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The Suitability of Using Environmental Waste (Polystyrene Foam, Sawdust and Eggshells) for Developing a Hybrid Composite for Ceiling Boards

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Abstract

This study considers the suitability of using environmental wastes (polystyrene foam, sawdust and eggshell) for the development of composite materials for ceiling boards. The materials were collected from dumping sites and processed accordingly. The elemental compositions of the processed sawdust and eggshell were examined using Atomic Absorption Spectrometer (ASS) and plasma-optical emission spectrometer (Optimal 3100XL Perkin Elmer) respectively. Properties of the composite samples were determined using appropriate ASTM standards (ASTM D570, C109-95, D3479, E1530 and D7336/D7336M). The results show that the composite with a mix ratio of 5% Polystyrene, 10% sawdust and 40% eggshell exhibited the most suitable properties for ceiling board production or indoor uses in building: water absorption (0.52 and 6.17% for 2 and 24hours respectively), tensile strength (2.362 N/mm^2), elongation at break (0.677 mm), compressive strength (0.1575 N/mm^2), energy to break (0.016 N.m) and thermal conductivity of 0.0221 W/M.K. Thus, the production of suitable ceiling board using some bio-wastes can be domesticated in Nigeria.

Keywords: Ceiling boards, Composites, Wastes, Polystyrene Foam, Sawdust, and Eggshell particles

1.0 INTRODUCTION

Ceiling boards are lightweight structural elements usually designed to enhance aesthetics and acoustics in industrial applications, apartments for commercial and residential purposes, among others. In modern buildings smoke detectors, security cameras, electric lights and signage are commonly attached to ceilings [1]. Ceiling boards are mostly made from mineral fiber, though other materials such as fiberglass are also used [2-8]. Over the years, the fiber found in rocks (asbestos) due to its properties of strength, low heat conductivity, and high fire resistance is used to make ceiling planks. However, asbestos develops asbestosis in human inhabitants that which is cancerogenic [9-14]. Thus awake the interests of researchers and other stakeholders in finding a suitable replacement for asbestos in the manufacture of boards. Sawdust, cellulose fiber, agricultural waste, and other materials can be used as a replacement [15-22].

The wood industry is strategic in the use of planks from sawmills. It forms the major market for wood products in Nigeria. The increase in applications of wood for furniture, building construction and interior decorations in Nigeria has led to a significant increase in the numbers of sawmills in the country [23]. The amount of sawdust generated per annum in Nigeria is estimated to be around 1.8 million tonnes [24-27]. Sawmills generate a huge amount of wood wastes, such as sawdust, up to 93% [28]. About 5.2 million tonnes per year of wood residue is also being generated in Nigeria [29, 30].

Aquatic and terrestrial ecosystems are affected by inappropriate management of wood dust. Indiscriminately burning of waste distorts water eco-systems, environmental problems, health challenges especially at eye and respiratory tract, water and air pollution, and also contribute to climate change as a result of greenhouse gases that are released into the atmosphere [31-34].

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The development meets the requirements of the current generation without affecting the future generation's ability to fulfil their own needs [35]. More so, the adverse effect of poor methods of waste management, as a result of large amounts of the wood residues not adequately managed within the environment is a common phenomenon in Nigeria [29]. Therefore, the use of sawdust in the production of ceiling tiles will help to control environmental pollution and subsequently reduce health issues. It will also be of benefit to domesticate the production of ceiling boards, which shall help in job creation and address social problems in Nigeria.

Polystyrene is a versatile plastic used to make a wide variety of consumer products, such as food packaging and laboratory ware, packaging of appliances, etc. It is also made into foam material called expanded polystyrene or extruded polystyrene which is valued for its insulating and cushioning properties. It is a material that does not degrade. It is made from benzene and styrene, suspected carcinogens and neurotoxins that are hazardous to humans [36, 37]. Polystyrene is a toxin and non-recyclable material that never break down but goes directly to landfills because it is made of petroleum and other heavily polluting ingredients, toxic and non-sustainable materials [38]. It is highly flammable because it can be easily ignited and cause huge fires and losses of life. For instance, at Dusseldorf International Airport and channel tunnel where polystyrene was inside the railcar that caught fire [39]. Polystyrene is known to be hazardous household waste and is also linked to adverse effects in humans since it is a possible carcinogen [40]. Burning polystyrene releases toxic chemicals and smoke like carbon monoxide and styrene monomers into the environment which is extremely hazardous to human health [41, 42].

Studies have revealed that chicken eggshell is an agricultural by-product that has been considered as one of the worst environmental problems especially in countries where the egg product industry is well developed [43]. In Nigeria, an estimate of about 5000-6000 tons of eggshell waste is been expected to be disposed of as of 2005 [44]. Eggs are a key ingredient in a wide range of confectionaries and processed quick meals, the manufacture of which generates many tonnes of eggshell waste every day and incurs significant disposal expenses across the world. Every year, around 250,000 tonnes of eggshell trash are created globally [45], even though there have been multiple attempts to employ eggshell components for various purposes. Eggshell's chemical composition and availability make it a viable filler in polymer composites [46, 47]. Egg Shell is a good substitute for low-load-bearing composite applications, including the automobile industry, residences, offices, and factories due to its affordability, lightweight in polymer composites, eggshell has been employed as reinforcement.

The sawdust and eggshell reinforced matrix composite is being investigated. The study shall be of benefit to individuals and Nigeria at large, in the creation of wealth, reduction in the cost of production of goods and products; conservation of planet's beauty, secure effective, sustainable natural resources and ecological sound environment [48-50].

This study is therefore based on examining the suitability of sawdust, polystyrene foam and eggshells, which are wastes, in the development of ceiling boards. The results of this study will aid the domestication of ceiling boards, reduce the cost of production, and proffer solutions to the problem of unemployment among youths and help in waste management in Nigeria.

