

Evaluation of properties of graded density fibreboard produced from wood residues (sawdust and corrugated paper)

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Abstract

Reuse of materials from industrial and services waste streams is pertinent to achieving sustainable forest production. The enormous wood residues generated at sawmill and the disposal of wood-based products poses threat not only to sustenance of the forest resources but also has negative adverse effect on the environment. Limitation exists in the utilization of wood residues as raw material for panel board production in developing countries.

This study examined the physical and mechanical properties of graded density fibreboards produced from varying mixture of sawdust and corrugated paper (pulp) at the Forestry Research Institute of Nigeria (FRIN) in 2019. A 2×9 factorial experiment in one-way analysis of variance was used to test for significant difference between the factors (density and mixing ratio) considered. The results showed that densities of all boards produced varied relating to mixing proportions. The densities increased with increasing content of corrugated paper. Boards produced at 0.45 g/cm³ showed higher density (0.648 g/cm³), bending strength (MOR) (1.47 N/mm²) and lesser water absorption (118.69%) than those produced at 0.65 g/cm³ having values of 0.58 g/cm³, 1.32 N/mm² and 153.67%, respectively. However, boards produced at 0.65 g/cm³ had higher elasticity in bending (MOE) (209.19 N/mm²) and lesser thickness swelling (6.29%) than those produced at 0.45 g/cm³ having values of 74.87 N/mm² and 10.88%, respectively. Panels G (mixing ratio = sawdust : corrugated paper : urea formaldehyde = 20 : 60 : 20), E (30 : 50 : 20) and I (0 : 70 : 20) showed superior features in physical and mechanical properties comparing with panel I being the best mixture. Conclusively, wood residues (sawdust and corrugated paper) are suitable raw materials for fibreboard production.

Keywords: wood residues, reuse, fibreboard, density, physico-mechanical indices

Introduction

The exponential growth of global population and its attendant effect on resources extraction is alarming (Alejandro and Pierre 2017). Hence for sustainable development (SD) on a global scale it is imperative to efficiently utilize environmental resources via research, innovation and value addition in order to ensure a sustainable consumption and production pattern with minimal carbon footprint, as addressed by goals 9 and 12 of SD (UNEP 2016). Efficient utilization of wood resources by forest-based industries is of paramount concern because of its environmental implications especially as carbon sink (Roh et al. 2017). It is well-known that woods are demanded and used as a versa-

tile unrefined material in the world that lots of people have depended on for satisfying various purposes; such as fuel, construction material, farming tools, feedstock for industry, etc. (Jacob et al. 2016). In Nigeria, there are various wood-based industries which convert logs from the forest into useful products for mass consumption generating lots of unused residues from tree off-cuts, sawdust and tree barks (Sekumade and Oluwatayo 2011).

Wood residues generation in Nigeria is constantly at an increasing rate (Peter et al. 2017). This is related to the fact that lumber recovery in the forest as well as sawmilling industries and other wood processing enterprises is generally low. This is not far from the use of obsolete equipment,

reduced size of timber available for processing and low technical know-how (Ogunwusi 2014). Studies show that the Nigerian sawmill industry generates 1.8 million tonnes of sawdust (Sambo 2009) and 5.2 million tonnes of wood residues per annum (Francescato et al. 2008). These residues when left unattended to, begin to decompose thereby releasing methane, which is a very harmful greenhouse gas (GHG) contributing much to global warming. As reported by Odeunmi (2001), when combusted, wood residues cause air pollution as it discharges dangerous substances, like carbon monoxide, sulphur dioxide and nitrogen oxide, to the atmosphere. Polycyclic aromatic hydrocarbons (PAHs) and dioxins presenting in smoke are assumed to be cancer-causing agents (Aina et al. 2009). When these residues are dumped into water bodies, they leach their extractives into water causing water pollution which endangers the existence of aquatic organisms (Ogunwusi 2014). They also obstruct drainage which is leading to flooding during the raining season followed by loss of human lives and possessions (Elijah and Elegbade 2015). These various wood residues disposal practices in Nigeria and Africa at large contrasts with global solid waste management experience which encourage the maximization of recycling potential to achieve efficient and sound use of wood resources (Pianosi 2012).

The enlarged generation of wood residues coupled with the low percentage of timber recovered from forest and wood conversion industries has become a real source of threat to the forest estate ability to sustain the wood industries (Ogunwusi 2014). Various studies have narrated a decrease in the Nigerian Forest Industries (RMRDC 2003, Oriola 2009) which necessitates efficient utilization of wood resources to help rejuvenate the performance of the sector. Authors (Ogunwusi 2014, Jacob et al. 2016, Peter et al. 2017) recommended that these residues can serve as useful resources for producing engineered wood products of which fibreboard is the most important one.

