Thermal Properties of Pineapple Leaf Composite and Its Suitability as A Viable Alternative for Efficient Roofing Material

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Abstract

For self-cooling building designs, the thermal properties of pineapple (Ananas Comosus) stalk composite were investigated and compared with those of asbestos with a view to establishing its suitability as ceiling material. Sample boards from pineapple leaves were prepared by drying and grinding, then forming them into boards without an external binder. The major parameter, thermal conductivity K was determined using Lee's Disc apparatus. Other parameters determined were specific heat capacity c, density ρ, thermal resistivity ρ_{th}, thermal diffusivity λ, and thermal absorptivity α, were determined by using the appropriate experimental methods or calculations. The thermal conductivity of Ananas Comosus was determined to be $0.0719\pm0.0007 Wm^{-1}K^{-1}$. Using the same Lee's Disc apparatus method, the thermal conductivity of the commercial asbestos ceiling sheet was measured to be $0.195Wm^{-1}K^{-1}$. This value is about 85% of the value ($0.17Wm^{-1}K^{-1)}$ \) quoted in textbooks. Our pineapple stalk sheet is clearly a poorer heat conductor than the asbestos sheet. Other parameters determined here – the specific heat capacity, the thermal diffusivity, etc, support our findings that the investigated material can serve as a good material for efficient "cool roof" building design.

Keywords: Ananas Comosus, Thermal Conductivity, Density, Specific Heat Capacity, Roof Ceiling.

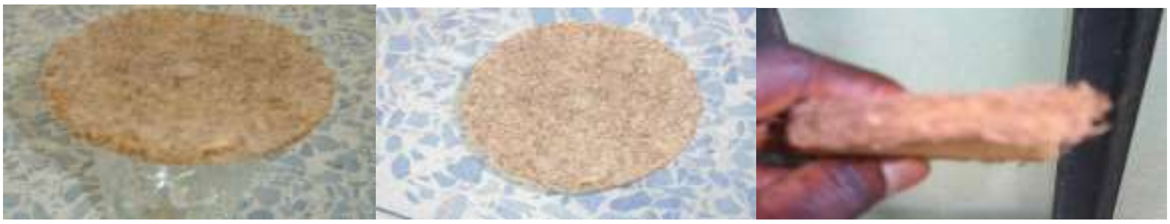
1.0 Introduction

Some materials in nature have an enhanced ability for conduction, convection, or radiation of heat and this ability is dependent on the thermophysical properties of such materials. The thermal properties of any material influence the temperature around it. Once heated, the rate at which any material transfers the absorbed heat to the surrounding is determined by the thermal effusivity (or thermal inertia) of the material, and this depends on the thermal conductivity and specific heat capacity (Jayalakshmy & Philip, 2010). An investigation of these parameters may be beneficial to the scientific body in harnessing some natural resources like pineapple leaf, formerly regarded as domestic waste, for composite heat-protective purposes.

Pineapple is a long-leafed desert plant belonging to the Bromeliaceae family. Its botanical name is Ananas Comosus, and the plant is normally grown in nurseries for the first year or so and matures about 12-20 months later. The width of each mature leaf is about 50-75mm. The fibers are contained in the spiky leaf of the plant. Pineapple is a fibrous plant and it has been reported that its fiber serves as reinforcement or filler in some composites. Pineapple fibers have been widely studied to develop better thermoplastic composites such as polyester and polypropylene (Chollakup, R., Tantatherdtam, R. & Smitthipong, W., 2013; Neto, W.P., dos Santos, R.M., Silverio, H.A., Martins, D.F., Dantas, N.O. & Pasquini, D., 2013). The leaves can also be used as animal feeds (Joy, 2010). Additionally, pineapple waste can be utilized to produce vinegar and vanillin. Thus, it can serve as a good alternative for chemical tenderizers. On the other hand, the *bromelain* can be used in the leather tanning process and stabilized latex paints (Joy, 2010). Major research studies on pineapple have focused on the fruits and their phytochemical properties. Studies have also been made on the thermal properties of pineapple leaf fiber reinforced composites (Mangal, 2003 & Kaewpirom, 2014). Mechanical and thermal properties of *Josapine* pineapple leaf fiber (Mohamed, 2014) have also been conducted. Hence the only few known works and investigations have been carried out on the thermal properties of reinforced pineapple leaf fibers. This study, therefore, focuses on examining the thermal properties of Pineapple leaf or stalk composite. The properties to be studied are the thermal conductivity and resistivity, density, specific heat capacity, thermal diffusivity, and thermal absorptivity. The purpose of the study is to compare these thermal properties of the pineapple stalk composite with those of a standard Asbestos ceiling sheet and analyze its suitability in reducing thermal radiation in buildings, as ceiling material.