2.0 MATERIALS AND METHODS

The materials used in this study are wastes which include polystyrene foam, eggshells and sawdust and gasoline as solvent. Polystyrene was sourced from an electronics shop in Ilorin, Nigeria, while the sawdust (mahogany) was obtained at the dumping site of a commercial Sawmill at Tanke, Ilorin, Nigeria. Eggshells were sourced from a pastry shop waste bin.

2.1 Production of Celling Board Samples

The samples were prepared using polystyrene as a binder; and sawdust and eggshell as reinforcement. The sawdust was sun-dried for 30 hours and sieved with mesh 0.03 mm grain size, while the eggshell was washed; sun-dried for 6 hours and pulverized using an electric blender produced made in China (Model No: PM-Y44B3, AC 220V-50Hz 350W). The sieved sawdust and blender for pulverizing the eggshell are presented in Figures 1 and 2 respectively. Subsequently, the polystyrene (1.5 kg) was dissolved in 4 liters of petrol and stirred until an aqueous solution was formed. The dissolved polystyrene is as shown in Figure 3.

Figure 1: Sieved sawdust

Figure 2: Blender for pulverizing eggshell

Figure 3: Dissolved Polystyrene Foam

The sieved sawdust pulverized eggshell and dissolved polystyrene foam were manually mixed in a container using the formulation presented in Table 1 until a homogeneous mixture of the materials was attained. Table 1 shows the formulation of the ceiling board containing the weight ratio of polystyrene foam solution, sawdust and pulverized eggshell used in producing the ceiling board samples.

The mixture containing the polystyrene solution, sawdust and eggshell was poured and compacted manually with a 1560 kN compression machine (Hemel Hempstead Hertfordshire, England) into the moulds (19.0 x 9.5 mm) to produce the samples of the ceiling board. The samples were left to dry in the air (curing) for 21 days in an open and ventilated atmosphere, to attain perfect drying. Curing for 21 days to solidify naturally will prevent the composite from having internal micro-cracking due to induced stresses [51]. Figure 4 depicts the processes and the product is presented in Figure 5 respectively.

Table 1: Mixing proportion of the materials (Formulation)

Composite	Polystyrene Foam Solution By Wt % (PS)	Pulverized Sawdust By Wt% (SW)	Pulverized Eggshell By Wt % (ES)
A	100	0	0
B	50	50	0
C	50	40	10
D	50	30	20
E	50	20	30
F	50	10	40
G	50	0	50

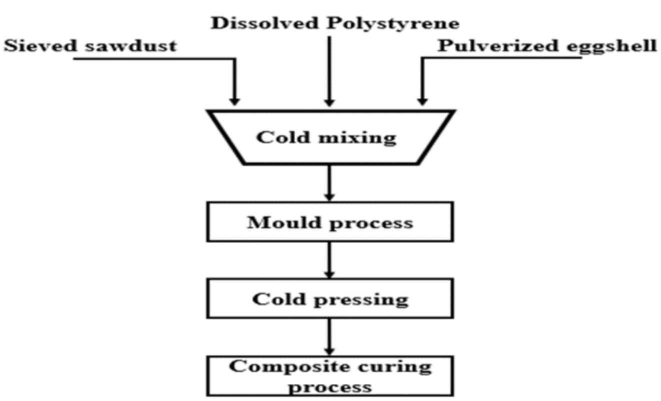

Figure 4: The processes of producing the composite samples

2.2 Characterization of the Samples

From the samples of the processed sawdust and eggshell, the elemental compositions of the materials were examined using Plasma-Optical Emission Spectrometer (Optimal 3100XL Perkin Elmer) and Atomic Absorption Spectrometer (ASS) respectively. The properties of samples such as percentage water absorption, tensile and compressive strength, thermal conductivity and resistivity, energy absorbed before failure were tested to characterize the samples.

2.2.1 Rate of water absorption

The rate of water absorption in the samples was determined following guidelines in ASTM D570 [52]. A pair of the samples of the board was selected and left to dry for 48 hours at room temperature. The dried samples were then weighed and recorded as and socked in water for 2 hours and 24 hours to determine the water absorption rates for short and longer periods respectively. The weight of the socked sample was measured and recorded as M2. The percentage water absorption of each sample was determined using Equation 1.

$$\frac{(m_2 - m_1)}{m_1} \times 100 \tag{1}$$

Where: M_1 = mass of the dried sample and M_2 = mass of the wet sample

Figure 5: *Some of the samples of the composites produced*

2.2.2 Compressive strength test

The compressive test was carried out following the guidelines in ASTM C109-95 standard [53] using a 50 kN Testometric Material Testing Machine (Model Number M500-50AT) using winTestTM Analysis. Each of the samples was mounted on the jaws of the machine one after the other. The loading was increased gradually from zero force loads at a test speed of 100 mm/min until the sample was fractured. The measurements were displayed on the monitor of a computer desktop system attached to the Testometric Machine.

2.2.3 Tensile strength

The tensile test was performed based on the ASTM D3479 specifications [54] using the Testometric machine shown in Figure 10. The samples were clamped at both ends after being placed on the machine. The tensioned ends were stretched until failure by splitting occurred. Modulus of elasticity was calculated using Equation 2.

$$\text{Modulus of elasticity} = \frac{\text{tensile stress}}{\text{tensile strain}} \tag{2}$$

$$\text{Tensile stress} = \frac{\text{load at break}}{\text{area}} \tag{3}$$

$$\text{Strain} = \frac{L - L_{\circ}}{L_{\circ}} \tag{4}$$

2.2.4 Thermal conductivity

The characterization was carried out using 'Guarded heat flow meter method in accordance with ASTM E 1530 [55]. 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 (°C); heated section at mid-temperature (°C); heated section at low temperature (°C); cooled section high temperature (°C); cooled section at mid-temperature (°C); cooled section at low temperature (°C); and thickness of the specimen x (m). Figure 6 shows the Computer Compatible Linear Heat Conduction Apparatus setup for determining thermal conductivity. The thermal conductivity of the samples was determined using equations 5, 6, 7, 8, 9 and 10.

