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Thermal Conductivity of Different Grain Sizes of Top Bond, Clay and Starch Bonded NIPA Palm Wood Composite Products

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Abstract:
The study examines the thermal conductivity of five different grain sizes of Nipa palm seed bonded in a varying proportions with 10% to 50 %of three separate binders. These binders are; Top bond, Starch and Clay. The samples grain sizes of 300 µm, 425 µm, 500 µm, 850 µm and 1000 µm were sieved out of Nipa palm Seed and fabricated to an appropriate disc shape using a modified hydraulic press. The modified Lee's disc apparatus incorporated with temperature data logger was used to determine the thermal conductivities of the samples. The results showed that for any particular grain size, increasing the binder content resulted to decrease in the thermal conductivity of the samples. The thermal conductivity values obtained for the samples fall within the range 0.094 - 0.667 $Wm^{-1}K^{-1}$. This range lies within the thermal conductivity values of common wood materials. The grain sizes that is best insulating due to its lower thermal conductivity are 850 µm and 1000 µm and were all top bond samples. In addition, the sample with 1000 µm grain size and 50 % top bond as a binder pose to be the best among the samples considered. With this property and further improvement, Nipa palm plant can be harnessed for possible usage as industrial insulating devices and thermal insulators.

Keywords: *Wood composite, Nipa palm, Binders, Binder content, Grain sizes*

1. Introduction

The interest in using fast growing agricultural residues for the production of fiber panels started at the beginning of the 20^{th} century owing to the rise in wood consumption and the decreasing reserves of native woody species(Atchinson and Collins 1976, Philippou and Karastergiou 2001).

These composite wood products or lignocelluloses based composites as they are sometimes called is continuously increasing throughout the world because of their lightweight and excellent thermal properties arising from its pore structures (Zheng et al., 2006). Hence cushioning the high demand for wooden materials created by increasing population and pressure on forestland due to deforestation rate that causes negative impacts on the environment (Seller, 2001; Youngquist, 1999; Zheng et al., 2006). Developing countries, especially in Africa face an increasing demand for building materials due to fast growing urban population and subsequent need for better shelters (Bisan, etal., 2003; Elbadawi et al., 2015). This makes the production of panel products from other agro-based residues (agricultural residues) important considering the increasing world-wide wood fiber shortage.

Generally, wood composites are defined as any product, which is manufactured on the basis of mechanically chopped, milled, and grinded wood (veneers, strands, particle, fiber etc) and bonded by adhesives usually by an operation at high temperature or pressure (Kiies, 2007; Farrokhpayam et al., 2006; Zheng et al., 2006). And have been the subject of research lately as a result either they are a co-products or by-products, or agricultural waste that are readily and cheaply available and suitable for products such as box container boards, insulation, non-load bearing building panels, architectural and decorative panels (Zheng et al., 2006: Nemli et al., 2004).

The major type of adhesives used to produce particleboards and other wood based panels is Urea Formaldehyde resins (Conner, 1996). Several researches are looking for alternative adhesive system due to the highly toxic nature of Formaldehyde as well as its environmental pollution effect(Peng et al., 1997; Amini et al., 2013). Several of such research had used either starch, clay or silica and some oxidants to improve the mechanical properties, water resistance properties and decay resistance of particleboards.Starch is a natural material used as an adhesive in a wide range of products including binders, sizing materials, glues and pastes(Moubarik, et al., 2010). More recently, the development of a starch-based wood adhesive in interior applications has been described. Starch yields adhesives with excellent affinity for polar materials such as cellulose and has become one of the most promising candidate as a substitute for urea formaldehyde resin (Moubarik et al., 2010).

Clay is a cohesive and usually plastic when wet. It serves as a primary binder and fires at different colors depending on the type. It is a poor conductor and that is why clay materials are used as thermal insulators (Richardson, 1982)

Top bond is a general purpose white glue for furniture, domestic applications, book binding, decorative laminates, chip board and hard board.

The lignocellulosic material used in this study due to its availability was Nipa palm as experimented by Ekpunobi and Onuegbu, 2012.

