DEVELOPMENT OF CHICKEN FEATHER REINFORCED INSULATION PAPERBOARD FROM WASTE CARTON AND PORTLAND CEMENT

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ABSTRACT: Cartons and chicken feathers are common wastes which we need to dispose in one way or another. Disposal problems associated with these wastes can be solved by processing them into useful products such as insulation and ceiling boards. In this study, chicken feather reinforced ceiling board was developed from waste carton and Portland cement. The quantity of the chicken feather was kept constant at 10% based on previous findings, while the cement and waste carton contents were varied to produce 5 samples of different compositions. The density of the board was found to range between 337.8 and 700.7 kg/m^2, while the thickness swelling ranges between 0.81 and 9.02%. Water absorption values of the samples varied between 7.16 and 24.41%, while the compressive strength and modulus of elasticity values varied from 4.8 - 10.3 N/mm^2 and 1.03 - 1.60 GPa, respectively. The values of modulus of rupture ranges between 1.34 and 2.2 MPa while the thermal conductivity of the samples ranges from 0.951 to 1.077 W/m.K. Density, compressive strength, modulus of elasticity, modulus of rupture and thermal conductivity of the samples increased as the cement content increased, while the thickness swelling and water absorption decreased with increase in cement content. The results revealed that the properties of ceiling boards developed from 80% cement, 10% carton and 10% chicken feather can compete favorably with most ceiling boards available in the market.

Keywords: Carton; Chicken feather; Cement; Physical properties; Thermal conductivity; Waste management.

تطوير لوح ورقي عازل مقوى من ريش الدجاج ونفايات الكرتون وأسمنت بورتلاند

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الملخص: يعد الكرتون وريش الدجاج من نفايات البيئة والتي يجب التخلص منها بطريقة ما أو بأخرى. فيمكن حل مشاكل التخلص من هذه النفايات بتحويلها إلى منتجات مفيدة مثل ألواح عزل واسقف. ففي هذه الدراسة ، تم تطوير لوح سقف مدعم بالريش من نفايات الكرتون وأسمنت بورتلاند. بقيت كمية ريش الدجاج ثابتة عند نسة 10٪ بناءً على النتائج السابقة ، بينما تفاوتت محتويات نفايات الكرتون والخرسانة لإنتاج 5 عينات من التراكيب المختلفة. وتبين أن كثافة اللوح تتراوح بين 337.8 و 700.7 كجم/م^3 ، في حين يتراوح معدل الانتفاخ بين 0.81 و 9.02٪. وتراوحت قيم امتصاص الماء للعينات بين 7.16 و 24.41٪ ، بينما تفاوتت قوة الضغط ومعامل قيم المرونة من 4.8-10.3 نيوتن / مم^2 و 1.03-1.60 جيجا، على التوالي. وتتراوح قيم معامل التمزق بين 1.34 و 2.2 ميجا باسكال ، في حين تتراوح نسة التوصيل الحراري للعينات من 0.0951 إلى 0.1077 واط/م ك. كما زادت كثافة وقوة الانضغاط ومعامل المرونة ومعامل التمزق والتوصيل الحراري للعينات مع زيادة محتوى الأسمنت ، في حين تناقص سمك الانتفاخ وامتصاص الماء مع زيادة محتوى الأسمنت. وبينت النتائج أن خصائص ألواح الأسقف التي تم تطويرها من 80٪ أسمنت و 10٪ كرتون و 10٪ ريش الدجاج يمكن أن تتنافس بشكل إيجابي مع معظم ألواح الاسقف المتوفرة في السوق.

الكلمات المفتاحية : كرتون؛ ريش الدجاج؛ الاسمنت؛ الخصائص الفيزيائية؛ التوصيل الحراري؛ إدارة المخلفات.

