Thermal Conductivity of Three Different Wood Products of Combretaceae Family; *Terminalia superb, Terminalia ivorensis and Quisqualis indica*.

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Abstract

The uses of wood and wood based materials in everyday life ranging from domestic to industrial applications had called for renewed updating of the information on various thermal properties of the materials at different stages. The ability of wood materials to withstand shock and deformation depends basically on their thermal responses at specific temperature and time. The study examines the thermal behavior of three wood species of the family of combretaceae (*Terminalia superb, Terminalia ivorensis and Quisqualis indica*) using the modified Lee's method. Within an interval of time, the thermal agitation in the samples increases as the temperature increases, after which thermal stability was attained. The thermal agitation is seen to be more prominent during the rising temperature than at the falling temperature. All samples attained stability after about 105 minutes of continuous agitation during the rising temperature and much more faster at the falling temperature. In addition, the thermal conductivity values obtained for the samples fall within the general range of conductivity (0.1-0.8 $Wm^{-1}K^{-1}$) for wood materials.

Key words: Wood materials, thermal conductivity, Lee's method, temperature and time.

1. Introduction

Thermal conductivity is a measure of the rate of heat flow through one unit thickness of a material subject to a temperature gradient. Wood exhibits low thermal conductivity (high heat-insulating capacity) compared with materials such as metals, marble, glass, and concrete. Thermal conductivity is highest in the axial direction and increases with density. Wood is one of the most useful materials touching the history of man and his environment especially in the provision of shelter (the habitation of man), tools, weapons, furniture, packaging, artworks, and paper (Ahn et al, 2009; Wag and Kumaran 1999). In fact, wood is one of the materials used to achieve some of the basic needs of man. Wood has different properties ranging from specie to specie. Although wood expands and contracts with varying temperature, these dimensional changes are small compared with shrinkage and swelling caused by varying moisture content. In most cases, such temperature-related expansion and contraction are negligible and without practical importance. Only temperatures below 0 °C (32 °F) have the potential to cause surface checks; in living trees, unequal contraction of outer and inner layers may result in frost cracks.

The use of wooden materials for numerous purposes cannot be over emphasized. Various researches had been carried out on these materials at different stages and conditions. A systematic investigation of the variation in the hygrothermal properties of several wood-based building products investigated by (Kumaran 2003 et al) revealed a new information on the variations of thermal conductivity, water vapour permeability, moisture diffusivity, water absorption coefficient and air permeability of some classes of wood products. The research also presents detailed description of a range of properties such as the density and temperature dependences of thermal conductivity, dependence of vapour resistance factor on relative humidity, dependence of moisture diffusivity on moisture concentration, equilibrium moisture content for the full range of relative humidity, variations in the water absorption coefficients and dependence of air permeability on pressure difference. The development of hygrothermal computer models which have become powerful tools for building scientist and building practitioners alike had been acknowledged to require a set of reliable inputs to yield meaningful results (Hens 1996; Kumaran 1996;, Trechel 2001)

As building materials evolve, there is a need for continuous updating of the information on various thermal properties of wood products. Researches (Kumaran et al 2002a; Kumaran et al 2002b) conducted at the Institute for Research in Construction generated detailed information on the hygrothermal properties of more than 70 building products that are currently used in Canada and the United States of America. These researches specifically looked at