Where: Heat flow (power of heater),

$$Q = VI\,(Watts) \tag{5}$$

The cross-sectional area of the specimen,

$$A = \frac{\pi D^2}{4} \quad (\mathrm{m}) \tag{6}$$

Temperature difference across specimen,

$$\Delta T_{SP} = T_{Hotface} - T_{Coldface} \tag{7}$$

Temperature of hot face of specimen

$$T_{hotface} = T_1 - \frac{T_{2} - T_3}{2}\,(°\mathrm{C}) \tag{8}$$

Temperature of cold face of Specimen

$$T_{coldface} = T_6 - \frac{T_{7-T_8}}{2} \quad (°C) \tag{9}$$

$$K = \frac{QX}{A\,(T_{hotface} - T_{coldface})} \tag{10}$$

Thermal conductivity,

Figure 6: Computer compatible linear heat conduction apparatus setup for determining thermal conductivity.

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).

2.2.5 Thermal resistivity (TR) and energy absorption

The thermal resistivity of the sample, which is the reciprocal of thermal conductivity, was calculated. Energy absorption by each of the samples before failure was determined on the Testometric Material Testing Machine (Model Number M500-50AT) using winTestTM Analysis alongside the tensile stress. The test was conducted in accordance with ASTM D7336/D7336M-16 guidelines [56].

3.0 RESULTS AND DISCUSSION

3.1 Elemental Compositions

The percentage chemical compositions of sawdust and eggshell are presented in Tables 2 and 3 respectively. It is revealed in the results that carbon (60.5%) served as the primary constituent in the sawdust (being an element with the highest value in the material), followed by oxygen (32.8%), an abundant element in sawdust. The presence of other trace elements, such as hydrogen and nitrogen were also revealed. The results align with the results obtained by Phonphuak et al. [57] and Phonphuak & Chindaprasirt [58]. Carbon-based materials are widely for the high thermal and mechanical properties of materials, and as a filler due to their qualities and behavior [59, 60]. Thus, it is an indication of the possibility of sawdust being a suitable material for ceiling boards.

Calcium carbonate was found to be the dominant element in the eggshell with the value of 96.5%, and the presence of other elements, such as MgO, Na_2O and SO_3 was revealed, which is in line with the results of Amu et al. [61]. Therefore, the presence of calcium carbonate in eggshells is likely to make the shell a good material for ceiling boards' production because of its strength property.

Table 2: Chemical composition of sawdust

Composition	Percentage (%)
Carbon	60.5
Hydrogen	6.2
Oxygen	32.8
Nitrogen	0.5

Table 3: Chemical composition of eggshell

Composition	Percentage
$CaCO_3$	96.5
MgO	1.0
Na_2O	1.5
SO_3	1.0

3.2 Water absorption test

The results of the water absorption of the samples are presented in Figure 7. The values are in the range of 0.82-16.54% and 13.17-47.2% for periods of two (2) hours and twenty-four hours respectively. It was observed that the value of water absorption exhibited by the samples increases with the inclusion of sawdust as shown in Figure 7. The sample's water absorption increases with an increase in the percentage of sawdust in the sample, both at short and longer periods (2 and 24 hours). Thus, the repellent property of the sample reduces with an increase in the quantity of sawdust in the sample. This is in line with the results of Mogaji [51] that water absorption of the sample decreases with a decrease in sawdust content. This might be attributed to the presence of cellulose and hemicelluloses which causes a high rate of water uptake [62]. Also, poor adhesion between wood particles and polystyrene matrix generates void space which causes high water absorption [63]. The samples with no sawdust (Sample A, 100% polystyrene and sample G, 50% polystyrene with 50% eggshell), exhibited very low water absorption compared to that of samples with the inclusion of sawdust at all levels. This is an Indication of good miscibility and a low level of a void between the polystyrene and sawdust particle [51].

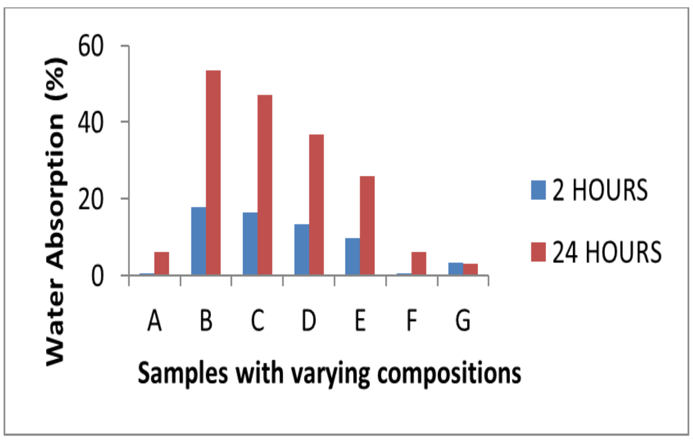

Figure 7: Rate of Water Absorption

The presence of an eggshell particle in the sample also enhances the ceiling board sample's water repellent property. The rate of water absorption by the samples increases with time, except for sample G (50% polystyrene and 50% eggshell). This might be attributed to the fact that eggshell particle is not hydrophilic. It is an indication that more sawdust in the composite leads to more void and low miscibility between the particles of the composite constituents. The values of the water absorption exhibited by the hybrid samples (0.82-16.54% and 13.17-47.2% for 2 hours and 24 hours respectively) exceeded the 0.64% moisture content specified as engineering and materials standards for ceiling board [50]. Meanwhile, Indian Standard IS-14276 recommended 13% as the water absorption for particleboard for 2 hours and 24 hours [64].

3.2 Compressive strength

The compressive strengths exhibited by the ceiling board are presented in Figure 8. The samples' strengths fall within the range of 0.0662 and 0.1575 N/mm^2. The sample's compressive strength increases with an increase in the percentage of the eggshell particle in the composite. This is also reflected in the compressive strength exhibited by sample G, containing 50% polystyrene and 50% eggshell (0.0615 N/mm^2), compared to that of sample A (100% polystyrene) having 0.0564 N/mm^2. The chemical compositions of eggshells contain 96.5% calcium carbonate. Calcium carbonate might be responsible for the increase in the strength of the materials. It was confirmed that calcium carbonate increases the compressive strength of the materials [65]. Calcium carbonate is the most widely used filler in polymer formulations, since it improves mechanical properties, such as strength and gives room for cost reduction [66].