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DOI: 10.24200/tjer.vol16iss1pp44-52

1. INTRODUCTION

Wastes are generated from virtually all human activities in solid, liquid or gaseous forms. Carton and chicken feather are solid wastes that can be found across Nigeria, causing a serious environmental problem. Carton is a form of paper, which has been utilized mainly for packaging in everyday activities for more than 20 decades. After usage, cartons are usually discarded, thereby forming major components of municipal solid wastes. Thus, there is a need to develop alternative methods of disposing or re-processing of this waste for re-using. Chicken feathers, on the other hand, are waste products from poultry processing industries. It was estimated in 2015 that Nigeria has over 180 million chickens (birds) (National Veterinary Research Institute 2015). Most of these chickens are supplied to supermarkets and fast food outlets to meet the demand for white meat. However, since about 6% of the total weight of mature chicken is feather, large amount of feathers are generated as waste through the processing of chickens (Parkinson 1998; McGovern 2000). Traditional disposal strategies of chicken feathers and cartons/papers, as shown in Fig. 1, are unhealthy and uneconomical. They are often burned in incineration plants or buried in landfills. Burning of these wastes generates greenhouse gases and poses a great danger to the wellbeing of people living around the dumpsites. In addition, burning can also damage the environment.

Disposal problems associated with these wastes can be solved by processing them into useful products such as ceiling boards, notice boards, paperboards, etc. Odusote *et al.* (2016). Thus, the aim of this work is to utilize corrugated paper (carton) to develop chicken feather reinforced insulation ceiling boards using a varied amount of ordinary Portland cement as binder. These boards will be eco-friendly and they are more likely to be cheaper. The boards can also find application in large quantities in construction industry. The use of this eco-friendly ceiling boards in construction industry will reduce the reliance on imported materials for roofing and assist in solving the environmental challenges associated with unhealthy disposal of cartons and chicken feathers.

2. MATERIALS AND METHODS

2.1 Materials

The materials used for this study are corrugated paper (cartons), chicken feathers, Portland cement (commercially available Dangote 3X Portland cement of grade 42.5N with composition as presented in Table 1), water, 600 mm x 600 mm fiber glass moulds, trowel, straight edge, a labtech BL20001 electronic compact scale, ball mill (model 48-D0500/D and serial No. 14002201), electric oven model (SDO/225 and serial No. Y9C227), and a vibratory sieving machine.

According to Fraser and Parry, (1996), chicken feathers contain 91% protein (keratin), 1% lipids, and 8% water. Keratin fibers are strictly non-abrasive, having low density, biodegradable, renewable, eco-friendly, insoluble in organic solvents, hydrophobic, warmth retention and cost effective Meyers *et al.* (2008). The density of chicken feathers is usually about 0.89 g/cm^3, while the specific gravity ranges between 0.7 and 1.2, and the strength varied between 41 – 130 MPa Hong and Wool (2005).

Figure 1. Traditional disposal method of wastes: (a) Chicken feather (b) Carton and household wastes.

Table 1. Composition of ordinary Dangote Portland cement (Yahaya 2009).

Component	CaO	SiO_2	Al_2O_3	Fe_2O_3	*LOI	*IR	*Free CaO	SO_3	MgO
Quantity (wt %)	63.14	16.56	4.78	10.5	5.22	2.03	2.15	1.4	1.45

*LOI = Loss on ignition; IR = Insoluble residue and Free CaO = Free lime.

2.2 Samples Preparation

Staple pins, cenotaph and other unwanted materials were manually removed from the collected cartons, which were then soaked in about 200 liters of water for a period of 5 days to ensure adequate softening. After soaking, the mixture was first pulverized using mortar and pestle and then followed by ball mill (model 48- D0500/D) to obtain the finest texture. The pulverized cartons were then sieved using a 1 mm sieve size and drained to reduce the amount of water present in the formed slurry. The dewatered carton was then dried in the sun for 3 days, and then further pulverized in the ball mill for about 1 h and sieved in the vibratory sieving machine using 500 µm sized sieve.

The feathers were washed several times with warm water mixed with detergent to remove blood, manure and extraneous materials. The clean feathers were then spread on aluminum sheet to dry for 3 days. It was further dried in an oven at 150℃ for 1 h before grinding in the ball mill into powder of about 150 µm. The compositions of carton, cement and chicken feather in the 5 different samples of the insulation ceiling boards are presented in Table 2.

Chicken feather was kept constant at 10% for all the formulations based on the result of Acda (2010). It was reported that increasing the proportion of chicken feather above 10% resulted in the significant reduction of modulus of elasticity and modulus of rupture.

