Properties of Ceiling Board Produced from *Piliostigma Thonningii* Using Styrofoam Adhesive as Binder

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ABSTRACT

The cost of building materials is high and beyond the reach of many people in developing countries. This research aims to produce a ceiling board composite from *piliostigma thonningii* fibre particulate reinforced with styrofoam adhesive. The board was produced with low cost materials having good thermal properties. Furthermore, the *piliostigma thonningii* board yields the mean values of density of 145.37kg/m^3, water absorption of 10.062 % and thermal conductivity of 0.148 W/mK. The *piliostigma thonningii* ceiling board has low density values; percentage water absorption is within the range and good thermal conductivity values that falls within the requirement. Hence, the board has greater insulating properties and shows good potential to be used as ceiling board. The macrostructure of the board sample, revealed a reasonably uniform distribution of *piliostigma thonningii* particles and styrofoam adhesive matrix. The diameter of fibre ranges between 1.0 – 12.61μm.

1. INTRODUCTION

The growth of population and global warning problem have led to an increase in energy consumption in many countries worldwide, due to increase in both building and comfort inside buildings for living (Lombard *et al.,* 2008; Radhi, 2008). The increased demands for raw materials in wood composite industries led researchers to investigate lignocellulosic fibre materials from locally available agricultural resource. The shift towards the use of locally available lignocellulosic agro fibres is because they are in great abundance in Nigeria from variety of sources especially plant origins which are environmental friendly, light weight, renewable, cheap and their ability in enhancing quality of composite (Abdullahi and Umar, 2010). This is supported by La mantia and Morreala (2011) who opined that the rising concern towards the environmental issues on one hand and the need for more versatile polymer-based materials on the other hand has led to increasing interest in polymers filled with natural lignocellulosic agro fibre. Lignocellulosic fibers are low cost raw material, abundant in nature and renewable. Besides that, the less abrasive nature of the lignocellulose fibers offers a friendlier processing environment and offered good thermal and insulating properties, easily recyclable and biodegradable especially when used as reinforcement in a biopolymer. Natural reinforcements have advantages over reinforcements as a result of natural alignment of carbon-carbon bonds and also significant strength, stiffness (Justiz-smith *et al.,* 2008), low density, low cost and biodegradability they offer.

Piliostigma thonningii is a woody plant which found in savannah regions that are moist and wooded grass land in low to medium altitudes. It is widely distributed in Africa. The English name is monkey bread, camel's foot. It is a plant which contains lignocellulose fibre, which grows abundantly as a wild uncultivated tree in many parts of Nigeria. The basic chemical component of lignocellulose fibres in *piliostigma thonningii* are cellulose, hemicellulose, lignin (Lange, 2013). The cellulose consists of high molecular weight polymers accounts for 40 wt% of the lignocellulose. Hemicellulose consists of shorter polymers usually accounts for 25 wt% of the lignocellulose, while lignin accounts for 20 wt% of the lignocellulose (Lange, 2013). The increased environmental awareness leads to the usage of lignocellulose fibers as a potential replacement for synthetic fibers such as carbon, aramid and glass fibers in composite materials. Lignocellulose fibers have the potential to be an effective reinforcement in thermoplastics and thermosetting materials (Bledzki and Gassan, 1999). The styrofoam is an environmental unfriendly solid waste styrene, non-biodegradable and normally thrown away after use during ceremonies, occasions and after other materials being packaged were removed.

Styrofoam is a very lightweight, hard plastic material. However, it is formed when air (or other "blowing agents") blow through molten polystyrene as it is extruded to foam up and produces the light foamy material known as "Styrofoam". They are non-biodegradable and readily soluble in acetone but insoluble in water (Aroke *et al.,* 2012).

Fiber board is a building material composed of wood chips or plant fibers bonded together and compressed into rigid sheets. It is also a type of engineered wood product that is made out of wood fibers. The ceiling composite board is a panel product manufactured under pressure from particles of wood or other cellulose fibre materials using an adhesive as a binder.

Ceiling plays an important role in creating the perfect ambience that have ability to improve the acoustical system in place for a controlled environment that can bring in the desired results (small room or a large hall), absorbing the unwanted sounds (controlling the transfer of sound from one room to the next), reduces noise, heat insulators, sound insulators and enhances the appearance and adds value to the existing architecture of buildings, and can be used in holding up building materials such as electric lights, smoke detector, security cameras and signage which are commonly attached to the ceilings (Nemli and Aydin, 2007).