Enhance compressive strength exhibited by the samples with the inclusion of the mixture sawdust and eggshell may be attributed. Also, good compatibility attained in the mixture of eggshell and sawdust as a result of their particle sizes (0.03 mm) may be a contributing factor to the samples (B - G)s' better compressive strengths.

The compressive strengths exhibited by the hybrid composite samples (0.0662 – 0.1575 N/mm^2) did not meet the specified compressive strength of 448 – 868 MPa (0.448 – 0.868 N/mm^2) for ceiling boards by Engineering and Material Science Standards [50].

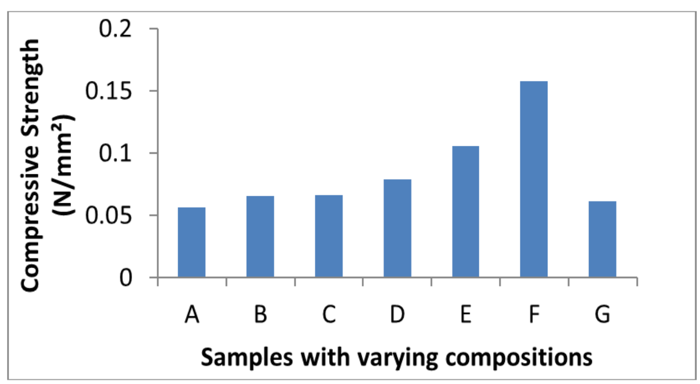

Figure 8: Compressive strength of samples

3.3 Tensile strength

The various tensile strengths exhibited by the composite samples for the production of the ceiling board are presented in Figure 9. The tensile strength exhibited by the samples is in the range of 0.7459 to 2.656 N/mm^2, with Samples A and B exhibiting the highest value of 2.656 N/mm^2 and the least value (0.7459 N/mm^2) by sample B.

The inclusion of sawdust in the composite reduces the tensile strength of the composite. This is due to an increase in interfacial area with worsening interfacial bonding between the sawdust and polystyrene [67, 68]. The presence of sawdust in the sample probably leads to moisture adsorbed on the fiber and poor dispersion of fiber in the matrix reduces the tensile strength of the composite [69]. Either insufficient hydrogen bonding between the fiber–polypropylene and the sawdust or the aggregation of the sawdust probably decreases the tensile strength of a composite [70]. With a higher sawdust percentage, a drop in tensile strength occurs due to agglomeration of sawdust, which results in improper curing of the samples [71]. An increase in sawdust also increased microspores between matrix which in turn weakens adhesion between matrix and filler interface affecting tensile behaviour [72]. This result is in line with the assumption of Abdulkareem [73] that the tensile strength of the sample increases with an increase in polystyrene content and decreases with an increase in sawdust content. The presence of an eggshell particle in the composite is appreciably better than that of sawdust relatively in tensile strength property. Sample G exhibited tensile strength (2.656 N/mm²) less than, but relatively closer to that of the control sample, (sample A, 2.650 N/mm²). This may be attributed to the fine nature of the eggshell particle with little void and good miscibility, and adhesive properties between the eggshell particle and polystyrene.

Fiberboard products with tensile strength of 0.69 and 4.1 N/mm^2 are classified as low-density and high-density respectively [74]. All the hybrid composite sample's strength are greater than 0.69 N/mm^2, but lower than 4.1 N/mm^2, an indication that the composite material met the strength requirement for low-density fiberboard.

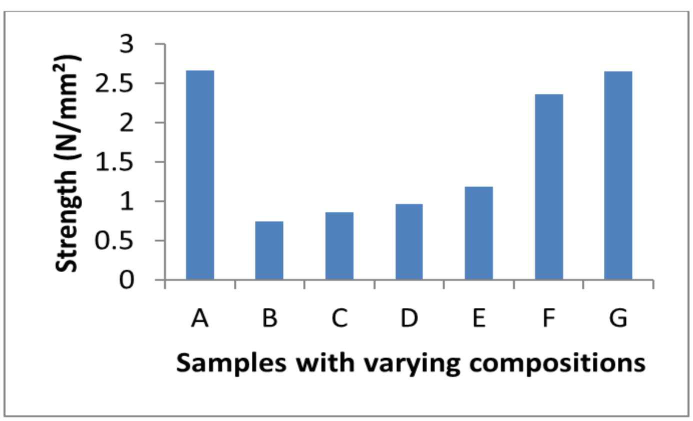

Figure 9: The samples' tensile strengths

3.4 Elongation at Break

The various values of elongations (under load) of the composite samples till failure are presented in Figure 10. The elongation of the samples is between 2.739 and 0.469 mm, with Samples A exhibiting the highest value of 2.739 mm and the least value of 0.469 mm by sample B. Polystyrene is known for high ductility [75].

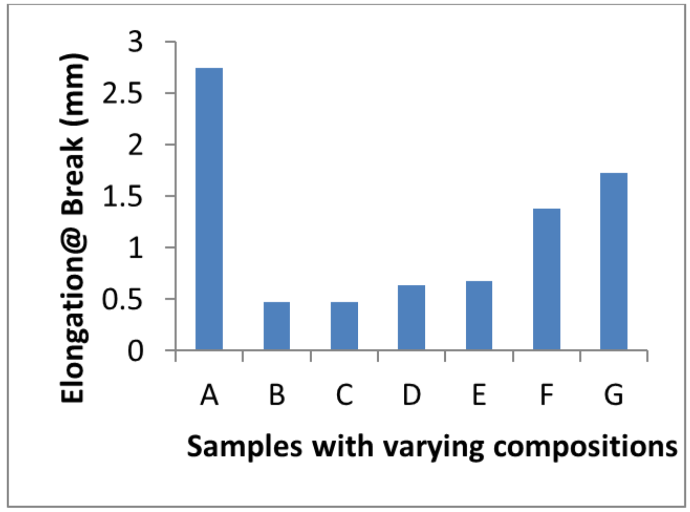

Figure 10: Samples' elongation at break

As reflected in the samples' tensile property, the inclusion of sawdust in the composite also reduces the samples' elongation at break. As sawdust percentage weight in the samples increases, the material's elongation at break decreases, Increase in sawdust also increased microspores between matrix which in turn weakens adhesion between matrix and filler interface also affecting the ductility like tensile property. The percentage elongation decreases with filler (sawdust and eggshell) contents.