the ranges of the thermal properties by contemporary products in North America. The products chosen included wood and wood based materials, bricks, mortar, stucco and building membranes. Information on wood-based products such as Oriented Strand Board (OSB), plywood, wood fibre-board and wood siding were also reported.
Thermal conductivity is a critical attribute when offering energy conserving building products. This is due to the fact that wood has excellent heat insulation properties. Lower thermal conductivity values equates to greater heat insulating properties (Daniel 2010). The prevalence of wood product in construction industries is driven by their high stiffness to weight ratio allowing for the use of lightweight assemblies and innovative design. However, field experience suggests that fire performance on engineered wood products is inferior to traditional timber (Mahmood).
Wood plastic composites (WPC) (i.e. composites from materials from wood and thermo plastically processable matrices) is known to have drawn increasing attention over the years. To this end, wood materials had been preferred to inorganic materials like talcum or fibre due to the density of the composite, which is considerable lower and therefore of interest for transportation applications, as well as the renewability and enhanced recyclability of the wood plastic composites (Daniel 2003; Burgstaller 2006; Burgstaller 2007). The influence of processing parameters e.g. throughput and temperature of the compounding step of wood plastic composites and bamboo blast were investigated by (Vanchai 2010; Li et al 1995). The effects on the mechanical properties, colour of the produced composites correlated with the different processing parameters showed a wide range of good processability, only at high temperature and low throughput strong darkening occurred, as well as loss of tensile strength was found for the samples in the study.
Hitherto, available studies in the literatures are mainly concerned with the relationship between the thermal conductivity of the materials with some processing parameters such as temperature, strength, density etc. As a result, some salient properties like the therrmal behavior with the temperature and within some time interval are not investigated. In this study therefore, the conductivity as well as the thermal behaviour of three different wood species found and utilized in the environment of the research are examined at different regimes of temperature and time. This is necessary for wood/building engineers to be able to effectively categorise these species materials by virtue of their thermal behaviour within given temperature range and time.

2. Materials and method

The materials used in the study include three different wood species growing in the rainforest region, South Western Nigeria (Terminalia superb, Terminalia ivorensis and Quisqualis indica) of the family of Combretaceae. The samples used were obtained in the sizes of 0.3x0.3 and 0.3x0.5 inches and about 8.0 inches long. These were machined down to about the same diameter of the Lee disc (i.e. 40mm) and 4mm thickness. The surfaces of the samples were also smoothened for good thermal contacts. The basic apparatus used was a modification of the standard Lees' disc method for the measurement of thermal conductivity by the absolute plane parallel plate technique (Griffin 2002; Duncan 2000). This consists of three brass discs A, B, and C drilled to accept liquid-in-glass thermometers and a 6W electrical plate heater of the same diameter as the discs. Each sample was placed between discs A and B one after the other. The heater was sandwiched between discs B and **C** and, after tightening the clamp screw to hold all the discs together. The set-up was connected to a DC power supply. The whole assembly was placed in an enclosure to minimize the effects of draughts. A thermometer was placed close to the apparatus, to measure the ambient temperature. The complete set-up is shown in figure 1. At the beginning of each determination, the voltage from the stabilized Direct Current supply was set on to about 6.0V while the temperatures of the discs (i.e. the temperatures of plates A, B and C) were monitored until the temperature of disc A attained a desired value of 50^{o}C. This took several hours. Readings were taken at 15 minutes intervals during this period. At this stage, the Voltage supply was reduced and temperature readings of the discs were monitored at every 5 minutes interval. In order to effectively analyse the thermal agitation in the samples, the thermal conductivity were estimated at every 15 minutes interval up to a point at which the temperatures of the discs had stabilised to within ±0.1°C for at least 30 minutes. The value for the thermal conductivity (λ) of each sample of thickness *d* and radius *r* was estimated from the relation.

$$\lambda = \frac{ed}{2\pi r^2 (T_B - T_A)} \left[a_S \frac{T_A + T_B}{2} + 2a_A T_A \right] \quad (1)$$

where e is given by

$$e = \frac{VI}{\left[a_A T_A + a_S \frac{T_A + T_B}{2} + a_B T_B + a_C T\right]} \quad (2)$$

and

$$a_A = a_C = \pi r^2 + 2\pi r l_d$$
$$a_B = 2\pi r l_d \quad (3)$$
$$a_s = 2\pi r l_s$$

were $l_d and l_s$ are the thicknesses of disc and sample, while a_A, a_B, a_C, and a_S are the exposed surface areas of discs A, B, C and the specimen respectively. T_A, T_B and T_C are the temperatures of the discs A, B and C above ambient (i.e. the thermal equilibrium temperature of the disc minus the ambient temperature). V is the potential difference across the heater and I is the current which flows through it. In order to fully analyse the thermal behaviour of the samples within the temperature range, a MATLAB programme was written to compute the thermal conductivities at given time interval.