Fibreboard is an important option for utilization of wood residues in Nigeria (Peter et al. 2017). Fibreboards find a variety of ways into manufacturing furniture, kitchen cabinets and counters, doors, bookcases, moulding and shelving. In recent times the utilization of medium density fibreboards (MDFs) has increased considerably worldwide. In 2012 Canada and the U.S.A. manufactured 440,000 m³ and 1,600,000 m³ of MDFs, respectively. Currently, China fabricates more than 40% of the global MDF production supplying the speedily increasing national furniture industry (Natural Resources Canada 2016). Furthermore, in the continuing effort to sustain the stability of Nigeria's foreign exchange (Central Bank of Nigeria 2015), it has become imperative to develop adequate technology for the production of fibreboard, which will contribute in conserving Nigeria's foreign exchange reserves and encourage the local production of commodities.

For efficiency of resource use, sawdust as a derivative of cutting, drilling, sanding or macerating wood with saw

(Rizki et al. 2010), and corrugated paper as a product of pulping process with timber as raw material, which is used for packaging industrial products by many manufacturers were considered as the raw materials for this study. The aim is to promote the production of value-added products as well as to help reduce first negative environmental and ecological consequences of unacceptable discarding of these residues (Ogunwusi 2014). Although over the years many products have been generated from wood residues (Cocca et al. 2011), there is limited information on the use of corrugated cardboard and sawdust for fibreboard production. Therefore, this study examined the physico-mechanical properties of fibreboards made of sawdust and corrugated cardboard with a view to ensure sustainable use of wood industry resources.

Materials and methods

The experiment was conducted at the Forestry Research Institute of Nigeria (FRIN), Jericho Hills, Ibadan, Oyo State, Nigeria. Sawdust of *Gmelina arborea* was obtained from a wood workshop in Ibadan during wood conversion process while corrugated paper was procured from local dealers of electronics in Ibadan. The sawdust of *Gmelina arborea* was sieved with a 2.00 mm sieve mesh to obtain uniform material, as well as to remove impurities, and thereafter sundried for three (3) days to minimize moisture content. The corrugated paper was shredded into pieces and soaked for (3) days to de-pulp into mesh. The de-pulped paper was pulverized to obtain short fibres and subsequently sundried to reduce moisture content in it.

Appropriate quantities of each material, sawdust, corrugated paper and adhesive, were weighed according to the production variable densities (0.45 g/cm³ and 0.65 g/cm³) and mixed at the following ratios: 40:40:20 (A), 80:0:20 (B), 0:80:20 (C), 50:30:20 (D), 30:50:20 (E), 60:20:20 (F), 20:60:20 (G), 70:10:20 (H), and 10:70:20 (I) with three (3) replicates. A known weight of sawdust and corrugated paper were manually mixed into a homogenous material for about 10 minutes. A known weight of urea formaldehyde was added to the mixture and thoroughly mixed. The mixture was fed into a wooden mould with dimension of 35×35×1 cm and pre-pressed. The moulded boards were conveyed into a hydraulic press for 24 hours to get firm. Then obtained boards were demoulded and stacked to dry for 3 days.

Specimens were cut from the experimental panels at room temperature of 23°C for mechanical (modulus of elasticity and rupture) and physical properties (density, water absorption (WA), thickness swelling (TS) tests. Measurements of the modulus of rupture (MOR) and the modulus of elasticity (MOE) were performed in conformance with the test methods described in ASTM D1037 (ASTM 1998, 2006) using an universal testing machine while thickness swelling and water absorption measurements were carried out by immersing specimens in water horizontally for 24 hours at ambient temperature.

The experiment was designed according to the scheme of completely randomized 2×9 factorial one. Data obtained were analysed using one-way ANOVA.

Results

The tests of physical properties of the board showed that panel C (0.95 g/cm³) had the highest mean density (HMD), while the least density was recorded in panel H (0.45 g/cm³) as shown in Table 1. For panel boards produced at 0.45 g/cm³, the HMD value of 0.09 ±0.01 g/cm³ was observed in panel C, while the least values (0.05 ±0.00 g/cm³) were observed in both panel B and H (Figure 1). For panel boards produced at 0.65 g/cm³, the HMD (0.10 ±0.01 g/cm³) was observed in panel C comparing with panel F and H which have the least density of 0.04 ±0.00 g/cm³. It was observed from the mean values that most of the boards produced at 0.45 g/cm³ had higher mean values compared to those produced at 0.65 g/cm³ (Figure 1).