2.0 Methods

The samples for the experiment were obtained from three different locations in Apu-na-Ekpu village in Isiala Ngwa North Local government area of Abia State, Nigeria, while the asbestos ceiling sheet was collected at the laboratory premises in the University of Uyo, Nigeria. In order to prepare these specimens for use, they were stored in a dry atmosphere, at room temperature for about three (3) weeks to ensure that they were dry. This was done before grinding them into powdery form with infinitesimally small particle size, like sawdust. This was obtained by sieving the ground leaf. The powdered leaf was prepared in liquid pastry and clamped together to hold the particles tightly fixed together. The laboratory methods used in this work include Lee's disc apparatus for determining thermal conductivity K, weighing and displacement method (Archimedes principle), for determining density ρ, modified calorimetry method, for specific heat capacity c. The other parameters: thermal diffusivity, thermal resistivity and thermal absorptivity, were calculated using appropriate formulas and the results from the experimental data. Figure 1 shows two samples in their final stage of preparation.



Sample I Sample II Sample III

Figure 1: Some samples at the final stage of preparation.

Thermal Conductivity

There are several ways of determining the thermal conductivity of materials: the guarded hot plate method, the double disk method, the Searl's method, the Stanton Redcroft method, and Lee's Disc method (Alam *et al.*, 2012). In this work, we adopt Lee's Disc method as also used by Ekpe & Akpabio (1994), Akpabio, *et al.* (2001), etc.

The schematic set-up of Lee's Disc apparatus is shown in Figure 2.

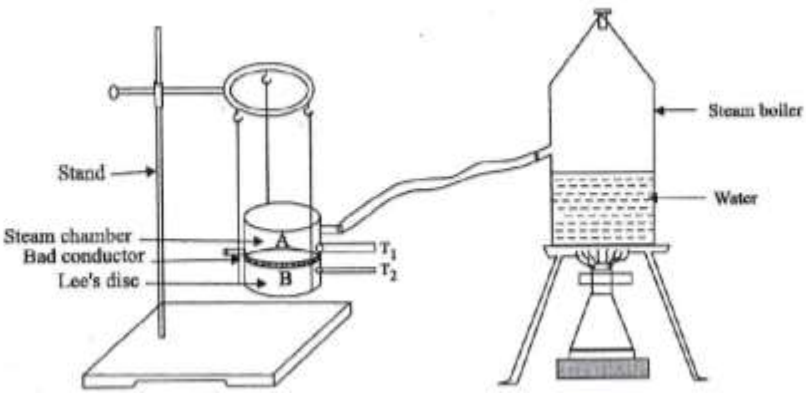


Figure 2: Schematics of Lee's Disk apparatus setup (Courtesy: www.arunkumard.yolasite.com)

It consists of two circular brass discs (upper and lower disc), with the sample usually placed between the two-disc during the experiment. Experiments show that the rate of heat conducted across the prepared sample, at steady state is equal to the price at which it is emitted down to the lower disc. Thus, the rate at which heat flows through the sample is directly proportional to its area A, and the temperature difference (T_2-T_1), while inversely proportional to the thickness (x) of the sample. This is expressed by the heat flow equation.

$$\frac{dQ}{dt} = KA\,\frac{T_2 - T_1}{x}, \qquad (1)$$

Where: K is the thermal conductivity of the bad conductor (sample), A (= πr^2) is the surface area of the sample, T_2 is the mean temperature of the upper brass disc, T_1 is the mean temperature of the lower brass disc, and x is the thickness of the sample.