3. Results and Discussion

The result of the direct measurements of the samples at different current-voltage stages are shown in tables 1-3 for both rising and falling temperatures. The temperatures of the discs increase as the time increases up to stability for each disc. In addition, slight increase was noticed for the ambient temperature. This could be attributed to increase in environmental activities at the vicinity of the experiment. The increase in temperature with time results to gradual decrease in the thermal conductivity of the samples to equilibrium values. This feature was also noticed for the falling temperature with a gradual increase in thermal conductivity to stability..

Figures 2-4 show the variation of the thermal conductivities with time for the three samples. The thermal agitation of the samples was found to increase gradually and approaches stability with time. The samples attained equilibrium after about 105 minutes of continuous agitation. This equilibrium values suggests the thermal conductivities of the various samples. The rate at which thermal equilibrium was attained was found to be faster at the falling temperature than for the rising temperature. This effect could be attributed to the fact that initially, enough energy is required to break the bonds of the particles in the samples and on reaching their maximum excited positions, and as the thermal energy reduces, the particles tend to return to their mean position. Hence withdrawal of heat from the system would course the particles to return back to their mean position faster and more regular than when the temperature was rising. It is evident that as the temperature of the samples increases the particles receive thermal agitation and thereby are scattered away from their equilibrium position. This is more prominent at the rising temperature.

Figure 5 shows the variation of the thermal conductivities of the three samples with time. The *Terminalia superba* exhibits the highest thermal agitation followed by *Terminalia invoresis* while *Quisqualis indica* had the lowest thermal agitation. According to [10], the thermal properties of wood vary with species type with conductivity values generally in the range of 0.1-0.8 $Wm^{-1}K^{-1}$. The values of the thermal conductivities obtained in this report conform with this result. They are also found to possess good thermal behaviour. However, the *Terminalia* wood types have both higher thermal agitation and conductivities than the *Quisqualis* type.

4. Conclusion

The prevalence of different wood products in the society especially in the construction industry calls for concerted efforts to examine the various thermal responses of these materials to stress and other environmental conditions. In addition as building materials evolve, there is need for continuous updating of the information on their thermal properties. This would assist building engineers in the choice of construction material to adopt for effective use. The wood materials in this study have been sourced from the immediate vicinity of the research. The thermal properties of three different species (*Terminalia superb, Terminalia ivorensis* and *Quisqualis indica*) of the family of *Combretacea* were examined in the study. The results obtained revealed that the wood materials in the study possess good thermal properties. The thermal conductivities values for the samples were found to conform with the general range of conductivity for wood materials.

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Table 4.1: Results obtained for both rising and falling temperature of *Termilania superb* sample

Rising temperature Voltage = 6.00V, Current = 0.315A							Falling temperature Voltage=3.71V, Current = 0.20A					
TIME (Min)	T_A (°C)	T_B (°C)	T_C (°C)	$T_{Amb.}$ (°C)	*e* (W/m².°C)	λ (W/m.°C)	T_A (°C)	T_B (°C)	T_C (°C)	$T_{Amb.}$ (°C)	*e* (W/m².°C)	λ (W/m.°C)
0	33.5	35.5	36	28.5	10.02231	1.164787821	44.5	52.5	53	30	2.780706	0.107684551
15	36	43	43.5	29	8.680664	0.310931097	42.5	46.5	47	30	3.046954	0.224842913
30	38.5	46.5	47	29.5	8.063982	0.270389247	40	44	44	30	3.241354	0.225155504
45	41	48.5	49	29.5	7.672327	0.292022484	39	43	43.5	30	3.303871	0.223776809
60	42	50	50.5	29.5	7.461144	0.272786704	38.5	42	42.5	30	3.367862	0.257271788
75	43	51	51.5	30	7.305113	0.273407231	38.5	41.5	42	30	3.391909	0.302183256
90	44	52	52.5	30	7.155475	0.274002335	38	41	41.5	30	3.434381	0.302002127
105	44.5	52.5	53	30	7.082931	0.274290838	38	41	41.5	30	3.434381	0.302002127
120	44.5	52.5	53	30	7.082931	0.274290838	38	41	41.5	30	3.434381	0.302002127