Water absorption of composites is of great concern, particularly for possible indoor and outdoor use. The TS of a composite board is relative to its water absorption (WA). The mean WA of panel boards with varying mixing ratio ranged from 99.46% to 157.34% with panel C and F having the least and highest values of the index as shown in Table 2. For panel boards produced at 0.45 g/cm³, the highest and least WA was recorded in panel F (143.90 ±16.37%) and panel G (92.26 ±20.07%) respectively as shown in

Table 1. Mean value for density of panel boards

Panel	Mixing ratio (%)	Density (0.45 g/cm ³)	Density (0.65 g/cm ³)	Mean
A	40/40/20	0.05 ±0.00	0.05 ±0.01	0.48a
B	80/0/20	0.05 ±0.01	0.07 ±0.01	0.60b
C	0/80/20	0.09 ±0.01	0.10 ±0.01	0.95a
D	50/30/20	0.07 ±0.01	0.05 ±0.00	0.58b
E	30/50/20	0.07 ±0.00	0.05 ±0.01	0.58b
F	60/20/20	0.05 ±0.01	0.04 ±0.00	0.46a
G	20/60/20	0.08 ±0.01	0.06 ±0.01	0.70c
H	70/10/20	0.05 ±0.00	0.04 ±0.00	0.45a
I	10/70/20	0.08 ±0.01	0.07 ±0.01	0.72c

Note: Means with the same alphabetical symbols are not significantly different (*P* < 0.05).

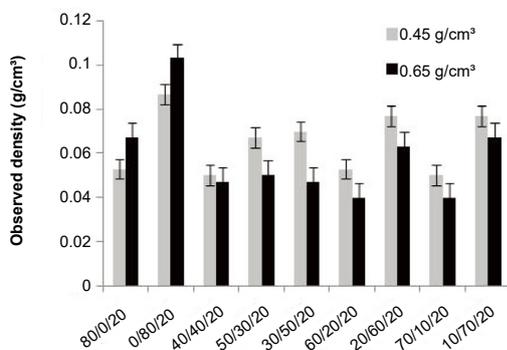


Figure 1. Density of fibreboard produced at varying densities and mixing ratios

Figure 2. For panel boards produced at 0.65 g/cm³, panel E had the highest WA (188.40 ±7.12%) while panel C had the least WA (105.96 ±6.06%).

The TS of panel boards produced (Table 2) ranged from 5.64% in panel F to 14.25% in panel G. Panel G (17.58 ±1.41%) and H (7.87 ±1.96%) had the highest and least thickness swelling for 0.45 g/cm³ while Panel G and A had the highest and least TS of 10.93 ±3.79% and 4.00 ±3.49%, respectively, for 0.65 g/cm³ as shown in Figure 3. The value for TS after 24 hours of immersion in water was below 12% for all panel boards except for panel G having a value of 14.25%. The result of analysis

Table 2. Mean value for water absorption of panel board

Panel	Mixing ratio (%)	Water absorption	Thickness swelling
A	40/40/20	145.63c	7.07ab
B	80/0/20	145.13c	7.23ab
C	0/80/20	99.46a	8.01ab
D	50/30/20	145.41c	7.28ab
E	30/50/20	146.47c	10.09ab
F	60/20/20	157.34c	5.64a
G	20/60/20	112.42ab	14.25c
H	70/10/20	150.08c	6.03a
I	10/70/20	123.72b	11.74bc

Note: Means with the same alphabetical symbols are not significantly different (*P* < 0.05) from each other.

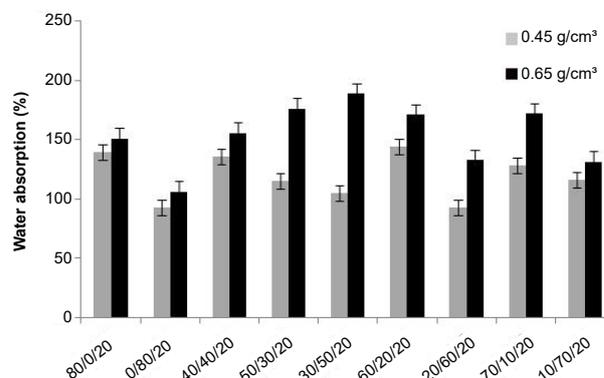


Figure 2. Water absorption of fibreboards produced at varying densities and mixing ratios