3.5 Energy to break

It is essential to know the amount of energy a material will withstand up to failure, to avoid any possible catastrophic failure from excessive loading, pre-existing flaws, inadequate properties of the material, among others [76]. The values of the energy to break exhibited by the samples range from 0.04 – 0.0016 N.m with sample E having the highest value (0.04 N.m) and sample C exhibiting the lowest (0.001 N.m). The energy to break exhibited by all the samples is generally low.

3.6 Thermal Conductivity

The heat conductivity of the samples is relatively low having a value of 0.0221 (W/m.K) for all the samples (Table 6), which means the thermal conductivity of the samples is not influenced by the variation in the mix proportioning of the samples. According to Kim et al. [77], the thermal conductivity will greatly reduce, with an increase in porosity

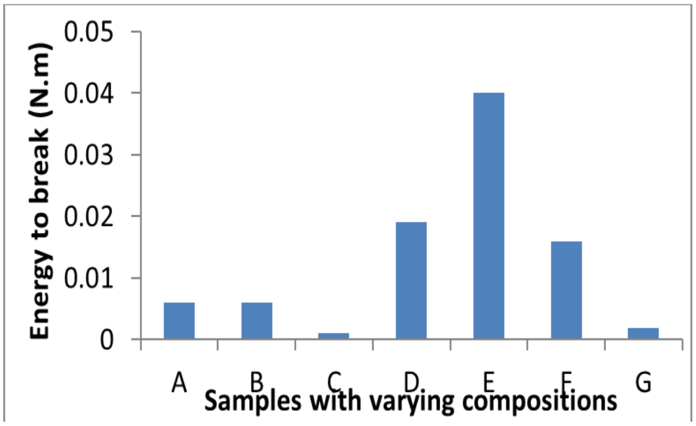

Figure 11: Samples' energy Absorb by the sample up to failure

Thus, the result of the thermal conductivity is an indication that the rate of heat conduction by the composites' samples is minimal. The thermal conductivity's standard value for a commercial ceiling board given by Engineering and Material Science Standards for ceiling boards is between 0.052 and 0.057 W/M.K [50], which is greater than 0.0221 W/m.K exhibited by the samples developed in this study. A material that is associated with high thermal conductivity or low heat capacity will obviously possess a large thermal diffusivity [78]. Meanwhile, the hybrid composite thermal conductivity value met the recommended thermal conductivity value suitable for good construction and heat insulating materials is between 0.023 and 2.900 W/m.K [79].

Table 6: Thermal conductivity of the samples

Samples	Area(m)	Thickness(m)	$T_{Coldface}$(℃)	$T_{Hotface}$(℃)	Q(W)	W/m.K
A	0.000491	0.0025	28.7	30	1.2	0.0221
B	0.000491	0.0025	28.7	30	1.2	0.0221
C	0.000491	0.0025	28.7	30	1.2	0.0221
D	0.000491	0.0025	28.7	30	1.2	0.0221

Considering the evaluated properties of the hybrid composite materials, the samples may not be suitable for structural or load bearing purposes due to low values of mechanical properties exhibited, but are suitable for indoor uses in building. The strength of the composite samples tends to be improved as the composition of eggshell increases in the composite.

4 CONCLUSION

The waste materials can be recycled into a useful material thereby preventing environmental pollution. Waste polystyrene foam, sawdust and eggshell composites can be used to produce ceiling boards and also for any other non-structural applications in low-cost housing projects in Nigeria. Sample H (60% polystyrene, 10% eggshell and 30% sawdust) gave the lowest percentage of water absorption, the highest tensile strength and sample G (50% polystyrene, 25% sawdust and 25% eggshell) has a slight improvement in compressive strength of the sample. Thus, recommended for a ceiling board application. Sample D (20% polystyrene, 70% sawdust and 10% eggshell) gave the highest compressive strength and percentage water absorption which is not advisable for use. Increasing fiber load improves the strength of the composite but decreases elongation and energy to break. The thermal conductivity of the samples produced was a bit lesser compared with the Asbestos board which ranges from 0.052 - 0.057 (W/m.K), though can be improved by decreasing the proportion of sawdust and increasing the proportion of eggshell in the composite. Meanwhile, the property is an indication that the composite material from Polystyrene foam, sawdust and eggshell is suitable for good construction and heat insulating materials and can be used for indoor uses in building, but may not be suitable for structural or load bearing purposes.

Polystyrene foam, sawdust and eggshell are readily available in our environment and they are often discarded as wastes. Thus, ceiling boards produced from these wastes are expected to be relatively cheaper than most commercially available boards and should be more environmentally friendly.

REFERENCES

[1] Meyers-Levy, J., and Zhu, R. "The influence of ceiling height: The effect of priming on the type of processing that people use", *Journal of Consumer Research*, 34(2), 2007, pp 174-186.

[2] Oladele I. O., Akinwekomi A. D., Aribo S. and Aladenika A.K. "Development of fibre reinforced cementitious composite for ceiling application." *Journal of Minerals and Materials Characterization and Engineering*, 8(8), 2009, pp. 583–590.

[3] Sanjay, M. R., and Yogesha B. "Studies on mechanical properties of jute/E-glass fiber reinforced epoxy hybrid composites." *Journal of Minerals and Materials Characterization and Engineering*, 4(1), 2016, pp. 15–25. doi:10.4236/jmmce.2016.41002.