Nipapalm is one of the most important family of non-wood forest products and materials. It is said to be one of the oldest angiosperm plant, probably the oldest plant species with a pan-tropical distribution some million years ago (Corner, 1966). It occupies a unique position in the palmae species with a very long history of existence and variety of uses (Ekpunobi and Onuegbu, 2012).

Nipa palm grows mainly in equatorial zones and in sub-tropical rain forest brackish water swamps along slow moving tidal rivers, estuaries of tidal flood plains and soft muddy banks where nutrients are slowly deposited, and can be found as far inland as the tide can deposit the floating seeds (Melena, 1980). It was introduced as an exotic species into Nigeria (Calabar and Oron) in early 20th century (1906 and 1912 respectively) from their native home of Malaysia and later to IkotAbasi and Opobo 1930 and Andoni in 1936 from Singapore Botanical Garden, for the purpose of checking erosion in the Eastern Niger Delta Mangrove swamps and wetland. It has since then spread itself throughout and invaded the entire Central and Eastern Niger Delta environment, covering Calabar, Oron, Opobo, Andoni, Bonny and Okirika Rivers, due to its prostate nature, thereby turning itself into an indigenous species having been here for over one hundred years now, and have in most cases displaced the indigenous mangrove species of the Niger Delta wetlands (Peters, 1993). Traditionally it is used as a roof material and wall partitioning, the outer layers of the leaf-stalk yields pulps suitable for making good quality boards of intermediate density and the matured seeds are used as vegetable ivory and buttons (Sebastian et al., 2011; Hossain and Islam 2015).

Abraham, 2014 in his studies of Nipa palm leaves using starch and lime as binders showed that flat boards of ceiling materials can be manufactured from Nipa palm.

2. Thermal Conductivity

Thermal conductivity is a measure of the rate of heat flow through one unit thickness of a material subjected to a temperature gradient(Simpson and Tenwold, 1999). In wood, the rate depends on the direction of heat flow with respect to the grain orientation, density, moisture content and structural irregularities such as knots. Information on the thermal conductivity of wood and its relationship to other wood properties is of interest due to the significance of wood and wood products in buildings and other applications (Oluyamo and Adekoya, 2015). Wood exhibits low thermal conductivity(high heat-insulating capacity) compared with materials such as metals, marble, glass and concrete. Several studies had been carried out on the thermal properties of wood, palm species and wood-based materials used for construction and heat insulation.

Ogunleye and Awogbemi (2012), studied the effects of silica clay on the thermo-physical properties of Iroko sawdust cement board with a Lee's disc apparatus and show that as the silica clay content of each sample increases its thermal resistivity increases.

Oluyamo and Bello(2014), in their study of particle size and thermal insulation properties of some selected wood materials for solar device applications revealed that all samples have their highest thermal conductivity at 300 μm with Celtics Zenkeri recording the highest thermal conductivity value of 0.148 W/mK.

Akpabio et al.(2010), determined the thermal conductivity of six different wood samples using Lee's disc apparatus lied between 0.061 to 0.112 W/mK and concluded that it is within the limit of conductivities of construction and heat insulating materials(0.023 and 2.9 W/mk)

Also Akpabio et al. (2001), studied the thermal properties of oil and raffia palms fibers and established that Raffia palms fiber are good thermal insulators.

Alausa et al.(2011), compared the thermal properties of Rattan, Raffia palm and that of synthetic asbestos. The range of thermal conductivity value between 0.046 – 0.084 W/mK was determined.

Etuk et al. (2005), in their experimental studies conducted on Coconut (Cocos nucifera) trunk using the Lee's disc apparatus revealed a thermal conductivity value of 0.121 W/mK.

This study focuses on determining the thermal conductivity of wood composites of different grain sizes of Nipa palm seed bonded by varied proportion of three different binders using the (Lee's disc apparatus) steady state method as a way to utilize Nipa Palm plant which is an invasive palm threatening Nigeria's extensive mangrove vegetation.