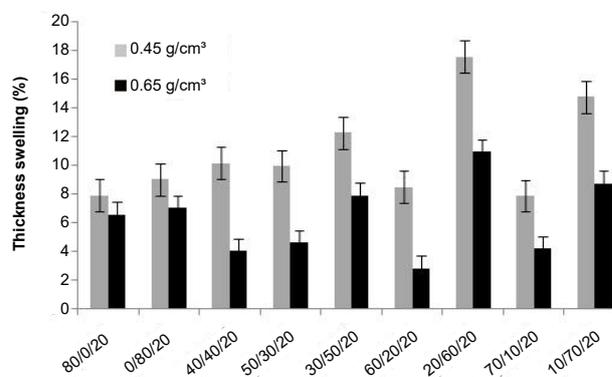


Figure 3. Thickness swelling of fibreboards produced at varying densities and mixing ratios

of variance presented in Table 3 revealed that all factors (observed density, thickness swelling and water absorption) considered in the study were significantly different ($P > 0.05$), while factor interaction of density and mixing proportion were not significant at 5% level of probability.

The result of the mechanical properties of the fibreboards is presented in Table 4. The mean value for the modulus of elasticity (MOE) of the boards produced from varying mixtures of sawdust, corrugated paper and adhesive ranged from 50.48 N/mm² to 236.72 N/mm² recorded by panel C and G, respectively. For the boards produced at 0.45 g/cm³, panel E had the highest MOE (129.32 N/mm²) while panel C had the least one (32.48 N/mm²) as shown in Figure 4. Boards G (361.57 N/mm²) and C (68.48 N/mm²) had the highest and least MOE for fibreboards of 0.65 g/cm³. Fibreboards with 0.65 g/cm³ had higher MOE values than 0.45 g/cm³.

The mean modulus of rupture (MOR) (Table 4) for the boards ranged from 0.67 N/mm² to 1.88 N/mm². The MOR of 2.07 N/mm² (panel E) and 0.47 N/mm² (panel C); and 2.15 N/mm² (panel I) and 0.86 N/mm² (panel C) have the highest and least values as observed in boards of 0.45 g/cm³ and 0.65 g/cm³, respectively (Figure 5). Majority of the boards made from 0.65 g/cm³ had higher MOR values than 0.45 g/cm³ except for panel A, E and F.

The analysis of variance showed that significant difference among MOE, MOR and their interactions existed, as presented in Table 5.

Table 3. Results of analysis of variance for physical properties of fibreboards

Source of variation	Degree of freedom	Density	Water absorption	Thickness swelling
Density	1	0.00*	0.00*	0.00*
Mixing proportion	8	0.00*	0.00*	0.02*
Interaction	8	0.00*	0.00*	0.95N.S
Error	36			
Total	53			

Notes: * Significant; N.S stands for Not significant. Source: Data analysis (2019).

Table 4. Mean value for modulus of elasticity and rupture of fiberboards

Panel	Mixing ratio (%)	Mean MOE	Mean MOR
A	40/40/20	126.54c	1.14bc
B	80/0/20	68.44d	1.32b
C	0/80/20	50.48d	0.67d
D	50/30/20	108.99c	0.95c
E	30/50/20	213.65ab	1.88a
F	60/20/20	134.28c	1.23b
G	20/60/20	236.72a	1.70a
H	70/10/20	142.85c	1.27b
I	10/70/20	196.34b	1.74a

Notes: Means with the same alphabetical symbols are not significantly different ($P < 0.05$) from each other. Source: Data analysis (2019).

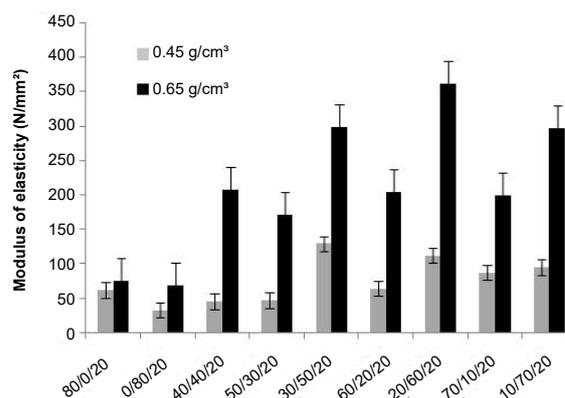


Figure 4. Mean Modulus of elasticity of fibreboards produced at varying densities