[4] "How Product are made". http://www.madehow.com/Volume-2/Fiberglass.html, Accessed on December 10, 2021.

[5] ODEN C. "MANUFACTURE OF CEILING BOARD USING LOCAL MATERIALS".

[6] https://www.projecttopics.org/manufacture-ceiling-board-using-local-materials.html, Accessed on October 10, 2021.

[7] JOHN D. K., MARK R. G., RICHARD N. C., OWEN C. F. "PROCESS FOR THE MANUFACTURE OF

[8] CEILING TILE, US5194206A", HTTPS://PATENTS.GOOGLE.COM/PATENT/US5194206A/EN, ACCESSED ON NOVEMBER 20, 2021.

[9] Ichetaonye S. I., Ajekwene K. K., Ulaeto S. B., Yibowei M. E., Alosaimi A. M., Hussein M. A. and Khan A., "Sustainable alternative ceiling boards using palm kernel shell (PKS) and balanite shell (BS)", *Journal of Polymers and Environment*, 29, 2021, pp. 3878-3886.

[10] Martias C., Joliff Y. and Favotto C., "Effects of the addition of glass fibers, mica and vermiculite on the mechanical properties of a gypsum-based composite at room temperature and during a fire test", *Composites Part B: Engineering*, 62, 2014, pp. 37–53.

[11] Kyeongmin, K., Kyung, E. Z. and Domyung, P., "Incidence of cancer and asbestos-related diseases among residents living near abandoned asbestos mines in South Korea: A retrospective cohort study using national health insurance database, *International Journal of Environmental Research and Public Health*, 18(875), 2021, pp 2-15

[12] National Statistics. "Asbestos-related disease statistics", Health Safety Executive (HSE), Great Britain, pp 1-28, 2021. www.hse.gov.uk/statistics/causdis. Accessed on November 1, 2021.

[13] National Cancer Institute. "Asbestos exposure and cancer risk fact sheet". www.cancer.gov>cause? Accessed on October 21, 2021.

[14] WHO. *Crysotile asbestos*, World Health Organization, Geneva, 2014.

[15] Amellie J., Brochard P., Letourneux M., Paris C. and Pairon J. C., "Asbestos-related cancer risk in the presence of asbestosis or pleural plaques", *Rev. Mal Respir*, 28(2), pp .11-7.

[16] Binggeli, C. *Interior graphic standards*, Vol. 21, John Wiley & Sons, 2011

[17] Yakubu I., Yahaya B. S., Mbishida M A., Achema F., and Karfe S. G., "Production of agro waste composite ceiling board (A case study of the mechanical properties)", *Journal of Scienti□c and Engineering Research*, 4(6), 2017, pp. 208–212.

[18] Dagwa I. M., Builders P. F. and Achebo J., "Characterization of Palm Kernel Shell Powder for Use in Polymer Matrix Composites." *International Journal of Mechanical and Mechatronics Engineering*, 12(4), 2012, pp 88–93.

[19] Edmund C. O., Saffron C. M. and Kamdem P. D., "Characterization of palm kernel shell for materials reinforcement and water treatment", *Journal of Chemical Engineering and Materials Science*, 5(1), 2014, pp 1–6.

[20] Obam S. O. "Properties of saw-dust, paper and starch composite ceiling board", *American Journal of Scientific and Industrial Research*, 3(5), 2012, pp 300-304.

[21] Isheni Y., Yahya B. S., Mbishida M. A., Achema F., Karfe G. S., "Production of agrowaste composite ceiling board (A case study of the mechanical properties). *Journal of Scientific and Engineering Research*, 4(6), 2017, pp. 208-212.

[22] Idris U. D., Aigbodion V. S., Abubakar I. J., Nwoye C. I., "Eco-friendly asbestos free brake-pad using banana peels", *Journal of of King Saud University – Engineering Sciences*, 27(2), 2015, pp 185-192.

[23] Kumar P. R., Sreelekshmi K. S., Anjana S. B., Harikrishnan S., Santhanu G. N., Leena V. P., "Role of agricultural wastes in construction industry, 9(3), 2015, pp. 66-69

[24] Kolo S.S., Amad A., Adeleke O. O., Obebe J. O., Oyelade O. A. and Yusuf L. T., "Production of ceiling board using waste materials", *International Civil Engineering Conference (ICEC), Federal University of Technology, Minna,* 2018. https://staff.futminna.edu.ng/CIE/Contact?journal/PF0883/15.pdf, Accessed on December 20, 2021.

[25] Rominiyi O. L, Adaramola B. A., Ikumapayi O. O., Oginni O. T. and Akinola S. A.. "Potential utilization of sawdust in energy, manufacturing and agricultural industry: Waste to Health", *World Journal of Engineering and Technology*, 5, 2017, pp 526-539.

[26] Tilak L. N., Santhosh Kumar M. B, Manvendra S., Niranjan, "Use of Sawdust as fine aggregate in concrete mixture", *International Research Journal of Engineering and Technology*, 5(9), 2017, pp 1249 - 1253

[27] LN M. T., Kumar M. S., Singh M. M., and Niranjan M., "Use of saw dust as fine aggregate in concrete mixture, *International Research Journal of*

Engineering and Technology, 5(9), 2018, pp 1249-1253.

[28] Peter A., Albert O., Anthony U., "Nigerian wood waste: A potential resource for economic development", *Journal of Applied Sciences, Environmental and Management*, 21(2), 2017, pp 246-251

[29] Sambo, A. S., "The Place of Renewable Energy in the Nigerian Energy Sector", *World Future Council Workshop on Renewable Energy Policies*, 10 October 2009, Addis Abbaba, Ethiopia.

[30] Ogunwusi A. A., "Wood waste generation in the forest industry in Nigeria and prospects for its industrial utilization, *Civil and Environmental Research*, 6(9), 2014, pp 62 - 69.