3. Materials and Methods

3.1. Materials

Nipa palm seeds were collected at Eastern By-pass in Port Harcourt, Rivers state, Nigeria. The fruits were dehusked to separate the nuts and the fiber (Endocarp). The nuts was sun dried, macerated manually into tiny particles and crushed milled using a Glen Creston Ltd jaw crusher, Model 20130A to achieve a suitable grain size. The ground particles were then sieve into five different grain sizes; 300 μm, 425 μm, 500 μm, 850 μm, and 1000 μm respectively using different meshes. Starch, Top Bond and clay were the dominate adhesives used for binding the composite of Nipa palm seed. Starch (dry powder) was purchase locally, a product of TGI-Ireland (branch company, Cormart Nigeria Limited). Top Bond (Gel), a product of Purechem manufacturing Nigeria Limited, Clay was sourced locally from the laboratory of ceramics and glass technology of Akanu Ibiam Federal Polytechnic, Unwana, Ebonyi State Nigeria. The equipment used are weighing balance, modified hydraulic press, vernier caliper, Ammeter, Voltmeter, Rheostat, Power supply, Modified Lee's disc apparatus incorporated with digital logger to sense the temperatures of the discs and the ambient respectively.

3.2. Methods

3.2.1. Sample Preparation
Composite samples of Nipa palm were produced by mixing the different grain sizes of Nipa palm seed with a particular binder concentrations from 10 % to 50 %. Mixing of each grain size of Nipa palm seed with a binder concentration were done manually at varying ratio of 90 %:10 %, 80 %: 20 %, 70 %: 30 %, 60 %: 40 %, 50 %: 50 % (byweight) of Nipa palm seed and binder respectively by thoroughly turning it over until consistency was achieved and 1 ml of water added in segments and further mixed to achieve an adequate workability(leather hard mixture). The above procedure was repeated at different binder concentration (10, 20, 30, 40 and 50 %) respectively. After mixing, the resulting mixture were compacted into a circular disc shape using a modified hydraulic press. A total of seventy-five (75) disc shaped samples were prepared for analysis.

3.2.2. Experimental Method
The apparatus used was a modification of the Lees' disc thermal conductivity apparatus incorporated with a digital temperature data logger to sense the discs temperature changes and that of the ambient temperature at a given time interval five minutes. This method, in its simplest form, utilizes the same procedure given by (Oluyamo and Bello, 2014), except that it uses temperature data logger that has port for 8 GB memory card for easy retrieval and analysis of temperature result and probes inserted into the drilled holes of the discs. The samples to be studied were moulded to the same diameter as the brass discs and to an approximate thickness and its mass measured.
The thermal conductivity (K) of each sample of thickness (l) and radius (r) at a given time interval was estimated using equations (1) and (2) below. Details of this method can be sourced from literature (Oluyamo and Bello, 2014);

$$K = \frac{el_s}{2\pi r^2(\theta_B - \theta_A)}\left[a_s \frac{\theta_A + \theta_B - 2\theta_{amb}}{2} + 2a_A(\theta_A - \theta_{amb})\right] (1)$$

And

$$e = \frac{IV}{a_A(\theta_A - \theta_{amb}) + a_s\frac{(\theta_A - \theta_{amb}) + (\theta_B - \theta_{amb})}{2} + a_B(\theta_B - \theta_{amb}) + a_C(\theta_C - \theta_{amb})} (2)$$

Where a_A, a_B, a_C, anda_S are the exposed surfaced areas of disc A, B, C and the sample when mounted on the apparatus. Alsoθ_A,θ_B, θ_C and θ_{amb} are the temperatures of the discs and ambient at steady state as recorded by the digital temperature logger. In equation (1) l_s and r represents the thickness and radius of the samples. V is the potential difference across the heater and I is the current which flows through it. In order to fully analyze a given sample both temperature of the disc and ambient, areas of the discs and sample were charted in an excel sheet thus obtaining its thermal conductivity.

