee chaff composite were better than the *Ceiba pentandra* composite. Furthermore, composites made from higher production variables of rLDPE/lignocellulosic ratio of 3:1 and density of 700kgm^{-3} were better in bending and stiffness strength than the others rLDPE/lignocellulosic ratio and density considered is this study.

Table 1

The mean values of flexural strength of 10mm WPBB made from coffee-chaff and Ceiba pentandra particle

PRODUCTION VARIABLES			BENDING STRENGTH	
Particles	Density (kgm^{-3})	Mixing ratio	MOR (N/mm^2)	MOE (N/mm^2)
Coffee chaff	500	1:1	1.39 ± 0.31	4833.6 ± 391.9
		2:1	2.01 ± 0.89	6599.73 ± 965.78
		3:1	2.35 ± 0.36	13225.87 ± 2579.28
	600	1:1	2.38 ± 0.54	6739.70 ± 1259.07
		2:1	2.57 ± 0.88	13496.30 ± 2220.78
		3:1	3.26 ± 0.28	15921.67 ± 940.33
	700	1:1	2.24 ± 0.27	8514.27 ± 775.48
		2:1	4.03 ± 0.17	15247.40 ± 1487.84
		3:1	4.79 ± 0.19	16415.87 ± 1432.06
Ceiba pentandra	500	1:1	0.25 ± 0.04	891.00 ± 359.10
		2:1	0.38 ± 0.02	954.20 ± 76.50
		3:1	0.46 ± 0.06	1867.90 ± 764.10
	600	1:1	0.45 ± 0.07	1011.90 ± 69.20
		2:1	0.46 ± 0.06	1247.60 ± 406.50
		3:1	0.49± 0.05	1819.10 ± 341.80
	700	1:1	0.54 ± 0.04	1102.50 ± 85.3
		2:1	0.55± 0.05	1438.90 ± 203.90
		3:1	0.71± 0.24	2512.40 ± 751.15

Each value is the mean value of five replicates

Table 2

The result of analysis of variance conducted on WPBB produced from Ceiba pentandra and coffee chaff particle

Source of variance	df	Modulus of elasticity				Modulus of rupture			
		SS	MS	F	Sig	SS	MS	F	Sig
Particle	1	1295037116	1295037116	1077.977	0.000*	71.599	71.599	814.621	0.000*
MRL	2	206297636	103148817.8	85.860	0.000*	5.823	2.911	33.125	0.000*
Density	2	74988886.0	37494442.99	31.210	0.000*	9.049	4.524	51.477	0.000*
Particle x MRL	2	128156422	64078211.12	53.338	0.000*	4.011	2.006	22.819	0.000*
Particle x density	2	55703319.4	27851659.69	23.183	0.000*	5.274	2.637	30.005	0.000*
MRL x density	4	17373987.3	434396.822	3.615	0.014*	1.684	0.421	4.790	0.003*
Particle x MRL x density	4	16686181.4	4171545.347	3.472	0.017*	1.612	0.403	4.585	0.004*
Error	36	43248897.1	12013558.253			3.164	0.088		
Total	53	1837492445				102.217			

*denotes significant at $P \leq 0.05$

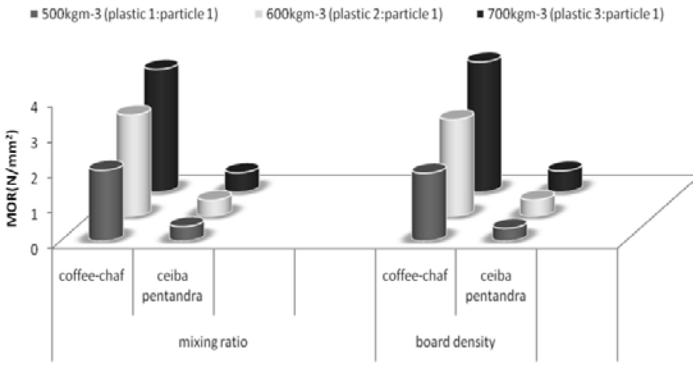

Fig. 5.
Effect of production variables on modulus of rupture of the 10mm thickness wood – and agro-plastic bonded boards.

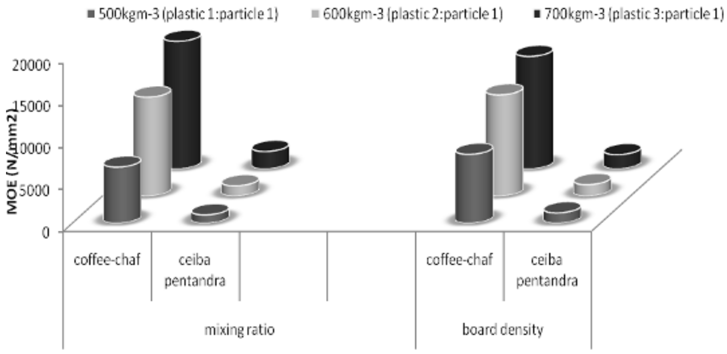

Fig. 6.
Effect of production variables on modulus of elasticity of the 10mm thickness wood – and agro-plastic bonded boards.

CONCLUSION

The mechanical properties of the WPBB made from *Ceiba pentandra* and coffee chaff at three rLDPE/lignocellulosic proportional ratio and with densities were successfully investigated in this study. The flexural strength of the WPBB made from coffee chaff were stronger and stiffer than WPBB made from *Ceiba pentandra.* The flexural strength of WPBB produced at density 700kgm^{-3} and rLDPE/lignocellulosic ratio of 3:1 were better than the others two densities and ratio. Composites made from *Ceiba pentandra* at the same production variables with rLDPE/lignocellulosic of 3:1 and density 700kgm^{-3} shows better strength and stiffness than the others two densities and ratio. The boards made from the wood particle were lower in flexural strength values to composites made from agro particle. Based on the results obtained from this study, it could be concluded that high proportion of polymer added to lignocellulosic particles are of better standard to meet high load bearing structural composite. With the incorporation of Agro residues as filler into the matrices of plastic bonded composite production could as well be favourable advantages in plastic composite manufacturing industry. Agro-residue like coffee chaff could form a baseline strategy for further research efforts on utilizing other agro-residues wastes as alternative raw-materials for the production of WPBB products.

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