Table 2: Results obtained for both rising and falling temperature of *Termilania ivorensis* sample

Rising temperature Voltage = 6.00V, Current = 0.316A							Falling temperature Voltage = 4.67V, Current = 0.20A					
TIME (Min)	T_A (°C)	T_B (°C)	T_C (°C)	$T_{Amb.}$ (°C)	*e* (W/m².°C)	λ (W/m.°C)	T_A (°C)	T_B (°C)	T_C (°C)	$T_{Amb.}$ (°C)	*e* (W/m².°C)	λ (W/m.°C)
0	30.5	38.0	38.0	28.5	10.061	0.285372447	38.0	46.5	47.0	29.0	4.004592	0.1247916
15	32.0	40.0	40.0	28.5	9.56956	0.267014058	36.0	41.0	40.5	29.0	4.462075	0.223408485
30	34.5	42.0	42.5	28.5	8.978486	0.287837118	34.0	40.0	40.0	29.0	4.607763	0.181763121
45	35.5	43.0	44.0	28.5	8.710799	0.287300548	33.5	39.5	40.0	29.0	4.645032	0.180552018
60	36.5	45.0	45.5	29.0	8.422308	0.252161722	33.0	39.5	39.5	29.0	4.69694	0.166093677
75	37.0	45.0	46.0	29.0	8.339982	0.268811854	33.0	39.5	39.5	29.0	4.69694	0.155779508
90	37.5	46.0	46.5	29.0	8.224634	0.252945853	33.0	39.5	39.5	29.0	4.69694	0.155779508
105	38.0	46.5	47.0	29.0	8.129237	0.253324275	33.0	39.5	39.5	29.0	4.69694	0.155779508
120	38.0	46.5	47.0	29.0	8.129237	0.253324275	33.0	39.5	39.5	29.0	4.69694	0.155779508

Table 3: Results obtained for both rising and falling temperature of *Quisqualis indica* sample

Rising temperature Voltage=6.02V, Current=0.30A							Falling temperature Voltage=4.38V, Current=0.20A					
TIME (Min)	T_A (°C)	T_B (°C)	T_C (°C)	$T_{Amb.}$ (°C)	*e* (W/m².°C)	λ (W/m.°C)	T_A (°C)	T_B (°C)	T_C (°C)	$T_{Amb.}$ (°C)	*e* (W/m².°C)	λ (W/m.°C)
0	23	30	28	24	12.67659	0.290987313	35.5	45	46	27.5	3.912308	0.102031391
15	25	33	33.5	24.5	11.15702	0.243685569	34.8	42	42	27.5	4.15602	0.139953145
30	28.5	37	38	24.5	9.840844	0.230476242	33.5	40	40	27.5	4.346141	0.156004443
45	30.5	39	40	25	9.291177	0.23274598	32.5	39	39.5	27.5	4.441594	0.154697476
60	32	41	42	26	8.849125	0.21966934	32	39	39.5	27.5	4.467492	0.142337086
75	33	42.5	42.5	26	8.644509	0.209687608	32	39	39.5	27.5	4.467492	0.142337086
90	34	43	44	26	8.402146	0.221506979	32	39	39.5	27.5	4.467492	0.142337086
105	34.5	44	44.5	26.5	8.278933	0.209874663	32	39	39.5	27.5	4.467492	0.142337086
120	35	44.8	45	26.5	8.166434	0.203620216	32	39	39.5	27.5	4.467492	0.142337086
135	35.5	45	46	26.5	8.03899	0.209653544	32	39	39.5	27.5	4.467492	0.142337086
150	35.5	45	46	27	8.03899	0.209653544	32	39	39.5	27.5	4.467492	0.142337086

