EFFECT OF PARTICLE SIZES ON THE PHYSIO-MECHANICAL PROPERTIES OF BAMBOO PARTICLEBOARD

ABSTRACT

The focus on timber species as the main source of raw material for wood based panel is alarming. This research work evaluated the effect of particle sizes on bamboo particleboard. The study was carried out in the Scientific Equipment Development Institution, Awkuke Enugu State. Laboratory tests were conducted both for physical and mechanical properties of the board at the Fredrick Research Centre, Agbani in Enugu state. Board density, moisture content and weight were variables measured for physical properties while internal bond, Modulus of elasticity (MOE), Modulus of rupture (MOR) were measured for mechanical properties using Shimadzu Universal Testing Machine. Data collected were analyzed using analysis of variance (ANOVA) and significant means separated with Duncan Multiple Range Test (DMRT) at 5% level of probability. Results recorded that T1 (fine particle) at 1.0 mm had higher values of MOR, MOE and internal bonding at 29.57, 1958.10 and 1.54 respectively followed by T3 (mixture of fine and coarse) and T2 (coarse particles). T2 had the highest moisture content of 8.22%, followed by T3 8.05% and T1 7.91% while T1 had the highest density (0.364g/cm^3) and weight of 1.13 kg respectively. This study showed that particleboard made of fine particles (T1) of bamboo at 1.0 mm had better properties than T2and T3 in terms of their mechanical properties and physical properties with the exception of moisture content. It could be proposed that the finer the particles, the higher the strength of the board, thus recommends that smaller particles sizes like 0.5mm, 0.1mm and 0.3mm be used to increase the board strength.

Keywords: Bamboo, Particleboard, Mechanical properties, Physical properties, wood based product.

INTRODUCTION

The demand for composite wood products, such as plywood, oriented strand board (OSB), hardboard, particleboard, and fiberboard have increased tremendously as a result of improvement in technology leading to decline in timber resources in natural forest. Successful development of wood-based panels can be attributed to the economic advantage of low-cost wood, other lignocelluloses fibrous materials, and inexpensive processing with various types of binders (Anon, 2003). The use of renewable biomass as a raw material in wood panel production is one approach to solving the problem of scarce resources (Rowell, 1995). Today renewable biomass is mostly accepted as waste materials for particleboard production and it seems that the manufacture of particleboard from recycled wood-based wastes is the most common way to reuse such waste materials (Yang, 2007, Lykidis, 2008).

Particleboard has become one of the most popular wood-based composite materials for integrating decoration because of its low density, good thermal insulation, sound absorption, and wonderful machining properties. Particleboard which is mostly utilized of all wood based panels consumes about 57% of all wood panels and its use is increasing 2-5% annually (Drake, 1997). The challenging effect of deforestation, forest degradation, and increasing demand for wood based panels has led to a shortage of raw materials in the sector for a long time (Colak, *et al.*, 2007). There is therefore, need for alternative source of raw materials for panel production to reduce the demand on forest resources. One of these alternative materials is bamboo.

Bamboo represents one of the greatest potential alternative non-wood materials that can be utilized as raw material for making particleboard since it is a lignocellulosic material with a high amount of lignin, cellulose, and fiber (Li, 2004). According to Calegari *et al.* (2007), the interest in this material has increased worldwide because it is a perennial plant, renewable, fast growing resource of high productivity by area, low cost and diverse use. In addition, it is considered an excellent carbon sequester. It has a very high strength and can be used as a structural material and is found mostly in tropical and sub-tropical zones (Papadopoulos *et al.,* 2004; Pannipa *et al.,* 2011). It has higher tensile strength than other wood (Zeng *et al.,* 1995). To optimize development in the forest industry, the need to develop bamboo as a sustainable, climate friendly alternative that has potentials for alleviating the social and environmental problems in Nigeria has become imperative.

Materials and Methods

Study Area

This study was carried out in the Scientific Equipment Development Institution, Awkuke Enugu State. The institution is located at the South Eastern part of Nigeria. It lies between latitudes 6.26211˚N-6.38469˚N and longitude 7.28572˚E-7.49339˚E. Scientific Equipment Development Institute (SEDI), Enugu is an institute under the National Agency for Science and Engineering Infrastructure (NASENI). It is located at Akwuke, Enugu South Local Government Area. The institute is actively involved in research and popularization of science research results which have been of great help to the growth and development of the nation.