[31] Sambe L.N., Origbo B., Gbande, S., and Ande P.U., "Assessment of wood waste generation and utilization in Makurdi metropolis: Implication for sustainable management of forest resources", *Journal of Research in Forestry, Wildlife and Environment*, 13(1), 2021, pp. 188 – 196.

[32] Francescato V., Antonini E., Bergomi L. Z., Metschina C., Schnedl C., Krajne N., Koscik K., Gradziuk P., Nocentini G., Stranieri S., "Wood Fuels Handbook", AIEL: Italian Agriforestry Energy Association, Legnaro, 2008.

[33] Idise O., Okoko F., Aire P., Ogor O., and Egbah, A., "The effects of solid wood waste discharge on the physico-chemical and microbial characteristics of the Warri river". *African Journal of Microbiology Research*, 6(20), 2012, pp 4302-4314.

[34] Anselm E. O. E. and Stephen N. O. "Mitigating the impact of climate change through waste recycling", *Research Journal of Environmental and Earth Sciences*, 4(8), 2012, pp 776-781.

[35] Kang S., Kim S., Lee J., Yun H., Kim K. H. and Jeon E. C.. "The Study of biomass fraction estimate methodology of municipal solid waste incinerator in Korea", *Journal of Air Waste Management*, 2016, pp 7- 971.

[36] Cogut A., "Open burning of waste: A global health disaster, R20 Regions of Climate Action", 2016. Available at https://regions20.org/wp-content/uploads/2016/08/OPEN-BURNING-OF-WASTE-A-GLOBAL-HEALTH-DISASTER_R20-Research-Paper_Final_29.05.2017.pdf, Accessed on September 07, 2021.

[37] IISD. "Sustainable development". Available at http://www.iisd.org/topic/sustainabledevelopment. Accessed on July 11, 2021.

[38] Alabi O. A., Ologbojaye K. I., Awosolu O. and Alalade O. E., "Public and environmental health effects of plastic wastes disposal: A review", *Journal of Toxicology and Risk Assess*, 5(21), 2019, pp 1-13

[39] Farrelly, T. A. and Ian C. S., "Polystyrene as hazardous household waste", IntechOpen Book Series, London, 2017. DOI: 10.5772/65865

[40] GoingGreen Services. "The truth about polystyrene (styrofoam): why you should never use styrofoam again", https://www.goinggreenservices.com/Articles.asp?ID=260. Accessed on August 07, 2021.

[41] Scheirs J. and Priddy, D. "Modern styrenic polymers: polystyrenes and styrenic copolymers" Vol. 6, John Wiley & Sons, United State of America, 2003.

[42] Trisia, A. F. and Ian, C. S. "Polystyrene as hazardous household waste", In Daniel Mmereki Edited Hazardous Waste Management, IntechOpen Book Series, London, 2017.

[43] Johnson-Gerard M., "What are the dangers of accidentally burning styrofoam? https://www.ehow.co.uk/info_8313527_dangers-accidentally-burning-styrofoam.html, Accessed on August 27, 2021.

[44] Yang S. S., Brandon A. M., Xing D. F., Yang J., Pang J. W., Criddle C. S., Ren N. Q. and Wu W. M., "Progresses in polystyrene biodegradation and prospects for solutions to plastic waste pollution", *IOP Conf. Series: Earth and Environmental Science*, 150, 2018

[45] Gongruttananun N., "Effects of eggshell calcium on productive performance, plasma calcium, bone mineralization, and gonadal characteristics in laying hens", *Poultry Science*, 90(2), pp 524-529, 2011.

[46] Amu O. O., Fajobi A.B. and Oke B. O., "Effect of Eggshell Powder on the Stabilizing Potential of Lime on an Expansive Clay Soil", *Journal of Applied Sciences*, 5, pp 1474-1478.

[47] Banerjee A., Panda S., Sidhantha M., Chakrabarti S., Chaudhuri B. and Bhattacharjee S., "Utilisation of eggshell membrane as an adsorbent for carbon dioxide", *International Journal of*

[48] Gaurang G., "Extraction of calcium carbonate from waste eggshells as fillers in composites", *A Postgraduate Thesis Submitted to the College of Graduate and Postdoctoral Studies*, Department of Mechanical Engineering, University of Saskatchewan, Saskatoon, 2010.

[49] Patricio T., Raúl Q., Mehrdad Y. and José L. A., "Eggshell, a new bio-filler for polypropylene composites", *Materials Letters*, September 2007. DOI: 10.1016/j.matlet.2007.01.102.

[50] Solo Team. "The Importance of Waste Management in Business. Solo Resource Recovery", https://www.solo.com.au/latest_news/the-importance-of-waste-management-in-business/. Accessed on October 2, 2021.

[51] Mohammed D., "The importance of waste management and recycling, vehicle commercial weighing Ltd", 2006. https://www.linkedin.com/pulse/importance-waste-management-recycling-dee-mohammed/, Accessed on August 22, 2021.

[52] Ekpunobi U. K., Ohaekenyem E. C., Ogbuagu A. S. and Orjiako E. N. "The mechanical properties of ceiling board produced from waste paper", *British Journal of Applied Science & Technology*, 5(2), 2015, pp 166-172.

[53] Mogaji P. B., Ayodeji S. P., Olatise A. D. and Oladele I. O., "Investigation of the properties and production of sawdust ceiling tile using polystyrene as a binder", *African Journal of Science, Technology, Innovation and Development*, 9(6), 2017, pp 655-659.

[54] ASTM D570-98, "Standard test method for water absorption of plastics", ASTM International, West Conshohocken, PA, 2018.

[55] ASTM C 109-95, "Standard test method for compressive strength of hydraulic cement mortars". ASTM International, West Conshohocken, PA, 1995.

[56] ASTM D3479 / D3479M-19, Standard test method for tension-tension fatigue of polymer matrix composite materials, ASTM International, West Conshohocken, PA, 2019.

[57] ASTM E1530-11. “Standard test method for evaluating the resistance to thermal transmission of materials by the guarded heat flow meter technique”, ASTM International, West Conshohocken, PA, 2018.