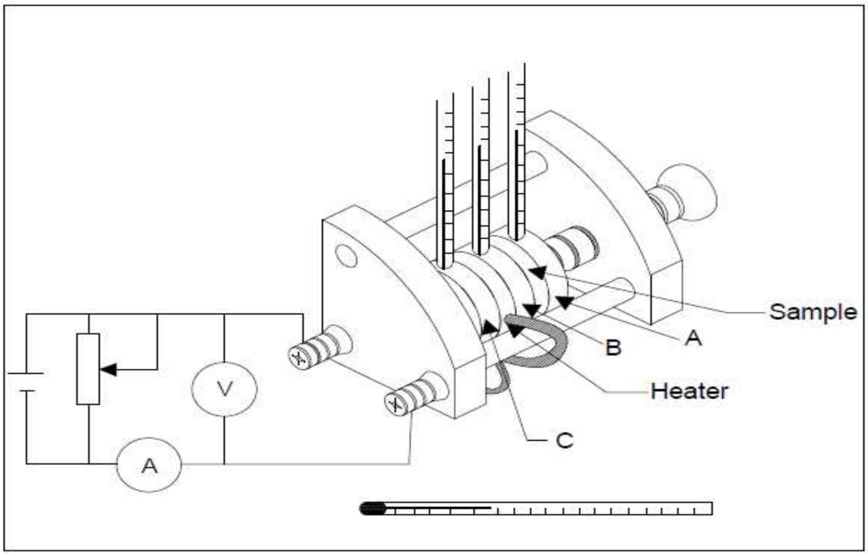

Figure 1. Schematic diagram of the Lee's Disc apparatus used for the measurement of the samples.

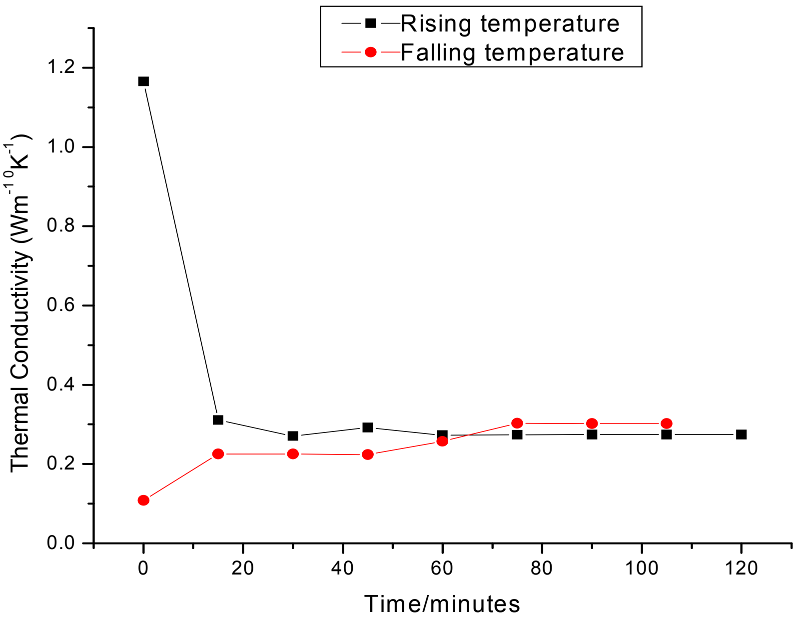

Figure 2. Variation of thermal conductivity of *Terminalia superba's* sample with time

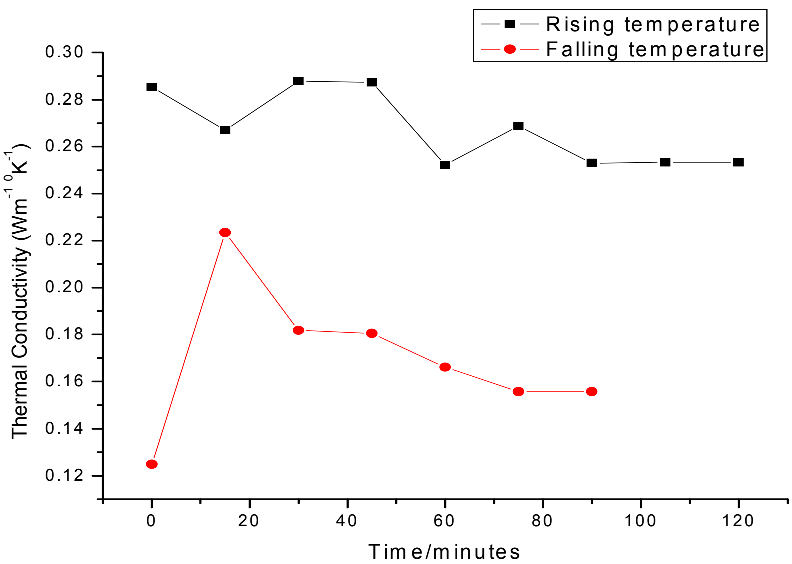

Figure 3. Variation of thermal conductivity of *Terminalia ivorensis's* sample with time