When the system has reached a steady-state, that is, when T_1 and T_2 are constant, the rate of heat conduction is equal to the price of heat lost from the sample (bad conductor). Thus, the rate of cooling at steady-state dQ/dt and the amount of heat radiated per second can be expressed as:

$$dQ/dt = Mc\; d\theta/dt \qquad (2)$$

Using eq. (1) in eq. (2) and simplifying, the thermal conductivity K can be determined as:

$$K = \frac{Mc\ (d\theta/dt)\ x}{A\ (T_2 - T_1)} \qquad (3)$$

where is the mass of the brass disc, c is specific heat capacity of the brass disc and $d\theta/dt$ is the temperature gradient determined from the Lee Disc cooling curve (www.iiserpune.ac.in/~bhasbapat/phy221_files/Lee's_Method.pdf)? A table of observation is gotten from the temperature variation readings taken, with a thermometer and stopwatch and a graph of temperature vs time, was plotted and the slope of the graph dθ/DT = Δθ/Δt, determined at the steady temperature from the graph.

Density and Specific Heat Capacity Measurements

Density was measured for the irregular porous samples by weighing and displacement method; a method that involved direct weighing of the mass of the dried samples using weighing balance and then measuring the volume by placing the sample on a test tube immersed into a measuring cylinder half-filled with water and then taking note of the difference in the water level of the measuring cylinder (Anyakoha, 2016).

Specific heat capacities were determined for the sample by the method of mixtures, also called modified calorimetry (Burton *et al.,* 1957). The specific heat capacity of the sample c_s is given by:

$$c_s = \frac{m_1 c_1(\theta_3 - \theta_1) + (m_2 - m_1)c_w(\theta_3 - \theta_1)}{m_s(\theta_1 - \theta_2)} \qquad (4)$$

where m_1,m_2 and $m_s$are the masses of the calorimeter, mass of calorimeter + water, and mass of sample; θ_1, θ_2 and θ_3 are the initial temperature of the water, the temperature of boiling water, and the highest temperature of the mixture; $c_1$andc_w are the specific heat capacities of the calorimeter and water.

Other Thermal Parameters

The thermal resistivity, diffusion and absorptivity were calculated for each sample using the following equations:

Thermal Resistivity:

The thermal resistivity ρ_{th} is the inverse of the thermal conductivity K

$$\rho_{th} = \frac{1}{K} \quad (5)$$

Thermal Diffusivity

The thermal diffusivity, λ measures the rate of transfer of heat of material from the hot end to the cold end. It has the SI derived unit of m^2/s.

$$\lambda = K/\rho c_s \quad (6)$$

Where ρ is the density of the material in kgm^{-3}, and c_s is the sample-specific heat capacity at constant pressure (Silvia et al, 1998; Suleiman, et al, 1997).

3.0 Results

We present the result of our investigation on the thermal properties pineapple stalk composites using three samples (I, II and III) – see Figure 1. We obtained their thermal conductivity, thermal resistivity, specific capacity and thermal diffusivity. We also investigated the thermal conductivity of a sample of commercial ceiling asbestos using Lee's Disc method as described in Section 2. Table 1 shows the input parameters used in obtaining the aforementioned thermal properties from eq. (3) to eq. (6).

Table 1: Experimental and calculation input parameters

	Thickness (m) x 10^{-2}	Radius (m)	Mass (kg) x 10^{-3}	Density (kg/m^3)
Sample I	0.1196	0.055	1.831	381.79
Sample II	0.1194	0.055	1.457	412.77
Sample III	0.1195	0.055	1.046	350.00
Asbestos	0.1125	0.055	3.250	1275.00

Table 2: Experimental and calculated results showing thermal properties of Pineapple stalk

