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Research Article

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Evaluation of fire resistance properties of selected wood species used as building materials

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Abstract Some selected wood species: Rubus hawaiensis, Gmelina arborea, Mansonia altissima, Milicea excelsa, Alstonia congensis, Khaya senegalensis, Tectona grandis, Cordia platythyrsa, Pterygota macrocarpa, Aningeria spp, Hevea brasiliences and Pterocarpus mildreadiiwere examined from the vantage point of ignitability, using an induction furnace. The calorific values of the various woods were also determined using the e2k-bomb calorimeter. The result of ignition data obtained from ignitability test showed that; Hevea brasiliences (softwood) with density 497.33 kg/m^3 ignites at temperature 306 ^{o}C at 1436 sec., while Tectona grandis with density 800.00 kg/m^3 ignites at temperature 342 ^{o}C at 1531 sec. This showed that the higher the density, the higher the temperature at which the wood ignites. Tectona grandis, Aningeria spp, Khaya senegalensis, Milicea excelsa, Mansonia altissima and Rubus hawaiensis with moisture contents 9.15%, 9.104%, 8.535%, 7.92%, and 6.85% respectively have better fire resistance, while Alstonia congensis, Gmelina arborea, Pterygota macrocarpa and, Hevea brasiliences with moisture contents; 7.69%, 7.252%, 7.106% and 6.746% respectively have the least fire resistance. These results obtained showed that wood with high moisture content had better fire performance, while wood with the least moisture content had the least resistance to fire propagation. The values obtained for the calorific values of the samples increases from sample K (Hevea brasiliences), 16.146 MJ/kg to the highest value for sample G (Tectona grandis), and 18.232 MJ/kg.

Keywords Wood species, fire resistance, ignition time, ignition temperature, building materials.

Introduction

Fire outbreak has become a tremendous hazardous happening in buildings and the kind of materials used in the construction, either combustible or non-combustible, will determine the rate at which the fire will spread. A careful selection of materials actually saves live.

Woods are combustible materials and enhance intensity of fire, but the choice of which species of wood has better property while in fire becomes a question that bothered many builders.

Different materials behave in different manner when exposed to fire. Fire performance is the ability of a particular structural element to fulfill its designed function for a period of time in the event of fire. The kind of materials used in construction and the manner in which they respond to fire, clearly has a great bearing on how a structure will respond to fire. Many studies have been carried out on fire propagation properties of wood species to determine the rate of heat released; ignition and burning rate of woods; ignition time and ignition temperature; smoke release rate and rate of flame spread. However, little emphasis has been laid on the effect of some wood properties such as moisture content; density and calorific value on the fire properties of wood. In this study, attention is focused on the effect of these wood properties. Fire resistance is defined as the ability of an element to withstand the effects of fire for a specified period of time without loss of its fire separating or load bearing function. This ability was determined by exposure in a furnace to sustained high temperatures.

It is important to construct a building in which fire would take effect slowly, allowing the occupants enough time to escape. This is why materials themselves are rated as class A, class B and class C in respect to how long it would take fire to affect its structural abilities [1]. Even heavy timber can be considered to be fire-resistant. It is combustible; however, while metals like aluminum or steel are not combustible instead, they tend to buckle under intense heat.

Wood possesses certain features that allow it to provide satisfactory performance in most building fires. One of these is that it is not easily ignitable, but the most important property of wood is the formation of char after ignition [2].

Tewarson [3] has systematically shown how fire properties of materials can be measured in order to describe their evolution of smoke and energy under different fire conditions. Standard test apparatus can be used to measure flame spread and ignition properties.

Andrew and Grenier [4] conducted a material study in order to gain an understanding of how cored composites perform under controlled fire conditions. The study was based on two types of cored composite materials used in shipbuilding: a GRP/Balsa Cored sandwich and a GRP/PVC Foam Cored sandwich.

Babrauskas [5] carried out a review on ignition of wood whilst notable research in fire resistance of building materials were carried out by Erin [6] and William [7].

Toshiro *et al*. [8], carried out fire resistance tests (ISO 134-1) cone calorimeter tests (ISO 5660-1) on thick plywood, particleboard, and medium density fiberboard with samples of about 28-30 mm, and their suitability for quasi-fire proof or fire-preventive structures were evaluated. The results obtained indicate that thick wood-based board is a suitable fire-preventive construction material.

Tuula [9] conducted a series of experiment to examine the temperature development and the charring behavior of timber structure. The experimental data and observation of full-scale fire test provide new information on the behavior of timber structure in natural fires.

Fire retardant material may improve the fire performance of wood products considerably by reducing ignitability, rate of heat released and flam spread [10].