Data Collection

Material Procurement: Bamboo culms were procured from Gariki timber market in Enugu South Local Government Area. Bamboo culms were converted into strips using chipper machine and then hammer mill machine was used to reduce the strips into chips of different sizes at Scientific Equipment Development Institution, Awkuke Enugu state. After conversion, wood chips were sieved and categorized into coarse size of 2.00 mm and fine size of 1.00 mm. Wood particles were oven dried for about 24 hours at temperature 60±2°C to obtain uniform moisture content. Sodium silicate solution commonly known as water glass at 70% solid content (SC) was used as Adhesive.

Particle Preparation and Board Fabrication: Board were produced using a laboratory ring-type flaker to reduce the waste to required sizes. All particles were initially screened and then dried in an oven at 60 C to a moisture content of less than 10% prior to adding adhesive. 1kg of each particle size with 60 cl of adhesive (Sodium Silicate) were used in production of each board. Randomly, oriented homogenous boards of 370 mm x 370 mm of 1.0-inch thickness were fabricated at different density levels ranging from 0.49 to 0.81 g/cm^3. Sodium Silicate solution at 70% solid content was applied to the board using a pressurized spray gun in a box-type blender. No waxes or other additives were applied. Hand-formed mats were pressed manually with a hard board and sundried for 24 hours.

Laboratory Test

The tests were conducted both for physical and mechanical properties of the board at the Fredrick Research Centre, Agbani Enugu state. Then, all boards were trimmed along the edges to obtain uniform size of 370 mm x 370 mm rectangles. The following properties were determined in accordance with appropriate Japanese Industrial Standard (JIS, 1994); board density, moisture content and weight for physical properties while internal bond, Modulus of elasticity (MOE), Modulus of rupture (MOR) were measured for mechanical properties using Shimadzu Universal Testing Machine.

Determination of physical and mechanical properties

Modulus of rupture (MOR): The static bending tests were carried out in accordance with British Standard Method BS 373 (British Standard, 1957). The tests were performed using universal testing machine at the Fredrick Research Centre. Samples dimension of (370 mm × 370 mm × 25 mm) were subjected to three-point bending test on the universal testing machine with varying load and were replicated three (3) times. The bending strength of wood usually expressed as MOR which is the equivalent fiber stress in the extreme fibers of the specimen at the point of failure, was then calculated using the expression below;

$$\text{MOR} = \frac{3pl}{2bd^2} \qquad 1$$

Where:

MOR = Modulus of rupture (N/mm^2)

p = load needed for failure (N)

l = span of the material between support (length) (mm)

b = width of the material (mm)

d = thickness of the material (mm)

Modulus of elasticity (MOE): Universal testing machine was used to obtain the force needed to reach elastic limit and its displacement. The modulus of elasticity was carried out using standard test specimen with dimension 370 mm × 370 mm × 25 mm from the MOR test and then corresponding MOE was recorded and replicated three (3) times. MOE was calculated using the formula below:

$$\text{MOE} = \frac{pl^3}{4bd^3{}_\Delta} \qquad 2$$

Where:

MOE = Modulus of elasticity (N/mm^2)

p = the failing load (N)

l = the specimen span between centers of support (mm)

b = width of the specimen (mm)

d = thickness of the specimen (mm)

Δ = the displacement at beam Centre at proportional load (slope from the graph) (mm)

Tensile strength or internal bonding: The z-directional tensile tester (ZDTT) was used to obtain the strength of the board before the deformation. The standard test specimen with dimension (370 mm × 370 mm × 25 mm) were subjected to the tester and anchored at both ends. As the tester was pumped manually both tensioned ends were stretched till it split. This was replicated three (3) times. The tensile strength was calculated using the formulae

$$\delta t = W_t \, b \times t \qquad 3$$

Where, δt = Tensile stress (N/mm²),

W_t = Failure tensile load (N)

b = Breadth of the specimen (mm) and

t = Thickness of the specimen (mm)

Moisture content

The test wood samples of (370 mm × 370 mm × 25 mm) were weighed with an electronic weighing balance. The initial weight was recorded and the test wood samples were placed in the oven at temperature of 103℃ $\pm$ 2 cool in a desiccators containing silica gel and weighed at interval until constant weight was obtained and this was replicated three (3) times. Moisture content was calculated in accordance with ASTMD 4442-84 (1984) using the equation:

$$\text{MC} = \frac{Wm - Wo}{Wo} \times 100 \qquad 4$$

Where:

MC = Moisture content

Wm = Weight of the wood samples before oven drying (g)

Wo = Weight of the test wood sample after oven drying (g)

Wood density: The wood density was determined using samples of (370 mm × 370 mm × 25 mm). All samples were weighted with electronic weighing balance while the volume of each sample was computed based on their dimensions. The samples were oven dried at a temperature of 103℃ $\pm$ 2 and weighed at interval until constant weight was obtained. The Samples were allowed to cool, over dry silica gel in a desiccator, weighed and their dimensions were measured with digital caliper. This procedure was replicated three (3) times. Density was then calculated as follows:

$$\rho = \frac{Wo}{Vo} \text{ --------------------------------------- } 5$$

Where:

ρ = density (kg/m^3)

Wo = oven dry weight (kg)

Vo = volume (m^3)

Data Analysis

Data obtained from laboratory test were analyzed using Analysis of Variance (ANOVA) and significant means separated using Duncan Multiple Range Test (DMRT) at 5% level of probability.

Result and Discussion

Mechanical Properties of Bamboo Particleboard

Table 1 showed the results of mean values of mechanical properties of bamboo particleboard which include: internal bonding (1.50), MOR (25.67) and MOE (1885.96). Result (Table 1) also revealed that T1 (fine particle) at 1.0 mm had highest mean values of MOR, MOE and internal bonding at 29.57, 1958.10 and 1.54 respectively. This was followed by T3 (mixture of fine and coarse) while T2 had the lowest values MOR, MOE and internal bonding (IB) of 21.74, 1804.20 and 1.48 respectively. Modulus of rupture and modulus of elasticity are the two variables usually used in the evaluation of the bending performance of timber in structural sizes. The MOR and MOE may vary among species and it is caused by density and the moisture content of that species. In this study, particleboard made with particle size of 1.00 mm (Fine particles) had the highest MOE, MOR and IB values. However, this study revealed that there was significant difference among the treatments (MOR, MOE and IB of board particle) as the particle sizes increased demonstrating that the particle size distribution influenced mechanical properties. This is in line with the report of Scatolino *et al.* (2013) who reported that finer and thinner particles yield higher aspect ratio, larger surface area, increased contact area in the glue line, which contributes to better interaction and thus, better strength. The result of the ANOVA from the follow up test showed that different particle sizes used in this study are significantly different from each other for all the parameters of mechanical properties tested. This could be attributed to the adhesive content applied not enough to cover the larger surface area of smaller-size particles, and therefore the increase in the contact area among particles did not result in sufficient number of adhesive bonds.

Furthermore, adhesive makes a strong connection between particles inside the board (Kong, 2012) and the best mechanical performance is achieved with the smallest particle size. This result is in agreement with the report of Gozdecki and Arnold (2015) who in their study on the effect of wood particle sizes and test specimen size on mechanical and water resistance properties of injected wood-high density polyethylene composite reported that wood plastic composites tensile and flexural properties increased with increasing wood particle size. According to Anisuzzaman *et al.* (2014), Ratkhe *et al*. (2012) and Salaria *et al.* (2013), the absorption and coverage of adhesive determines the bonding quality and board strength needs. This study (Table 1), revealed that the particle size T1 (Fine particles at 1.00mm) had more affinity to adhesive than other treatment leading to highest mean values of MOR, MOE and internal bonding. The differences in the wood type and size have been reported to have a remarkable effect on the properties of the produced particleboard according to the previous works of Frybort *et al.* (2008) and Maloney (1993). Boquillon *et al*. (2004) revealed that when the adhesive coverage increases, the mechanical properties also increase, which is caused by an increase in the surface contact between the adhesive and particles leading to improved bonding properties.