The carton/cement/chicken feather mixture was poured into an already made mould which was lubricated with engine oil to enhance easy removal and prevent the sticking of the board to the plate surface. After pouring, a stainless pipe roller was used to spread the mixture on the mould to allow for uniform mat formation. A pressure of 80 kg/m^3 was applied on the mixture in the mould after uniform spreading for 8 hours for proper setting. The mould was then dismantled to remove the cast ceiling board, which was then dried in the sun for 3 days to allow for proper drying. After drying, the cast was allowed to cure for 28 days.

2.3 Testing Procedure

The board edges were trimmed with a circular saw to avoid edge effect and cut into the required sizes for each test experiment. The following tests were carried out on all the amples: physical appearance (presence of crack); density; thickness swelling; water absorption; compressive strength; and thermal conductivity.

Table 2. Mixing ratios for the insulation boards formulation.

Formulation	(wt %)		
A	80	10	10
B	70	20	10
C	60	30	10
D	50	40	10
E	45	45	10

2.4 Density

The sample for board density evaluation of size 50 mm × 50 mm × 10 mm was cut from the produced board. The samples were weighed and the density was determined using:

$$Density = \frac{Mass}{Volume} \quad (1)$$

where Mass is in kg and Volume is in m^3.

2.5 Thickness Swelling

This was carried out by measuring the samples initial thickness (t_1) with the aid of a Mitutoyo digital caliper. The sample was then soaked in water for 24 hours and the final thickness (t_2) was measured with the same caliper. The thickness swelling was estimated as a percentage of the change in thickness.

2.6 Water Absorption

The initial weight of the sample of dimensions 50 mm 50 mm 10 mm that was cut out of the produced board was measured using an electronic compact scale, a labtech BL20001 of sensitivity 0.1 g.

The samples were soaked in water for 24 hours before they were then surface dried and re-weighed for their final weight. The initial weight (w_1) and the final weight (w_2) were noted and the water absorption rate was calculated following ASTM C 642 -06 standard using equation 2.

$$\text{Water absorption} = \left(\frac{w_2 - w_1}{w_1}\right) \times 100 \quad (2)$$

2.7 Compressive Strength

This test was conducted following ASTM C 109-95 standard using a 50 kN testometric computer controlled universal material testing machine, model number M500-50AT. Each ϕ38 mm 76 mm test specimen, was mounted on the jaws of the machine one after the other. The loading was increased gradually from 0 N at a test speed of 100 mm/min until the sample was fractured. The measurements were displayed on the monitor attached to the testometric machine as shown in Fig. 2.

2.8 Flexural Test

Flexural test is the measure of the force required to bend a beam under three-point loading. Test samples of 600 mm x 25.4 mm x 5 mm were mounted on an improvised test fixture on testrometric universal testing machine one after the other. The samples were placed on two supporting pins as shown in Fig. 3, which shows a sample under a load in a three-point bending setup. The load applied at fracture point, the length of the support span, the width, thickness and deflection values were used to calculate the Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) using Equations 3 and 4, respectively Bansal (2010).

$$MOE = \frac{PL^3}{4Hbd^3} \quad (3)$$

and

$$MOR = \frac{3PL}{2bd^2} \quad (4)$$

where P = Ultimate failure 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) and;

H = maximum deflection at the center of the beam.

2.9 Thermal Conductivity

The following parameters were obtained from arm field computer compatible linear heat conduction apparatus: heater voltage V (Volts); heater current I (Amps); heated section at high temperature T_1 (°C); heated section at mid temperature T_2(°C); heated section at low temperature T_3(°C); cooled section high temperature T_6(°C); cooled section at mid temperature T_7(°C); cooled section at low temperature T_8 (°C); and thickness of the specimen x(m).

Thermal conductivity of the specimen,

$$k_{sp} = \frac{\pi D_{sp}^{\;2}}{4} (m) \quad (5)$$

where:

Heat flow (power of heater), Q = VI (Watts) (6)

Cross sectional area of specimen,

$$A_{sp} = \frac{\pi D_{sp}^{\;2}}{4} (m) \quad (7)$$

Temperature difference across specimen,

$$\Delta T_{sp} = T_{hotface} - T_{coldface} \; (°C)$$

and

Temperature of hot face of specimen =

$$T_{hotface} = T_1 - \frac{(T_2 - T_3)}{2} \; (°C) \quad (8)$$

Temperature of cold face of Specimen =

$$T_{coldface} = T_6 \frac{(T_7 - T_8)}{2} \; (°C) \quad (9)$$

Figure 2. Set up for compressive test.