This research will focus on the production of ceiling board from *piliostigma thonningii* using styrofoam adhesive as binder, that can have a potential application of good acoustic and low thermal conductivity so as to reduce heat transfer into building as well decreases the energy consumption of building facilities (air-condition), reduce the operation cost and also help to preserve the environment.

2. MATERIALS AND METHODS

2.1 Materials and Equipments

Raw materials:- The major raw materials for this work are the stem fibres of *piliostigma thonningii* Other materials include styrofoam, unsaturated polyester resin, sodium hydroxide (NaOH), gasoline, distilled water.

Equipments:- Compatible linear heat conduction accessory, Grander(Gradplex M12), Digital Electrical weighing balance(Mettler P160N), Storage bowl 5000 ml, Stirrer (magnetic and glass rod), Electric drying oven(MC21438BPPLG), Press (94030626 Cat C 43/2), Sieve and aperture, Measuring Cylinders, steel mould, scanning electron microscope (SEM)

2.2 Sample Preparation

2.2.1 Preparation of stryofoam adhesive

The styrofoam were cleaned and made free of dirt. Forty grams (40g) of styrofoam was dissolved in 120ml of gasoline and stirred to enhance the dissolution of the styrofoam. In this research the 60% unsaturated polyester resin was mixed with 40% dissolved styrofoam adhesive. The formulated solution were stirred twice daily for a period of a week, until the formulated adhesive reaches homogeneity and stabilization.

2.2.2 Preparation of the *piliostigma thonningii* into wood particles

The *piliostigma thonningii* stems were collected and washed thoroughly with clean water to remove any unwanted particles. The cleaned *piliostigma thonningii* (stem) were reduced into chips, then mercerized using 5%w/v sodium hydroxide (NaOH) solution at room temperature for 24 hours. The *piliostigma thonningii* (chips) were thoroughly washed in a fresh tap water and air dried. The dried chips were ground into small particle sizes. The sieve analysis of particles was carried out in accordance with BS2377:1990.

Table 1: composition of mixing

S/NO.	*Piliostigma Thonningii*	Styrofoam adhesive	Temperature (^{O}C)	Pressure (kg/m^3)
1	100	50	100	500
2	50	50	100	500
3	50	100	100	500
4	100	50	50	250
5	50	50	50	250
6	50	100	50	250
7	100	50	25	50
8	50	50	25	50
9	50	100	25	50

2.2.3 Sample Productions

Three (3) numbers of moulds of 0.15 m by 0.15 m were constructed with thickness of 0.10 m. The required quantity of *piliostigma thonningii* particle sizes were mixed with prepared styrofoam adhesive ratios and compounded into the steel mould. Pressure and heat were applied for crosslinking and hardening the boards. Figure 1 show the production process flow diagram. The boards sample were cut and prepared for characterization tests subjected into:- Density, Water absorption, Thermal conductivity and Scanning electronic microscopy (SEM)