Table 1: Mechanical properties of bamboo particleboard produced

Particle Sizes	Modulus of rupture (MOR)	Modulus of elasticity (MOE)	Internal bonding (IB)
Fine (T1)	**29.57 ±0.14[a]**	**1958.10 ±0.05[a]**	**1.54 ±0.00[a]**
Coarse (T2)	**21.74 ±0.00[b]**	**1804.20 ±0.05[b]**	**1.48 ± 0.00[b]**
Mixture of fine and coarse (T3)	**25.71 ±0.00[c]**	**1895.60 ±0.05[c]**	**1.49 ±0.00[c]**

Table 2: Analysis of variance (ANOVA) for Mechanical and physical properties of Bamboo particleboard

Source of Variation	Degree of Freedom	Sum of Square	Mean Square	F-cal.	Sig. level
MOR	2	92.158	46.079	2138.526	.000*
MOE	2	35945.480	17972.710	1797271.000	.000*
Internal Bonding	2	.005	.003	2743.00	.000*
Moisture content	2	.149	.075	996.333	.000*
Weight	2	.081	.041	34.179	.001*
Density	2	.000186	.000093		.000*

Values with * are significantly different at 5% probability level while values with ns are not significantly different at 5% probability level.

Table 3: Duncan Multiple Range Test (DMRT) for MOR, MOE and IB of Bamboo particleboard

MOR	Subset 1	Subset 2	Subset 3
T_2 (Coarse particles)	21.740000[a]		
T3 (Mixture of coarse and fine particles)		25.715000[b]	
T1 (Fine particles)			29.578000[c]
Sig.	1.000	1.000	1.000
MOE			
T_2 (Coarse particles)	1804.200000[a]		
T3 (Mixture of coarse and fine particles)		1895.600000[b]	
T1 (Fine particles)			1958.10000[c]
Sig.	1.000	1.000	1.000
INTERNAL BONDING			
T_2 (Coarse particles)	1.485000[a]		
T3 (Mixture of coarse and fine particles		1.496000[b]	
T1 (Fine particles)			1.542000[c]
Sig.	1.000	1.000	1.000

***Means with same letters in same column are not significantly different (p>0.05) while means with different letters in same column are significantly different (p<0.05).

Physical Properties of Bamboo Particleboard

Moisture content, density and weight were the parameters recorded for physical properties. Result also revealed that T2 (Coarse particles) had the highest mean moisture content of 8.22 followed by T3 (Mixture of fine and coarse) and T1 (Fine particles). It was also recorded that T1 (Fine particles) had the highest density and weight as shown in Table 4. The mean basic density of bamboo particleboard was 0.35 g/cm^3 while that of moisture content recorded 8.06% (Table 4). This is in line with the work of Anokye *et al.* (2016) who recorded mean density values range from 0.40 g/cm^3 to 0.90 g/cm^3 for different bamboo species. According to the analysis of variance performed for the moisture content and density of panels, there was significant difference among treatments. For moisture content, T_2 (coarse particles) had higher moisture content of 8.22%, followed by T_3 (mixture of fine and coarse) 8.05%, while T_1 (fine particles) had the least moisture content of 7.91%. However, result revealed that T_1 (fine particles) had highest density of 0.36 g/cm^3 when compared with other treatments. Thus, particle size had influence on the moisture and density of the panel. From the result it could also be said that as the moisture content increases, the density of the panel decreases.

According to NBR 14810 standard (ABNT, 2013), the moisture content of particleboard panels ranged from 5 to 13%. It was observed that all mean values for different particle sizes presented in Table 4 are within this moisture range. Result showed that panels from all treatments were within the "medium density" category, as defined by NBR 14810 standards (ABNT, 2013). However, the mean density values of panels were below the experimentally planned nominal value (0.65 g/cm^3). This research finding may be associated with loss of adhesive and paraffin during application and material loss during the manual formation of the particle mattress, as well as during the pre-pressing and hot-pressing steps. Melo *et al.* (2015**)** also reported similar research findings and attributed factors such as loss of adhesive and paraffin at the application time due to adhesion on the edges of the drum and differences in the specific mass and moisture content of particles. The analysis of variance performed for the weight of panels revealed that there were significant differences among treatments (fine particle, coarse particle and mixture of both). This could be attributed to the disparities during particle size distribution. It could also be traced to the manual formation of the particle mattress and manual pressing as a result of insufficient equipment in the institute.