According to the literature, the critical ignition temperature for wood varied from 210 to 497^{o}c and mostly from 310 to 360 ^{o}C for piloted ignition and from 240 to 400 ^{o}C for auto ignition [11].

Wood is composed of a mixture of cellulose, hemicellulose, and lignin bound together in a complex network.A build-up of char tends to protect the unburnt wood from rapid pyrolysis. The unburnt timber, being a good insulator, results in the timber close to the char edge being unaffected by the fire [12].

In combination with a low thermal conductivity, and a protective layer of char, heavy timber sections can provide excellent fire resistance and therefore continue to be used [2].

For an exposed wood member, the fire resistance rating is the time for structural failure when subjected to the standard fire exposure [13].

The Heat Released Rate (HRR) is an important parameter to assess the fire hazard of a particular material and product as it easily quantifies fire size, rate of fire growth and consequently the release of associated smoke and fire toxic gases [14].

The calorific (or heating) value of a solid material indicates the amount of heat developed from the complete combustion of a sample with a given mass [15]. While moisture content refers to water that is contained within a piece of wood, but is not part of the wood molecule. It is also known as “free water” [16]. Fire performance properties are affected by density, moisture content, and chemical composition. Woods of higher density and moisture content have better fire performance [13].

Poespowati [17] conducted an experimental study on the fire properties of auto ignition of wood samples. The result obtained indicated in general that; ignition temperature, ignition time, end-ignition temperature, end-ignition time, and charring rate of wood based materials are all functions of their moisture content and their chemical composition. Gunther*et al* [18] stated that the variance in calorific values can be attributed to the chemical composition of the sample materials. Also, lignin and extractive content have a considerable influence and the higher the lignin and extractive content of a material, the higher the respective calorific value.

Material and Methods

Different species of wood from local saw-mill industries in South Western Nigeria were collected and two different tests were carried out on them in order to determine their ignitability properties.

Experimental tests were carried out using an induction furnace shown in Plate 1. A temperature controller (Plate 2) and a contactor (Plate 3) were improvised into the furnace.

The furnace was drilled along its side for the introduction of the type K thermocouple having an accuracy of ±0.7^{o}C. The temperature controller, the contactor and the thermocouple were connected together with the induction furnace as shown in Plate 4. The furnace was powered using electricity and the firing voltage was recorded.

The ignition temperature was obtained directly from temperature controller, while the time to ignition was measured using a stop watch.


Plate 1: The Induction Furnace

Plate 2: Temperature Controller


Plate 3: Contactor


Plate4: Connection of the thermocouple, temperature controller and the contactor


Plate 5: Samples of the wood species

Woods that are commonly used in building construction and that are locally available in South-Western Nigeria were investigated in this study. Table 1 shows the different species of wood that were investigated.

Samples of the wood species (Plate 5) were sun dried to a constant mass. Five samples of each specimen were cut to the size required by the induction furnace (20mm × 20mm × 15mm) and their masses were measured using an electronic balance with the measuring error of 0.1%.

Table 1: Wood samples and their botanical name

Samples	Local Name	Scientific Name (Botanical Name)	Types of Wood
A	Akala	*Rubus hawaiensis*	Hardwood
B	Melina	*Gmelina arborea*	Softwood
C	Mansonia	*Mansonia altissima*	Hardwood
D	Iroko	*Milicea excelsa*	Hardwood
E	Ahun	*Alstonia congensis*	Softwood
F	Mahogany	*Khaya senegalensis*	Hardwood
G	Teak	*Tectona grandis*	Hardwood
H	Omo	*Cordia platythyrsa*	Semi-hard
I	Oporoporo	*Pterygota macrocarpa*	Softwood
J	Osan	*Aningeria spp*	Hardwood
K	Rubber	*Hevea brasiliences*	Softwood
L	Ure	*Pterocarpus mildreadii*	Semi-hard

Thermal conductivity measurement

The power generated through the coil of the furnace through the samples was generated as follows:

Ambient temperature = 30 °C
Firing voltage of furnace = 200 V
Resistance of the heating coil (R) = 77.1Ω
Sample size = 20 mm × 20 mm x 15mm
Density (ρ) = $\frac{mass}{volume}$ kg/m^3
Volume of sample = (20 × 20 × 15) mm^3
= 6×10^{-6} m^3
Diameter of the furnace (D) = 120mm
= 0.12m
Cross sectional area of the furnace (A) = $\frac{\pi D^2}{4}$
= $\frac{\pi \times 0.12^2}{4}$
= 0.0113m^2

$$Power\ (P) = \frac{V^2}{R} \qquad (1)$$

Where V = firing voltage and R =resistance of the heating coil.
Therefore,

$$P = \frac{220^2}{77.1} = 627.756\text{ W}$$

Heat flow rate in Watt/metre^2 = $\frac{power\ \ generated}{cross\ section\ \ area}$ (2)
= $\frac{627.756}{0.0113}$
= 55.55 kW/m^2