PRODUCTION FLOW DIAGRAM

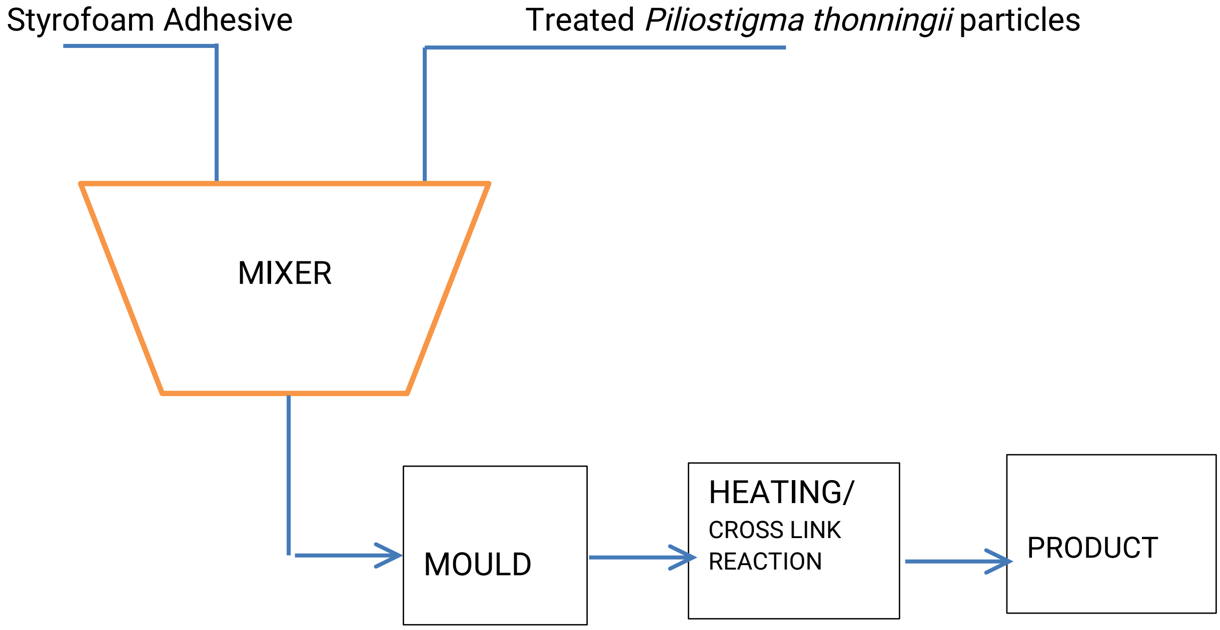

Figure 1: Process flow diagram of the production of ceiling board

2.3 Test Procedures

The samples were cut from the produced ceiling board for the tests according to the recommended standard. Prior to the test, all the samples were conditioned at a temperature of 23±2°C.

2.3.1 Determination of density

The densities of the boards were determined in accordance with the American Society for Testing and Materials (ASTM) C303-02 (Standard test method for dimensions and density of preformed block and board type thermal insulation) (ASTM, 2004). From each of the boards prepared, three (3) sample specimens were cut for test.

The volumes of each specimen were calculated using equation as follows:

$$\text{Volume } (m^3) = \text{length (m)} \times \text{thickness(m)} \times \text{width (m)} \quad (1)$$

The mass of each specimen were determined using digital weighing balance and the mass recorded. The density of each specimen is determined using equation (2) based on ASTM C303-02, Dagwa *et al* (2012).

$$\textit{Density } \frac{kg}{m^3} = \frac{\text{weight of the composite}}{\text{volume of the composite}} \quad (2)$$

2.3.2 Determination of water absorption

The water absorption test were conducted according to ASTM D1037, 2004. The specimens of dimension 0.14m x 0.14m x 0.1m used in the determination of the density each specimen was immersed in water at ambient temperature of 24 hours until equilibrium. The specimens were removed and patted dry with a towel (lint free) and then weighed using a digital weighing balance. The dry weight before immersion

(W_1) and the weight after immersion (W_2) were noted. The water absorption was expressed as the percentage increase in volume based on the volume before immersion. Equation (3) was applied to determine the percentage water absorption in accordance with ASTM D570 (Klyosov, 2007).

$$W_A = \frac{w_2 - w_1}{w_1} \times 100\ \% \qquad (3)$$

Where: w_1 is the weight of the sample before immersion in water and w_2 the weight of the sample after immersion in water.

2.3.3 Determination of thermal conductivity

The thermal conductivity of the boards was determined in accordance with ASTM. The equipment used for the test was Armfield HT10XC Heat Transfer Service Unit and HT11C Computer Compatible Linear Heat Conduction Accessory. From each of the boards, four (3) specimens were cut in form of a disc of diameter (d) 25 1mm and the thickness (x) was measured and recorded. The temperatures T_1, T_2, T_3, T_7, and T_8 were read and recorded from the console display. The thermal conductivity (k) of a material was determined from equation (4), (5) and (6).

$$k = \frac{\text{Heat} \times \text{Distance}}{\text{Area} \times \text{Temperaturegradient}} \qquad (4)$$

The temperature difference across the specimen

$$\Delta T = T_{hot} - T_{cold} \qquad (5)$$

Where $T_{hot} = T_{2} - \frac{(T_{2} - T_{3})}{2}$ and $T_{cold} = T_{6} - \frac{(T_{6} - T_{7})}{2}$

Apply Fourier rate equation to determine the thermal conductivity (k) of a specimen

$$Q = -kA\frac{\Delta T}{\Delta x}\left(\frac{W}{mK}\right) \qquad (6)$$

2.3.4 Microscopic Analysis

The scanning electron microscope (SEM) (JEOL JSM-6480LV) was used to identify the surface morphology of the ceiling board composite specimens. The microstructure analysis of the prepared boards was performed on the surface of the boards by Scanning Electron Microscopy (SEM). A specimen of about 3 cm was cut from each sample to serve as a true representation of the sample for surface preparation. The surface was then thoroughly cleaned and polished to reveal the surface contrast and then mounted on a specimen stage.