	Density ρ (kgm^{-3})	**Thermal Conductivity κ ($Wm^{-1} K^{-1}$)**	**Thermal Resistivity R_{th} (mKW^{-1})**	**Specific Heat Capacity c_s (J/kg K)**	**Thermal Diffusivity λ_s ($m^2 s^{-1}$)**
Sample I	409.25	0.0719	13.908	1949.16	9.1
Sample II	412.77	0.0723	13.568	1949.95	9.0
Sample III	416.30	0.0730	13.495	1948.95	9.0
Mean Value ± SE	412.77 ± 2.35	0.0719 ± 0.0007	3.908 ± 0.007	1949.16 ± 0.07	9.1 ± 0.4
Asbestos Ceiling Sheet	1275.00 ± 16.67	0.195 ± 0.009	5.128 ± 0.009	1456.20 ± 0.03	10.5 ± 0.5

Table 1 shows the experimental results for the thermal conductivity K, specific heat capacity C, density P, thermal diffusivity λ, and thermal absorptivity α for the pineapple leaf samples. From the table, it is observed that the thermal conductivity of *Ananas Comosus* stalk ranges between 0.0719 and 0.0741 $wm^{-1} k^{-1}$. The range of bulk density for the completely dried sample is between 409.25 – 416.30 kgm^{-3}. The specific heat capacity of the examples is between 1948.95 – 1949.37 $kg^{-1} k^{-1}$. The thermal absorptivity of the samples lies between 27.9 – 28.3 m^{-1}, while the thermal diffusivity of the sample lies between 8.6 – 9.1 m^2s^{-1}. All these parameters were measured for standard asbestos ceiling sheet using the same method, and the result shows for thermal conductivity (the major parameter) lies between 0.182 – 0.210 $Wm^{-1} K^{-1}$ with a mean value of 0.195$Wm^{-1}K^{-1}$. This value is about 85% of the previously established value of 0.17$Wm^{-1} K^{-1}$ (Giambastista, et al, 2007). The results of the experiment show that the thermal conductivity of *Ananas Comosus* stalk falls within the range of good heat insulators. Its thermal conductivity value is lower than most of the commonly used ceiling sheets (Nandwani, 1988; Agarwal, 1967). Also, according to Isachenko, Osipove & Sukomal (1987) and Twidell & Weir (1990), the thermal conductivities of construction and heat-insulating materials lie between 0.023 and 2.9$Wm^{-1} K^{-1}$. This is in agreement with our result, which shows that *Ananas Comosus* stalk composite is an excellent heat insulating material and suitable for ceiling construction materials.

Thermal conductivity can be affected by some factors such as moisture content, temperature, density, porosity and particle size (Ajibola and Onabanjo, 1995; Ekpe and Akpabio, 1994; Van Straaten, 1961; Zemanusky and Dittman, 1982). The high thermal resistivity value, low density, high specific heat capacity and low thermal diffusivity value of *Ananas Comosus* stalk are considerable advantages which it has as an insulating material. The calculation of the rate of cooling from the temperature vs time cooling curve shows that the pineapple leaf composite sample attained a steady-state at 0.0122°C which is the gradient obtained from the graph shown below. The steady-state temperature is the temperature when the thermometer reading of the upper disc and the lower disc with the sample in-between become steady, hence the temperature stops evolving. This low steady-state temperature indicates that the *Ananas Comosus leaf composite* would record a possible low thermal response than asbestos if they are both placed under the same environmental condition, thus it is a better heat-insulating material. The slope and the calculation from the cooling curve are shown below.