Figure 3. Flexural test showing a sample under a load in a three-point bending setup.

Figure 4. Computer compatible linear heat conduction Apparatus setup for determining thermal conductivity.

where Δx_{sp} is the thickness of the specimen board.

The following constants are applicable:

The diameter of the specimen in contact with the bar = 0.025 (m).

The distance between each thermocouple = 0.015 (m).

The distance between thermocouple T3 or T6 and the end face I = 0.0075 (m).

The conductivity of the brass sections is approximately = 121 (W/m °C).

3 RESULTS AND DISCUSSION

3.1 Physical Appearance

The first formulation that was produced is sample E and it was observed that the sample edges cracked, as shown in Fig. 5, while the cast was being removed from the mould.

This was however taken care of in the subsequent cast by proper lubrication of the mould prior to pouring of the mixed formulation and adequate force was applied to the board before removal from the mould. In addition, the chamfering at the edges of the mould was increased in order to allow for easy removal.

Samples A, B, C, D and E of the produced ceiling board are shown in Fig. 6. It can be observed that there are variation in the samples' colors which is attributed to the composition process, that is, chicken feather and paper contents in each of the samples. Sample A is found to be bluish while Sample E is brownish, taking the color of carton, since it has the highest carton content of 45% by weight.

Figure 5. First cast (Sample E: 45 – 45 -10 weight %) of the ceiling board.

3.2 Density

The densities of the samples are presented in Fig. 7. The densities of the samples were found to range between 337.8 and 700.7 kg/m^3. The densities increased with the increase in cement content. This indicates that the more the cement content the lesser the voids in the particle boards and thus the higher the density. The densities of the ceiling boards in the present study were lower than those of the other types of ceiling boards such as asbestos ceiling board (1500-1950 kg/ m^3), fiber cement flat sheets (1250-1350 kg/ m^3) and trilite (1000-1050 kg/ m^3) as reported by Ataguba (2016). Lower density implies that the load that the ceiling board will exert on the walls and the reinforcement of buildings will be lower. However, the density should not be too low so that it can also support the structure.

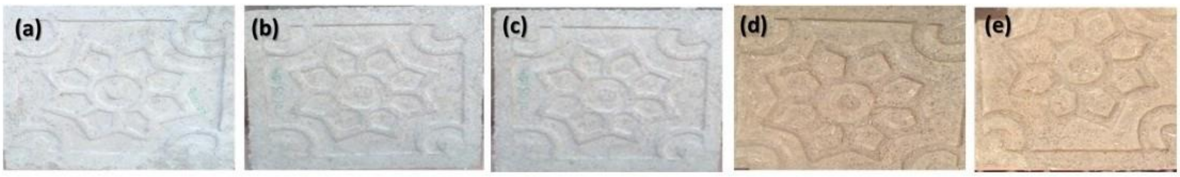

Figure 6. Produced ceiling board samples showing color variations.

3.3 Swelling Thickness and Water Absorption

Thickness swelling and water absorption of the ceiling board decreased with increased quantity of the cement as shown in Fig. 8 (a & b). Thickness swelling (Fig. 8a) has values ranging from 0.81% to 9.02% while the water absorption (Fig. 8b) ranges between 7.16 and 21.41%. Boards produced from sample E exhibited the highest thickness swelling and water absorption. This is due to the fact that, low density boards have more permeable voids than dense ones so that more water can be absorbed. In addition, large numbers of micro voids present in the sample can accelerate the penetration of water by the capillary action (Salem and Al-Salami 2016). After saturating the cell wall, water then occupies the micro voids. Therefore, increasing board density decreases the voids and reduces swelling rate and water absorption.

3.4 Modulus of Elasticity and Modulus of Rupture.

Modulus of Elasticity (M.O.E.) and Modulus of Rupture (M.O.R.) of the ceiling board increased with the increased quantity of the cement as shown in Fig. 9 (a & b). Modulus of Elasticity (Fig. 8a) has values ranging from 1.03 GPa to 1.6 GPa while the Modulus of Rupture (Fig. 9b) ranges from 1.34 MPa and 2.2 MPa. Boards produced from sample E exhibited the lowest M.O.E. and M.O.R. This is due to the fact that porosities and voids in the composite ceiling board increased as the cement content decreased thereby reducing flexural and load bearing capacity of the board.