[58] ASTM D7336/D7336M-16. “Standard Test Method for Static Energy Absorption Properties of Honeycomb Sandwich Core Materials”, ASTM International, West Conshohocken, PA, 2018.

[59] Phonphuak N., Teerakun M., Srisuwan A., Ruenruangrit P. and Saraphirom, P., "The use of sawdust waste on physical properties and thermal conductivity of fired clay brick production", *International Journal of Geomate*, 18(6), 2020, pp 24- 29.

[60] Phonphuak N. and Chindaprasirt P., "Types of waste, properties, and durability of pore-forming waste-based fired masonry bricks", *In Eco-Efficient Masonry Bricks and Blocks: Design, Properties and Durability*, 1st Edition, Fernando Pacheco-Torgal Paulo B. Lourenco Joao Labrincha P Chindaprasirt S Kumar (Edited), Woodhead Publishing, 2014.

[61] Tanusree Bera, S. K. and Acharya P. M., "Synthesis, mechanical and thermal properties of carbon black/epoxy composites", *International Journal of Engineering, Science and Technology*, 10(4), 2018, pp 12-20.

[62] Bo Z., Yuanyuan T., Xiaoyan J., Tommy Y. L. and Hongzhi C., "Thermal and mechanical properties of expanded graphite/paraffin gypsum-based composite material reinforced by carbon fiber", *Materials 11*(2205), 2018, pp 2-17.

[63] Amu S., Saunders S. P., Kronenberg M., Mangan N. E., Atzberger A., and Fallon P. G., "Regulatory B cells prevent and reverse allergic airway inflammation via FoxP3-positive T regulatory cells in a murine model", *Journal of Allergy and Clinical Immunology*, 125(5), 2010. Pp 1114-1124. e1118.

[64] Spiridon I. and Popa V., "Hemicelluloses: major sources, properties and applications". 10.1016/B978-0-08-045316-3.00013-2, 2008.

[65] Hafizuddin M., Ghani Ab and Ahmad S., "The comparison of water absorption analysis between counterrotating and corotating twin-screw extruders with different antioxidants content in wood plastic composites", *Advances in Materials Science and Engineering*, 2011, pp 1-4.

[66] Indian Standard IS-14276, Indian Standard, Cement Bonded Particle Boards Specification, Bureau of Indian Standards (BIS) Division, New Delhi, 1995

[67] Ali M., Abdullah M. S. and Saad S. A., "Effect of calcium carbonate replacement on workability and mechanical strength of portland cement concrete", *Advanced Materials Research*, 1115, 2015, pp 137-141.

[68] Dilland C. A., Pocius A. V. and Chaudhury M., "Adhesion science and engineering", *In The Mechanics of Adhesion*, 1st Edition, Elsevier Science B. V., 2002.

[69] Mosadeghzad Z., Ahmad I., Daik R., Ramli A. and Jalaludin Z., "Preparation and properties of acacia sawdust/UPR composite based on recycled PET", *Malaysian Polymer Journal*, 4(1), 2009, pp 30-41.

[70] Kaelble D. H., Dynes P. J. and Cirli E. H., "Interfacial Bonding and Environmental Stability of Polymer Matrix Composites", *The Journal of Adhesion*, 6, 2006, pp. 23-48.

[71] Peretomode T. M., Eboibi B. E. and Fakrogha J. J., "Preparation and characterization of wood dust natural fiber re-enforced polymer composite",

Journal of Applied Science, Environmental Management, 23(6), 2019, pp 1103-1107.

[72] Ferede E. "Evaluation of mechanical and water absorption properties of alkaline-treated sawdust-reinforced polypropylene composite", *Hindawi Journal of Engineering*, 2020, pp 1-8.

[73] Kumar R., Kumar K., Sahoo P. and Bhowmik S., "Study of mechanical properties of wood dust reinforced epoxy composite", *3rd International Conference on Materials Processing and Characterisation (ICMPC 2014), Procedia Materials Science 6*, 2014, pp 551 – 556.

[74] Nair M. M., Kamath K. S., Shetty N., "Study on tensile and hardness behavior of sawdust impregnated on short coir fiber reinforced epoxy composite", *Indian Journal of Advances in Chemical Science*, S1, 2016, pp 118-121.

[75] Abdulkareem S. A., Raji S. A., and Adeniyi A. G., "Development of particleboard from waste styrofoam and sawdust", *Nigerian Journal of Technological Development*, 14(1), 2017, pp. 18-22.

[76] Caiz Z. and Ross R. J., "Mechanical properties of wood-based composite materials wood handbook: Wood as an engineering material: Chapter 12, Centennial Ed., General technical report FPL; GTR-190". Madison, WI: US Department of Agriculture, Forest Service, Forest Products Laboratory, 2010, pp. 12.1-12.12. .

[77] AcmePlastic.com, "The Difference between polystyrene and polyethylene – Acme", https://www.acmeplastics.com › content › the-difference. Accessed on October 10, 2021 Industrial Heating (2010), "Toughness", https://www.industrialheating.com/articles/89754-toughness. Accessed on October 2, 2021.

[78] Kim D., Naaman A. and El-Tawil E., "Comparative flexural behavior of four fibers reinforced cementitious composites", *Cem Concer Compos*, 2008, pp 917-928

[79] Adepitan J. O., Ogunsanwo F.O., Ayanda J. D., Okusanya A. A., Adelaja A. D., Oni O.O., and Odumosy O. O., "Determination of thermal properties of some ceiling material commonly used in Ijebu-Ode, Nigeria, *Nigeria Journal of Pure & Applied Physics*, 9(1), 2019, pp. 23-27.

[80] Ettah E. B., Egbe J. G., Takim S. A., Akpan U. P. and Oyom E. B., "Investigation of the thermal conductivity of polyvinyl chloride (PVC) ceiling material produced by EPZ Calabar, for application tropical climate zones, *IOSR Journal of Polymer and Textile Engineering*, 3(2), 2016, pp. 34-38.