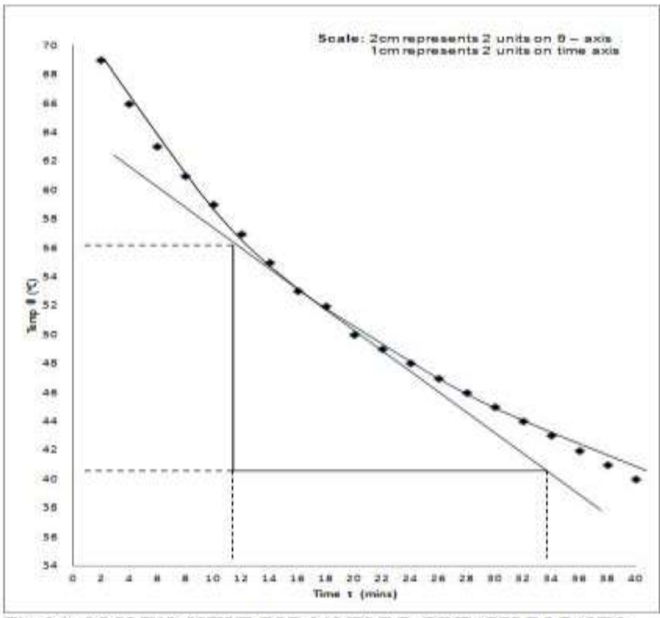


Fig. 3.2: COOLING CURVE FOR SAMPLE B: PINEAPPLE LEAVES

Slope for Sample (Pineapple Leaves)

Gradient $= \frac{\Delta\theta}{t(s)}$

$= \frac{\theta_2}{t_2} - \frac{\theta_1}{t_1}$

Where: $\theta_1 = 39.5$, $\theta_2 = 56$

$t_1 = 11.4$ $t_2 = 34.0$

Gradient $= \frac{56.0 - 39.5}{(34.0 - 11.4) \times 60}$

$= \frac{16.5}{1356}$ = $\underline{0.0122^{o}C/S}$

Gradient for Sample B (Pineapple leaves) = 0.0122°C/S

Conclusion:

The results obtained in the study show that *Ananas Comosus* stalk has low thermal conductivity but high thermal resistivity compared with those of other good thermal insulators. This shows that the stalk of pineapple that is commercially useful as animal feed and sometimes as waste can effectively be used in the building/construction industry as ceiling boards to reduce the amount of heat flow through the roofing material into the interior space of the building. *AnanasComosus* stalk can be processed from the freshness and seasoned to complete dryness, treated and manufactured into a suitable ceiling board.

Planting of *Ananas Comosus* with the aim of using the stalk or leaf as a ceiling board should be encouraged and embarked upon in order to augment the source of insulators.

Individuals, as well as the government, are advised to grow pineapple fruit not just for the purpose of harvesting its juice but for the production of heat-resistant ceiling sheets for naturally cooled building design using *AnanasComosus* stalk. This would serve as advancement in our local technologies, boost the economy of both the individuals and government, and make the ceiling material affordable to people in the low-income class.

Since the production is non-sophisticated technology, it needs no additional raw materials except by synthetic pre-treatment against possible insect attack.

The researcher recommends that the study should be carried out on the mechanical stability, weather solidity with humidity and heat, flexural strength, optical and electrical properties, as well as fire resistance and safety of the sample.

References

1. Agarwal, K.N. (1967). Thermal data of building fabrics and their applications in building design. *Building Digest,* No. 47. Central Building Research Institute, Roorkee, India.

2. Ajibola, K. & Onabanjo, B.O. (1995). Investigation of *Cocosnucifera* as a potential cooling material for passively cooled building design. *Trod. J. Physics*. l8. 117-122.

3. Akpabio, L.E, Ekpe, S.D, Etuk, S.E, and Essien, K.E (2001). Thermal properties of oil and raffia palm fibers. *Global J. Pure Apply. Sci.* 3.575-578.

4. Alam, M., Rahman, S., Halder, P.K., Raquib, A., & Hasan, M. (2012). Lee's and Chariton's method for Investigation of Thermal Conductivity of Insulating Materials. *Journal of Mechanical and Civil Engineering,* 3(1), 53 -60. http://iosriournals.org

5. Anyakoha, M.W. (2016). *New School Physics for Senior Secondary School,* Revised Edition. Onitsha: Africana First Publisher. Pg 157-217.

6. Burton E.F., Grayson-Smith H., Quinlan F. M., (1957) *College Physics* Canada: Sir Pitman & Sons, Ltd. Pg 201-203.

7. Chollakup, R., Tantatherdtam, R. & Smitthipong, W. (2013). Effect of pineapple leaf fiber-reinforced thermoplastic starch/poly (lactic acid) green composite: Mechanical, viscosity, and water resistance properties. *Journal of Thermoplastic Composite Materials,* 28(5):717-729.