This heat flow rate in kW/m^2 is the heat flux or irradiance generated by the furnace in igniting the samples. The thermal conductivity of the samples can be calculated using equation 3:

$$k = \frac{Q\ t}{A\ \Delta\theta} \qquad (3)$$

Where;

k = thermal conductivity (W/m K)
Q = heat generated (W);
t = samples thickness (m);
A = cross section area (m^2); and
$\Delta\theta$ = change in temperature(K).

Moisture content and calorific value of the samples

The wood samples were milled using emery paper to reduce the particle size. 1.5 g each of the twelve samples was weighed and placed in the Petri-dish that has been washed and stored in a desiccator. The samples were then placed inside an oven at a steady temperature of 1000 °C for four hours to dry off the moisture content.

The calorific values (CV) were determined using e2k-combustion calorimeters (bomb calorimeter). 0.5 g each of the samples was measured into the combustion chamber of the calorimeter and a constant firing voltage of 25.0 volts was used.

Rate of heat released

The rate of heat released by each samples were calculated using equation 4:

$$Q_T = R \times q \tag{4}$$

Where;

R = the rate of burning (kg/min) and

q = calorific value of wood (kJ/kg).

The mass of the samples were measured using an electronic balance with the measuring error of 0.1%. Figures 1, 2 and 3 show the result of obtained for the densities, ignition temperature and times to ignition. The ignition temperature (T_{ig}) and time to ignition (t_{ig}) recorded are the average value of five different experimental results for each sample. The time to ignition and ignition temperature were recorded in terms of standard error.

$$\text{Standard Error} = \frac{SD}{\sqrt{N}} \tag{5}$$

Where SD = standard deviation, and N = no of samples tested.

Results and Discussion

Figures 4 and 5 show the obtained values for thermal conductivity and rate of heat released for the wood samples. The values obtained for heat released rate showed that ignition properties were functions of wood species. Samples K, E, I and B have the least values for heat released rate and higher values for thermal conductivity respectively. The thermal conductivity of wood varies considerably with moisture content, temperature, grain orientation and voids.