3.0 RESULTS AND ANALYSIS

The results of density are shown in Table 2

Sample No.	Length(m)	width(m)	Thickness(m) X	Weight (Kg)	Volume(m^3)	Density(Kg/m^3)
1	0.14	0.14	0.0085	0.0268	0.0001666	160.86
2	0.14	0.14	0.009	0.0325	0.0001764	184.24

3	0.14	0.14	0.0085	0.02685	0.0001666	161.16
4	0.14	0.14	0.0085	0.0336	0.0001666	201.68
5	0.14	0.14	0.008	0.0233	0.0001568	148.59
6	0.14	0.14	0.009	0.0364	0.0001764	206.35
7	0.14	0.14	0.009	0.02325	0.0001764	131.80
8	0.14	0.14	0.009	0.02852	0.0001764	161.67
9	0.14	0.14	0.0085	0.0242	0.0001666	158.34
					Mean	**145.37**

Table 2: Result of water absorption tests

Sample No.	Weight(w_1) (Kg)	Weight(w_2) (Kg)	Water Absorption (%)
1	0.02836	0.03601	19.97
2	0.0362	0.0365	0.83
3	0.0243	0.03038	18.02
4	0.0336	0.03383	0.68
5	0.0259	0.0326	18.87
6	0.0385	0.0388	0.78
7	0.02532	0.02899	10.49
8	0.02852	0.03288	11.28
9	0.02856	0.03217	9.64
		Mean	**10.062**

Table 3: Result of Thermal conductivity tests

Sample	V	I	Q	ΔX	A	T1	T2	T3	Th	T6	T7	T8	Tc	ΔT	k
1	10	1.05	10.5	0.05	0.0006688	110	119.8	118	117.1	36.5	35.1	35	37.2	79.9	0
2	10	1.05	10.5	0.0094	0.0005766	110	95	60	42.5	35	36	36	34.5	8	0
3	10	1.05	10.5	0.0085	0.0004913	110	93.2	74	64.4	34.8	34.9	35.4	34.75	29.65	0
4	10	1.05	10.5	0.009	0.0006218	110	97	60	41.5	36	36.4	36	35.8	5.7	0
5	10	1.05	10.5	0.008	0.0005331	110	90.5	62	47.75	35	35.2	35.5	34.9	12.85	0
6	10	1.05	10.5	0.009	0.0005331	110	98.2	60	40.9	34	34	34.6	34	6.9	0
7	10	1.05	10.5	0.008	0.0005331	110	90	72.8	64.2	35	35	35.2	35	29.2	0
8	10	1.05	10.5	0.009	0.0005331	110	98	64.5	47.75	35	35.5	36	34.75	13	0
9	10	1.05	10.5	0.0085	0.000599	110	95	63	47	34.5	34.7	34.8	34.4	12.6	0
													Average		**0**