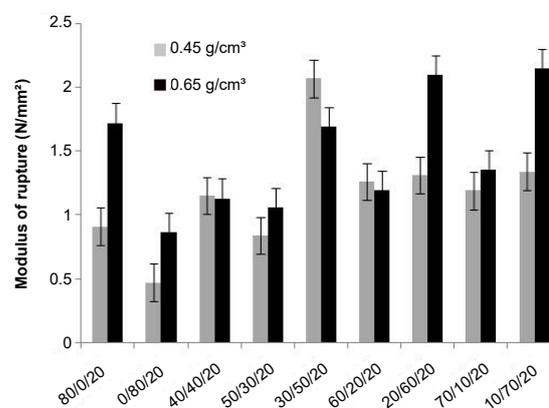


Figure 5. Mean Modulus of rupture of fibreboards produced at varying densities

Table 5. Results of analysis of variance conducted for mechanical properties of fiberboards

Sources of variation	Degree of freedom	MOE	MOR
Density (D)	1	0.00*	0.00*
Mixing ratio (MR)	8	0.00*	0.00*
Interaction	8	0.00*	0.00*
Error	36		
Total	53		

Notes: * Significant. Source: Data analysis (2019).

Discussion and conclusion

Density expresses the quantity of a material present in a specified volume, while the board density is a proportion of dry weight to its volume (Erwinsyah 2008). Mohd Yunus et al. (2018) cited that higher density boards have more intimate contact among particles. The higher density value of panel boards of 0.45 g/cm³ implied that the panel boards produced at 0.45 g/cm³ adhere better, when compared to those produced at 0.65 g/cm³. This may be because of the panel thickness of board produced at 0.65 g/cm³. Most mechanical properties of boards are strongly linked to density (Yuhui et al. 2020). It was also observed that with increase in the paper content, there was a corresponding increase in the observed density. This observation is diverged with the

study of Odusote et al. (2016) who produced paperboard briquettes from a mixture of shredded wastepaper (pulp) and sawdust using starch as binder.

The increase in water absorption and thickness swelling with increased corrugated paper content in the board is like the findings of Ellis (1993), Jaber (2013) and Nasir et al. (2014). These authors reported that water absorption and thickness swelling increases with increasing paper content in fiberboards and paperboards because of the hydrophilic nature of paper. The higher water absorption percentage observed in all boards produced at 0.65 g/cm³ when compared to boards produced at 0.45 g/cm³, corroborates the report of Akbulut and Ayrimis (2019) who observed that MDF with higher densities absorbs less moisture compared to those of lower densities. The reduced value of the boards thickness swelling after 24 hours immersion in water guaranteed their dimensional stability and suitability for use as a material for interior application and furniture production (I.S. EN 622-5: 2009).

The increased MOE and MOR with increased corrugated paper content of the boards corroborates the finding of Ellis et al. (1993) and Jaber (2013), who observed a linear relationship between the MOE and paper content in a composite produced from phone books and various waste vinyl products; as well as fibreboards produced from old newspapers, respectively. However, it is contrary to the observations of Nourbakhsh et al. (2010), who reported that mechanical properties of panel boards decrease with increasing paper content in MDF made from old newsprint fibres. The obtained values of bending strength and the modulus of elasticity in bending of tested panel falls below the minimum values for general purpose fibreboard but can be used for indoor roofing and furniture (20 N/mm² for the bending strength and 2200 N/mm² for the modulus of elasticity in bending) (EN622-5: 2009).

The experiment revealed that corrugated paper was the major determinant of the properties of the panel boards produced as it significantly influenced both the physical and mechanical properties. However, the influence of the corrugated paper on water absorption negatively influenced the dimensional stability of the panel boards. It was also observed that panels with more paper content included in panels E (sawdust : paper : urea formaldehyde = 30 : 50 : 20), G (sawdust : paper : urea formaldehyde = 20 : 60 : 20) and panel I (sawdust : paper : urea formaldehyde = 10 : 70 : 20) showed greater physical and mechanical properties alike in the others. The panel boards produced from a combination of sawdust and corrugated paper has a prospective used as a substitute to wood especially for interior soft woodwork.

This study has proved that corrugated paper with addition of sawdust can serve as suitable raw material to produce panel board. Their utilization will help reduce the wasteful deterioration of sawdust at mill site and burning of corrugated paper by consumers thereby

reducing the release of GHGs to the atmosphere. Furthermore, the maximum utilization of wood resource will be achieved as soon as corrugated paper and sawdust will be involved as raw materials for production of panel board leading to value addition of these residues. This in turn will stimulate sustainable utilization of wood resource.

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