4. Results and Discussion

The results of the experimentally determined thermal conductivities values of the Nipa palm composite with different binder contents shown in Table 1 have been compared with values given by other researchers for wood-based heat insulating materials. The thermal conductivity values obtained in this investigation are within the range of values of other commonly used wood-based insulators given by (Onyeaju et al., 2012; Kiran et al., 2012; Alausa et al., 2011; Oluyamo et al., 2012) as shown in Table 2**.** The thermal conductivity values obtained ranged from 0.094 – 0.336 $Wm^{-1}K^{-1}$ for top bond as binder, 0.115 – 0.440 $Wm^{-1}K^{-1}$ for starch as binder and between 0.127 – 0.667 $Wm^{-1}K^{-1}$ for clay as binder. Generally for the three binders used the thermal conductivity decreases as the binder content increases for all grain sizes. The grain sizes that is best insulating among the particles considered due to its lower thermal conductivity is 850 and 1000 µm. It was revealed that they were all samples with top bond as binder having the lowest thermal conductivity for all binder content and hence the best binder type with 50 % binder content at 1000 µm having a thermal conductivity value of 0.094 $Wm^{-1}K^{-1}$ posing the best thermal insulation material of all samples considered. On the other hand, the grain size that is least insulating, yet falls within the range of values of heat insulating materials is 300 – 500 µm. where it revealed a combination of clay and top bond as binders having the highest thermal conductivity. The samples with clay as binder being dominate as seen in Table 1 with the 10 % binder content, 500 µm having a thermal conductivity value of 0.667 $Wm^{-1}K^{-1}$as the least in thermal insulation for all samples considered.

Binder Content (%)	Thermal conductivity $Wm^{-1}K^{-1}$														
	Top Bond Composite					Starch Composite					Clay Composite				
	300 µm	425 µm	500 µm	850 µm	1000 µm	300 µm	425 µm	500 µm	850 µm	1000 µm	300 µm	425 µm	500 µm	850 µm	1000 µm
10	0.336	0.315	0.331	0.274	0.209	0.316	0.389	0.440	0.332	0.291	0.432	0.389	0.667	0.302	0.301
20	0.328	0.262	0.249	0.238	0.199	0.273	0.363	0.269	0.332	0.246	0.367	0.274	0.379	0.280	0.293
30	0.303	0.185	0.238	0.140	0.189	0.224	0.236	0.169	0.232	0.180	0.281	0.169	0.245	0.158	0.195
40	0.136	0.137	0.148	0.129	0.126	0.130	0.183	0.135	0.133	0.145	0.162	0.146	0.199	0.139	0.191
50	0.113	0.117	0.141	0.119	0.094	0.136	0.127	0.123	0.115	0.133	0.135	0.127	0.156	0.131	0.135

Table 1: Thermal conductivity values of the samples for different composition of binder

Materials	Thermal Conductivity $Wm^{-1}K^{-1}$
Pine wood	0.138
Coconut Palm	0.121
Wood Materials	0.1 – 0.8
Thermalite Board	0.190
Bamboo Mat Board	0.12-0.38
Saw dust Cement Board	0.3223 – 0.4923
Bricks Building	0.60
Asbestos Board	0.319
Raffia palm (Raphia Hookeri)	0.056
Rattan Palm (Calamus Deerratus)	0.046
Fiber Board	0.06

Table 2: Thermal conductivity of some common Insulator Materials
Sources (Onyeaju et al., 2012; Kiran et al., 2012; Alausa et al., 2011; Oluyamo et al., 2012)

5. Conclusion

The results obtained in this research revealed that the thermal conductivity of Nipa palm composite falls between 0.094 – 0.667 $Wm^{-1}K^{-1}$ which compared favorably with those of other good thermal insulators already in used in construction and heat insulating materials. From the fore-going experimental results of all the three binder materials and grain size tested, their thermal conductivity decreases with increase of binder. The 50 % top bond as binder with a grain size of 1000 µm had a lower thermal conductivity that favors it as an interior building insulating material for building designs. Although top bond sample is deciphered to be the best thermal insulator for building designs, starch and clay samples are also recommended for the design of thermal insulating building in the absence of top bond samples, mostly for use in ceiling panels, construction of doors and windows and other padded building design where thermal insulation is held at high esteem.

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