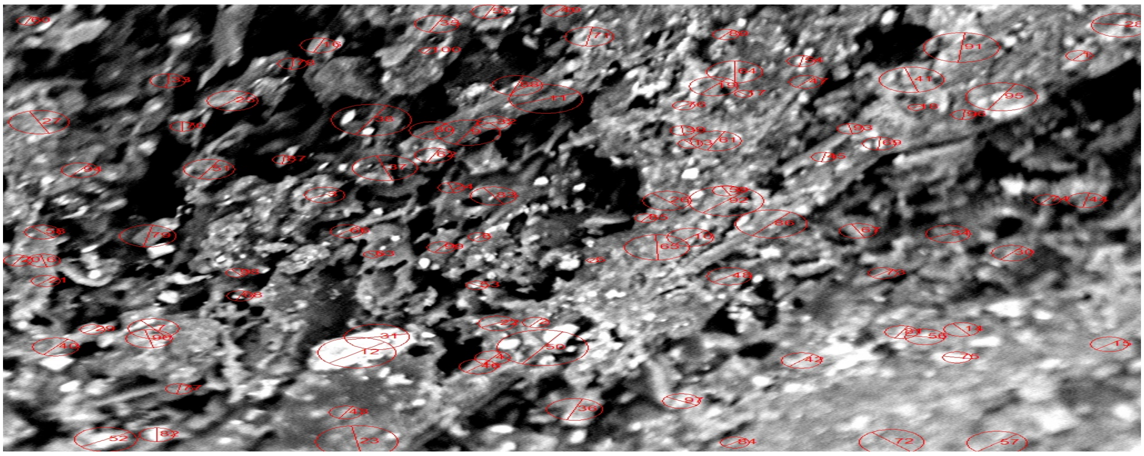

Plate I: *Piliostigma thonningii* board fibre matric sizes

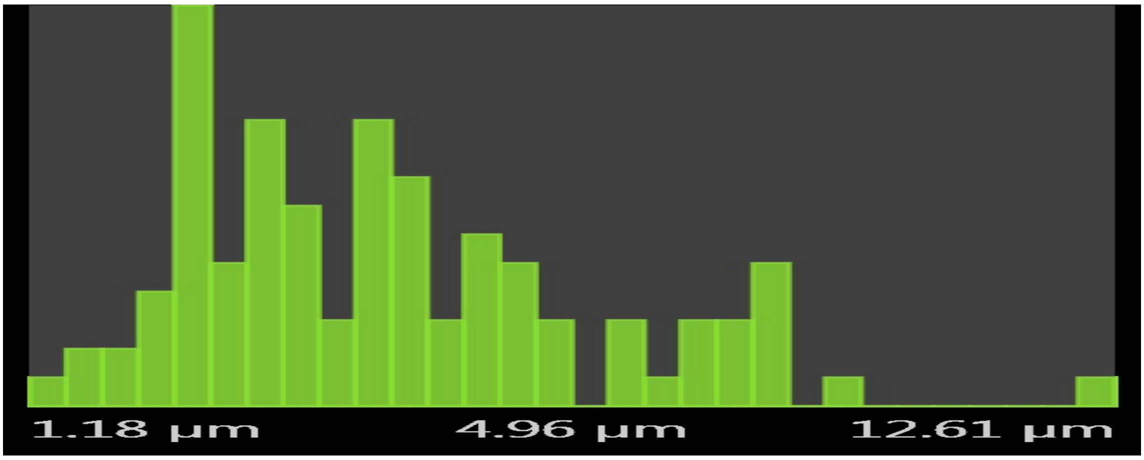

Figure 2: *Piliostigma thonningii* board fibre histogram

3.1 ANALYSIS

The results of the tests on ceiling boards produced from *piliostigma thonningii* fibre using styrofoam adhesive as binder in Table 3 above shows that the density of the ceiling boards is between 131.80 kg/m^3 to 206.35 kg/m^3. The board's density increases as the ratio of the binder to the fibre increases. The *piliostigma thonningii* fibre ceiling boards recorded lower density than that of conventional standard ceiling board ranged from 350 to 400 kg/m^3. Therefore, increasing the binder in the composition will reflect increase in density. The lower density composites boards derived from natural fibres have higher voids and pores as a results, the board absorbed more moisture (Rakesh et al, 2011). The percentage water absorption of the produced *piliostigma thonningii* fibre ceiling boards, ranged from 0.68% to 19.97%. The results can be favourably compared with that of conventional standard ceiling board. Organic materials generally absorb water readily. In addition, natural fibres derived from lignocellulose are hydrophilic in nature which contain strongly polarized group, thus, increasing the quantity of the fibre in a composition increases the percentage of water absorption (Rakesh *et al.*, 2011). The thermal conductivity values ranged from 0.050 W/mK to 0.27W/mK. The decrease in thermal conductivity of the lower density boards was as a result of the presence of air, which is a poor conductor within the voids in the board's structure thereby reducing its conductivity Panyakaew and Fotios (2011). The *piliostigma thonningii* fibre ceiling boards recorded thermal conductivity values that are comparable to that of conventional standard ceiling board, this offered a great potential for use as ceiling board. The macrostructural study of the board sample, revealed a reasonably uniform distribution of *piliostigma thonningii particles and* styrofoam adhesive matrix. It can be seen that the *piliostigma thonningii* particle are not detached from the binder surface. The strong bond occurred as a result of good interfacial bonding between the binder and reinforcement. The histogram shows that the diameter of fibre range between 1.0 – 12.61μm.

Table 5: Contains the p*iliostigma thonningii* ceiling boards results gotten were compared with standard ceiling board

Board type	Density (kg/m^3)	Water absorption %	Thermal conductivity W/m K
Piliostigma Thonningii Ceiling Boards	131.80 - 206.35	0.68 - 19.97	0.050- 0.27
Standard Ceiling Board SON; ISO(8302; 1991)	350 - 400	< 10%	0.050 - 0.150

4. Conclusion

The *piliostigma thonningii* fibre board composite was produced with low cost material having an overall light weight and fairly good property. The board's density increases as the ratio of the binder to the fibre increases. The boards have correspondingly lower densities compared to the standard boards. The board's percentage water absorption falls within the conventional standard board values made from organic materials. The *piliostigma thonningii* fibre boards have potentials for use as thermal insulation having thermal conductivity values, thermal conductivity values falls within the requirement.

The utilization of locally available agro lignocellulosic fibre from *piliostigma thonningii* for the production of ceiling board using styrofoam adhesive as binder, with a view to explore its potentials for use as a ceiling board with good thermal properties and Conversion of non-biodegradable waste material (styrofoam), to wealth

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