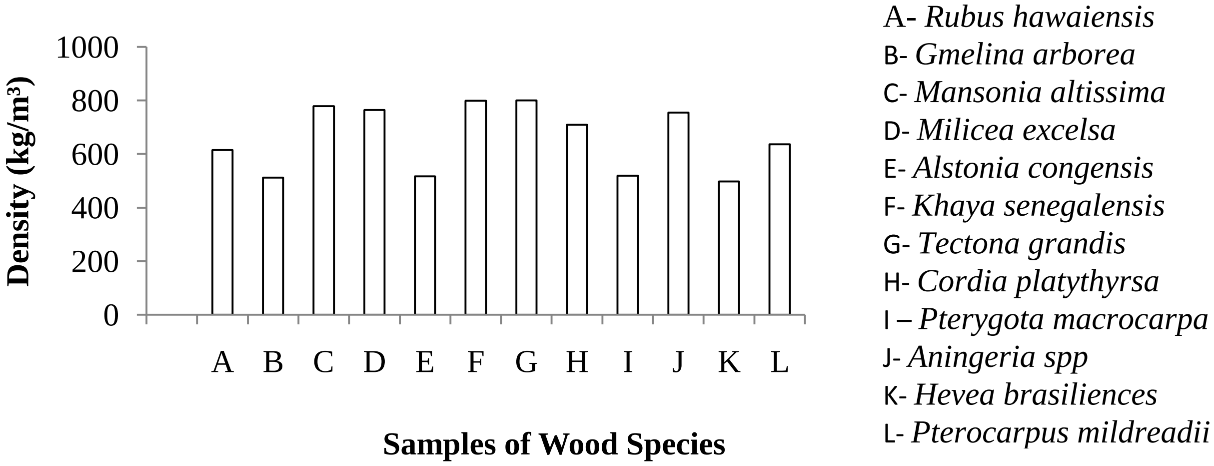

Figure 1: Density of samples of wood species

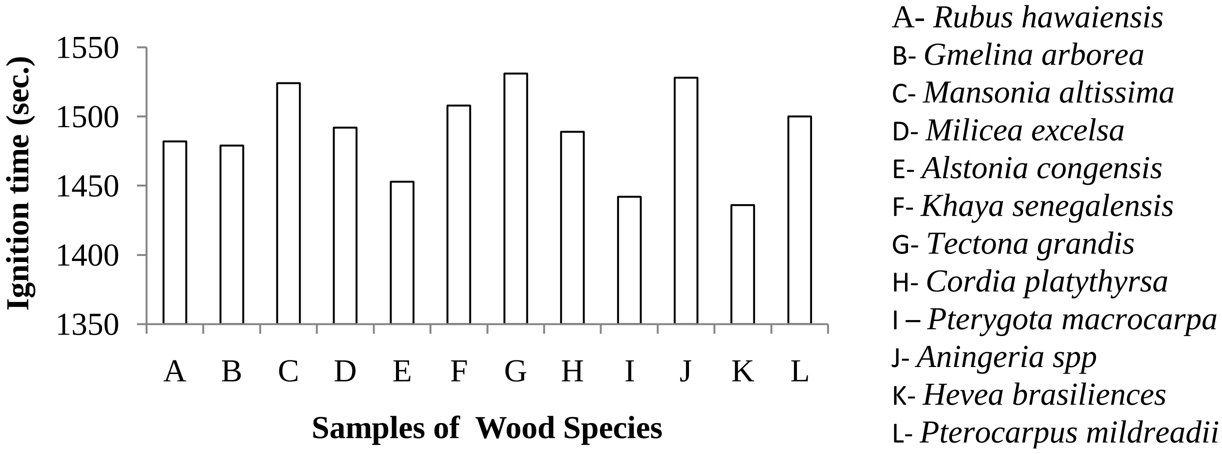

Figure 2: Ignition time samples of wood species

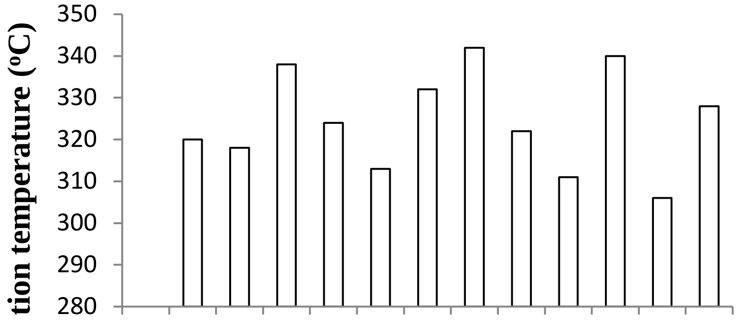

Figure 3: Ignition temperature of samples of wood species

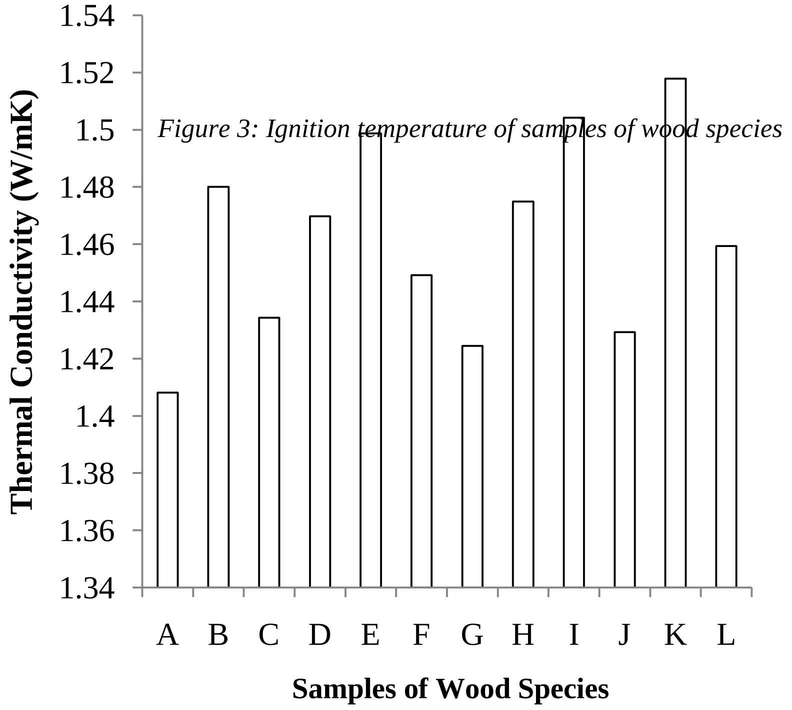

Figure 4: Thermal conductivity of samples of wood species

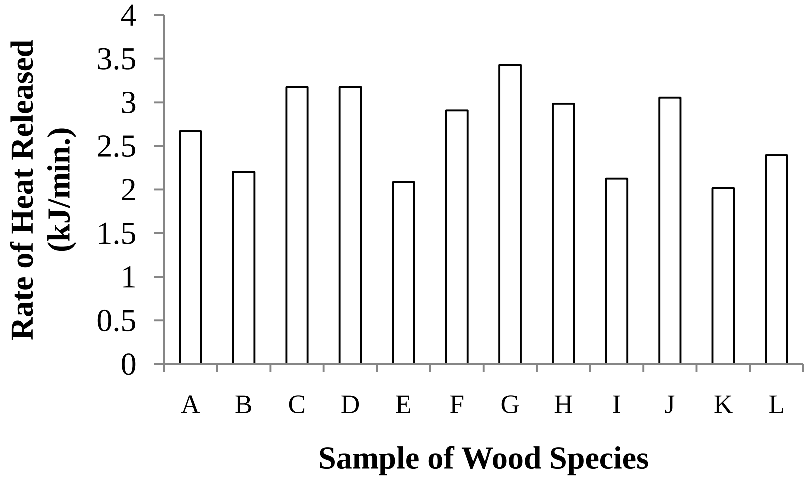

Figure 5: Rate of heat released wood sample codes

In general, the ignition time increases with the increase in the moisture content. This is due to the higher the moisture content the more water inside the wood structure, as such, more time to evaporate the water prior to ignition process.

Chemicals such as ammonium phosphate and soleplate, borax and boric acid can be applied as coatings to the surface of wood to enhance the fire resistance of wood. After the treatment, the wood becomes more resistant to heat.

The experimental result shows that the less the density the more quickly the material ignites. Samples B, E, I and K with densities 512,517, 519 and 497kg/m^3 ignited at temperature 313' 318, 311 and 306°C. The ignition temperature increases proportionally with density to sample G of density 800kg/m^3 and ignition temperature of 342°C. This trend is in accordance with. Fire performance properties are affected by density, moisture content, and chemical composition. Woods of higher density and moisture content have better fire performance.

Sample G (*Tectona grandis*) which is a hardwood with 1531s time to ignition would be considered to have better fire resistance among the selected wood while sample K (*Hevea brasiliences*) softwood with time to ignition of 1436 s. had the least fire resistance amongst the rest.

Figure 1 shows that there is little variation in the density of samples C, D, F, G and J and this might account for their close range in time to ignition as indicated in Figure 2.

Table 2 shows the result obtained for moisture content and calorific values for the various samples of the wood species. Sample G has the highest moisture content of 9.15% with time to ignition of 1531 s., this value reduced proportionally to sample K with the least moisture content of 6.747% and time to ignition of 1436 s., except for sample C with moisture content of 7.80% and time to ignition of 1524 s.