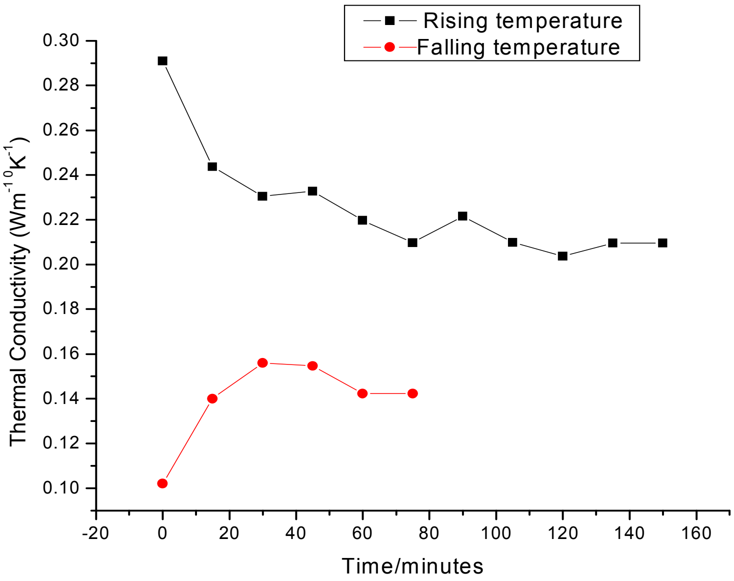

Figure 4. Variation of thermal conductivity of *Quisqualis indica's* sample with time

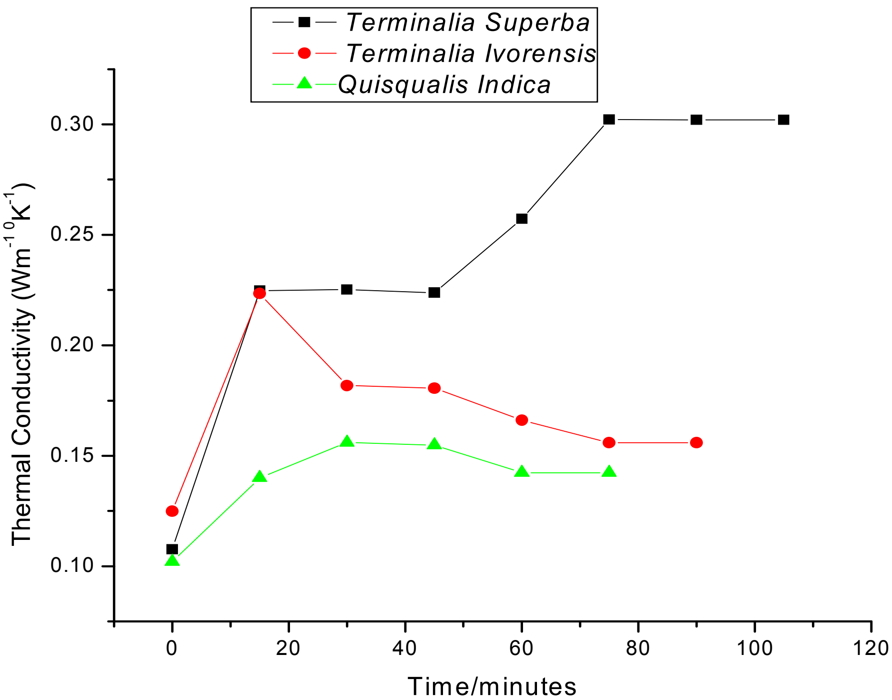

Figure 5. Variation of the thermal conductivity of the three samples with time