8. Ekpe, S.D. and Akpabio, G.T. (1994). Comparison of thermal properties of soil samples for a passively cooled building design. *Turkey Journal of Physics*. 18.117-122.

9. Etuk, S.E., Akpabio, I.O., Udo, E.M. (2003). Comparison of the thermal properties of clay samples as potential walling material for naturally cooled building design. *Journal of Environmental Science,* 15 (1) 65:68

10. Giambattista, A., McCarthy-Richardson, B. & Richardson, R.C. (2007). *College Physics.* Vol. 1, 2nd ed. New York: McGraw-Hill.

11. Isachenko, V.P., Osipove, V.A. & Sukomel, A.S. (1987). *Heat Transfer.* Moscow: Mir Publishers.

12. Jayalaskshmy, M.S. & J. Philip (2010). Thermophysical properties of plant leaves and their influence on the environment. *International Journal of Thermophysics,* 31 (11-12). 2295-2304.

13. Kaewpirom, S. & Worrarat, C. (2014). Preparation and properties of pineapple leaf fiber reinforced poly (lactic acid) green composites. *Journal of Fibres and Polymers,* 15(7):1469.

14. Larrauri, J.A., Ruperez, P. & Saura-Calixto, F. (1997). Effect of drying temperature on the stability of polyphenols and antioxidant activity of red grape pomace peels. *Journal of Agric. & Food Chemistry,* Vol. 45, Issue 4, pp. 1390-1393, April 16. https://doi.org/10.1021/jf960282f

15. Mohd, S. (2014). *Tropical natural fiber composites: properties, manufacture and applications.* London: Springer Science + Business Media.

16. Nandwani, S.S. (1988). Experimental theoretical analysis of a simple solar oven in the climate of Costa Rica – 1. *Solar Wind Technol.* 8, 159-170.

17. Neto, W.P., dos Santos, R.M., Silverio, H.A., Martins, D.F., Dantas, N.O. & Pasquini, D. (2013). Cellulose nanocrystals from pineapple leaf, a new approach for the reuse of this agro-waste. *Journal of Industrial Crops and Products.* www.elsevier.com/locate/indcrop

18. Onyeaju, M.C., Osarolube, E.., Chukwuocha, E.O., Ekuma, C. E., Omasheye, G.A.J., (2012). Comparison of the thermal properties of asbestos and polyvinylchloride (PVC) ceiling sheets. *Journal of Material Sciences and Applications*. 240-244. http://wv.sciRp.org/j journal/msa.doi/org/1 0,423 6/msa.20 12.34035.

19. Silva, T.S., Alves, A.S., Pepe, U., Tsuzuki, H., Nakamura, O., D. Aguila, N.M.F., Ferreira da Silva, A., &Vesissid, N. (1998). Thermal diffusivity of lead iodide. *J. Appl. Phys.* 83 (11); 6193-6195.

20. Twidell, J. & Weir, T. (1990). *Renewable energy resources.* London: E and F.N. Spon.

21. Van Straaten, J.F (1967). *The Thermal Performance of Buildings*. Elsevier Publishing Company. Amsterdam. London. New York. 126.

22. Welty, J.R., Wicks, C.E, and Wilson, R.E. (1984). Fundamentals of Momentum, Heat and Mass Transfer. New York: John Wiley and Sons Inc.

23. Woodall, A.J., (1971). *Heat,* 4th Edition. London: D.P. Publications Limited. pp. 163- 168.

24. www.arunkumard.yolasite.com/resourcesExp_I_Lees_Disc_Apparatus.pdf

25. www.iiserpune.ac.in/~bhaspabat/phy221_files/Lee's_Method.pdf

26. Zemansky, M.W. and Dittman, R.H. (1981). Heat and Thermodynamics (6th edition) McGraw Hill. London.132-136.