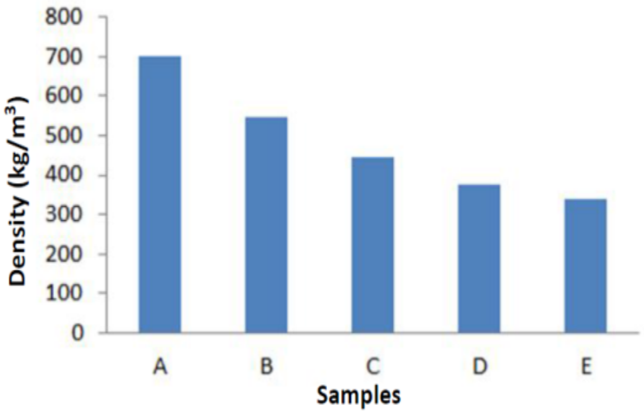

Figure 7. The influence of sample composition on density of the board produced.

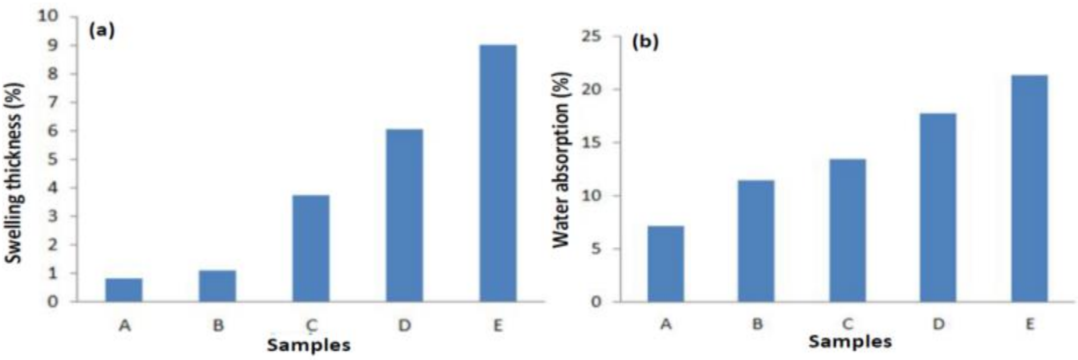

Figure 8. The influence of sample composition on (a) Swelling thickness (b) Water absorption of the ceiling board.

3.5 Compressive Strength

The compressive strength of the ceiling board is presented in Fig. 10 (a). It is observed that the compressive strength decreased with the increase in the carton content of the mix. Sample A has the highest compressive strength of 10.3 N/mm^2. This is probably due to the fact that higher amount of Portland cement is present in the sample, since cement has high compressive strength. Sample E, which is 45% carton, has the least compressive strength of 4.8 N/mm^2 this is probably due to the fact that the carton content yields a lot of voids and porosity in the samples, leading to a lower compressive strength Paramisivam *et al*. (1984).

3.6 Thermal Conductivity

The thermal conductivity of the samples is relatively low ranging from 0.1077 to 0.0951 (*W/m.K*), which is decreased with the increase in the carton content of the mix as shown in Fig. 10 (b). This is due to the inclusion of supplementary cementitious materials has composites which; according to Kim *et al.* (2003), will greatly reduce the thermal conductivity, but increase porosity. Porosity in composite materials has dramatic influence on thermal conductivity; increasing the pore volume will, under most circumstances, result in reduction of thermal conductivity. In fact, many materials that are used for thermal insulation are porous. Heat transfer across pores is ordinarily slow and inefficient. Internal pores normally contain still air, which has an extremely low thermal conductivity.