Table 4: Physical properties of bamboo particleboard produced

Particle Sizes	Moisture content (%)	Density(g/cm^3)	Weight(kg)

Fine	**7.91 ± .0057**	**0.364 ± .0057**	**1.13 ± .0101**
Coarse	**8.22 ± .0027**	0.353 ± **.0153**	**0.09 ± .0023**
Mixture of fine and coarse	**8.05 ± .0057**	**0.357 ± .0235**	**1.06 ± .0329**

Table 5: Duncan Multiple Range Test (DMRT) for Moisture content, weight and density of Bamboo particleboard

	Subset		
MC	**1**	**2**	**3**
T_1 (Fine particles)	7.910000^{a}		
T3 (Mixture of coarse and fine particles)		8.050000^{b}	
T2 (Coarse particles)			8.225000^{c}
Sig.	1.000	1.000	1.000
Weight			
T_2 (Coarse particles)	.904000^{a}		
T_3 (Mixture of coarse and fine particles)		1.061000^{b}	
T_1 (Fine particles)			1.131500^{c}
Sig.	1.000	1.000	1.000
Density			
T_1 (Fine particles)	.364000^{a}		
T_3 (Mixture of coarse and fine particles		.357000^{b}	
T_2 (Coarse particles)			.353000^{c}

Sig.	1.000	1.000	1.000

***Means with different letters in different column are significantly different ($p<0.05$).

Effect of Particle Sizes on Physical and Mechanical Properties

Results of Table 1 and 2 revealed that particle sizes had influence on moisture content, density, weight, modulus of rupture, modulus of elasticity and internal bonding. Result showed that the smaller the particles, the higher modulus of elasticity, modulus of rupture and internal bonding. That is as the particle size of the board increases, there is tendency for the mean MOR, MOE and IB values to decreases. From the result it could also be said that as the moisture content increases, the density of the panel decreases since the T_2 (Coarse particles) had high moisture content compared to other treatments with a decrease in density values. Table 1 showed result of the bending test, it points out that modulus of elasticity, modulus of rupture and internal bonding depend on the particleboard's density. When the board is denser, the MOE, MOR and IB value increases. When particle sizes are considered, T_1 (fine particles) gives better MOE, MOR and IB values when compared with T2 and T3. On the other hand, works of Valarelli *et al., (*2014) showed higher MOE and MOR values of particleboards made from chips of Dendrocalamus Asper bamboo culms than the values of sheath based particleboards at similar density. It possibly states that the shoot sheath particleboard provides less flexural strength than those made out of the bamboo culms. In this study, when MOE and MOR values were compared to the JIS standard stipulated minimum of 3,000 MPa and 18 MPa, respectively (Japanese Standard Association, 2003), It was found that most of the densities of the particleboard had MOE and MOR values within the standard criteria. Therefore, it indicates that the utilization of particleboard made from the bamboo culms can be suitable for the structural work.

In particleboard production, there are several factors affecting the properties of the board. Particle size, type of particle and adhesive percentage are among those factors. Sekaluvu *et al* (2013) studied the effect of resin content and particle size in particleboard production using maize cobs. It is also reported that particle size and adhesive quantity affects the bond density, MOE and MOR of the board. In addition, Cheng *et al.* (2016) also investigated the effect of particle geometry and adhesive percentage on the mechanical and physical properties of the particleboard made from peanut hulls. Similar to Cheng *et al.* (2016), it is reported that particle geometry, adhesive type and adhesive mass percentage directly affects the mechanical performance of the board.

Conclusion

This research work evaluated the effect of particle sizes on bamboo particleboard. Based on the findings from the study, experimental particleboard panels made of fine particles of bamboo at 1.0 mm resulted in better properties than those of coarse and mixture of fine and coarse in terms of their mechanical properties and physical properties with the exception of moisture content, which means that the finer the particles, the higher the strength of the board. Coarse particle had highest moisture content among all the treatments.

The values obtained from all the particle sizes met the requirements listed in the Japanese and European standards for particleboard general interior use. Although panels produced had relatively rough surface with the coarse material having high moisture content which also falls within the standard. However, this study has shown that even fine particles of bamboo would have potential to be used as raw material to produce value-added panel products. Finally, bamboo can be considered as excellent alternative to replace wood in the market. Its use in the production of particleboard is well accepted, because it behaves similarly like those produced with wood. It is therefore recommended that small particle sizes should be used for particleboard production to increase bond strength. Also anatomical, mechanical and chemical properties of bamboo should be carried out to help determine the quality of board produced.

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