Table 2: Effect of moisture content on time to ignition of selected wood

Samples	% Moisture Content	CV (MJ/kg)	Ignition Time (sec.)
A	6.850	16.403	1482
B	7.252	17.648	1479
C	7.830	17.246	1524
D	7.920	17.228	1492
E	7.690	16.272	1453
F	8.535	15.222	1508
G	9.150	18.232	1531
H	7.875	17.432	1489
I	7.106	16.384	1442
J	9.104	17.183	1528
K	6.747	16.146	1436
L	9.046	15.665	1500

The results also show that the differences in the ignition of wood species can be attributed to the differences in wood characteristics such as density, moisture content, and chemical compositions like cellulose, hemicellulose, and lignin.

There is a larger amount of cellulose in hardwood when compare with the softwood and also, softwood contain higher content of lignin compare to hardwood [15] and lignin have considerable influence on net calorific value which is the amount of heat developed from complete combustion of the wood.

From Table 2, sample K with the least calorific value of 16.146 MJ/kg have the shortest time to ignition, while sample G with the highest value of calorific value of 18.232 MJ/kg have the longest time to ignition. Sample G had the best fire performance among the list while sample K has the least fire performance.

Conclusion

The result obtained shows density, moisture content, calorific value and rate of heat released and thermal conductivity of wood species are all factors to be considered while selecting wood species to be used in building constructions. Hardwoods can be considered generally as the best wood for the construction of buildings as shown from the results obtained. However, the research shows that even with the hardwood, they can still be categorized according to their resistance to fire so as to determine their suitability for use as building materials. In order to safeguard against risk of fire in a real building construction, samples G, J, C and L; that is *Tectona grandis*, *Aningeria spp*, *Mansonia altissima* and *Pterocarpus mildereadii* with long time to ignition respectively are recommended for building constructions among the selected wood species.

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