ASSESSMENT OF THE SUITABILITY OF TIGER NUT FIBRE FOR STRUCTURAL APPLICATIONS
(PENILAIAN KESESUAIAN SERAT TEKI KUNING UNTUK APLIKASI STRUKTURAL)

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ABSTRACT

In this work, the properties of the composite produced from waste carton with various tiger nut fibre contents having cassava starch slurry as binder were investigated. The results obtained showed the ranges of the mean thermal conductivity, bulk density, specific heat capacity, thermal diffusivity, thermal absorptivity, nailability, flexural strength and compressive strength values to be $(0.0447 – 0.0603)\ Wm^{-1}K^{-1}$, $(683.62 – 746.32)\ kgm^{-3}$, $(1439.811 – 1840.554)\ J/kg/K$, $(5.612 - 3.553)\ 10^{-8}\ m^2s^{-1}$, $(25.456 – 31.993)\ m^{-1}$, $(23.9 – 100)\%$, $(1.58 – 1.86)\ MPa$ and $(2.16 – 2.78)\ MPa$ respectively between 8.3% and 43.1% of the fibre content. It was generally observed that with a choice variation in the fibre content, the performance of the developed board can be optimized for structural applications. Hence, instead of discarding the fibre as waste, recycling it can help to provide raw material for the production of cost effective and environmentally friendly materials. This will in turn reduce health risk caused by environmental pollution due to improper waste disposal practice of such material.

Keywords: Thermal conductivity, bulk density, specific heat capacity, thermal diffusivity, thermal absorptivity, nailability, flexural strength.

INTRODUCTION

Tiger nut is not really nut, but chewy marble-sized tuber obtained from plant called 'yellow nutsedge' (*cyperus esculentus),* and its name is got from the stripes on the tuber's exterior. It grows freely under the soil's surface. In Nigeria, tiger nut is grown mainly in the Northern region and Middle belt (Bamishaiye and Bamishaiye, 2011; Nwaoguikpe, 2010), and the tuber is available all year round. Also, the tuber is consumed widely in East Africa, Spain, Arabian Peninsula, Nigeria and other parts of West Africa (Abaejoh, et al., 2006).

For over a decade now, there has been a noticeable increase in the use of tiger nut. Apart from being eaten raw as food (Ebojele and Ezenwanne, 2014), for instance, tiger nut can be used for production commercial starch for industrial purpose (Adama et al., 2014). In their research work, (Chimma et al., 2009) observed that tiger nut product can be used in the manufacture of soap, perfume and biofuel in industrial scale. According to the report by Adejuyitan, 2011, tiger nut flour still finds its application in food formulation. Notably, the composite flour can be used to make bakery products, which serve as replacement for wheat flour in confectionery industries.

Despite the health benefits, tiger nut has been under-utilized ever since it was discovered some years ago. A seemed to be neglected facet of it is the fibre. Tiger nut fibre is usually treated as solid waste after all necessary extraction of oil and milk from the tuber. Jorgenson and Johnson, 1989, reported that the amount of solid waste per capita generated in developing countries has risen to about 20 tons yearly. In Nigeria, 25 million tons of municipal solid waste are generated per year. This ranges from 0.66kg/cap/day in urban areas to 0.44kg/cap/day in rural areas (Ogwueleka, 2009).

It has been observed that tiger nut fibre is usually dumped on roadsides or drainage channels with other waste materials. Due to the problem of waste management in Nigeria, this practice results in serious environmental pollution which poses health hazard. This research work has been designed to recycle tiger nut fibre and determine the thermal and mechanical properties of the new product, in order to ascertain its suitability for use in structural design.

Materials & Method

In this work, unused carton, tiger nut fibre and cassava starch were the waste materials used. The carton was picked from a dump site. Also, the fibre was obtained as discarded material from tiger nut oil and juice processing unit. Again, the cassava starch was obtained from local cassava processing unit. All these materials were obtained within Uyo Local Government Area, Akwa Ibom State, Nigeria.

The waste carton was cut into pieces and soaked in hot water for 24 hours. The soaked materials were then pounded into paste. Also, 10% weight per volume of cassava starch slurry was prepared and allowed to cool. The waste carton paste and tiger nut fibre were sun-dried to constant weight. Then-after, the dry waste carton pastes and various mix ratios of the dry fibre were used to prepare composite boards by hand lay-up technique. Each board contained the prepared cassava starch slurry as binding agent with binder to composite ratio of 0.8. The samples were cast into a 150mm x 150mm x 10mm mould and then compacted using a laboratory - made compacting machine maintained under pressure at 20kN for 0ne hour. For each mix ratio adopted in this work, the boards were developed in triplicates and after curing at room temperature for 24 hours, they were sun-dried to constant weight. The dry boards obtained were then cut to sizes needed in this work for thermal conductivity, bulk density, specific heat capacity, nailability, flexural strength and compressive strength tests. All measurements were taken at room temperature and mean value of the data obtained in each case was tabulated. Analysis was done graphically.