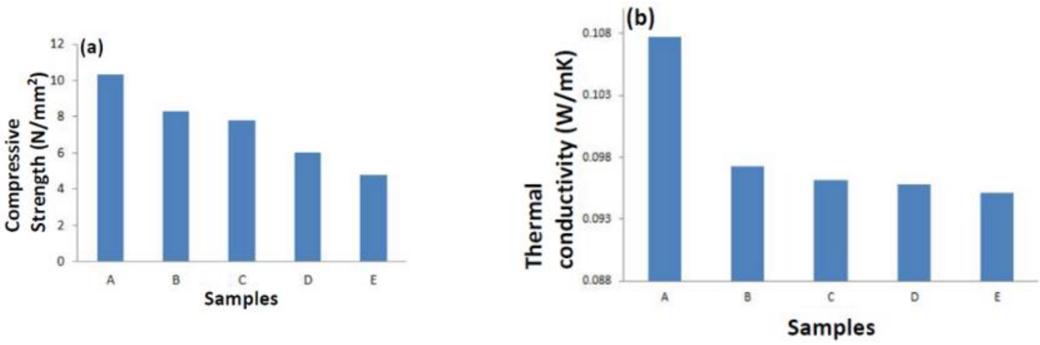

Figure 9. The influence of sample composition on: (a) Modulus of elasticity; and (b) Modulus of rupture of the ceiling board.

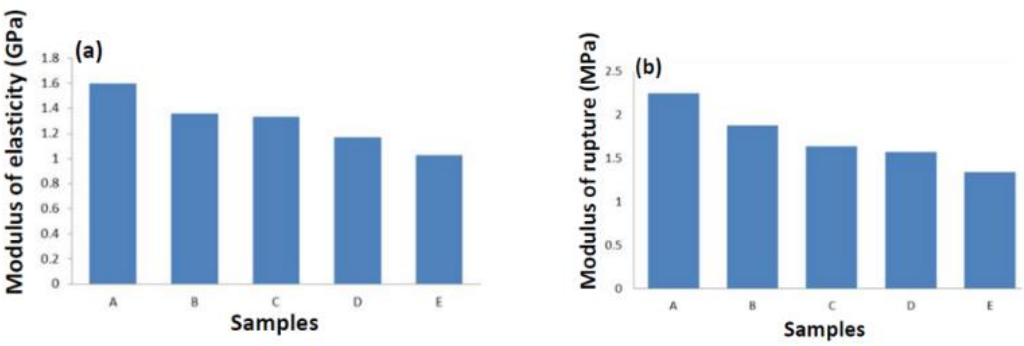

Figure 10. The influence of sample composition on: (a) Compressive strength; and (b) Thermal conductivity.

As the carton content in the samples increased, the thermal conductivity and the density decreased, because the extent of voids in the samples increases considerably. The thermal conductivity of a porous medium is inversely proportional to the level of voids in the specimen, so it can be concluded that the thermal insulation efficiency of a material is inversely proportional to its density (Salas Alvarez 1986).

In asbestos cement sheets, asbestos cement board, asbestos loosely packed and asbestos mill board, the values for thermal conductivity are 0.166, 0.744, 0.15 and 0.14 (*W/m.K*), respectively (www.engineering toolbox.com). Comparing these values with the samples in the present study revealed that they have better thermal conductivity properties than all the asbestos boards. Table 3 compares the density and thermal conductivity of insulating ceiling board produced in this study with asbestos and Nigerite board.

4. CONCLUSION

Waste carton and chicken feather in cement bonded composites can be used to produce ceiling boards and also for any other non-structural applications in low cost housing projects in Nigeria.

Sample A (80%-cement, 10% chicken feather, 10% carton) gave the lowest water absorption and swelling thickness, and thus recommended for ceiling board applications. Sample E (45% cement, 10% chicken feather, 45% carton) has weight advantage over other insulation board samples, and can hereby be used as notice board in offices. The produced board samples produced were better in terms of density and thermal conductivity compared with other available ceiling boards including Nigerite boards. Cartons and chicken feathers are readily available in our environment and they are often discarded as wastes. Thus, insulation ceiling boards produced from these wastes are expected to be relatively cheaper than most commercially available boards and should be more environmentally friendly.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

FUNDING

No funding was received for this project.

ACKNOWLEDGMENT

The authors wish to thank the technical staff of the Department of Mechanical Engineering as well as the management of Landmark University Omu Aran, Kwara State, Nigeria, for their technical support and provision of facilities for the laboratory tests, respectively.

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Table 3. Properties of insulation boards produced compared with asbestos and Nigerite board.

Material	Density (kg/m^3)	Thermal conductivity (W/mK)	Reference(s)
Asbestos board	1500 – 1950	0.15 -2.07	Ataguba, (2016),
Nigerite board	1350	0.2	http://www.nigeritelimited.com
A	700.7	0.1077	This study
B	547.0	0.0973	This study
C	443.5	0.0962	This study
D	373.9	0.0958	This study
E	337.8	0.0951	This study

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