Tests Implementation

(a) Thermal Conductivity, k

This test was performed by means of Lee - Charlton disc apparatus based on steady state method (Gesa et al., 2014). Since the samples used were completely dried, the problem of redistribution of water under the influence of temperature gradient was avoided (Etuk et al., 2005). The value of the thermal conductivity of each sample was calculated using the relation:

$$k = \left(\frac{Mcx}{A\Delta T} \right) \frac{d\theta}{dt} \qquad (1)$$

where $\frac{d\theta}{dt}$ is the rate of cooling of brass disc of specific heat capacity c, x is the thickness of the sample under test, A is the cross sectional area of the sample and ΔT is the temperature difference across the sample's thickness.

(b) **Bulk density, ρ**

Since the degree of compactness of a material affects its thermal insulation, this test was deemed necessary. In this work, the bulk density of each sample was determined by weighing and displacement method (Akpabio 2001). The value of the bulk density for each sample was computed based on the equation

$$\rho = \frac{m}{v} \qquad (2)$$

where m is the mass of the sample, and v is the bulk volume of the sample.

(c) **Specific Heat Capacity, c**

This parameter was determined for each of the samples by method of cooling correction, described elsewhere (Tyler, 1971), which takes care of any heat loss due to radiation. For temperature measurement, copper-constantan thermocouple was used.

(d) **Thermal Diffusivity, λ and Thermal Absorptivity, α**

The mean values of thermal conductivity, k, bulk density, ρ and specific heat capacity, c were used to calculate the mean thermal diffusivity values of each sample according to the relation

$$\lambda = \frac{k}{\rho c} \qquad (3)$$

Also, the mean values of thermal absorptivity were computed using the equation

$$\alpha = \sqrt{\frac{\omega}{2\lambda}} \qquad (4)$$

where $\omega = \frac{2\pi}{\text{period}}$. In this work, a period of one day (24 hours) was considered.

(e) **Nailability, $\cap_b$**

In order to properly assess the ability of each sample to withstand nailing, this test was performed using carpenter's hammer and a 50mm nail. The nail was driven with hammer blow into each sample. In case of a sample developing sign of visible crack, the nailing process was stopped. The nailability value was calculated based on the following relation:

$$\cap_b = \left(\frac{h}{x} \right) 100\% \qquad (5)$$

where h is the depth of nail penetration in the sample and x is the thickness of the sample.

(f) **Flexural Strength, σ and Compressive Strength, C_s**

These tests were carried out using Universal Testing Machine (Model 5565). The flexural strength of each sample was performed by three point - bending method using standard procedure as described in ref. (ASTM D790, 2017). In computing its value, the equation below was used.

$$\sigma = \frac{3PL}{2bx^2} \qquad (6)$$

where P is the load recorded at bending, L is the span length of the

test sample, b is the width of the sample and x is the thickness of the sample. Also, the compressive strength of each sample was tested based on ref. (ASTM D1037, 2012) and computed using the relation

$$C_s = \frac{F}{A} \qquad (7)$$

where F is the maximum load applied to the sample of area, A.

RESULTS AND DISCUSSION

The mean value of the properties investigated for our test sample boards are presented in Table 1. It can be seen from the table that the mean thermal conductivity values decrease with increase in Tiger nut fibre proportion in the sample. This,

basically, is due to the fibre having a mean value lower than that of the waste carton. Also, the mean bulk density values show a similar trend. In this case, it may be attributed to the dusty nature of the fibre. As can be inferred from figure 1, there is direct relationship between the mean values of bulk density and those of thermal conductivity with respect to their fibre proportions in the test sample. The implication of this observation is that the developed sample board becomes lighter in weight and also more resistive to heat flow as the proportion of the fibre in it increases.

Table 1: Mean values of the measured properties per fibre proportion

Fibre proportion (%)	Thermal Conductivity, k (Wm^{-1}K^{-1})	Bulk Density, ρ (Kgm^{-3})	Nailability, $\cap_b$ (%)	Flexural Strength, σ (MP$_a$)	Compressive Strength, C_s (MP$_a$)	Specific Heat Capacity, c (JKg^{-1}K^{-1})	Thermal Diffusivity, λ (10^{-8}m^{2}S^{-1})	Thermal Absorptivity, α (m^{-1})
0.0	0.0648	761.49	100.0	1.97	2.86	1340.535	6.348	23.935
8.3	0.0603	746.32	100.0	1.86	2.78	1439.811	5.611	25.456
12.8	0.0581	739.10	100.0	1.83	2.63	1482.375	5.303	26.187
25.6	0.0527	714.32	57.1	1.74	2.44	1636.971	4.507	28.406
37.5	0.0475	691.66	45.7	1.66	2.21	1758.345	3.906	30.513
43.1	0.0447	683.62	23.9	1.58	2.16	1840.554	3.553	31.993
100.0	0.0210	580.79	6.2	1.18	1.44	2459.882	1.470	49.738

Again, the mean values of flexural strength and compressive strength of the sample board decrease by 15.1% and 22.3% respectively for the fibre proportion increase from 8.3% to 43.1%. This portrays the fact that the board losses the ability to withstand bending load and compression as the fibre content in it increases. Plausibly, this is due to the

loosed nature of the fibre. From figure 2, it can be observed that between 12.8% and 25.6% of the fibre content, the mechanical strength of the board begins to reduce sharply. This is clearly supported by its nailability value decrease by about 42.9%.
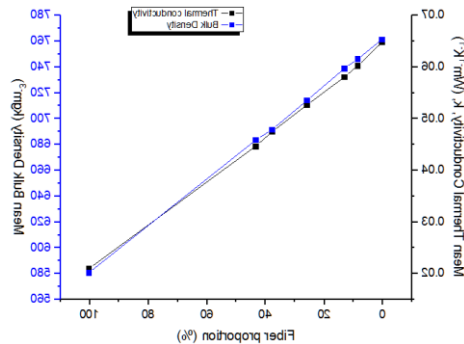
Figure 1: Mean thermal conductivity and mean bulk density variations with fibre proportion

Moreover, the improvement in the mechanical properties of the sample board shows an inverse relationship with thermal properties. However, a balanced situation can be observed at 12.8% fibre content. By comparing our results with the property values for conventional materials recorded in Table 2, it is possible to decipher that our sample board can alternatively be a suitable material for interior partition of building.

Table 2: Properties of some conventional boards (Dai et al., 2005; Onyeaju et al., 2012)

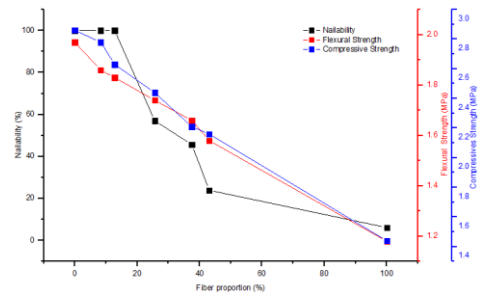| Board/Material	Density, ρ (Kgm^{-3})	Thermal Conductivity, k (Wm^{-1}K^{-1})
Plywood - faced sandwich	340	0.089
Pine fibre board	256	0.052
Siporex board	550	0.120
Thermalite board	753	0.190
Fibre board	300	0.060

Figure 2: Nailability, Flexural strength and Compressive strength variations with fibre proportion

The recorded values for both specific heat capacity and thermal diffusivity show a trend opposite to that of the values obtained for the thermal absorptivity in relation to the fibre proportion. In the case of specific heat capacity, this simply portrays the fact that as the fibre content in the sample increases, more quantity of heat is required by a kilogramme mass of the sample in order to effect a change in its temperature by one Kelvin. Considering the values of thermal diffusivity, it is an indication that while the heat is being absorbed, its speed of spread within the sample decreases as the proportion of the fibre used increases. This is supported by the reverse trend in thermal absorptivity of the sample, as it shows an increase in heat retention ability of the sample with increase in the fibre proportion.

CONCLUSION

The results of investigation showed that the thermal conductivity values of the test sample boards lie between the range (being 0.023 to 2.900Wm^{-1}K^{-1}) recommended for good heat insulation and conduction materials (Twidel and Weir 1990). Also the mean bulk density values were found

to be less than $1000kgm^{-3}$. On comparing with conventional materials/boards, it was generally observed that the fibre content can be varied for optimum performance of the board as a suitable alternative for structural applications. In addition to the environmental friendliness and cost effectiveness of the developed board, recycling tiger nut fibre with cassava starch a well as unused carton can help to reduce environmental pollution and provide raw material for industries.

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